CHAPTER 2

Transportation Planning and Modeling

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Transportation can have significant effects on *mobility*, *economic development*, *environmental quality*, *government finance* and the *quality of life*. Wise planning is, thus, needed to help create high quality transportation facilities and services at a reasonable cost with minimal environmental impact and to enhance economic activity. Failure to plan can lead to severe traffic congestion, dangerous travel patterns, slow economic growth, adverse environmental impact and wasteful use of money and resources.

Transportation planning is a process that develops information to help make decisions on the future development and management of transportation systems, especially in urban areas. It involves the determination of the need for transport facilities such as new highways, transit systems, freight facilities, and transportation terminals. The planning process also allows determining the location, capacity and management of these facilities.

Transportation planning is primarily focused on developing long range (15-30 years) transportation plans that can be used to set priorities for project implementation in the future. Such plans should ideally balance the need to build new roads and transit facilities (supply) with future travel demand patterns with a minimum of environmental effect and within the funding capabilities of the government agencies involved.

Problems addressed can range from broad issues of policy at the federal or state level to specific programs and projects at a local level. Besides problems of congestion and travel growth, these could include the following:

- Travel demand alternatives for congestion reduction
- Land use/transportation coordination
- Fuel reduction measures
- Air quality measures
- Safety measures
- Economic development/redevelopment activity

The transportation planning process is direct application of problem solving via system analysis. It provides a framework for the identification of transportation problems and the development of alternative potential solutions. In its simplest form, it can be depicted by figure 2.1.

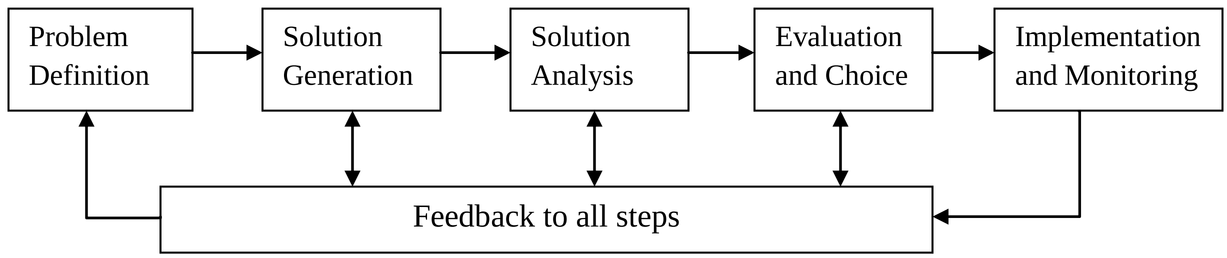


Figure 2.1-The Transportation Planning Process

The simplified planning process can be summarized as follows:

- A problem is a deviation from expected or desired performance. Goals and objectives, reflecting national or regional values, define the expected or desired performance.
- Solution generation is a subjective process that reflects regional goals and objectives, the nature of the identified problems, the nature of the existing transportation system and regional preferences, as much as it reflects technical and economic functionality.
- When the set of alternative solutions is identified, the process enters solution analysis where each alternative is subject to formal technical analysis (such as transport models) to assess resulting performance.
- The estimated performance of each generated alternative is then evaluated using various measures of performance (MOEs). These MOEs describe volumes, travel times or speed on links and intersections, and the associated impacts (such as air quality or noise). The MOEs must also be coupled with estimated cost and standard economic analysis techniques to assess the relative overall performance and cost of each alternative.
- The preferred alternative is selected for implementation, thus entering programming and project planning processes. Once the selected option is implemented, the overall system must be monitored to assess (a) real-world performance, (b) the degree that the problem has been addressed, and (c) the emergence of additional performance problems.

The transportation planning process is continuous- it is applied simultaneously at multiple levels, including various spatial scales. It is also characterized by extensive feedback. The process may iterate in defining alternatives and then estimating and assessing the associated performance. The results might be that new alternatives must be found, or perhaps the problem needs to be re-defined. Note that the planning process continues both during and after project construction to assess the effectiveness of the selected alternative in addressing the identified problems.

2.1 Transport Policy and Strategic Planning

Policy, defined conservatively, is a guiding principle that influences how a system behaves. It is a plan of action agreed on or chosen by a government, business entity etc. to satisfy the desires of a society. In this broad sense, a **transport policy** is a guiding principle that influences how the transport system should behave to achieve desired outcomes and avoid transport problems. Examples of such policies may include road expansion plans, transit system priorities, fuel tax, emission limits etc.

It is the task of politicians, and of the skilled professionals who advise them, to identify the most appropriate solutions to today's and tomorrow's transport problems. These solutions form the basis of a transport policy, which can be designed for a nation, a city, a town or a rural area. But it is essential that professionals are clear on the reasons for such solutions: that is, that the *objectives* which are to be achieved should be specified.

An objective is a statement of a desired end-state. However, that statement can range from the very general, such as a successful urban economy or a high standard quality of life, to the very specific, such as avoiding pollution levels above a specified threshold. Both are helpful, the first in providing the context for the strategy, and a direction to it; the second in providing a basis for assessing whether the objective is being met. Objectives in transport policy can be categorized into four classes:

- **Statements of Vision:** Broad indications of the type of area which politicians or the public wish to see. These serve to identify long-term goals to which more detailed transport policy objectives can contribute. These broad statements often say nothing about transport itself: instead they raise the question:"how best can transport help to realize this vision?'.
- **Higher level objectives:** These higher level objectives, sometimes referred to as aims or goals, identify attributes of transport system, or its side effects, which can be improved as a means of realizing the vision. Typical among are to reduce congestions, protect the environment, avoid accidents and improve accessibility. These broad objectives indicate the directions in which strategies should be developed.
- **Quantified objectives:** Quantified objectives may indicate a requirement, for example, to avoid residents without cars being more than 30 minutes from the nearest bus station. They provide a clear basis for assessing performance of the strategy, but they do require careful definition if the specified thresholds are to be

realistic. Once this is done, quantified objectives provide a direct basis for identifying problems, for current or future conditions, on the basis that a problem occurs wherever the quantified objective is not met.

- **Solution-specific 'objectives':** It is important to avoid specifying solutions within the objectives, since this constrains the search for solutions, and may lead to an overall strategy which is less appropriate to the area's needs. Where politicians, or interest groups, wish to introduce general objectives such as to impose physical restrictions on car use, it is preferable to ask why this solution is being proposed and what it is designed to achieve. Answer to such questions should lead to clearer specification of the true underlying objectives.

The transport policy formulation process

There are in practice two different types of policy formulation approaches: objective-led and problem oriented approaches.

1. **Objective-led strategy formulation:** broad (or more detailed) objectives are first specified. These are then used to identify problems by assessing the extent to which current, or predicted future conditions in the absence of new policy measures, fail to meet the objectives. Possible solutions are then identified as ways of overcoming the problems which have been identified. The potential solutions are then compared, often by means of predictive model of transport systems, by appraising them against the objectives which they are designed to meet. As the measures are implemented, their impact is assessed, through before and after studies, again in terms of achievement against objectives. On regular basis, too, conditions are monitored and the current conditions and problems are reassessed, in terms of overall objectives. Figure 2.2 presents a structure for strategy formulation in which objectives are the starting point.

