A Model for Generating Socially Desirable Transportation Network Configurations

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Preface

The author has been engaged in the research of the urban transportation planning over half a century. His life-long aim is to utilize the transportation system to achieve the betterment of the society. His research in this theme began when he started his doctoral program in the late sixties in the United States. In those days, social disparity and urban sprawl due to motorization were in progress, and the author tried to develop a theory to solve these problems. The potential application of the model was in the planning of new mode of transportation network system. To verify the effectiveness of his theory, he extensively used computer systems which was still in the early stage of development. Man-machine interaction to assist transportation planners was also a new attempt in those days.

In Japan, we face the same problem of urban sprawl and hollowing of CBD due to motorization as fifty years ago in the United States, and now the public transport system like LRT is being seriously considered. The author feels that his theory and methodology are still valid even now and worthwhile to present here. The following is the excerpts from his doctoral dissertation published in 1970. Although the entire paper is more than 200 pages long with 56 references, only the abstract and the introductory chapters are reproduced below.

Abstract

This study represents an effort to develop a model which is capable of designing a new or improving an existing transportation network system in a way that will lead to the achievement of a given social goal. The goal used is the increase of an index called satisfaction level. This index is a function of opportunity (transportation accessibility or of employment) and socio-economic status. The model is structured to produce a transportation network design that has a higher and more equitable distribution of the satisfaction level index than a given baseline. The design process is guided by a weighting function which is a public policy determination. It gives people with a low level of satisfaction proportionately more weight than those who are presently highly satisfied. The travel desires of this weighted population distribution are then used to guide the design or improvement of the transportation network.

Thus the model is operated to design a transportation network configuration that will both increase and improve the equity of the baseline satisfaction level distribution. The model can design an entirely new system. It can also be used to evaluate intuitively derived designs or proposals for improving an existing system from a socially relevant viewpoint.

Several experiments were designed and implemented to test some of the concepts involved and to determine the sensitivity of the model to changes in some of its key parameters. The results of these experiments show that the model does produce high performance network designs under a wide variety of conditions and over a wide range of parameter variations. We cannot conclude that it produces optimal solutions but some evidence is presented which indicates that the solutions are near-optimal. It was found that a large number of alternative solutions had nearly identical performance measures which indicates that there are probably a large number of good solutions to problems of this type.

The model is based on several philosophical propositions that may be impossible to verify empirically. The basic concept is that the improvement of opportunity is a widely held social goal in most societies. A method is proposed that measures the amount of opportunity of employment that is available to urban residents. This measure, in association with other factors, is then used to guide the transportation network design process. The model presently contains only a few of the factors that are relevant to this problem but several ways of extending it are discussed.

1 Problem Setting

One of the major characteristics of urban living is the magnitude and wide spectrum of opportunity that permits urban residents to interact with a wide variety of urban activities. People who reside in an urban area generally have great freedom in their choice of social, economic, educational, and recreational opportunities. Activities in an urban area are much more abundant in their quality and quantity than in a rural area. People can look for jobs which are suitable for them among many alternatives. They have a wider range of selection available in their shopping activity regardless of their tastes and financial capabilities. A wide range of recreational and entertainment opportunities are also available in the urban area.

The very existence of these richly varied potential opportunities is the main force that attracts people into the urban area. This urbanization trend has been world-wide in the recent past and probably will continue in the future. However, because the absolute size of many urban agglomerations is very large, there inevitably exist many conflicts among individual urban residents who wish to enjoy these various opportunities. As an urban area grows, these adverse effects tend to become worse and produce many serious problems that are characteristic of large metropolitan areas around the world. Deterioration of the environmental condition is found in blighted slum areas, urban sprawl, longer daily travel requirements, congested traffic conditions and various kinds of pollution.

People living in the urban area are faced with a dilemma. On the one hand, they chose the large city because it offered a better opportunity to improve their living conditions, while on the other hand, big city life forces them to sacrifice some of the environmental quality which they may have previously enjoyed.

The duty of the urban planner and the administrative personnel whose task is to implement plans is to assist the people to move toward better living conditions in two ways. One is to provide them with more opportunity, both in qualitative and quantitative terms, and the other is to minimize the adverse effects of doing so.

In the complex urban system, various components that have many different kinds of attributes interact with each other. It is usually very difficult to identify these components and to clarify the mechanism that characterizes these interrelationships. The major objective of this study is clarify some of the important interrelationships which characterizes the urban system with some simplified modeling procedures. A special effort is made to keep the interaction of the components of the model as simple and basic as possible.

