TRANSPORT PLANS:
METHODOLOGY AND AREAS
OF APPLICATION

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Discussion Paper

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ANNEXES

Annex 1 - Bibliography
Annex 2 - Descriptions of Studies Concerning Some Transport Plans
Annex 3 - Short-Term and Long-Term Marginal Cost and Development
   Cost in Transport
Annex 4 - Characteristic Elasticities and Multipliers
1.1 Transport plans are commonly used as a programming tool. Particularly in developing countries, many studies include this expression in their titles. Given their role in decisions concerning the transport sector, and the importance of that sector to economic development, it is worth examining this aid to decision-making, especially as the term covers widely differing concepts and an extremely varied range of both objectives and methods.

1.2 The bibliographic index provided in Annex 1 consists of a list of recent transport plans. Annex 2 provides comments on some of them, with their salient features. These lists are far from exhaustive, but they suffice to show the large number of countries that have engaged in this exercise and the variety of the questions which the concept of transport plans attempts to address. Such questions can be classified into two major categories, according to whether they bear on transport policy or the links between transport and the rest of the economy.

1.3 With respect to transport policy, the main objective of transport plans concerns the establishment of investment programs: evaluation of the usefulness of isolated investments, coordination of modes, assessment of the sector's overall needs, and especially the preparation of investment programs and optimum distribution of the funds available for the transport sector. But transport plans are also often relied on in reaching decisions on charging for the use of infrastructure and on regulation, as well as, more generally, procedures for management and government intervention.

1.4 To sum up, the word "plan" in "transport plan" can be taken either in a narrow sense, that of a projected series of steps, or in a broad sense, that of organizing any purposeful activity -- with a view, of course, to achieving a transport-related goal.

1.5 Another objective often assigned to transport plans is the study of the relationship between transport and the rest of the economy. The first question to arise in this connection is what the effects of macroeconomic entities such as GDP, the breakdown of final demand, and input-output matrices might be on the various components of transport policy (with particular reference to investment policies). Other topics, such as employment or external trade and their relationship to transport policy, might also prove interesting.

1.6 One can also approach the subject from the other side and examine the influence of transport supply, or more precisely, a change in that supply, on economic development, either at the regional geographic level (how would a change in the transport system affect the
geographic distribution of economic activity?) or at the macroeconomic level (how would a change in the transport system affect macroeconomic aggregates?).

1.7 This diversity of objectives is mirrored by a diversity of methods: one need only glance through some of the studies mentioned to see how widely they differ. Some studies are not tied to geographic locations (cf. 31), focusing on general issues such as determining rates, choosing investments, or deciding the total amount to spend. Others, more commonly encountered, focus on geographically defined investment programs; such programs may cover specific countries (cf. 34, 35, 23), trade among a group of countries (cf. 24, 40), matters concerning a particular region (cf. 29), or even a "corridor," i.e., a number of transport systems serving the same cities or zones. The methods used can range from highly quantitative to essentially qualitative. Means of quantification can in turn range from great sophistication involving computer models based on detailed user surveys to the simplest kind of reasoning based on extrapolations of total figures.

1.8 First to be analyzed will be the basic techniques used in transport plans. An attempt will be made to draw up an exhaustive list of them, but the longest discussions will be devoted to the most specialized and sophisticated tools, namely traffic models and economic cost-effectiveness estimates. The section following will be devoted to the use of those techniques as aids in the decisionmaking process and to the results that can be expected of them in terms of improved economic efficiency.

1.9 A remaining point calling for attention is the time horizon. Transport plans are generally thought of as long-term, but this is a loose expression, and the horizons of the examples of transport plans cited in the bibliography and in Annex 2 range from 5 to 20 years, except where they are not specified, in which case they are implicitly set in the neighborhood of 10 to 20 years.

1.10 Economic analysis normally distinguishes between the following three terms:

- The short term, which does not interest us here, spans one to two years. Decisions governing such a brief lapse of time are of a special kind: for purposes of investment, it is less than the average length of time needed to complete major infrastructure, and decisions depend mainly on financial constraints that determine how fast the commitments undertaken can be carried out, or how soon new operations can be started. Where forecasts are concerned, the short term is a familiar feature of methods based on extrapolation (ARMA, ARIMA, autoregressive, etc. models).

- The medium term traditionally covers some 5 to 10 years. In connection with decisions and aids to decisionmaking, it is associated with econometric relationships, in which certain
variables, called endogenous, are explained by formulas that make use of exogenous variables and parameters, stipulated or obtained by separate estimation. The medium term is a time interval far enough removed for casual relationships to have time to take effect, but also near enough for the parameters of those casual relationships remain stable.

Time spans longer than 10 to 15 years are generally referred to as long-term. For purposes of modeling, however, the long term is the period of time in which econometric relationships no longer hold true, and their parameters can no longer be considered stable; casual relationships become more complex and less reliable. At this point quantitative modeling gives way to qualitative methods, forecasting and systems analysis.

1.11 This new definition of time spans, then, is based not on fixed durations but on the structure of causal relationships. The terms will therefore differ according to the nature of the phenomenon studied; thus a period of five years may at the same time be considered to represent the medium term, indeed almost the short term, for demographic phenomena, and the long term for more volatile variables, e.g. oil prices.

1.12 In accordance with the foregoing definitions, what follows will be concerned essentially with long-term plans, but the reader should bear in mind that almost everything said about quantitative methods in this context is also valid for medium-term plans.

PART I

The Techniques Used to Prepare Transport Plans

1.13 After a preliminary chapter outlining the proper use of models, this section will introduce the tools and models used to prepare transport plans, with a view to defining their scope and the limits of their validity.

CHAPTER II

THE PROPER USE OF MODELS

2.1 For an accurate understanding of the scope and limits of the models applied in transport planning, one must have a clear idea of what one can generally expect from a model.

2.2 First of all, a model is a simplified representation of a reality which it cannot claim to reproduce totally. It is not
surprising that different models must be constructed to study different aspects of that reality. There is no all-purpose model, and the only model that could answer all questions about a phenomenon would be the unsimplified reproduction of that phenomenon.

2.3 A model seeking to portray a reality that is at all complex will be complex itself; it will have numerous equations, numerous variables and numerous parameters. The estimation of all of them will be subject to errors and uncertainties, due to imprecisions in the specification of the model and to errors in the statistical measurement of the variables. Results of models must therefore be treated with caution and carefully analyzed. Calculations of the standard deviation of such results, when they can be accurately made, are useful in that regard; hence it is advisable to verify and match the quantities obtained by sophisticated methods on the basis of simple reasoning and alternative methods. In a more general sense, the results of models will often be more useful in the form of sensitivity analyses or studies of variants than in the form of gross absolute values.

2.4 This leads to the general point that a model is not designed to produce a single final result (for example an optimal investment program) but must rather provide a permanent working tool with which the decisionmaker can explore, refine and update approaches to a problem through an ongoing dialogue with the analyst, and test the sensitivity of the solutions to the value of the parameters and the nature of the hypotheses.

CHAPTER III

PURPOSES OF THE VARIOUS MODELS USED IN A TRANSPORT PLAN

3.1 Considered in all its facets, a transport plan comprises several stages and can call for a number of different models. Some pertain to the analysis of transport supply, but the most specific deal with traffic forecasts. One should begin with those showing how the transport system relates to general economic development affecting the development of the origin and destination pattern of traffic. Next come models that examine the traffic, in terms of its geographic distribution or its development over time. Finally come the models and methods that are more specifically designed to assist in decisionmaking, particularly with respect to investments.

3.2 Models showing the relationship between the transport system and the economy can be designed to do one of the following:

- Determine transport needs, primarily in terms of origin and destination flows, conditional upon the expected economic development. These models, which make up the generation phase, will belong upstream of the transport plan.
Evaluate the consequences of a given modification of the transport system for economic development. These models will then come downstream of the study, or set up a loop from development of the economy to development of transport to development of the economy.