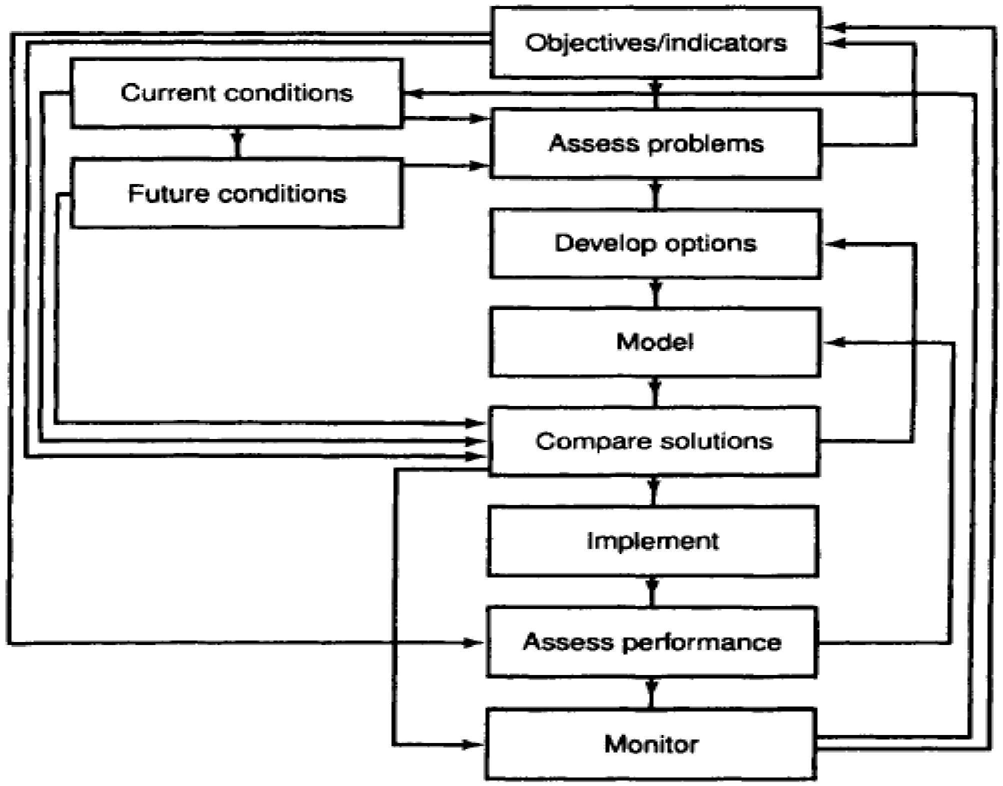


Figure 2.2 Objective-led policy formulations

This process may seem somewhat idealized and remote from standard practice, but it has several virtues. First, it offers a logical basis for proposing solutions, and also for assessing any proposals offered by others. Second, it ensures that the appraisal of alternatives is conducted in a logical, consistent, and comprehensive way against the full set of objectives. Third, assessing the performance of the implemented measures improves the ability to judge the potential of similar measures elsewhere, and to predict their impact. Fourth, regular monitoring provides a means of checking not just on the scale of current problems, but also, through attitude surveys, on the perception of those problems.

The main draw back with this approach is that many elected officials and the public are less familiar with the abstract concept of objectives (such as improving accessibility) than they are with concrete problems (such as the nearest job centre being 50 minutes away).

2. **Problem oriented approach:** The alternative problem-oriented approach is to start by defining types of problem and to use data on current (or predicted future) conditions to identify when and where these problems occur. This approach starts at the second box in the flow chart in figure 2.2. The objectives are implicit in the specified problem, and may never actually be stated.
   It has the merit of being easily understood. However, it is critically dependent on developing a full list of potential problems at the outset. If particular types of problem (like access to job centers) are not identified because the underlying objective (accessibility) has not been considered, the resulting strategy will be partial in its impact. It is thus probably still wise to check with elected members and the public that the full set of problems has been identified.

As noted above, the problem-oriented approach to transport planning starts by identifying problems and developing solutions to them. The objective-led approach defines problems in terms of specified objectives. Both methods converge at the stage of problem identification and then use these as a basis for identifying solutions and strategies (Figure 2.2). In either case it is essential to be comprehensive in the list of types of problem. This may be difficult to achieve with the problem-oriented planning approach in which there is no pre-defined set of objectives to prompt the question 'how do we know that we have a problem?'

Policy Instruments/Measures

Transport planners have available to them, at least in principle, a wide range of instruments/ strategies of transport policy. These are the means by which the objectives described above can be achieved, and problems overcome. These instruments can be categorized in several ways:

1. Infrastructures- new or expansion of roads, new rail lines, parking, pedestrian walk ways etc.
2. Management- traffic management, traffic calming, bus priorities, HOV lanes etc
3. Information- signs and markings, signals, real-time transit times etc.
4. Pricing- fuel taxes, bus fares, parking charges etc.
5. Land use- development densities, master plan, urban form etc
6. Attitudinal and behavioral measures

The key question with each of the measures is its ability to achieve one or more of the objectives.

(For more detail and exhaustive explanation of transport policy and strategies, please refer to O'Flaherty 1997, Chapters 3 and 6)

2.2 Transport modeling

Modeling principles

Models are a simplified representation of a part of reality. Their function is to give insight into complex interrelationships in the real world and to enable statements about what (most probably) will happen if changes occur or put in that (part of) reality.

Models are invaluable in offering a common ground for discussing policy and examining the inevitable compromises required in practice with a minimum of objectivity. During their formulation, calibration and use, planners can also learn much about the behavior and internal workings of the system under scrutiny.

However, a model is only realistic from a particular perspective. Its appropriateness is highly dependent on the context where it will be used i.e. its value is limited to a range of problems under specific conditions. Therefore, extreme care should be taken when choosing and adapting models for a particular context.

Transport models study of the behavior of individuals in making decisions regarding the provision and use of transport. Models in transportation planning are abstract mathematical models, put into the form of (systems of) mathematical equations in which the behavior of a dependent variable Y (e.g. the number of daily bus passengers in the Addis Ababa) can be derived from one or more explaining or independent variables X (e.g. number of transit lines, bus fares, etc) and related parameters a. Generally, they take the form;

$$Y = f(a, X)$$

Where, the parameters describe the sensitivity of Y to a unit change in X.

Model development starts from the formation of a hypothesis to explain the given phenomenon or system from a particular point of view. These sets of hypotheses will form the theory. The translation of such a theory into a quantitative model with quantifiable variables and associated parameters we call a conceptual model. The Estimation/ Calibration process determines the numerical values of the associated parameters from the given data. The model then needs further testing and verification on another set of data that has not been used during the calibration process. It is when the model is finally verified and approved that it can be applied to the transport system. The process of the model development is shown in the figure below.