The result of this interactive process which is designed to maximize individual opportunity is a dynamic equilibrium solution which satisfies certain conditions at a point in time, given that the whole urban area is viewed as one entire system. This equilibrium solution will tend to be unstable and will vary with changes in the parameters of the various components of the model.

Even in an equilibrium state, the amount of freedom to choose among various alternatives will differ for each urban resident. Besides differences in personal tastes, three other major factors are considered. They are the land use configuration, the transportation system, and the relative socio-economic status of each resident. The first two factors characterize the physical configuration of the urban system, and they interact with each other as well as internally within each category.

Let us examine these two factors in more detail. First, it is a basic assumption that any urban resident is inclined to participate in the various urban activities that take place within and near his community. People want or have to work to sustain themselves; they must go shopping; they may participate in educational and social activities, such as school, church, etc. They also might be interested in recreational activities not only within their own community but also in nearby or distant areas.

We can see that there exist supply and demand type relationships for the consumption of opportunities by residents from various urban activities. Land use refers to the spatial configuration of the supply of and demand for opportunity. For instance, if we follow the definitions common in economics, resident are regarded as the labor supply and job opportunities as the demand side for those in the labor force. If we change our viewpoint, we can state that people demand jobs, shopping and other opportunities, and that institutional, commercial, industrial and other nonresidential activities supply these opportunities. Following this definition, the supply of opportunity is measured in terms of the intensity of attractiveness of an urban activity which may be expressed by the number of jobs, floor space, enrollment, etc., according to the nature of the interaction process involved. The spatial location and size of these entities (supplies of and demands for opportunities) in relation to each other are the major attributes of the land use components of the urban system.

The actual interactions between these supply and demand schedules are made through one of the following means, namely, communication and transportation. The former relates to the exchange of information, while the latter involves the movement of persons and goods. Conveyance of information is usually done with the telephone, letters, internets and through various mass media. These flows are rather insensitive to distance differences within the metropolitan area. The movement of persons and goods, on the other hand, is much more sensitive to the change of various conditions that together determine the amount and characteristics of impedance which deters movement and interaction. Accordingly, we can take the transportation system into consideration as one of the major factors that contributes to the differences in the amount of opportunity available to individual urban residents. Another major factor is the relative location of their residence in relation to the area-wide supply and demand pattern mentioned in the land use discussion.

The transportation system determines the ease of interaction between the supply and demand configurations. The transportation system has two attributes. One is the transportation network, which determines the spatial coverage of its service, and the other is the level of service or quality of the transportation system. Both factors have an effect on the volume and the nature of action between activities. For instance, if the network is not available in a certain area, the people who reside there cannot make trips as easiry as those who are provided access to a network. Even when their network is close at hand, people cannot, or will not, use it if the speed or capacity is too low, the level of service inferior, or the cost of travel too expensive. This last factor, cost of travel, has some particular problems which needs to be mentioned. Clearly, travel is expensive to some but not to others. Here we must consider the financial capabilities of the users, (i.e., the socio-economic status of the population groups who use the transportation systems). Costs should also be mode-specific as they often vary widely by mode for the same trip.

The transportation system and land use patterns are not the only factors which influence the level of interaction among various activities nor are they the only factors that distinguish individual living conditions, though they are both very important.

Even in the same community, values differ greatly among individuals. For this reason, it is necessary to introduce a third factor, socio-economic status, which is closely related to the quality of life.

The socio-economic status of each individual resident is the combined result of his income, family composition, education level, lifestyle, and many other factors. The residents of the same community do not always have the same quality of life nor the same amount of opportunity to interact with various urban activities. Let us examine this statement by using the following example of a work activity.

The qualitative attributes of a population and jobs vary widely. These attributes may be categorized by socio-economic status. Some people are blue-collar and some are white-collar workers. Some families earn a high income, others do not. Some jobs are managerial-professional, and some are unskilled. A certain person may not always be able to or want to get certain kinds of jobs. Everybody does not want to nor can afford to have the same level of housing, living conditions, etc. To account for factors such as these, we must introduce some kind of status-based matching concept between population and job opportunities. Therefore, if the transportation connections between two areas are good but the status matched is bad, only a few people will use these transportation means. On the other hand, without the proper means of transportation, one cannot take advantage of the opportunity even if the status much is perfect.