3.3 The most frequent processes of geographic traffic distribution normally comprise several stages, involving:

- Distribution (how are the flows from a given center shared among potential destinations?);
- Mode selection;
- Itinerary selection.

3.4 The explanatory variables of greatest relevance to the evolution of transport flows are macroeconomic data such as GDP, household income and output by sector of economic activity. Such models are very close to the generation models referred to in the preceding paragraph and will be considered at the same time.

3.5 Models relating to supply focus on the ongoing situation and prospects for the future in terms of infrastructure, vehicles and, more generally, transport management.

3.6 Models designed to assist in decisionmaking tie in with the traffic models and seek to determine the cost-effectiveness of the projected investments or the desirability of proposed changes in rates or management.

CHAPTER IV

MODELS LINKING TRANSPORT TO THE REST OF THE ECONOMY

4.1 This part of the transport plan establishes the relationship between the transport sector and the rest of the economy. Upstream, the general characteristics of economic activity determine transport activity. Downstream, the characteristics of the transport sector influence economic development. However, these two aspects of the relationship exist at different points in the construction of the model.

A. Economic Activity Generates Transport

4.2 The level and structure of economic activity determine the demand for transport, and the relationship between the two can be depicted with varying degrees of sophistication.

4.3 The simplest approach is to link the general figures representing transport activity to economic aggregates. For instance,
domestic freight traffic, expressed in tons and t x km, can be linked to GDP, or domestic travel, expressed in passengers or in passengers x kilometers, to final household consumption.

4.4 In a more refined version, these values can be broken down. For example, freight traffic can be broken down by goods carried and traffic in each of the goods explained in terms of a characteristic value of the sector concerned, for example, volume of output (valued in constant money). Passenger traffic can be broken down by distance. Often, too, separate econometric relations are estimated for distinct modes.

4.5 These analyses may seem crude. They generally tend to overlook a number of factors such as structural effects which, for example, steadily reduce T x km for a given amount of GDP as development progresses. However, that is not necessarily objectionable if the time horizon of the study is relatively short and if it can be assumed that the effect of those factors, relatively permanent for that horizon, is implicitly incorporated in the structure of the relationship.

4.6 In more general terms, these simple models often ignore transport supply, assuming it to have no effect on demand. This assumption, which also underlies the more elaborate models discussed in the next paragraph, may seem natural as regards the transport of goods. Transport makes up a small share of their price, and the corresponding price effect is also small. This is, however, only true on average. The composition of the basket of goods produced can be altered by a change in the supply of those for which transport cost is a sizeable portion of the final price.

4.7 On the other hand, this assumption is more difficult to sustain with regard to passengers. Many analyses show that the volume of travel is influenced by the price and quality of transport, including service. Some of these comprehensive models reflect the price of transport, but none takes account of the quality of service. This is a surprising omission. It negates the very effect that downstream models try to measure, namely the impact of transport on economic development. Would it not be possible to introduce into the econometric relationships a variable reflecting the average speed of travel on the highway system, or the frequency and speed of public transport?

4.8 The partial econometric relationships thus brought to light, like those that explain the transport of a given commodity by sector output value, run the risk of producing inconsistent forecasts if the individual outputs of the different sectors are estimated in isolation from others. To prevent that, a more complete econometric model taking economic interdependencies into account is required. The prevailing method begins, therefore, with national economic planning projects and goes on to deduce from them the final demand vector, from which is obtained, by inverting the input-output matrix, the basic output for each sector.
4.9 How fine a breakdown by commodities should be attempted? The answer to this question must be based on the consideration that the finer the resolution, the easier it is to reflect behavior (because there is less distortion due to aggregation), yet the number of categories cannot be allowed to proliferate excessively. In practice a limit of about 10 commodities makes sense, with some that represent high tonnages singled out and a catch-all category established for miscellaneous merchandise that does not permit precise distinctions.

4.10 Two difficult problems arise however, in all cases. These involve the geographic distribution of the origins and destinations of the flows, and the prediction of their change over time, especially in the long term. Geographic distribution is not predicted by the methods referred to above, which simply show temporal change at the country level. But regions can evolve in very different ways, and rarely do available statistics reflect sufficiently fine geographic resolution. One must then use methods designed to obtain geographic breakdowns on a national scale, such as the R.A.S. method or the "shift and share" method (cf. 7 and 43). Their common aim is essentially to determine the elements of a matrix (whose rows are regions and whose columns are economic sectors), the margins of that matrix (total output per region and national output of each sector) being known. They can be applied to the regionalization of the input-output matrices, as well as to that of econometric relations.

4.11 However, these mechanical methods are in fact founded on extrapolation from past developments; they cannot deal with breaks in trends or unexpected changes of direction.

4.12 Forecasting presents other problems inasmuch as it is directly or indirectly based on econometric relationships that cause explanatory variables to intervene. The first is forecasting the future value of the explanatory variables, a fundamental difficulty that is too well known to require further comment. The second lies in the stability of the relationships and the parameters that enter into them. This stability may well hold over the medium term; it cannot be guaranteed over the long term, a period in which more complex and less easily quantifiable factors tend generally to arise.

4.13 These considerations make it advisable to follow up the quantitative analysis whose methods have just been outlined with more qualitative studies designed to take account of nonmeasurable factors and of the effects of unforeseen policies of macro-decisionmakers (particularly the State), evaluate the principal trends and risks of breaks in them, assess the impact of technical progress, create alternative scenarios if warranted, and make international comparisons.

4.14 Such studies can address sectoral or cross-sectoral topics. Sectoral studies will actually be monographs about commodities or groups of commodities. Cross-sectoral studies may deal with changes in the coefficients of the input-output matrix and with issues such as regional energy policies, the impact of technical progress, etc.
3. The Influence of Transport on Economic Development

4.15 This effect is symmetrical with the one just considered, and concerns the consequences of transport supply on economic development. This classic subject, whose importance is often affirmed but which is poorly understood, can be approached from either the spatial or the macroeconomic point of view.

4.16 Many statements have been made about the influence of transport in the development and opening up of a geographic area; they often shape national policy, especially in developing countries. However, a precise understanding of the mechanisms linking the two is still lacking. Experimental studies have been few and their results inconclusive. Substantial work went into the construction of theoretical models, but interest in them has lessened in the past decade and in the rare instances when use has been made of them to solve specific problems, those have been regarded more as a form of experimental research than as a real means of furthering the decision-making process. One hopes that research and studies in this field will be pursued and developed, but currently existing methods are extremely unlikely to produce immediate concrete results.

4.17 At the macroeconomic level, some modest but more operational methods exist. These make it possible to define the direct consequences of certain transport policy measures on macroeconomic indicators such as rate of growth, unemployment, inflation and external balance. Accordingly, the direct effects of investments can be measured, either those arising from the activity itself (investment multiplier, accelerator effect, Leontieff multiplier) or those caused by the method of financing; the consequences of rate-setting measures or of changes in transport costs can also be studied. These effects are assessed by introducing the particular transport policy measures into a macromodel. The simplest versions operate with Leontieff matrices or consumption and investment functions, and relations explaining imports and exports. More refined versions include a financial component to determine the price level (cf. 7, 26, 27, 43).

CHAPTER V

FREIGHT TRAFFIC MODELS

5.1 These models are usually divided into several stages: the traffic distribution stage grows out of the preceding traffic generation phase which yields the volumes of each commodity (and numbers of passengers) leaving and arriving at each location. The transport flows between each point of origin and destination can thus be determined. The modal choice stage distributes the traffic between each origin-destination pair over the different modes available. The itinerary
selection stage distributes the traffic of each mode over the different possible itineraries.

5.2 Some models collapse two, or even three, of the stages described above into one, but since they are less common they will not be mentioned further. What follows is a discussion of the problems posed by the various stages.