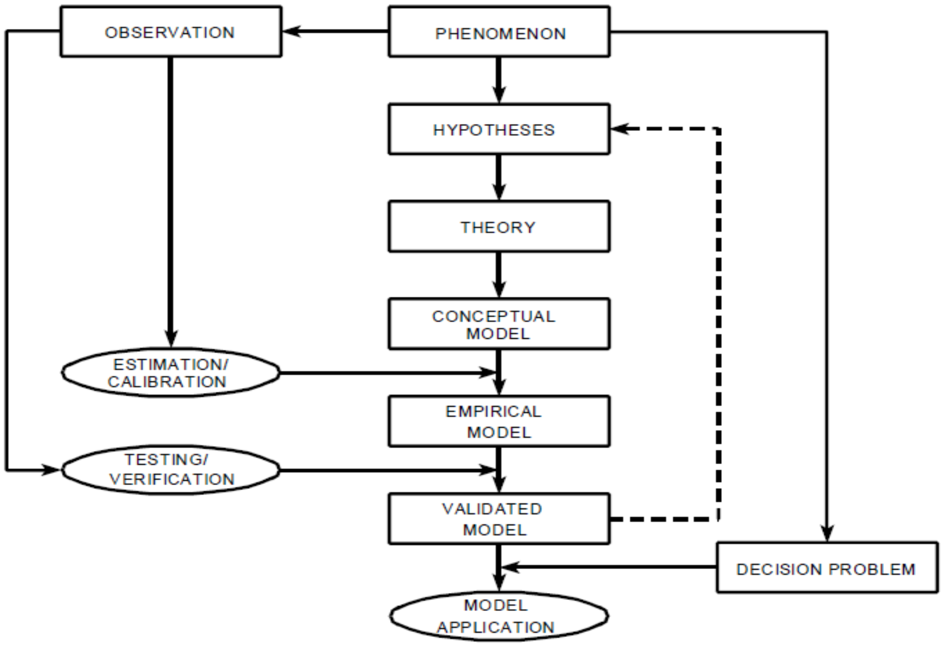


Figure 2.3 Model formulation process

The mathematical models have several purposes for transport planning, some of which are:

- To gain a modern structural analysis of the complex transport system
- To find out which factors play an important role, and how sensitive the transport system is to changes in the different factors
- To analyze the effect of alternative traffic projects and contribute towards their economic appraisal
- To help transport planners make reliable predictions and forecasts of future changes in usage of traffic facilities for sake of facility design, control and operation.
- To enable quantified calculations of expected effects in the transportation system when changes (policy measures or interventions) are put in the system
- To find design parameters that lead to an optimal performance of the modeled system

Thus, transport modeling contributes greatly to improved decision making and planning in the transport field. However, transport modeling is only one element in transport planning: administrative practices, an institutional framework, skilled professionals and good level of communication with decision makers, the media and the public are some of the other requisites for an effective planning system.

(For more detail on the basics of modeling, please refer O'Flaherty 1997 chapter 5)

Prerequisite for transport modeling

Before embarking on the modeling of transport systems in the context of this chapter, the modeler should be familiar with the basic terminologies, grasp the fundamental characteristics of transport problems, gather the necessary data and understand basic regression analysis. These four prerequisites are treated in more detail below:

Characteristics of transport problems

Both the demand for travel and the supply for transport facilities exhibit distinct characteristics that the modeler should bear in mind. These characters include:

- The demand for transport services is highly qualitative and differentiated. There is a whole range of specific demands for transport which are differentiated by time of day, day of week, journey purpose, type of cargo, and so on.
- The demand for transport is derived; it is not an end by itself. People travel in order to satisfy a need (work, leisure, health) at their destination.
- Transport demand takes place over space. It is the distribution of activities over space that makes for transport demand.
- Both transport demand and supply have very strong dynamic elements. A good deal of the demand for transport is concentrated on a few hours of the day.
- Transport is a service and not a good. Therefore, it is not possible to stock it.
- The transport system requires fixed assets and the mobile units. It is often the case that the infrastructure and the vehicles are not owned nor operated by the same entity.
- Transport infrastructure is lumpy; one cannot provide half a runway or one-third of a railway station. They take a long time to carry out and significant expenses.
- Transport investment has an important political role.
- Transport services come with side effects: accidents, pollution and environmental degradation.

Basic terms and definitions

Activity	An *activity* occurs at the end of every trip and reflects the trip purpose, that is, what the trip maker did at the trip destination. *Activities* are categorized according to schemes such as subsistence/maintenance/discretionary or work/shop/social/etc.
Calibration	Calibration is the fitting of a model to observed data, primarily by adjusting model parameters. In travel forecasting, the terms estimation and calibration often have been used interchangeably.
Centroid	A defined point within a TAZ from which all trips are assumed to start or end. It should be located to reflect the center of activity in a TAZ and not necessarily the geographic center.
Centroid Connector	Abstract links that connect centroids to network nodes and represent general access from a TAZ to the formal transportation network.
Corridor	A linear study area along one or more transportation facilities for which estimates of travel demand and system performance are desired.
Cordon Line	An abstract line defining the external boundary of a study area.
Estimation	Estimation, part of the model specification process, is the formal computation of the parameters for a hypothesized model, to maximize the likelihood of fitting observed data.
External Station	A "door" on the cordon line of a study area corresponding to major entry and exit points for external trips through, into, and out of the study area.
Home-based	A classification for trips that either begin and/or end at a trip maker's home regardless of the origin and destination, the home location is always the production for home-based trips; the other end is always the attraction.
Home-based Other	A trip with one end at home and the other end at a non-work location.

Home-based Work	A trip with one end at work and the other end at home.
Household	A fundamental sampling unit for travel surveys, the household (HH) is a behavioral unit of one or more individuals who share a dwelling unit, resources (e.g., income, automobiles), and travel responsibilities. Interaction among HH members influences travel and activity behavior.
Impedance	Impedance, a computed measure of the disincentive to travel due to spatial separation, is a composite function of travel time (often split by access, in-vehicle, and egress time), travel cost, and/or distance.
Incidence Matrix	An efficient means of storing network topology relationships, including node-link, link-path, and path-OD incidence matrices.
External Trip	A trip with either its origin or its destination located outside of the study area. The external trip end is assigned to an external station.
Internal Trip	A trip with both its origin and its destination located inside of the study area. If both trip ends are outside the study area, it is a through trip.
Inter-zonal Trip	A trip between two different analysis zones.
Intra-zonal Trip	A trip with both origin and destination in the same zone. In trip assignment, intra-zonal trips are not loaded on the network.
Land Use	The primary activity for which a parcel of land is used (residential, commercial, industrial, open space, undeveloped, etc.).
Link	A fundamental element of a transportation network defined by a starting and an ending node and having attributes such as length, travel time and/or speed, and capacity.
Mode	A means of conveyance between origins and destinations, modes are motorized (cars and other private vehicles, buses, rail transit) and non-motorized (walking, bikes).

Network	A graphical and/or mathematical representation of a region's transportation infrastructure and services, comprising links and nodes and their corresponding characteristics.
Node	A point joining two or more links in a transportation network, and having attributes such as spatial coordinates, turn penalties and prohibitions.
Non-Home-Based	A classification for trips which neither begin nor end at a trip maker's residence (home). The origin of a NHB trip is also the production; the destination of a NHB trip is also the attraction.
OD Matrix	A trip table in origin / destination format
Origin	The location or zone where a trip begins
Parameter	A constant describing a population property utilized in a model development process.
Path	A sequence of links and nodes connecting an origin to a destination in a network. Used interchangeably with route.
Peak Hour	For a transportation facility or network, the hour of the day during which the maximum traffic volume occurs.
Person-Trip	A single trip by a single person. The output of trip generation is measured in person-trips. On the other hand, a vehicle-trip is a single trip by a vehicle, regardless of the number of occupants in the vehicle.
Prediction	A general term for the estimation of the value of a variable of interest in an unknown situation.
Production	The location or zone responsible for a trip occurring but also used for the produced trip itself: a zone is a production for N trip productions). Home-based trips, by definition, have their production in the zone containing the household, regardless of the origin and destination of the trip. The productions for non-home-based trips must be allocated to the NHB trip's origin zone.
Route	A path through a network; a series of links and nodes connecting an origin

	and a destination. Used interchangeably with path.
Study Area	A defined region within which estimates of travel demand and system performance are desired.
Traffic Analysis Zone	A defined zone for travel forecasting and traffic simulation studies, represented in the network by a centroid.
Transportation System	The Transportation System constitutes the networks (modes, links, nodes, etc.) connecting a region's Activity System.
Validation	An independent test of a calibrated model's predictive capabilities using data that was not used in estimating or calibrating the model. The objective is to verify that the model can replicate observed system performance.