So far we have observed that there are very close interrelationships among these three factors and that their combined outcome describes, in very general terms, one aspect of the living quality of each individual resident. To make this description, we have adopted two values with which to measure the quality of urban life. They are the individual resident's freedom of choice among many alternative activities and the quality of the living standard each resident possesses. The former is called the opportunity index and the latter is represented by a socio-economic status index. A detailed definition will be given later.

Each person who lives in the urban area may be said to have a certain level of satisfaction which is determined as some function of the amount of opportunity available to him and his socio-economic status. This may be measured with an index of satisfaction and it will be different for each individual depending on his background, tastes, attitudes toward life, etc.

As mentioned before, the role of the planner is to increase the satisfaction level of the citizens. How can we increase the satisfaction level? What changes to which components of the urban system will contribute to this objective? To what extent does an unequal distribution of satisfaction levels in different parts of a city exists and should such inequalities be corrected? These are some of the questions to be examined as part of the development of the model in this study.

With these general objectives in mind, the specific task is to concentrate on the transportation system planning problem. Where should the new transportation facilities be located to improve the overall satisfaction level of the resident in the community? How should resources be allocated among various parts of the city? How can one choose the best plan from among several alternatives?

Special attention is given to the capability of human intuition in solving the planning problems posed above. Its appropriateness in a planning process oriented toward the design of a transportation system that is optimal in terms of the increase in the satisfaction level of our community will be assessed.

2 Conceptual Framework

In the previous section, three major components of an urban system were identified. They are the land use pattern, the transportation system, and the socio-economic status of the residents. To measure the interrelationship among these factors, two indices have been formulated: an opportunity index and a socio-economic status index. Figure 1 is designed to illustrate the role of these indices and to summarize the previous discussion. In this figure, the land use configuration and transportation system represent the physical attributes of the urban system, which means that these factors have fixed locations whereas socio-economic status is an attribute which is not fixed in space as it is possessed by individual residents who are mobile.

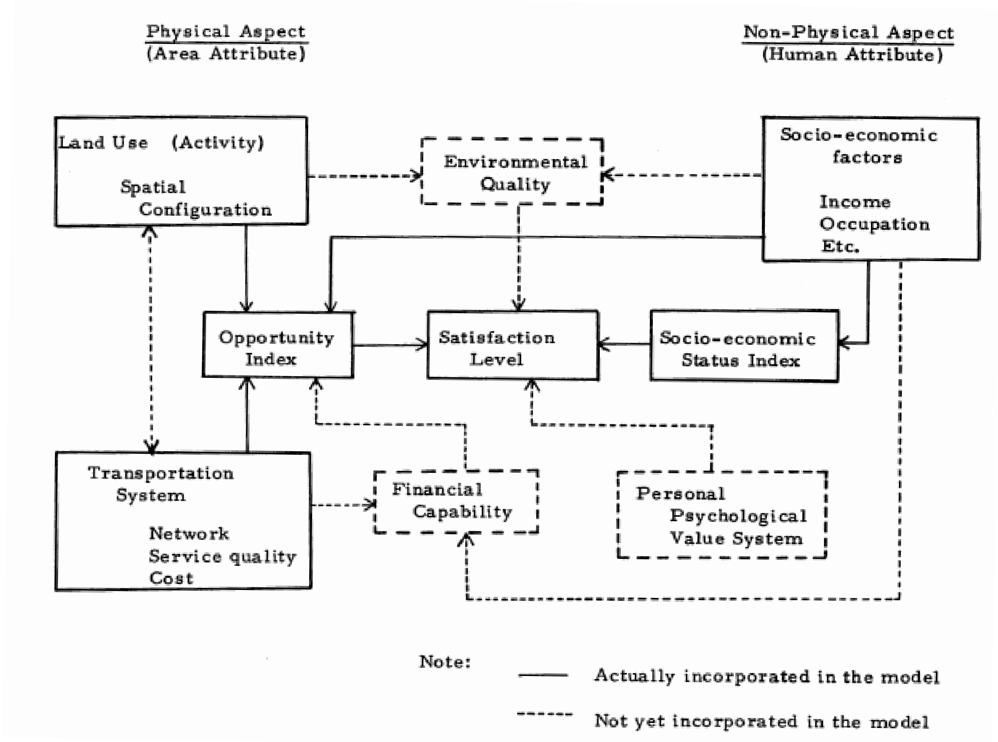

Figure1. Conceptual Framework of the Model

Although this diagram is quite simplistic and omits many factors, it does include several major factors and indices. The ultimate measure of urban living is the satisfaction level, which is expressed in the form of a multi-dimensional vector consisting of many components. Generally, the satisfaction level may be expressed as follows:

$$SL = f\ (\ a1,\ a2,\ a3,\ \ldots\ldots,\ an\ ) \qquad \text{(Equation 1)}$$

The components that comprise the satisfaction level vector are the opportunity to interact with other activities, the socio-economic status of residents, environmental quality, natural condition, psychological value system of each individual, etc.