A. Descriptive and Normative Models

5.3 The first problem is ascertaining whether a model is normative or descriptive. Normative models determine optimal traffic flows, flows as they ought to be. Descriptive models calculate the traffic as it is, taking into account the behavior of the economic actors. The difference between the two approaches appears great, but a number of observations will serve to temper this impression. First, in a market economy managed in optimal fashion, the two approaches would be equivalent, the rates set by the government having the precise purpose of ensuring optimal behavior on the part of the individual agents. Similarly, in a planned economy the observable real traffic will be optimal except for planning errors. To be sure, in a planned economy optimality cannot be achieved, and in a market economy it is impossible to set rates in truly optimal fashion. But by the same token, models inevitably distort reality, which they cannot reproduce in every detail.

5.4 It follows, therefore, that the distinction between the normative and the descriptive approach is completely left out. It must be added, moreover, that in the long run the progress in transport management should bring the two closer together. The two approaches must in any case complement each other. Along with normative modeling, one has to study the real behavior of the transport decisionmakers as well as that of the factors to which they are sensitive. This is essential for the establishment of the future regulations, incentives and rates by which the results of the normative study are to be translated into fact. In the many countries where economic decisions arise both from the play of market forces and from more or less centralized planning this task has its difficulties. Econometric analysis can come to grips with the former, but in dealing with decisions growing out of a planning process, one can only make assumptions and build scenarios and they will always be crude and approximative. The distinction between normative and descriptive approaches has an important bearing on the modeler's choice among possible transport-cost concepts and the various available submodels.

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1/ However, it is important to avoid the bias that might result from paying attention exclusively to prescriptive methods, and to remember that while they may say what the flows ought to be they remain silent about how to bring them about.
B. What Transport Costs Should be Used?

5.5 The two types of transport costs that can be used in modeling are: financial real costs borne by the transport operator, and costs for the community. The use of real financial (private) costs in the models rests on the implicit assumption that users' decisions are based on the profit motive (or on the desire for maximum satisfaction in the case of passenger transport). However, this is only partially true for the many types of mixed economy where planning plays an important role. Costs paid by the community are of course relevant to the normative solutions. The difference between the two types of cost appears in:

- infrastructure costs borne by the manager of the infrastructure, generally the government, but often not passed on to users;
- specific subsidies to, or levies on, the transport sector;
- external effects not charged to the user, such as loss of time, costs of safety required for other users, and environmental consequences.

It should be recalled that under optimal rate-setting conditions user costs and community (social) costs are equivalent.

5.6 What concept of cost should be used? The problem does not arise for real financial costs for which there is statistical evidence, but it is important for community costs. In the case of models describing decisions at the margin (choosing one destination or one mode over another), the concept to use is marginal cost. For the supply of transport infrastructure, where one generally expects increasing returns to scale, marginal cost should differ from average cost.

5.7 However, a problem arises for the real financial cost as well as the social cost, and that is the problem of its time frame. With respect to community costs, in optimally adjusted systems, marginal short-term cost is equal to marginal long-term cost whenever the latter has meaning, that is to say, when there is no indivisibility -- or rather the indivisibility is not too marked -- in the infrastructure investments. But this marginal cost varies with time, especially in response to the degree to which routes become saturated. One may however cope with this variation by working with an average cost over an appropriate stretch of time, a concept known as "Development Cost": 2/

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2/ See Annex 3 for a presentation of these notions and their relationships.
\[
\sum_{t=0}^{t=n} \frac{dD_t}{dT_t} \times \frac{dT_t}{(1+i)^t} \times \frac{1}{t=n} \sum_{t=0}^{T_t} \frac{dT_t}{(1+i)^t}
\]

where:
- \(t\) represents the year,
- \(n\) the period for averaging,
- \(D_t\) the expenditure for the year \(t\),
- \(T_t\) the traffic for the year \(t\),
- \(i\) the discount rate.

This formula is valid both for traffic models and for project evaluation, but it raises a number of technical difficulties stemming from the length of time \(n\), over which one averages, and from the profile of the series of traffic variations, \(dT_t\). These difficulties are explained, with proposed solutions, in Annex 3.

5.8 The problem of change over time arises less obviously but just as crucially for financial cost; the difficulty lies in foreseeing changes in its elements, especially as some of them, such as taxes, depend on government decisions.

C. **Diffuse Traffic**

5.9 This problem arises not only in connection with goods but also with passengers. It is specific to road-transport and stems from the existence and volume of the short-distance traffic characteristic of this mode, which the traffic models ignore because they are focused on long- and medium-distance activity. But this diffuse traffic can represent a very appreciable share of total traffic, especially in densely and evenly populated countries. This raises several problems relevant to decisionmaking:

- **How to evaluate it?** One might think of applying, on a different scale, the same models as for interurban traffic. But this solution would be too costly, and needlessly complicated.

- **Its evolution over the years can also be estimated:** for passengers, by projecting individual movement -- the number of short-distance journeys being closely tied to the level of economic development -- and for goods, by keeping track of the economic development of the area concerned.

- **In any case, if this traffic is substantial, it will determine the development of road infrastructure more than long-distance traffic, the smooth flow of which it may tend to**
hinder, 3/ and which may often be considered as economically more valuable. If warranted by the levels of traffic, the creation of specialized new roads might then be considered and thought given to the form they should take (limited access, toll, etc.).

D. Distribution Models

5.10 The archetype of normative distribution models is represented by linear programming (LP). Its principle is to minimize total transport cost, taking into account the unit cost on each section of the system and the constraints governing the total flow from each point of origin as well as the flow arriving at each destination. By contrast, most descriptive distribution models are of the gravity type (GM):

\[ T_{ij} = K \frac{A_i E_j}{C_{ij}} \]

where:

- \( T_{ij} \): traffic between i and j,
- \( A_i \): attraction potential of center i,
- \( E_j \): potential total outflow from center j,
- \( C_{ij} \): generalized cost of traveling between i and j,
- \( K, a \): parameters.

5.11 These models can take different forms:

- doubly constrained, so that the flows from each point of origin as well as those arriving at each destination each sum to a given total;
- singly constrained, in which only the flows from each point of origin (or the flows arriving at each destination) are constrained;
- unconstrained, in which the volume of the flows from each origin as well as the volume of the flows arriving at each destination can change as a function of the transport costs. This unconstrained model implicitly takes into account the effect of the quality of the transport on the level of economic activity.

5.12 The doubly constrained model is the one consistent with a stage of traffic generation of the type outlined in the previous

3/ Especially when that diffuse traffic involves non-motor vehicles.
chapter, and it is to it that the following comments apply. These comments address themselves to the relationships between LP and GM models, and a number of results are demonstrated (cf. 43).

- The GM is intended to represent the result of decentralized decisions of shippers seeking to minimize their cost of shipping from point of origin to destination, with the intrinsic attractiveness of each point of origin (or destination) -- measured, for example, by the sales price of the merchandise that can be obtained there -- distributed randomly and proportionally to the size of each point of origin (or destination). The GM therefore represents, as does the LP, a form of decentralized optimization.

- The LP is a limiting form of GM; more precisely for a given structure of origins and destinations, the coefficient $a$ is inversely related to the average transport distance resulting from the working of the GM. When $a$ is infinite, the average transport distance is minimum, and the GM produces the same result as the LP. The LP further contains numerous aggregation biases that distort it and that are the reason for the cross-movements which the LP itself does not reproduce.

- Heterogeneity of goods: Even with very detailed classification, transport costs are affected by heterogeneities within each class. The real optimal solution is more complex than the one produced by the LP model.

- The scatter of origins and destinations is too schematically represented by the use of centroids. Rational movements from zone to zone, especially between contiguous areas, can appear abnormal if their origin and destination are placed in each centroid.

- The aggregation over time may produce cross movements that would be irrational in a shorter time interval.