(For exhaustive terminologies, visit http://www.its.uci.edu/~mcnally/tdf-glos.html#t courtesy of Professor M.G. McNally)

Data requirements

Since transport models are applied to large systems, they require information about travelers of the area influenced by the system. Here the data requirement is very high, and can be broadly categorized into four:

- **Socio-economic data:** Information regarding the socio-economic characteristics of the study area. Important ones include income, vehicle ownership, family size, etc.
- **Travel surveys:** Origin-destination travel survey at households and traffic data from cordon lines. Former data include the number of trips made by each member of the household, the direction of travel, destination, the cost of the travel, etc. The latter include the traffic flow, speed, and travel time measurements.
- **Land use inventory:** This includes data on the housing density at residential zones, establishments at commercial and industrial zones.
- **Network data:** This includes data on the transport network and existing inventories. Transport network data includes road network, traffic signals, junctions etc. The service inventories include data on public and private transport networks.

The data required for modeling is primarily collected through surveys. These surveys include:

- Household survey
- External cordon and Intercept surveys
- Travel Diary
- O-D survey
- Questionnaire
- In-house and Roadside Interviews

Designing the data collection survey for the transportation projects requires considerable experience, skill, and a sound understanding of the study area. It is also important to know the purpose of the study and details of the modeling approaches. Further, many practical considerations like availability of time and money also has a strong bearing on the survey design.
(For more on data collection and sampling, please refer chapter 3 of Ortuzar & Willumsen 2001)

Mathematical background

For this particular chapter, the modeling student needs to revise:

- Multiple regression analysis
- Elementary statistics

(For more on the basic mathematical requirements, please refer chapter 2 of Ortuzar and Willumsen 2001)

The Four step model

The most popular of the transport modeling approaches is the classic Four-Step Model (FSM). The FSM aims to establish the spatial distribution of travel explicitly by means of an appropriate system of zones. It is presented as a sequence of four mathematical sub models:

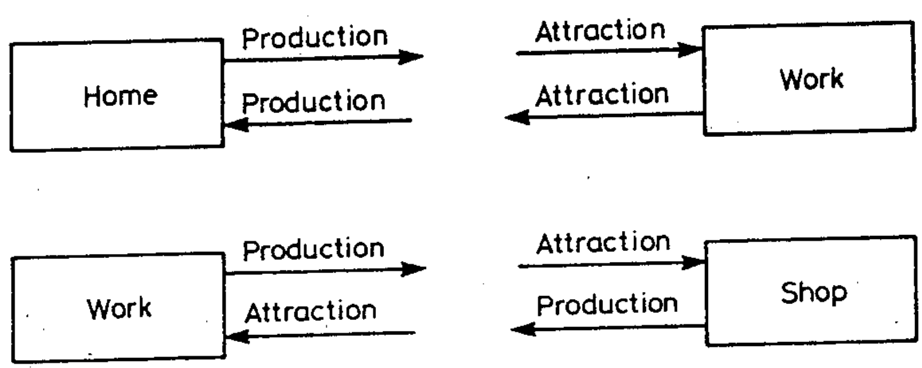
1. **Trip generation**- forecasts the number of trips that will be made.
2. **Trip distribution-** determines where the trips will go.
3. **Mode usage-** predicts how the trips will be divided among the available modes of travel.
4. **Trip assignment-** predicts the routes that the trips will take, resulting in traffic forecasts for the highway system and rider-ship forecasts for the transit system.

In a nutshell, the FSM aims at explaining where the trips come from and where they go, and what modes and which routes are used. The four sequential models result with the volume of traffic on the road network, the level of service and travel attributes on each link, the split between the private vehicles and the public transit, etc. They can also project the level of traffic and the challenges to be faced in the future.

1. Trip Generation

Some basic Definition

- **Home-Based (HB) Trip:-** one where the home of the trip maker is either the origin or the destination of the journey.
- **Non-Home- Based Trip:-** one where neither end of the trip is the home of the traveler.
- **Trip Production:-** is the home end of an HB trip or the origin of an NHB trip.
- **Trip Attraction:-**is the non-home end of an HB trip or the destination of an NHB trip.



Example 1

Trip Generation is Define the magnitude of total daily travel in the model system, at the household and zonal level, for various trip purposes (activities).

The objective of this first stage of the FSM process is to define the magnitude of total daily travel in the model system, at the household and zonal level, for various trip purposes (activities). This first stage also explicitly translates the FSM from activity-based to trip-based, and simultaneously separates each trip into a production and an attraction. It aims at predicting the total number of trips produced in the zone and attracted by it respectively for each TAZ of the study area. It has two basic functions:

- To develop a relationship between trip production or attraction and land use, and
- To use the relationship developed to estimate the number of trips generated at some future date under a new set of land-use conditions.

Trip generation (both production and attraction) depends on the nature and characteristics of the activity system. In production models, estimates are primarily based on the demographics of the population within a zone. For attraction models, the variables that have been found to have the best explanatory power are those based on characteristics of the land use, such as office and retail space or the employment levels of various sectors.

Some factors which have been found to have a considerable impact on the trip producing capacity of a TAZ are:

- Income
- Car ownership
- Household structure
- Family size
- Value of land
- Residential density
- Accessibility

While the following factors are widely used with the affinity of a zone to attract trips:

- Employment
- Sales
- Space available for industrial, commercial or other services

Trips can be modeled at the zonal, household, or personal level, with household level models most common for trip productions and zonal level models most common for trip attractions. Furthermore, it have been found in practice that better trip generation models can be obtained if trips by different purposes are identified and modeled separately. In the case of home-based (HB) trips, five categories have been usually employed:

- trips to work
- trips to school
- shopping trips
- social and recreational trips
- other trips

It is also important to classify trips into peak and off-peak periods as the proportion of journeys vary greatly with the time of the day. It is also wise to differentiate trips into personal and freight as the two types have significant difference in nature and characteristics.

Several modeling approaches are available for trip generation including growth factor, regression, discrete choice and category classification. In this course, only growth factor modeling and regression analysis will be discussed.

Growth Factor Models

Growth factor model tries to predict the number of trips produced or attracted by a house hold or a zone as a linear function of explanatory variables. The model has the following basic equation:

$$T_i = f_i t_i$$

Where T_i is the number of future trips in the zone and t_i is the number of current trips in that zone and f_i is the growth factor.

The growth factor f_i depends on the explanatory variable such as population (P) of the zone, average house hold income (I), average vehicle ownership (V). The simplest form of f_i is represented as follows:

$$f_i = \frac{f(P_i^d, I_i^d, V_i^d)}{f(P_i^c, I_i^c, V_i^c)}$$

Where the subscript "d" denotes the design year and the subscript "c" denotes the current year.