For the purpose of simplifying the model, and as our prime concern is that of clarifying the role of the transportation element of the urban system, only the first two variables will be taken into account. However, it is quite possible that some additional variables could be incorporated into the model in the future.

The general form of the satisfaction level equation is as follows:

$$SL = f\ (\ Op,\ Se\ ) \qquad \text{(Equation 2)}$$

Where: Op: Opportunity index

Se: Socio-economic status index

SL: Satisfaction Level

Up to this point, we have been using the term "opportunity" without having defined it. For our purposes, opportunity is defined as the amount of freedom of choice an individual has among the many kinds of activities that are available in various parts of the urban area. The amount of freedom consists of two factors. One, a function of the intensity of attraction at the location of those activities, is the availability of activities. Intensity is measured by the size of each activity, for instance, the number of jobs, floor space of commercial facilities, the enrollment of students in schools or universities, etc. The larger the size, the greater the opportunity for participation in the activity.

However, it is too simplified to state that the strength of attraction is determined only by the size of the attracting activity. Even in the same category of activity, qualitative differences between demand and supply exist. However large the attractive force of a place may be, many people may not be attracted to that place if their motivation to make trips is low. The decisive factor whether the interaction would take place is, other things being equal, dependent upon the qualitative characteristics of the attractive activity in relation to those of the individual residents. This factor, which is explained in detail later, has been termed the matching factor.

Including the matching factor, the first component that determines the opportunity index is the land use configuration (both the location and size) and the kind and level of the socio-economic characteristics of these land use components (e.g., the income and occupation composition of the residents in a community and the kind of jobs offered in the activity location).

Another component that determines the amount of opportunity available the ease of interaction for each resident with the activities he is interested in. The transportation system is the major component which determines the spatial impedance between two places. Impedance can be measured in several ways. Airline distance is the easiest, but one of the least appropriate measures in the urban area. Over-the-road distance is another impedance measure that coincides with the actual length of the trip. If all the trips are made by only one mode of transportation, this is a good measure of impedance. However, there are many modes of transportation such as walking, cycling, automobile, bus transit, rail transit, etc. Each mode has different speed, and the time required to traverse the same distance differs according to the average speed of each mode. The time required for making a trip to and from the activity location is considered as the additional time to be spent for that activity. For example, those who spend one hour (one way) to commute, work the same time as those who commute half an hour (one way), and the time the former spend for the working activity is one hour longer than the latter though their wages per day are the same. The total time available for a person is constant (24 hours a day), and so the time used for the trip is wasted except when the trip itself is the purpose (e.g., the scenic drive). The longer the time required to make a trip, the more people are discouraged from making such trips. Accordingly, time and distance is a good measure of spatial impedance.

There is another important measure related to the travel impedance. As mentioned above, the time spent for the commuting trip results in the reduction of the hourly wage level. In other words, one must actually work longer to cover the cost of commuting. There are more explicit costs related to the trip. The simple transportation cost that each individual traveler must spend directly is the transit fare, fuel consumption and maintenance of automobile, parking costs etc. There are other costs indirectly borne by the individual travelers. The cost of construction and operation of the system, its maintenance costs, air and noise pollution, partial loss of the esthetic value of the environment, and severance of some communities by the right-of-way of the transportation facility are examples of such costs. These indirect costs are to be considered as factors which influence the value of the whole community rather than any individual's socio-economic status. In this study we will consider only the direct costs in computing travel impedance. The amount of direct costs required to make trips is termed travel cost.

Some of the remaining factors which influence the ease of interaction are convenience, comfort, safety, and other non-measurable psychological factors. These are also important but more difficult to quantify for incorporation into the model.

The ease of interaction is dependent not on a single impedance factor, but the combination of these factors described above. In order to keep the model simple, we will use an abstract measure of travel impedance which is the combination of time distance and travel cost.

The opportunity index is thus defined as some combination of the attraction and impedance factors mentioned above. There are various ways that these factors can be combined. The one we used in our model is straightforward gravitational-type formula which will be discussed in detail later.