5.13 For all those reasons, the LP certainly gives rise to excessively small average transport distances and, by the same token, the GM to overestimated average distances. The two models are therefore likely to straddle reality, and their simultaneous use may produce accurate results. The foregoing considerations indicate that the LP's area of application is more restricted than that of the GM.

5.14 Another problem stemming from their use is that of the appropriate structure of costs. The GM uses only one cost figure for each origin-destination relation, while there are generally several modes of transport, and therefore several costs and possibly several itineraries. The solution generally adopted is then to use a weighted average of those costs, the weighing factor being each mode's share of total traffic. This choice may appear reasonable if arbitrary. As a
matter of fact, the precision of these models is not such that an assumption of this type affects the results appreciably; in the end results of the same quality will generally be obtained by taking distance or duration of the journey as a parameter.

5.15 The same considerations apply to the LP, although in that case the different modes could be treated separately by including distribution, mode choice and itinerary selection all together in a large linear program. However, the only advantage of this approach would be its logical coherence: the complication thus introduced would heavily outweigh the gain in accuracy.

5.16 Projection into the future is handled differently by the two models. With the LP there is no projection, strictly speaking. No parameter has to be estimated. The program is run twice, the first time in the current situation and the second in the future situation, with the estimated volumes flowing into or out of each centroid, and with the future transport costs. With the unconstrained GM, the calibration of the current situation furnishes the adjustment parameters $K$ and $a$, which are used in projecting to the horizon date. In the doubly constrained GM, however, the parameter $a$ changes with the distribution of origins and destinations. It should therefore be different in the initial and final situations, but as no means of calibrating the future value of $a$ is available, the value resulting from the initial estimate must be taken. It could of course be assumed that $a$, inversely related as it is to the average transport distance, diminishes over time because of improved management. But a number of other factors can alter that trend. In the absence of a specific contrary reason, it is therefore normal to assume the stability of that coefficient $a$, even if it means verifying afterwards that the average transport distance computed by the model on that basis is credible.

E. Choice of Mode and Itinerary

5.17 These two problems present obvious similarities and will be treated together. It should first be noted that often, especially in developing countries, the range of choices available to shippers is narrow because of a limited supply of transport; there may indeed be no choice at all in which case the problem does not exist. When that is not the case, several mathematical models exist to treat the two problems: the logit function; all-or-nothing distribution according to minimum cost; the transport cost relation raised to a given exponent. However, none of them brings satisfactory results. This is because the problem is not that of the model's mathematical structure but rather a statistical one stemming from the difficulty of classifying the goods in sufficiently homogeneous categories to be sure of obtaining identical behavior within each category, and from the difficulty of identifying significant parameters influencing shippers' decisions. In fact, modal choice decisions are generally influenced by the firm's condition of production, purchases and stocking, and the usual statistical data cannot reflect these. Under those circumstances, the difference between the normative and descriptive methods loses significance. All-or-
nothing distributions, which would be consistent with a normative point of view, will of course give erroneous results that can be accepted only if the final result is to be understood as the aggregate of numerous different flows among which there is much possibility of substitution and compensation.

5.18 These considerations suggest, for this phase of the modeling process:
   - rejection of an all-or-nothing distribution as an oversimplification of reality;
   - inclusion in the transport cost of all elements that count in transport decisions made as part of business policy, especially the value of time and the financial cost of inventories.

F. Some Specific Problems

5.19 Three points will be discussed here that can be of special importance in developing countries: system saturation, the risks of interrupted service and the problems of simultaneously optimizing plant location and transport.

5.20 Saturation can be frequent in countries where capital goods are in short supply and their production is low and transport flows are affected by sharp swings of economic conditions. This suggests that the models described above should be designed to reflect capacity constraints on the various links of the system that defines the supply.

5.21 A related problem is that of interrupted service, which can come about for different reasons: an unforeseen event that alters transport flows temporarily or permanently, a disruption in transport system supply. Without dismissing more sophisticated methods to analyze the consequences of such phenomena, the following simple procedures can be usefully applied: break down average annual traffic according to a seasonal profile in an attempt to detect the periods and geographic areas susceptible to strain, and identify alternative means (mode, itinerary) in terms of infrastructure capacity and the availability of vehicles.

5.22 A problem sometimes encountered by planners is how to optimize both the location of plant and the transport serving it (cf. 28). The problem is one of optimization under constraint, in which:
   - the variables are the number and size of the productive facilities to be installed in each location,
   - the objective function consists of the annual total cost including transport of finished products and raw materials, operations and factory depreciation;
the constraints reside in the access to raw materials and in the destination patterns of finished products, each in certain quantities.

5.23 Such models are mathematically complex. Their salient feature is that they are rarely reducible to a pure linear program. Generally they require large-scale mixed or quadratic programming. Furthermore, the quality of the results depends on knowledge of the transport costs and of the production functions of the plant under consideration; this means that the industrial sector must be precisely defined, both as to the product involved and the techniques used to manufacture it.

5.24 It should be added that the uncertainties of plant location are important only for the long term. The extrapolation of current needs and the follow-up on location decisions already made generally suffice to define a program of investment in plant construction, and the impact of unforeseen developments only begins to take on significance as one moves beyond the short and medium terms.

CHAPTER VI

PASSENGER TRAFFIC MODELS

6.1 The methods used in passenger traffic modeling obviously are often closely analogous to those in freight traffic models. One finds again, surrounded by the same considerations, the problems of the choice between descriptive and normative models, of costs to take into account, and of the treatment of diffuse traffic discussed in sections A, B and C of the preceding chapter.

6.2 In the modeling itself the stages described in the preceding chapter reappear, and the mathematical relations used will be very similar. However, the peculiarities of passenger transport can also be used to simplify the problem and find more precise solutions to it. This second approach will be the one followed.

A. Peculiarities of Passenger Transport

6.3 A first peculiarity pertains to the distinction between long- and short-distance transport. The latter uses, especially in developing countries, specific means such as two-wheelers, animal transport and so-called informal means of transport. Long-distance transport, on which the National Transport Plan will focus, uses conventional modes such as trains, aircraft, buses and automobiles.

6.4 A second peculiarity relates to the importance of car ownership or the lack of it to the analysis of user behavior. An estimate of total car ownership will therefore be required for purposes of passenger traffic modeling. Such ownership is generally very low in developing
countries and will remain so for a long time, but estimating it is important because the car-owning part of the population, though small, is the part that travels most, often by automobile. For this purpose, one may use traditional models that link car ownership to GDP and to prices and also take the effect of diffusion into account. Generally, however, car ownership in developing countries is closely tied to government decisions concerning import duties and quotas, as well as to the strategies of any national automobile-manufacturing enterprises, which are always under tight State control. The figures reflecting car ownership trends are therefore macrodecisions as well as estimates.

6.5 Supply of the other three modes -- bus, train and aircraft -- is often restricted in developing countries; it depends on decisions by the public authorities, and scarcity assures demand to a much greater degree than in developed countries. From this angle, problems of mode selection take a different form: often there is no choice, and when a choice does exist the result is often closely tied to government decisions and forced by penury.

6.6 Finally, in developing countries, road traffic flow cannot be modeled on the pattern appropriate to developed countries. One reason for this is that the proportion of large trucks and long-distance buses is considerably higher in the former. Another is that the performance of such vehicles is at once more varied and lower. In addition, other types of vehicles such as animal-drawn carts share the roadway with them and, even if only covering short distances, often cause congestion and slow traffic on main roads. Finally, these main roads themselves are generally more heterogeneous, of smaller capacity and less reliable.

6.7 All of this militates in favor of performing road traffic analysis with methods that can encompass these various peculiarities.