The growth factor method delivers a simple and easy to understand formulation. However, the method has usually resulted in an over-estimated number of trips (Check examples). Such an error at the early stage of the FSM will be carried down to the subsequent stages and will grossly mislead planners and decision makers.

Therefore, the growth factor method is only used in practice to predict the future number of external trips to an area. This is because they are not too many in the first place (so errors cannot be too large) and also because there are no simple ways to predict them.

Example 2

Regression analysis models

Regression methods can be used to establish a statistical relationship between the number of trips produced and the characteristics of the individuals, the zone, and the transportation network.

The most common form of trip generation model is a linear multiple regression function of the form:

$$T_i = a_0 + a_1 x_1 + a_2 x_2 + \ldots a_i x_i \ldots + a_k x_k$$

Where, x_i are explanatory variables such as income, car ownership, population etc. and T_i is generated trip. a_i are parameters determined through calibration process.

Model parameters and variables vary from one study area to another and are established by using base-year information. Once the equations are calibrated, they are used to estimate future travel for a target year. In developing regression equations the following is assumed:

1. All the independent variables are independent of each other.
2. All the independent variables are normally distributed.
3. The independent variables are continuous.

Two types of regression models are commonly used. The first uses data aggregated at the zonal level, with average number of trips per household in the zone as the dependent variable and average zonal characteristics as the independent (explanatory) variable. The second uses disaggregated data at the household or individual level, with the number of trips made by a household or individual as the dependent variable and the household and personal characteristics as the independent variables.

The zonal-based regression is a premier method for modeling trip attractions where as the household-based regression is primarily used with trip production.

(For more on trip generation models, refer chapter 4 of Ortuzar and Willumsen 2001 or chapter 4 of Bovy et.al 2006)

Example 3

2. Trip Distribution

The trip-generation analysis provides the planner with the numbers of trip productions and trip attraction that each zone will have. But where do the attractions in the zones come from and where do the productions go? What are the zone-to-zone travel volumes?

Trip-distribution procedures determine where the trips produced in each zone will go-how they will be divided among all other zones in the study area. The decision on where the trips go is represented by comparing the relative attractiveness and accessibility of all zones in the area.

The major product of trip distribution models is an O-D matrix that shows the number of trips originated in the study zone and where these trips are destined to. This is a two dimensional array of cells where rows and columns represent each of the zones in the study area. T_{ij} is the number of trips between origin i and destination j. O_i is the total number of trips originating in zone i and D_j is the total number of trips attracted to zone j.

Zones	1	2	...	j	...	n	O_i
1	T_{11}	T_{12}	...	T_{1j}	...	T_{1n}	O_1
2	T_{21}	T_{22}	...	T_{2j}	...	T_{2n}	O_2
$\vdots$	...	...	...	...	...	...	$\vdots$
	T_{i1}	T_{i2}	...	T_{ij}	...	T_{in}	O_i
$\vdots$	...	...	...	...	...	...	$\vdots$
n	T_{ni}	T_{n2}	...	T_{nj}	...	T_{nn}	O_n
D_j	D_1	D_2	...	D_j	...	D_n	T

where $D_j = \Sigma_i T_{ij}$,

$$O_i = \Sigma_j T_{ij}, \text{ and } T = \Sigma_{ij} T_{ij}.$$

Two basic categories of aggregate trip distribution methods predominate in urban transportation planning:

- The Growth Factor methods- These involve scaling an existing matrix (called base matrix) by applying multiplicative factors (often derived from predicted productions and/or attractions) to matrix cells.
- The Gravity Model- This explicitly relates flows between zones to inter-zonal impedance to travel. For gravity models, typical inputs include one or more flow matrices, an impedance matrix reflecting the distance, time, or cost of travel between zones, and estimates of future levels of productions and attractions.

The Growth Factor Methods

In this approach a base year matrix is needed. Each cell of this matrix is multiplied by a growth factor. Growth factors may be computed in a number of ways, e.g. as the output of an economic model, a trend model, etc. However, in these course notes, we only discuss methods of computing growth factors based on trip generation modeling.

The base year matrix contains an estimate of the trips being made in the base year. Depending on these estimates, we may be able to use different growth-factor methods in our estimation of future trip patterns.

Uniform Growth Factor

If the only information available is about a general growth rate for the whole of the study area, then we can only assume that it will apply to each cell in the matrix, which is a uniform growth rate. The equation can be written as:

$$T_{ij} = \tau t_{ij}$$

Where τ is the uniform growth factor, t_{ij} is the previous total number of trips and T_{ij} is the expected total number of trips.

Advantages are that they are simple to understand, and they are useful for short-term planning. Limitation is that the same growth factor is assumed for all zones, where as in most cases differential growth for different parts of the study area is expected.

Example 4

Singly Constrained Growth-Factor

If information is available on the expected growth of either trips originating or trips attracted to each zone, it will result in origin-specific τ_i and destination-specific τ_j growth factors respectively. In this case, the expected number of trips between origin-destination pairs is written as:

$T_{ij} = \tau_i t_{ij}$ for origin-specific factors

$T_{ij} = \tau_j t_{ij}$ for destination-specific factors

Example 5

Doubly Constrained Growth Factor

When information is available on the growth in the number of trips originating and terminating in each zone, we know that there will be different growth rates for trips in and out of each zone and consequently having two sets of growth factors for each zone.

This implies that there are two constraints for that model and such a model is called doubly constrained growth factor model. Historically a number of iterative methods have been proposed to obtain an estimated trip matrix which satisfies both sets of trip-end constraints, or the two sets of growth factors.

The best known of these methods is due to Furness (1965), who introduced balancing factors' A_i and B_j as follows:

$$T_{ij} = t_{ij}\tau_i\tau_j A_i B_j$$

Or incorporating the growth rates into new variables a_i and b_j:

$$T_{ij} = t_{ij}a_i b_j$$

With $a_i = \tau_i A_i$ and $b_j = \tau_j B_j$

The factors a_i and b_j must be calculated so that the constraints are satisfied. The procedure is:

1. Set $b_j = 1$
2. With $b_j = 1$, solve for a_i to satisfy trip generation constraint ($\sum_j T_{ij} = O_i$).
3. With a_i, solve for b_j to satisfy trip attraction constraint ($\sum_i T_{ij} = D_j$).
4. Update matrix and check for errors.
5. Repeat steps 2 and 3 till convergence.

The advantages of Growth Factor method are:

1. Simple to understand.
2. Preserve observed trip pattern.
3. Useful in short term-planning.

The limitations are:

1. Depends heavily on the observed trip pattern.
2. It cannot explain unobserved trips.
3. Do not consider changes in travel cost.
4. Not suitable for policy studies like introduction of a mode.

Example 6

<u>The Gravity model</u>

The gravity model derives its base from Newton's law of gravity, which states that the attractive force between any two bodies is directly related to their masses and inversely related to the distance between them. Similarly, in the gravity model, the number of trips between two zones is directly related to activities in the two zones, and inversely related to the separation between the zones as a function of the generalized cost. A more general term used to represent the generalized cost (for the separation between zones) is impedance or deterrence function.

In its simplest formulation, the model has the following functional form:

$$T_{ij} = \alpha O_i D_j f(c_{ij})$$

Where α is the proportionality factor and

$f(c_{ij})$ is a generalized function of the travel costs with one or more parameters for calibration.