Let us go back to the satisfaction level function given before:

$$SL = f (Op, Se)$$

This relationship can be shown as a surface in three-dimensional space. If we assign the opportunity value to the x axis, the socio-economic status value to the y axis, and the satisfaction level to the z axis, a surface is determined by the above equation. Various combinations of opportunity and the socio-economic values give unique values, each of which represents a point on the satisfaction level surface.(See Figure 2).

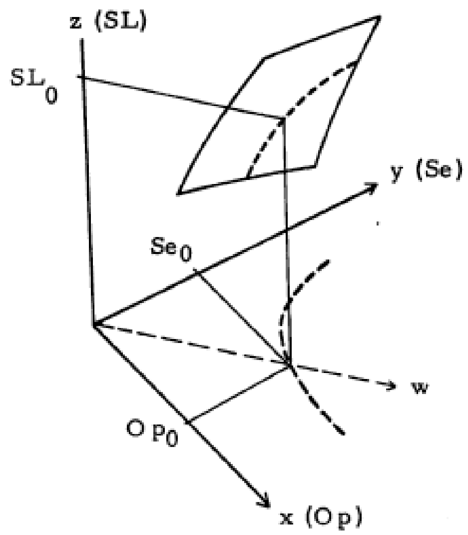

Figure 2. Three-dimensional Illustration of the Equation 2

After many experiments and surveys of actual data, we can plot sets of values (Op and Se) and connect the points which have the same SL (Satisfaction Level) value to form a curve. This curve is nothing more than the projection of the intersection of the satisfaction level surface and a plane which is parallel to the x-y plane. Therefore, different curves can be drawn for different SL values on the two-dimensional x-y plane. By such an inductive method, the satisfaction level equation can be obtained. A trade-off relationship between opportunity and socio-economic status is defined by each of these curves. Each curve represents a particular trade-off relationship between opportunity and socio-economic status for a unique level of satisfaction. Though it is beyond the scope of this study to conduct an actual survey concerning these values and we cannot derive these relationship inductively, we can develop our theory based on the deductive method.

Given certain opportunity and the socio-economic status values, we obtain a single satisfaction level value which is the value for the individual who share certain combinations of the above two indices. This satisfaction level is always the same for a given class of people who live in a specific urban region at a particular point in time. Therefore only one point is given for one combination of opportunity and the socio-economic status values. The values of opportunity index or socio-economic status index change continuously, and the transformation of two-dimensional Cartesian space (x-y plane) to the third dimension (z axis) is done by the function given in Equation 2.

The surface determined by this function is named the satisfaction level surface, and the distance from this surface to the base plane is the average satisfaction level the people who possess those combination of opportunity and socio-economic status values which are expressed as the coordinate point in the base surface.

The general characteristics of the satisfaction level surface are described below.

(1) Relationship between Op and Se

If we assume the simple linear relationship between opportunity and the socio-economic status, for instance, the arithmetic sum of two indices, the iso-satisfaction level curve will become linear. However, the trade-off relationship between these two indices cannot be expressed as a simple linear function. As is shown in the two-commodity case in the utility theory of economics, a number of units of one good cannot always be substituted for the same number of units of the other.

Suppose that the indifference relationship between opportunity and socio-economic status is expressed as a straight line as shown in Figure 3(a). Then people who have no opportunity (i.e., who are completely immobile), but are very well off, are assumed to have the same level of satisfaction as the people who have a moderate opportunity and are in a moderate socio-economic status. At the other extreme, people who are very badly off, but have a high opportunity are satisfied as much as the people who have moderate level of opportunity and socio-economic status. This is not usually the case in a typical society. The people in the extremely low socio-economic status would prefer an increase of one unit of socio-economic status for more than one unit of opportunity, because for these people the urgent concern is to increase their level of the socio-economic condition. They will be willing to give up several units of opportunity to gain an additional unit of socio-economic status. The same argument can be applied to the other extreme category which has high socio-economic status but very low opportunity.