B. Passenger Transport Models

6.8 A problem that arises in using these models is determining the costs to be factored into them. The full cost must be considered, including not only money costs but also the money value of non-monetized items such as time and safety. Road safety becomes an important problem in developing countries, where the death and injury tolls are higher in relation to traffic volume than in developed countries. The concept of a value of life, or value of death, has given rise to much debate. The first thing to note is that it is not the outcome of the working of a market and, furthermore, that it represents in reality the value of a change in the risk of accidents. One may seek to estimate this value by different methods: by an analysis of the demand on markets for risks, as reflected, for instance, in insurance contracts; by computing the discounted value of future production by the person at risk; or finally, when this value matters to collective decisions such as infrastructure investment projects, by forming a view of what the collective is willing to spend in order to save a human life. In practice, the valuation of human lives proceeds often by several of these methods which then yield
limits to the value actually selected. The value of time requires a
more subtle approach than in the developed countries. The value of time
must be seen as a function of income: the time of low-income groups has
a value of practically zero, but this does not hold for the high-income
groups, whose behavior is comparable to that of their counterparts in
developed countries. Many different methods have been used for deter-
mining the value of time. The value appears normally as a parameter in
whatever traffic model is applied, multiplying the variable ‘trip
duration’. A value of time -- or, indeed, several values, such as value
of time in transit and time in waiting -- can be computed from multi-
nominal logit models or time-price models when those are calibrated on
available statistical data. But there are also simpler methods, such as
those that relate the value of time to hourly wage rates.

6.9 The models used in passenger transport can be of the simul-
aneous type; it is on this principle that models for several corridor
studies have been constructed, such as the northeast corridor of the US,
where the area of study corresponds to that of a fairly sizable country.
Staged models are the ones most used, however, and these will now be
briefly discussed.

6.10 Traffic generation can be handled according to the methods
outlined in Chapter V. However, it is more usual to combine that stage
with the distribution stage in the framework of an unconstrained gravity
model introducing the populations and possibly the per capita incomes of
the various centroids. Two uses of this model are common: in the
first, the gravity model defines an overall volume of travel which is
then distributed by mode, and in the second, the gravity model is used
separately for each mode. The latter approach, which may seem less
satisfactory, is justified in the presence of a narrow range of
available modes. Automobile travel, for example, generally involves
distances for which there is little competition, and on longer distances
there may be little competition between rail and air travel. Under
other circumstances, modal distribution models can follow mathematical
formulations similar to those presented in the preceding chapter for
goods, and a model of the time/price type (cf. 377) can also be used.

CHAPTER VII

THE PROBLEM OF STATISTICAL INFORMATION

7.1 The quality and availability of statistical information are
crucial to transport plans; their lack can be a stumbling block and a
serious constraint on the choice of mathematical models. First, two of
the most common shortcomings will be considered: insufficient road data
and inadequate classification of goods. Some thoughts on remedying them
will follow.
A. Insufficient Road Data

7.2 Rail, air and water transport offer relatively easy means of obtaining statistics on origins and destinations. As regards passenger travel, ticket sales or easily conducted surveys provide fairly accurate information that can be supplemented by user surveys during actual travel. Where goods are concerned, shipping invoices, or more simply the official documents required by regulations, also provide detailed and fairly reliable information issued by substantial, organized entities with competent specialized staff. Road transport presents an altogether different situation. There are no tickets from which to create statistics; road counts do not give information on origins and destinations but simply indicate the volume of traffic using a given artery at a given place; technical data-gathering methods show neither the number of passengers per vehicle for buses or private cars nor the tonnage or nature of the goods carried by trucks. The trucking industry often consists of a welter of small businesses run by individuals neither trained nor inclined to fill out questionnaires and compile accurate statistics.

B. Difficulties in Classifying Goods

7.3 The difficulties encountered with respect to road transport statistics are often compounded by others pertaining to the classification of goods. These difficulties are twofold. First, transport nomenclatures (customs statistics, for example) cannot be easily matched with economic nomenclatures, since the former focus on characteristics of volume (density or size of shipments) and the latter are concerned with similarities of use or manufacturing process. This is a troublesome problem in moving from the economic submodel to the actual transport models.

7.4 Aside from that, transport nomenclatures are generally not suited to the needs of transport analysis. The categories of that nomenclature are too broad in relation to parameters that are important in modeling; some of those parameters are indeed totally ignored by the statistics, including those relating to the internal management of the shipping firm such as maintenance, the cost of a break in inventory supply, or the proximity of alternative sources of supply. Lastly, the existing statistics are usually collected at the level of industries or industrial sub-groups whereas a truly explanatory modal requires information at the level of the establishment. It is certainly this unsuitability and inaccuracy of the statistics that largely explains the difficulties in constructing freight transport models. By the same token, the most useful way to bring progress to this field would be to improve information-gathering rather than to perfect its mathematical structures.
C. Ways to Obtain the Necessary Information

7.5 Obtaining good statistics is a primary goal, and, in a sense, it can be said that one use of a transport plan is often that light is shed on the shortcomings of the statistics. However, while the goal may be recognized, the means of attaining it are costly and slow to bear fruit.

7.6 They are costly. One can attempt simple methods using existing sources of information, or more complex methods based on special surveys. But simple methods have severe limits. With respect to goods, the use of documents issued to enforce regulations is not a useful approach because such documents are often fraudulent. In addition, the agencies handling them and processing them for their initial purpose are rarely prepared to assist in attempts at using them for traffic analysis, which is of secondary importance to them. And in any case, such documents cannot answer all the questions relating to the transport field.

7.7 Therefore, specific methods must be tried, particularly ad hoc surveys. Field surveys are difficult to implement on roads; they do not produce many data and, in particular, they do not provide perfect comparability between modes. These disadvantages do not occur in surveys conducted directly with firms or households, but the costs are higher.

7.8 Improving information is a lengthy process. The development of a new survey or even the use of an existing source require, not counting preparation time, nearly one year if the seasonal phenomena typical of transport are to be covered. And it will be some years before any statistical anomalies can be pinpointed and corrected and actual trends identified.

7.9 The various traffic-estimating methods whose principles have been outlined above will not be further discussed here, for aside from the basic precautions and rules to which any statistical endeavor must refer, the special conditions of each country play a fundamental role. Here, we shall simply recall a method that can be used in the road transport area and which allows an origin-destination matrix to be constructed from vehicle counts. It begins by modeling the system by its arcs and its nodes, after which the shortest path between each point of origin and each destination is determined. The traffic between each origin "o" and each destination "d" is assumed to take the form:

\[ T_{od} = K \frac{(P_o P_d)^\alpha}{C_{od} \beta} \]

(or any other equivalent mathematical form).
In this formula, $P$ represents the populations, $C$ represents travel cost (generally the cost charged to users, but other resistance factors, such as distance or time, can be substituted), $o$ is the origin and $d$ the destination. $K$, $\alpha$ and $\beta$ are parameters.

7.10 By applying this formula to each o-d pair, and by assigning the traffic to the shortest route each time (but any other commonly applied assignment rule may be used), a traffic load $T_i$ is obtained on each arc $i$ of the system. By minimizing the divergence between the $T_i$'s calculated and the $T_i$'s observed in road counts, one obtains an estimate of the parameters $K$, $\alpha$ and $\beta$ and therefore of the law determining the origin-destination flows.

7.11 This method can be coupled with sample surveys on stratified samples in which certain important proportions are tied down, e.g.:

- for passengers, the proportions in which certain purposes of trips are sampled, or the number of passengers per vehicle,

- for goods, the proportions of different classes of merchandise or sizes of shipments within the sample.

7.12 With respect to freight traffic statistics, the welcome fact is that, for medium- and long-haul transport, a substantial proportion of the total ton-miles is provided by a small number of relatively homogeneous bulk commodities such as cement, ores and petroleum. The diversity of general merchandise, on the other hand, is irreducible. This makes it desirable to focus on those few commodities and subject them to close analysis.

CHAPTER VIII

ANALYZING THE SUPPLY

8.1 This analysis covers the representation of the transport system. The objective is to translate the appropriate data into terms that can be processed by the computer in a manner helpful to analyzing the demand. The two items thus to be modeled are infrastructure and vehicles.