The need to satisfy the constraints ($\sum_j T_{ij} = O_i$ and $\sum_i T_{ij} = D_j$) requires replacing the single proportionality factor α by two sets of balancing factors A_i and B_j as in the Furness model, yielding:

$$T_{ij} = A_i B_j O_i D_j f(c_{ij})$$

In the case of the doubly constrained model, the values of the balancing factors are:

$$A_i = 1 \Big/ \sum_j B_j D_j f(c_{ij})$$

$$B_j = 1 \Big/ \sum_i A_i O_i f(c_{ij})$$

The calculation of A_i and B_j, thus, requires an iterative process analogous to Furness's as shown in the Growth Factor modeling.

The deterrence function $f(c_{ij})$ is the essence of the gravity model. It takes several forms based on the decision of the modeler such as (the last one being empirical and more common):

$$f(c_{ij}) = \exp(-\beta c_{ij})$$

$$f(c_{ij}) = c_{ij}^{-n}$$

$$f(c_{ij}) = \sum_m F^m \delta_{ij}^m$$

Example 7-1

Other approach

The Gravity model is a synthetic model as opposed to the growth factor model. It estimates trips for each cell of the O-D matrix without directly using observed trip. This is the most widely used trip distribution model which states that the number of trips between two zones is directly proportional to the number of trip attraction generated by the zone of destination and inversely proportional to a function of time of travel between the two zones.

Mathematically, the gravity model is expressed as

$$T_{ij} = P_i \left[\frac{A_j F_{ij} K_{ij}}{\sum A_j F_{ij} K_{ij}} \right]$$

Where

T_{ij} = number of trips that are produced in zone i and attracted to zone j

P_i = the total number of trips produced in zone i

A_j = number of trips attracted to zone j

F_{ij} = a value which has an inverse function of travel time

K_{ij} = socioeconomic adjustment factor for interchange ij

The values of Pi and Aj have been determined in the trip generation process. The sum of the trip production for all zones must be equal to the sum of trip attraction for all zones.

Pattern i.e. it doesn’t require a base year matrix to forecast future trip patterns.

Note that the sum of productions in each zones is equal the number of production in the statement. However, the number of attractions estimated in the trip distribution phase differs from the number of attractions given. And it considered a **singly constrained gravity model.**

Hence, calculate the adjusted attraction factor according to the following formula

$$A_{jk} = \frac{A_j}{C_{j(k-1)}} A_{j(k-1)}$$

Where

A_{jk} = *adjusted attraction factor for attraction zone (column) j, iteration k*

A_{jk} = *Aj when k=1*

C_{jk} = *actual attraction (column) total for zone j, iteration k*

A_j = *desired attraction total for attraction zone (column) j*

j = attraction zone number, j=1, 2, 3…..n

n = number of zones

k = iteration number, k=1, 2, 3….n

m= number of iteration

To produce a mathematically correct result, repeat the trip distribution computation using the modified attraction values, so that the number of attracted will be increased or reduced as required. Therefore, the new attraction factors are adjusted downward by multiplying the original attraction value by the ratio of the original to estimated attraction values.

Example 7-2

3. Modal Choice

In this phase of travel-demand forecasting, we analyze people's decisions regarding mode of travel; auto, bus, train, and so on. Before we can predict how travel will be split among the modes available to the travelers, we must analyze the factors that affect the choices that people make. Three broad categories of factors are considered in mode usage:

1. The characteristics of the trip maker (e.g. family income, number of autos available, family size, residential density)
2. The characteristics of the trip (e.g. trip distance, time of day)
3. The characteristics of the transportation system (e.g. riding time, excess time)

Mode usage analysis can be done at various points in the forecasting process. Mode usage analyses are sometimes done within trip-generation analyses. However, the most common point is after trip distribution, because the information on where trips are going allows the mode usage relationship to compare the alternative transportation services competing for users. Mode choice models can also be done on both aggregate (Zonal) and disaggregate (Household or individual) levels. In this course, we will concentrate on aggregate post-distribution models.

The most common of these aggregate post-distribution models is the family of the logit models (binary logit, multinomial logit, nested logit etc.). A logit model is choice model that assumes an individual maximizes utility in choosing between available alternatives. The logit model's utility function comprises a deterministic component (which is a function of measurable characteristics of the individual and of the alternatives in the individual's choice set) and a stochastic component (or error term) assumed to have an extreme value distribution

The functional form of the logit model for k number of alternative modes is:

$$P_{ij}^{1} = \frac{T_{ij}^{1}}{T_{ij}} = \frac{\exp\,(-\beta C_{ij}^{1})}{\sum_k \exp\,(-\beta C_{ij}^{k})}$$

Where, P_{ij}^{1} is the proportion of trips travelling from i to j via mode 1. C_{ij}^{1} is the generalized cost of mode 1 and β is a calibrated parameter. The logit function results in an S-shaped curve.

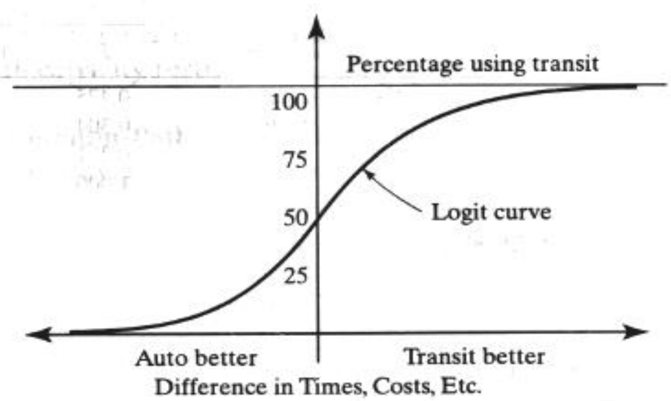


Figure 2.4- S-shaped logit mode choice curve

Some time instead of the generalized cost we use the utility of different mode in this case the proportion for one mode is given by:-

$$P(A) = \frac{e^{U_A}}{\sum e^{U_i}}$$

Where P(A) = the probability of choosing mode A
U_i = utility of any mode i
U_A = utility of mode A

Example 8 and 9

4. Trip Assignment

Traffic assignment is the step in traffic analysis in which inter-zonal trips are assigned to the network. The traffic demand, as described in the origin-destination (OD) tables per trip purpose and per travel mode (and sometimes per period), is confronted with the infrastructure supply, which is a network of links and nodes having characteristics as capacity, maximum travel speed, one-way streets, tolls and other factors of resistance.

Traffic assignment involves computing one or more optimal (usually shortest) routes between each origin and destination and distributing travel demand over these routes. The sum of all trips along these routes over all OD pairs results in a traffic load on all links and nodes. Usually, there is a separate assignment for each mode, since the networks for each of the modes is very different. For the sake of simplicity, we restrict ourselves to assignments of individual road traffic (car, bike); the more complex assignments on public transportation networks will not be discussed here.

The major aims of traffic assignment procedures are:

- To estimate the volume of traffic on the links of the network and obtain aggregate network measures.
- To analyze the travel pattern of each origin to destination (O-D) pair.
- To identify congested links and to collect traffic data useful for the design of future junctions

Necessary input for the assignment:

- an O-D table of trips between the zones, usually all trip purposes combined;
- a (computer)representation of the network;
- characteristics of the network elements (links and nodes);
- a route choice model.

Direct output of the assignment computation:

- the routes (consecutive series of adjacent links and nodes);
- the route characteristics (travel times, distances, costs);
- route loads: the number of trips per route;
- link and node loads: the number of trips per unit time (flow) on each link and each turn at junctions.