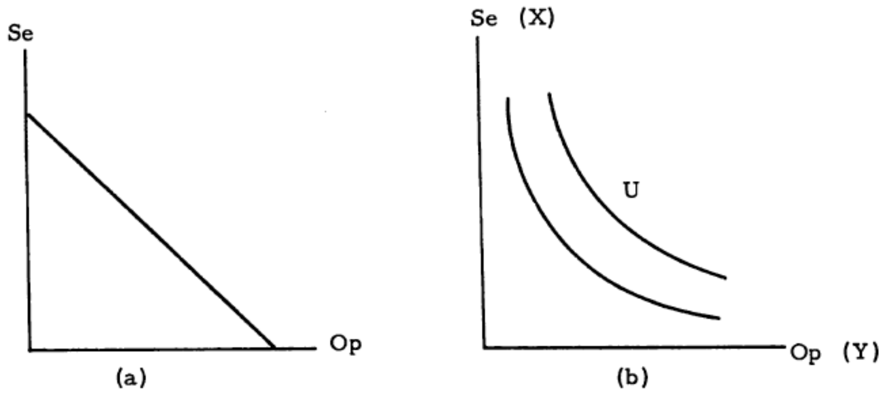

Figure 3. Indifference Relationship between Op and Se

In the concepts of utility theory in which two commodities are available, the indifference curve between two commodities X and Y (or in our case, two attributes of the level of living quality) has the following characteristics: for any given value of the utility index, U, an increase of X is accompanied by a decrease of Y; that is the slope of each curve in the indifference map is negative and the curve is convex toward the origin (See Figure 3(b)). Some mathematical functions which satisfied this condition the various types of generalized hyperbolas and closed ovals with the centers at a point distinct from the origin. In our study, the hyperbola function is used.

(2) Shape of Satisfaction Level Surface

The function is increasing as opportunity and/or socio-economic status increase, and the rate of increase attenuates as the satisfaction level becomes higher. The notion here is that the people in the low satisfaction levels are very sensitive to the change of either opportunity or the socio-economic status, but that those in the higher levels are less sensitive to a change in these indices. This is illustrated in the following example. Let us assume there are two persons who have different levels of satisfaction (i.e., the aggregated amount of Op and Se differs between them). A has 5 units of Op-Se (denoting the combination of Op and Se indices), and B has 50 units. The change of one unit of Op-Se is 20% change for A, but only 2% change for B. Accordingly, the gain or loss of one unit of Op-Se is quite significant to A's satisfaction level, but it will not affect B's satisfaction level much.

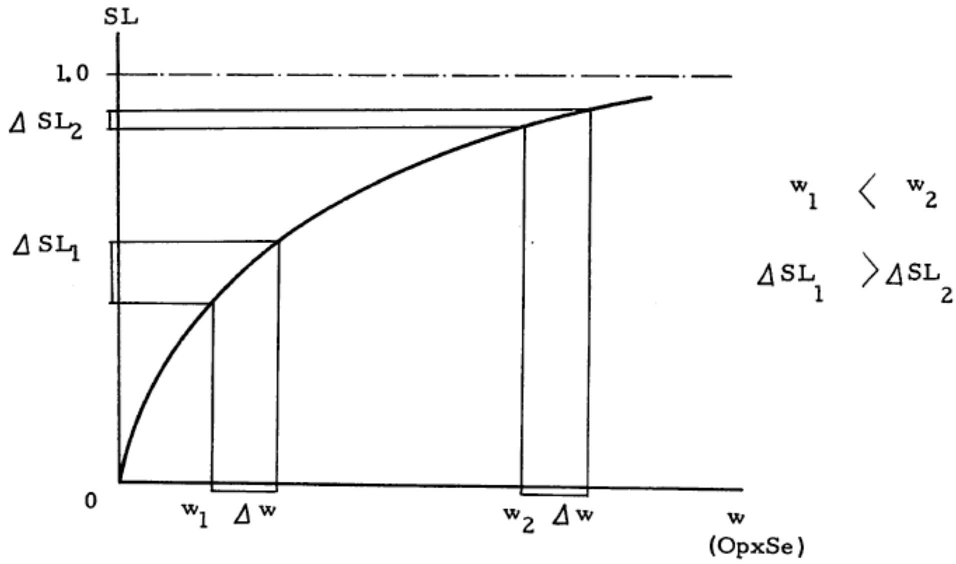

Figure 4. Satisfaction Level Curve (cross-sectional view)

This can be explained if we apply the concepts of utility theory. In our case, the satisfaction level is considered to be similar to utility, and both opportunity and the socio-economic status are goods which have prices. The measurement of opportunity and socio-economic status in monetary terms is not discussed here, but it is enough to say that these two indices can be considered to be additive when converted to equivalent monetary quantities with prices. Using the same analogy, we can draw a diminishing marginal satisfaction level curve (See Figure 4). The curve described in Figure 4 is a cross-section of the satisfaction level surface formed with the plane determined by the z (SL) axis and the point (Op, Se). If we take the line which goes through origin and (Op, Se) on the x-y plane as the w axis, the equation of satisfaction level is given as follows:

$$Z = 1 - \exp(-w / k) \qquad \text{(Equation 3)}$$

Where: k: constant

To combine the above two characteristics, the following three-dimensional sketch of the satisfaction level surface is given (see Figure 5).