A. Infrastructure

8.2 The infrastructure system is defined by its arcs and its nodes, mode by mode. The description of the system encompasses the characteristics of the arcs or limits (capacity, frequency of public transport, speed and its variation according to the flow on the route), and the terminal times for the nodes. The size of the system to be inputted depends, of course, on the particular features of the real system and the nature of the problem, but in general a few hundred arcs is a figure that is seldom exceeded.
8.3 Information on the system must be accompanied by information about costs of maintenance and the functioning of the infrastructure, as well as changes in them over time in terms of foreseeable productivity gains.

8.4 The compilation of those data presents no logical difficulties but does generally pose formidable practical problems as to data collection and processing.

B. Vehicles

8.5 The analysis of vehicles has to proceed in terms of vehicle-kms (rather than ton-kms as is the preceding case of o-d matrices) and the first step is therefore to determine the transport potential in those terms, i.e., numbers and capacity, and average utilization rates. However, this analysis may be of limited usefulness: the production of vehicles does not take long, they can be readily imported, and, in the absence of special constraints, their potential can be modified to meet new needs rather flexibly. A detailed analysis is called for only in cases where these conditions do not prevail, such as temporary situations on which some short-term plans tend to focus, or when the economy is being subjected to special constraints through the regulation of external trade and imports, or where governments intervene to control the increase in motorized traffic by restricting the supply of vehicles.

8.6 Information is further needed on operating costs and the future outlook for such costs. The first requirement is for statistical analyses which of course involves categorizing the vehicles. Such analyses are not exclusively financial, for they must take account of the vehicles’ occupancy rates or their carrying capacity.

8.7 A specific difficulty arises in forecasting the trend of those costs, which depends on technical progress as such and progress in fleet management. These fundamental problems cannot be handled by econometric and mathematical methods. Qualitative estimates are called for, and the most promising approach is probably to elicit opinions from groups of experts with competence in each mode. Their task would be to determine the natural prospects in these spheres, as well as to define ways in which the public authorities can maintain the desired progress.

CHAPTER IX
DESIGNING INVESTMENT PROGRAMS

9.1 Traffic models are not an end in themselves but simply a decisionmaking tool. Among the decisions they help to bring about, the most important concern investment, especially in infrastructure. The specific nature and practical importance of that end justify special
attention, first, to the evaluation of individual projects, and next, to the design and, more precisely, the optimization of a program of investments spread through a system over a period of time.

A. Evaluation of an Individual Project

9.2 Project evaluation can be based on several criteria rather than just one: it is obvious that economic cost-effectiveness estimates cannot embrace all the consequences of an investment. Impact on the environment and on local economic development and effects on life style can hardly be reduced to gains in time or operating savings. Nevertheless, project evaluation, or in any case, the part that is most relevant to traffic models, is based on cost-effectiveness estimates.

9.3 In their simplest formulations, such estimates are grounded in the theory -- or rather on approximations to the theoretically pure concept -- of surplus, and use discounted profit and the first-year rate of return. The discounted profit guides in the choice between incompatible projects, while the rate of first-year return determines the optimal start-up date for each project: it is the date for which the rate of first-year return is equal to the national discount rate.

9.4 The discounted profit is the discounted sum of the benefits procured each year:

\[ B = \sum_{t > t_0} \frac{a_t}{(1+i)^t} - \frac{I}{(1+i)^t} \]

\( a_t \): benefit of the year \( t \),
\( I \): investment cost,
\( t_0 \): start-up date,
\( i \): discount rate.

The discounted profit, the benefit of the year \( t \), can be calculated either as the variation in profit at constant prices of all enterprises or as the variation in consumption at a constant price.

9.5 In the case of transport, benefits must relate not only to normal goods but also to such goods as users' time or safety, bearing in mind that it is not possible to quantify environmental impact and pollution.

9.6 The rate of immediate return \( TRI \) is

\[ TRI_t = \frac{a_t}{I} \]
9.7 The rule is that, under some rather weak assumptions (growth of traffic), each investment must be completed for the year \( t_0 \) in such manner that its TRI will equal the discount rate: in that way, discounted benefits will be a maximum.

9.8 These rules show the links between economic design and traffic studies. The benefits \( a_x \) are actually constituted by consumer surplus, \( \frac{1}{2} \) which is in principle determined by the laws of demand; expressing these by the classic demand curve, it is the hatched area on the graph on the right. \( \frac{3}{2} \) It shows the traffic and the generalized transport costs with and without investment, data relevant to the traffic study or directly derived from it. This is the reason why profitability calculation programs are often very directly focused on traffic programs, of which they are only an appendix.

9.9 The application of those principles calls for several observations. The first is that the graph above represents transport reality in very rough fashion: many phenomena disturb the simplicity of the demand curve, which must be replaced with a set of laws derived from traffic modeling, and it is directly on the basis of those laws that the consumer’s surplus must be estimated. By way of example, when the reasoning is based on a given demand, which is the case for doubly constrained gravity models, the consumer surplus is reduced to the saving of transport unit costs, multiplied by the traffic.

9.10 Similarly, when modal choice is predicted by a disaggregated model of the logit type, it can happen that some users will stay with or switch to the higher-cost mode or itinerary. To see this, assume that generalized cost is entered into the function as an exact magnitude (i.e., without allowing for the random nature of this cost). Some users

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\( \frac{1}{2} \) To which must be added the variation in the expenses of the transport operators, but the evaluation of this item poses no problem.

\( \frac{3}{2} \) Certain problems posed by the use of development costs in estimating surpluses are discussed in Annex 3.
will then nevertheless select what appears to be the higher-cost mode (or itinerary) simply because for them the difference between the mean deviations (say, the standard deviation or the variance) of actual generalized cost around its mean outweighs the difference between mean costs, thus:

\[ e_i - c_i \overline{c} > e_1 - c_1 \overline{c} \]

where \( C \) is the average transport cost, \( \epsilon \) is the random deviation of cost from average cost, \( i \) marks the individual, and 0 and 1 represent the two modes (or itineraries). This benefit will, logically, have to be integrated into the user surplus.

9.11 When the argument of the function, specified as an exact magnitude, is not generalized cost, the appraisal of the benefits from a modification of supply follows less directly from this reasoning; it is not possible, of course, to supply general rules on how to proceed from one to the other here, but it is desirable to ensure logical coherence between the two.

9.12 Recall also that this scheme is based on the surplus theory. When applied to transport investments, the method will therefore only apply readily to marginal changes. To make it applicable to non-marginal changes requires major assumptions to hold, especially with respect to the economy's progression from the initial to the final state, which must be assumed to be continuously optimal. This entails assuming the existence of a social utility function covering the whole range of variation of the economic parameters and raises particular difficulties when the prices of several goods vary (cf. 22 bis and 38 bis).

9.13 It is frequently thought right to use fictitious (or 'shadow') prices. If that is done, the decision rules based on the fictitious prices are no longer consistent with the reactions of users which are based on the actual prices facing them. The use of fictitious prices responds of course to the demands of the elementary theory set out in the preceding paragraph (see Ref. 41). It is indeed to be recommended in certain situations that are not uncommon in developing countries, as, for example, where external and internal prices differ or where unemployment or an external deficit signals disequilibrium. But caution is advisable if one wants to avoid waste as would occur if tariffs or regulations are not adjusted so as to make the behavior of users consistent with the set of fictitious prices. It is easy to demonstrate that if the fictitious (shadow) value of time or use in investment decisions is less than the value revealed by an analysis of

\[ * \] And this only under certain hypotheses, the boldest of which is probably that of optimal income distribution.
user behavior, and if this difference is not compensated for in the tariff, the investment will be non-optimal (or, more precisely, will be under-investment: see Ref. 6). The same level of user satisfaction could in fact have been achieved with a smaller investment and a suitable tariff. The point is taken up again in para 10.1.