Technically, there are two broad assignment models: the minimum path assignment and the congested assignment. The minimum path assignment models assume that the capacity and travel cost of the links is unaffected by the volume of traffic and all the traffic will choose to travel on the shortest path. Whereas, the congested assignment models address the fact that the travel time and cost on a link increases as the volume of traffic on the link increases.

The all-or-nothing (AON) assignment is the basic form of the minimum path assignment models while incremental assignment, capacity restraint assignment, user equilibrium assignment (UE), stochastic user equilibrium assignment (SUE), system optimum assignment (SO), etc are some forms of the congested assignment models.

All-or-Nothing Assignment

In an All-Or-Nothing (AON) assignment, all traffic between an O-D pair is assigned to just one path (usually the shortest path) connecting the origin and destination. This model is unrealistic in that only one path between every O-D pair is utilized even if there is another path with the same or nearly the same travel time. Also, traffic is assigned to links without consideration of whether or not there is adequate capacity or heavy congestion; travel time is taken as a fixed input and does not vary depending on the congestion on a link.

However, this model may be reasonable in sparse and uncongested networks where there are few alternative routes and they have a large difference in travel cost. This model may also be used to identify the desired path: the path which the drivers would like to travel in the absence of congestion. In fact, this model's most important practical application is that it acts as a building block for other types of assignment techniques. It has a limitation that it ignores the fact that link travel time is a function of link volume and when there is congestion or that multiple paths are used to carry traffic.

One form of the AON is the *shortest path all-or-nothing assignment*. This is an assignment in which for each OD pair the corresponding flow is assigned to a single path that, according to a fixed set of link costs, has minimum path costs (congestion effects are not taken into account).

Finding the minimum path in the transportation network is an optimization problem. Several numerical formulations such as Moore’s and Dijksta’s are available to solve this minimum path problem. But this is outside the scope of this course.

Example 10

User Equilibrium Assignment

The user equilibrium assignment is based on Wardrop's first principle, which states that:

Under equilibrium conditions traffic arranges itself in congested networks in such a way that no individual trip maker can reduce his path costs by switching routes.

This means, in the congested network, all the used routes between an O-D pair have equal and minimum costs while all unused routes have greater or equal costs.

The user equilibrium assignment assumes that:

- The user has perfect knowledge of the path cost.
- Travel time on a given link is a function of the flow on that link only.
- Travel time functions are positive and increasing.

Example 11

<u>*System Optimum Assignment (SO)*</u>

The system optimum assignment is based on Wardrop's second principle, which states that:

Under social equilibrium conditions, traffic should be arranged in congested networks in such a way that the average (or total) travel cost is minimized.

This assignment can be thought of as a model in which congestion is minimised when drivers are told which routes to use. Obviously, this is not a behaviourally realistic model, but it can be useful to transport planners and engineers, trying to manage the traffic to minimise travel costs and therefore achieve an optimum social equilibrium.

In general the flows resulting from the two principles are not the same but one can only expect, in practice, to arrange itself following an approximation to Wardrop's first principle, i.e. selfish or users' equilibrium.

The indicator is often used to measure how close a solution is to Wardrop's equilibrium

$$\delta = \frac{\sum_{ijr} T_{ijr}(C_{ijr} - C_{ij}^*)}{\sum_{ij} T_{ij} C_{ij}^*}$$

Convergence criteria

Where: (Cijr – Cij*) excess cost between i & j relative to the minimum (Cij*)

Incremental Loading

✓ Parts of the matrix are assigned in each iteration. E.g.: 4 iterations: 40%, 30%, 20% or 10%, alternatively 25% at each iteration

- ✓ Does not necessarily converge to Wardrop's equilibrium!!
- ✓ Suffers from the limitation that once a flow has been assigned to a link it is not removed and loaded onto another one
    - ✓ *In other words, if one of the initial iterations assigns too much flow on a link for Wardrop's equilibrium to be met, then the algorithm will not converge to the correct solution.*

Step for Incremental Loading

1. Select initial set of link costs (free flow/warm start)
    - ❖ set all flows to 0
    - ❖ partition trip matrix
2. build set of minimum cost trees for all origins
3. load first (next) matrix segment using AON
4. calculate new set of link costs
5. Whole matrix assigned?
    - ❖ if yes, END
    - ❖ if no, go to (3)

Example 12
Successive Average

1. Select initial set of link costs (free flow/warm start)
    - ❖ get set of link costs (most likely free flow)
    - ❖ set all link volumes to 0,
    - ❖ set iteration number (n = 0)
2. Set n = n + 1
3. Update the minimum cost trees
4. All-or-nothing assignment, F_a^n
5. Update the link flows

$$V_a^n = \frac{n-1}{n} \cdot V_a^{n-1} + \frac{1}{n} \cdot F_a^n$$

6. Update link costs given V_a^n
7. Check for convergence; if no convergence then goes to step 2.

Example 13

(For detail explanation of traffic assignment models, please refer to Ortuzar and Willumsen Chapter 10)

2.3 Evaluation and Economic Appraisal of transport projects

Assessing whether an alternative solution is worthwhile clearly involves forecasting the effect it will have on policy indicators and weighing them up to decide whether overall the proposal is beneficial. This process is known as **appraisal**. Techniques of project appraisal generally rest, wholly or partly, on the concept of economic efficiency. An economically efficient allocation of resources is achieved when it is possible to make one person or group in society better off without making another group worse off. In other words, if projects could be found and undertaken which would make everyone better off, those projects would serve to promote economic efficiency.

A project is economically efficient if the benefits measured in money terms exceed the costs; the most efficient project is that for which the difference is greatest. A method is also required for dealing with the fact that costs and benefits of transport projects are spread over many years. Conventionally this is handled by the technique of *discounting for time*.

But some other indicators cannot be expressed in money terms and readily aggregated into a single measure of the net benefit of the project. These may arise for two reasons: first, the difficulty of finding satisfactory methodologies for valuing some benefits and costs in money terms, and second, that decision-takers may wish to look at a broader range of criteria than economic efficiency. In particular, equity, and the distribution of costs and benefits, is an objective that cannot be viewed simply as a part of the search for economic efficiency.

Valuing Transport Costs and Benefits

Many of the transport project expenditures can be readily valued using monitory terms. Costs such as capital and maintenance can be computed using the market price of the nation. Operating cost usually takes the form:

$$G = M + \gamma T$$

Where, G is the generalized cost, M is the monitory cost, T is the journey time and γ is the value of time.

But many costs of transport projects- pain and grief resulting from accidents, environmental effects- do not have a market price. In this case, a variety of methods have been used to try to establish what those affected would be willing to pay for the benefits or would require in compensation for the costs.

Turning to accidents, the costs may be divided into those that are readily valued in money terms, and those that are not. The former include damage to property and vehicles, health service, ambulance and police costs, and loss of production due to victims being unable to work (this again is typically valued at the gross wage). What is more difficult is to place a money value on the pain, grief and suffering caused by death or injury in an accident.

Transport projects have many important environmental effects, both at the local and global level. At the local level, they lead to property demolition, noise nuisance, visual intrusion and air pollution. They may add to the consumption of scarce and non-renewable resources such as oil. Property demolitions can be calculated using monitory terms while it is difficult to put a price on noise and air pollution.