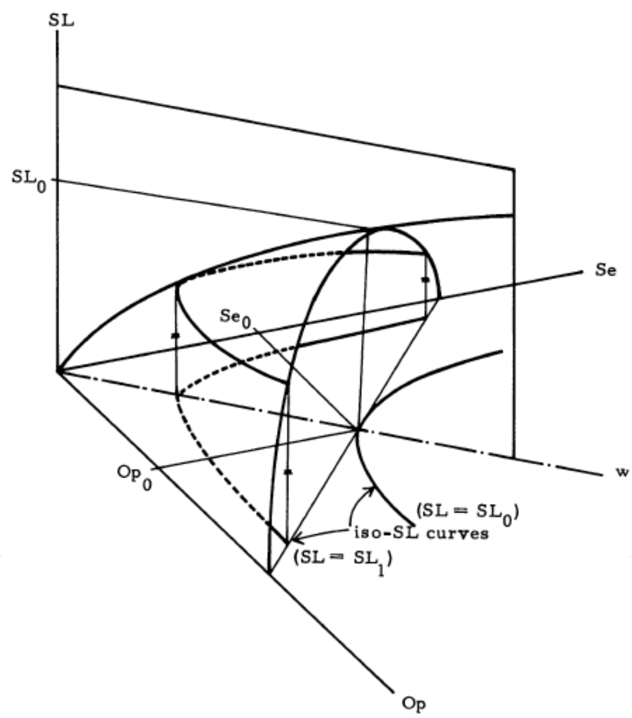

Figure 5. Three-dimensional Illustration of Satisfaction Level Surface

One simple example of the equation of such surface is the combination of an exponential and a hyperbolic functions as follows:

$$SL = 1 - \exp(-Op \times Se) \qquad \text{(Equation 4)}$$

This function is only one of the many surfaces which could be used to approximate the actual relationship among these three parameters which would be obtained by some experiments or actual survey.

Here we describe the nature of the satisfaction level surface and its relation with the opportunity and the socio-economic status indices. This relationship is one of the essential elements in our model construction and subsequent development of methodology.

3 General Methodology and Expected Results

In the previous section, we listed three components of the urban system: the land use configuration, the transportation system and the socio-economic status of the individual resident. These three components are subdivided into the following factors:

a) Land use configuration

- Size, kind and the location of non-residential activities
- Number, density and the location of residential activities

b) Transportation system

- Transportation networks, location and length
- Service level (speed, capacity, cost, frequency, safety, comfort, etc.)

c) Socio-economic status

- Income level of individual resident or household
- Occupation of individual residents or household

In the real world, these factors are interdependent and it is difficult to understand the mechanism of their interactions. To attack this problem, we have adopted a comparative statistics approach. By changing only one of the factors at a time while holding the others constant, we will be able to trace out the effect of changes in that factor.

Throughout this study, two of the three above components (i.e., land use configuration and the socio-economic status) are held constant. We chose to change only the elements of the transportation system first in order to explore the degree to which the existing opportunity and the satisfaction level distribution pattern can be influenced by changing only the configurations of the transportation network. Such a problem is common in transportation planning. The approach is oriented to finding the best possible incremental changes in the system. Our initial purposes are to evaluate existing plans or programs of transportation system improvements, and to choose the best from among many alternative proposals, or to generate an entirely new transportation network or to propose ways to improve the existing network in order to satisfy the predetermined objectives.

The objectives to be attained in this model are not uniquely determined. It is the role of the planners to feed the objectives into the model as the input data based on their best estimates of the social, political, and economic objectives at which the society aims. These objectives need not be fixed but can be changed according to the output of the model. This flexible characteristic of objective setting enables the interactive process between man and machine, who are cooperatively improving the results. In our initial study, we assume the following objectives:

a) The priority weight is given to the low satisfaction level zone more, but the actual choice of the links to be improved is also dependent on the number of people in each zone (weighted by the satisfaction level).

b) The system should be as efficient as possible in terms of the weighted potential trips, i.e., the process is aimed at the maximum loading of the potential trips.

These objectives are arbitrary but reasonable when we consider the social role of transportation systems, though more detailed discussion is needed.