B. The Search for the Optimal Program

9.14 The primary aim of a transport plan is not the evaluation of an isolated investment, but the design of an optimal investment program covering the system as a whole. This involves choosing, from among a number of basic operations, those to be included, defining the order in which to carry them out and setting a timetable for the completion of each one. This problem presents a higher degree of complication than the previous one, for there is no simple relation between the cost-effectiveness of a set of operations in a system and the cost-effectiveness of each isolated operation.

9.15 Theoretically, there is only a finite number of possible combinations, and the problem can be resolved by enumerating the combinations, computing the discounted profit for each one and selecting the one for which the discounted profit is highest. But this procedure is too costly in terms of computer time and money if the system under consideration exceeds a very small size. If one does not make very strong assumptions on the structure of the basic investment operations and their interactions, it is not possible to define a simple and rigorous optimization process. One can simply, as will now be done, propose approximate and plausible rules that will probably bring about a reasonably good solution.

9.16 The first step is to establish, among the investment operations, a set of three possible types of relationship:

- Independent: carrying out one does not affect the cost-effectiveness of another.

- Complementary: carrying out one increases the cost-effectiveness of another.

- Competition: carrying out one reduces the cost-effectiveness of another. A specific example is that of incompatible operations: carrying out one makes the other completely useless (case of different variants of development on the same arc of the system).

9.17 Practical experience shows that these relations can generally be considered reciprocal, transitive and stable regardless of the investment program. The classification is obviously based on the
discounted profit of the operation, but it can also be based on the results of the traffic model: the operations are complementary if completion of one contributes traffic to the arc pertaining to the other, and competing if it deprives the other of traffic. The basic operations can in fact often be classified at the beginning of the process on the basis of common sense and experience.

9.18 The basic projects should then be grouped into programs, with the complementary operations put together (keeping of the incompatible operations, the one that taken in isolation shows the greatest discounted profit).

9.19 The program is not yet defined, however: the order in which the basic operations are to be carried out and optimal scheduling still have to be determined. Here too, consideration of the cost-effectiveness of each investment taken in isolation may help determine the order of completion, the exact data resulting from the calculation of the immediate return on the operation, i.e., assuming all previous operations of the program completed.

9.20 Strictly applied, the preceding rules would produce a single program, but they are approximate, and in practice some of their underlying assumptions will be found implausible. This will lead to the eventual selection of not one but several programs, and a final choice will be made among these on the basis of precise and rigorous calculations of their discounted profit.

9.21 The process just described does not explain how to generate the package of basic projects from which a choice will be made to ensure the optimal process. Yet this is a crucial operation inasmuch as it conditions the final choice in a way that is not very visible, since the transport plan study will focus attention on the choice between projects that have already been identified. It is also well known that assistance in decisionmaking can be perversely transformed into advocacy for a pet project which can be set off against a few noncompetitive alternatives. Although it often gets rather short shrift, the generation of projects is therefore a phase of fundamental importance to a transport plan study. Yet it is even more difficult to provide a firm rule for the solution of this problem than for the choice of the optimal process. The best one can do is to recommend very extensive and open study drawing on the expertise of several organizations and consultants and allowing plenty of room for inventiveness and creativity, and to make some suggestions based on notions of investment for productivity increase and investment for capacity extension.

9.22 Each investment operation is in fact a combination in varying proportions of two extreme types: productivity investments.

More precisely, if the profit of operation A is greater when B is completed than it was without B, or vice versa, A and B are complementary.
which are instrumental in reducing the (generalized) cost of transport without substantially altering the capacity of the arc on which they lie, and capacity investments, which augment the capacity of the arc on which they lie without substantially reducing transport cost.

9.23 Both types can be made the subject of artificial case studies: on a simple network in which there is no transfer of traffic from one mode to another, one attempts to determine for what ranges of traffic volume they become cost-effective, given their average completion cost. This method is particularly reliable for pure productivity investments.

9.24 For capacity investments, one way to form an idea of the demand to be satisfied consists of conducting the traffic study, i.e., going through all the traffic models, by taking as the transport cost on each arc the long-term marginal cost, or rather an approximation thereof, called the development cost (called CDA in Annex 3), without capacity constraint. The difference between the traffics thus calculated without capacity constraint, and actual capacity provides an approximate indication of the capacity needs to be met.

9.25 Certainly these quantitative analyses, which are grounded in economic theory, do not preclude consideration of other factors not incorporated in conventional economic calculation, such as certain consequences on the environment (elements such as noise are difficult to translate into money terms) and on local economic development (models integrating economic development with true transport models are seldom operational). Such considerations would occur in conjunction with analyses of many criteria; however, the actual performance and scope of such analyses fall outside the range of this report. These comments parallel those made in para 9.2.

PART II

Incorporating Transport Plans into the Decisionmaking Process

9.26 Part I was devoted to the analysis of the techniques used for preparing transport plans. Part II will discuss ways of incorporating transport plans into the decisionmaking process. The first chapter will outline their areas of application and reexamine in greater detail some relevant issues briefly alluded to in the foregoing discussion of investment programs. A second chapter will be devoted to procedures for their use: how and with the aid of what methods should they be implemented? The third and last chapter will sum up the previous two and attempt to frame some recommendations on the methods to apply and the models to use in specific situations and on the nature of the questions to be asked by the planner.
CHAPTER X

AREAS IN WHICH TRANSPORT PLANS ARE USED

10.1 The area in which transport plans are most frequently used is the design of infrastructure investment programs. It is often for this vital purpose that they are devised. However legitimate a goal that may be, it must be kept firmly in mind that infrastructure investments are but one of several means to achieve the real final goal, namely optimization of the transport system. This can be achieved by a number of other means, including rate-setting, regulation, operational investments (especially in rolling stock) and, of course, ongoing measures to improve management. In fact it is important to realize that many problems that seem to call for an infrastructure investment can be resolved by one of these other means. Insufficient infrastructure capacity can thus be remedied by changing the level of user demand through appropriate charges. It can also be remedied by using vehicles with improved performance or better suited to the type of infrastructure. Or regulations with the same aims and consequences as new charges can be put into effect.

10.2 Conversely, there can be a contradiction between the measures taken through those three instruments: rates that are set too low will cause an overestimate of investment needs. This underscores the need to consider these three transport policy tools simultaneously. This requirement is made more pressing by the fact that these tools each have a special sphere: the short term for management measures and rates, and the long term for investments. This classification, which matches the different lead times for implementation, could create the erroneous impression that their consequences are dissociated and do not relate to the same aims, and that their examination can therefore also be dissociated.

10.3 One result of the foregoing is that the optimality of prices, costs and management must be studied prior to the drawing up of an investment plan, in order to ensure that investment will not be sought where the desired aim can be achieved at lower cost by other means. Under certain circumstances the "infrastructure investment" approach is the easiest: it is gratifying, it focuses on technical problems and, by steering clear of human conflict, at least in its more visible and direct forms, it avoids many obstacles. Yet it is not necessarily the best approach, and others should not be overlooked or rejected just because yardsticks by which to measure their effectiveness are lacking.

10.4 Looked at in this respect, Transport Plans do not appear a particularly suitable setting for investigating the probable effects of regulatory measures such as the imposition of quantity limits on the capacity of certain transport modes or routes or on the transport of certain commodities by particular modes. Only very simple measures, such as global restrictions on certain modes, can usefully be tested out
in Transport Plans. Simple tariff changes, on the other hand, can very well be examined within such plans. Consistent with the general methodology of the plans, the effect that such policies will have on user behavior can be predicted by means of descriptive models and the effect on the total or social benefit can be evaluated in terms of consumer surplus theory.

10.5 Thus, where policy judgments are concerned, transport plans can and should do more than what is generally demanded of them. By contrast, too much is generally expected of them in terms of precise results. In this regard a distinction must be observed between absolute and relative values.