But these projects result in a lot of benefits too. They result in the reduction of congestion and travel time, provision of accessibility, enhancement of environment and so on.

The time saving can be generally indicated by the change in the operating cost after the opening of the transport project. In the case of time savings, there is a distinction to be made between time spent travelling during working hours (which includes bus and lorry drivers as well as business travelers), and time spent travelling during one's own time. In the former case, it is usual to value the time at the wage rate of the employee concerned plus a markup to allow for overhead costs of employing labor (such as social insurance charges). This assumes that the time saved can be gainfully employed, and that the gross wage represents the value of the marginal product of labor in its alternative use.

$$\Delta G = G_i - G_f$$

Where ΔG the saving in operating is cost, G_i is the initial cost before the project and G_f is the current cost after the construction of the project.

The time saving should also consider the newly generated traffic. From basic economics, the demand for transport will increase when the operating cost decreases. Therefore, the transport project does not only benefit the existing traffic but also the latent demand that will be generated. Therefore, the total saving in operating cost is given by *(Check O'Flaherty 1997 for derivation):*

$$\sum_{m}\sum_{l} 0.5(G_i - G_f)(Q_i - Q_f)$$

Where Q_i and Q_f are the initial and final volume of traffic, m is the mode and l is the link.

In the case of public transport, usually a fare is charged for the journey, and often the fares and service decisions are left up to the operator, acting on a commercial basis.

Transport projects can also improve the safety of the society. At the same time, by taking traffic off other, perhaps more environmentally sensitive roads, projects may offer environmental benefits. Valuing such benefits in monitory terms requires advanced studies. Stated preference or revealed preference surveys are usually adopted to understand the value the society puts on these environmental and safety benefits.

Cost-Benefit Analysis: the Appraisal Process

The cost-benefit analysis mainly involves financial and social appraisal of the projects. Financial appraisal of a project involves measuring all the effects of the project on the cash flow of the agent undertaking it. These are then 'discounted' back to the present to find its Net Present Value (NPV) in financial terms. On the other hand, in a social appraisal, one is not just concerned with cash and not just concerned with the agent undertaking the project: the objective is to measure the benefits and costs whoever receives them and whatever form they take.

In order to undertake an appraisal, it is necessary to identify:

- The base case (i.e. what will happen without the project)
- The option (what will happen with it)

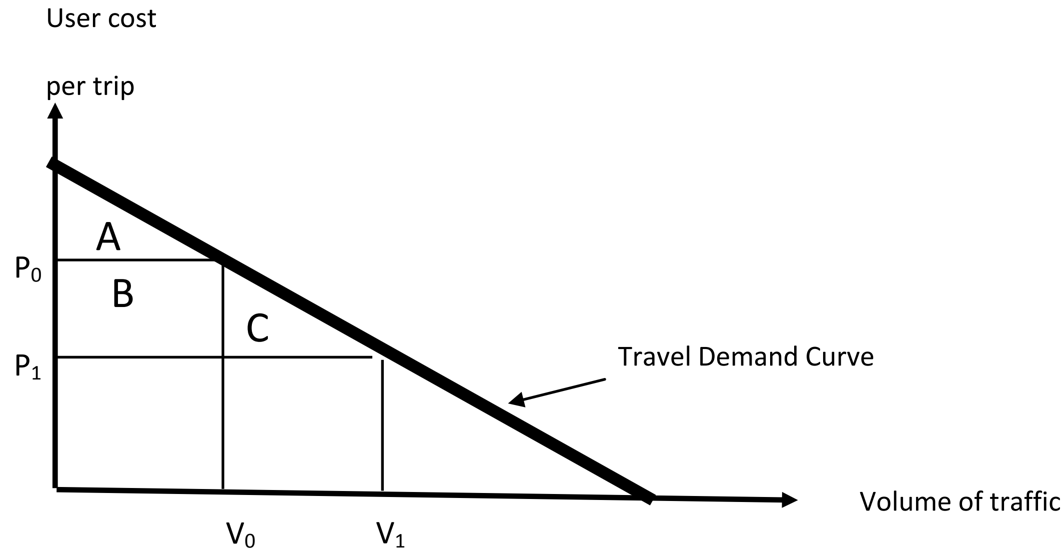
Consumers Surplus (Users Benefit)in the case of traffic

B = Users benefit for existing traffic V_0

A = Consumers surplus (users benefit for the existing facility) for V_0

C = CS for induced traffic

B + C= Total users benefit for the total traffic based



For a financial appraisal, one simply seeks to identify the change in cash flow between the above two cases. However, in considering cash flows it is necessary to allow for the fact that one would rather have cash now than in the future, because of the interest they could have earned if they had the money immediately. With an interest rate of r, one birr now is worth $(1 + r)$ after one year, $(1 + r)^2$ after 2 years and $(1 + r)^t$ after t years. Simply reversing the procedure, it may be said that the present value of one birr in one year's time, two year's time and t year's time is given by:

One year $\frac{1}{1+r}$

Two years $\frac{1}{(1+r)^2}$

T years $\frac{1}{(1+r)^t}$

This, therefore, is the basis of the method known as discounting for time to calculate the Net Present Value (NPV) of the project.

Net Present Value (NPV)

The NPV is simply the difference between the sum of the discounted costs and the discounted benefits. Note that the costs and benefits arising in each year of the life of the project are simply multiplied by the discount factor which converts them into present values. It is given by:

$$NPV = \sum_{i=1}^{t}\left[\frac{R_i - C_i}{(1+r)^i}\right]$$

A number of decision rules have been proposed for appraisal, but the simplest to use is to undertake all projects for which the net present value is positive. This is only valid, however, when there is no shortage of funds to undertake all the projects in question. If a number of projects are competing for scarce resources, a simple value for money index can then be derived by dividing the net present value of the benefits minus costs of the project by the net present value of the financial requirement, and then ranking the projects in order of this indicator.

The Net Present Value compares different alternatives satisfactorily when all costs and benefits can be valued in money terms. But in practice, many items are not valued in money terms, whether because of practical difficulties in ascertaining appropriate valuations or because of the inclusion of objectives other than economic efficiency. In this situation, some sort of 'framework' layout of costs and benefits by incidence group is the most popular approach to appraisal, whether or not it is accompanied by a formal multi-criteria weighting system.

Internal Rate of Return (IROR)

- ✓ Make the net present value at the given rate should be zero.
- ✓ Calculate the rate (i) and compare with the given rate. (r)

Determine i, (P/A-i-n) from $NPV_i=0$

If $r<i$ accept if not, don't accept

Equivalent Uniform Annual Value (EUAV)

- ✓ Calculate the total sum of the benefits and the initial investment of the project which is multiply by (A/P-i-n).
- ✓ If The result is (+ve) accept otherwise not.

Multi-criteria approaches require three stages:

1. Definition of a set of objectives, which may for instance relate to accessibility, the environment, safety, economy and equity
2. Measurement of the extent to which each project contributes towards the desired objective;

3. Weighting of the measures in order to aggregate them and produce a ranking of projects.

It appears then that, as currently practiced, multi-criteria decision-making techniques are essentially concerned with aiding and ensuring consistency in the latter stage of weighting by the decision-taker. But what is clear is that it must be provided in a sufficiently disaggregate form for the decision-taker to apply, explicitly or implicitly, his or her own weights.

Example 14
(For more on cost-benefit analysis, please refer to O'Flaherty 1997 chapter 4)

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