The study is divided into three stages. In the first stage of a model is constructed that is designed to enable us to measure the satisfaction level of each urban resident under a given condition. At this stage the model computes the indices for a set of input conditions. As the stage of the study proceeds, this portion of the model is incorporated as a part of the larger system.

The second stage of the study is oriented to the problem of selecting and making changes in the transportation system (i.e., development of a network change procedure). An attempt has been made to develop an automated network generation procedure, which is similar to the intuitive decision-making process of the transportation planner. The decision criteria for selecting the specific links to be improved are derived from the prespecified objectives such as the increase in the mean satisfaction level (i.e., an area-wide improvement) or a decrease in the standard deviation of the satisfaction level distribution (i.e., the equalization of opportunity among the urban residents).

The network generation procedure can be used to add new links to the high-type transportation system, and to delete those existing high-type links which are not heavily used. It can start from the null condition where no high-type system is in existence, or from an existing high-type network.

At this stage the model is operated iteratively to provide an incremental improvement process which continues until some conditions are satisfied. Change of the parameters of the model influences the result of network formation, and those sensitivities are discussed extensively in the next stage.

The third stage of the study involves the conduct of various experiments. The emphasis of the experiments is on the effect of a changing parameters in the model in the formation and performance of the network, and on a test of the possibility of using man-machine interaction (i.e., interactive computing) in the transportation planning process. For the former purpose, the main experiments are conducted with a rather simplified network base by changing the parameters in various ways. For the experiment of man-machine interaction, a larger network base is used. From these experiments, we expect to learn several things. What values of the parameters give the best results in terms of the objectives? How does the starting condition influence the network performance? How different are the alternative network patterns generated by the different set of parameters? To what extent can human intuition be utilized in the planning process? Are there any counter-intuitive results in the computer generated transportation network? How can heuristic methods be applied in this process? The questions are to be answered in the experiments.

The study is expected to produce several meaningful results. Among them are:

a) The distribution of the satisfaction level as well as the opportunity and the socio-economic indices among urban residents.
b) The nature of the transportation network configuration and its impact on the distribution of above indices.
c) The relationship between network performance and the physical pattern of the network configuration.
d) The guidance of the strategy of network improvement for the planner.
e) The elaboration of the network formation through the man-machine interaction process.
f) The limit of the improvement which is attainable by the transportation system improvement alone, and the necessity of the improvement of the other factors.
g) Some initial justification of the trade-off function between transportation and other factors.

4 Conclusions

The model developed in this study has several unique characteristics which do not appear in other studies of this kind. They are:

1) The satisfaction level of individual urban residents is used to represent his quality of life. Actually, this index should be multi-component index, but in this study only two components has been included. They are the opportunity index and the socio-economic status index.
2) A calibration method for determining the satisfaction level function has been developed which is based on setting the median satisfaction level of the baseline situation equal to the midpoint of the range of the satisfaction level index.

3) A weighting function was derived from the calibrated satisfaction level function. This weighting function reflects the local planning policy and is intended to give priority for transportation facility improvements to those geographic areas where the satisfaction level index is low.
4) The societal objectives were stated as a desire to increase the set to be the betterment and equity of the satisfaction index distribution among the urban residents. The model was designed to find a transportation network configuration that satisfies these objectives to the greatest possible extent.
5) The actual choice of the specific links to be improved is determined from an analysis of weighted potential loading procedure, in which the poorly satisfied people are assigned more weight than those who are highly satisfied in terms of their relative status and opportunity levels.
6) The evaluation of the results is measured by a performance measure called weighted population, which expresses the distribution of the weighted population in terms of the weighting scheme which has been adopted as a planning policy. Given this policy, we can measure the performance of alternative designs from the same standpoint.

Several experiments revealed many interesting characteristics of the model. The most important findings are that the model has consistently produced high performance network designs under a wide variety of starting condition and parameter variations. This suggests that the traditional network design method will not be able to achieve societal goals we have focused on. The network design problem addressed in this paper is a combinatorial problem of nearly infinite size. Our model can be used to define some approximate boundaries to this combinatorial space. These boundaries can be used to evaluate alternative transportation network designs from an explicit and socially relevant position.

Acknowledgement

This research has been supported by the U. S. Department of Transportation and U. S. Department of Housing and Urban Development under Joint Grant No. WASH-R11-32-69/URT-16 and conducted under the auspices of the Research and Training Program in Urban Transportation, University of Washington, Seattle.