10.6 With respect to the absolute values resulting from plan studies, all who have actively participated in the calibration of a traffic model know how sensitive those values are to assumptions and how difficult they are to determine. Statistical methods for obtaining them are often too complex and too lacking in theoretical foundation to permit the calculation of a standard deviation; but it is certain that if that were possible the standard deviation would be high. This conjecture is based on a number of features common to all these models: their complexity, the sheer number of parameters that have to be brought in and the imprecision of their basic data.

10.7 These difficulties are compounded by others, such as the imperfect specification of the model structure: variables that must be glossed over because no statistics are available for them; relations for which available observations cover only a limited range of variables; and statistics whose area of validity has to be extended by educated guesswork (particularly with regard to road speed-flow ratios which are fairly well known for small flows but much less precisely for high flows approaching saturation). Finally, it can happen that a parameter is estimated with a substantial error through a model whose results are not very sensitive to its value, and then used as input in another model whose results are very value-sensitive. This problem often occurs in connection with the "money value of time" parameter. The figure generally comes out of a modal choice or itinerary choice model, the results of which are often insensitive to that time value. But the cost-effectiveness estimates in which this value of time is used are very sensitive.

10.8 For all those reasons, it is wise to resist blind acceptance of the raw results of the models, to check them by simpler methods, to verify their overall magnitudes in the light of experience, to remember that the first results may subsequently need revision and to make every effort to improve and refine the results.

10.9 The need for great care in dealing with the absolute values of the results becomes much less pressing when one is dealing with differences or with sensitivity analyses. Here, specification errors, uncertainties as to the determination of statistical data and random errors can be expected to affect both terms of the comparison equally.
The questions to which it is possible to reply thus can be of several types. They can, first, concern the model's replies to variations in certain economic parameters, e.g.: how will the modal distribution vary (at the national level, on a particular route, for a particular commodity, etc.) if the charges for one mode change by a given percentage or if the price of an item (oil, wages, foreign exchange, etc.) changes? Those are classic calculations of response elasticity or of multipliers. The questions can also be directed to the sensitivity of the model's structures, e.g., how much do certain central results vary if a given parameter estimated in the modeling process is modified (for example, how much do those central results vary if the value of time varies by 10%).

Finally, if one has a model of the downstream effects of transport on economic development, these studies can explore the impact of transport policy measures on the rest of the economy. Given the embryonic state of modeling in this area, the sensitivities to be studied may have a bearing on macroeconomic indicators that are important in the country's public policy, such as the trade balance, employment, price levels, the budget deficit or the growth rate. And the elements of transport policy to be analyzed will be particularly relevant to the direct effects (Leontieff multiplier, Keynesian multiplier) of an investment and its financing procedures, or the consequences of price changes (petroleum, automobiles, transport, etc.), or overall changes in regulations.

CHAPTER XI

PROCEDURES FOR THE USE OF TRANSPORT PLANS

11.1 Two apparently contradictory principles govern the use of transport plan models: the first is that a model is not made to give a single answer to a single question but must be versatile, and the second is that no one model can answer all questions.

A. Versatility

11.2 The requirement of versatility grows out of the familiar concern for efficiency. Devising a transport plan is a long and costly operation and it is important to make it serve a range of uses. Given the conditions outlined in the preceding chapter, a model cannot be given perfect form at first try: the quality of the results and its flexibility improve with time and experience, and there is a period of trial-and-error as with the manufacture of any industrial product. Finally, the versatility must reflect the conditions that govern the planning and the decisionmaking process. Transport decisions, like those in other fields, do not come into existence full-blown at a specific moment and are not necessarily carved in stone. The real decisionmaking process is progressive, its focus narrowing slowly and always subject to widening again when a change of direction seems neces-
sary following a change of policy or circumstance. It will then be necessary to reexamine the model in the light of changing events and new ideas.

11.3 The convenience with which models can be updated is therefore an important facet of their quality, and the updating itself has several aspects. The first involves the convenience with which fresh data can be introduced. For this purpose a permanent source of statistics capable of providing regular input is far preferable to a one-time survey that cannot be extended or repeated, for with the latter one can neither note change nor check anomalies, and initial uncertainties remain. From a technical standpoint, updating also entails a convenient system for accessing and inputting data in the computer. The second aspect involves the flexibility with which the software that constitutes the model can be used and modified with a view to changing the value of the parameters and the form of the relationships, introducing new sub-programs, etc.

11.4 These constraints influence the procedures used in developing transport plans. They underscore the dangers of such development in a vacuum by a team of specialists foreign to the country who leave it once the work is done. It can certainly be useful and often it will even be essential to engage outside specialists possessing expertise and experience unavailable in the target country. But it will be necessary for such specialists to be integrated into a team of local researchers who will contribute their knowledge of the country's special characteristics while acquiring expertise in modeling which they will subsequently pass on to their compatriots. Additionally, it would be useful for the foreign specialists to remain in touch after the design phase, so that they can perfect and maintain the model, somewhat along the lines of after-sales service. The whole effort could be conducted by a task force composed of foreign and national experts and set up to complete the first version of the model and then, possibly under a slightly different form, to ensure its maintenance.

11.5 The normal operation of the model must be that of a dialogue between researchers and political leaders. The latter put forward their ideas on transport policy and their proposed investment programs; the researchers are responsible for evaluating those ideas and proposals in terms of their model; and the dialogue between the two makes it possible to pinpoint the problems and devise solutions. The dialogue would further lead to the establishment of criteria through a learning process that teaches decisionmakers the scope and limits of modeling and researchers the nature of the decisions to be made and the problems to be resolved. For this reason it would seem important for the task force to be sponsored by a group of national decisionmakers, politicians and senior management and professional personnel.
B. There Is No All-Purpose Model

11.6 These reflections on the desirable versatility of transport plan models must be qualified by the statement that there is no such thing as an all-purpose model. As in optics, the power of resolution decreases as the size of the field is enlarged. The more a model is designed to solve a particular problem, the less suited it will be for work on other problems. At the same time it can be argued that the idea of establishing a general transport model able to respond to a wide range of questions is an inexpensive approach when little statistical information is available, when the ground to be covered is unexplored by previous models, and when the answers sought do not have to be very precise. It is in fact academic to note that this approach is used especially in countries lacking a prior base of statistical information and experience with models, and that afterwards its prime accomplishment often seems to have been to get a development process aimed at filling those gaps underway.

11.7 Conversely, in countries where information is plentiful and modeling is fairly advanced there is generally no call for a national transport plan; but each particular problem is subjected to specifically focused modeling based on models previously applied to related problems and on the updating of their methods and statistics.

CHAPTER XII

MATCHING MODELS TO PROBLEMS

12.1 The conclusions outlined in the last chapter and elsewhere in this report point to certain recommendations concerning the use and implementation of transport plans.

12.2 Those recommendations must be based on the previously stated requirement that all transport policy instruments be studied simultaneously, and that development of an optimal investment program not be viewed as the only aim of that effort inasmuch as regulation, rate-setting and management improvement are also useful means of upgrading transport systems which can work either in synergy with or in opposition to the investment policy.

12.3 In that context, how can the traditional models discussed in the preceding chapters best be used in conjunction with a comprehensive national study? This is the question addressed in the first part of this chapter, with the second part devoted to the other questions.

A. Role and Limits of Transport Plans

12.4 The usefulness of comprehensive modeling will depend on how many of the following conditions are present.
12.5 The problem at hand has a geographic aspect. The typical case is that of infrastructure investments, but certain management measures also fall under this heading, as when the goal is to determine the optimal procedure for supplying a foodstuff and distributing it to different points of consumption (obviously, in this case the optimal solution will include an infrastructure investment component).

12.6 The problem at hand pertains to the whole geographic area of the country: when the problem does not fit this description and the questions to be resolved are geographically fragmented, seeking separate solutions is easier and allows for the development of a process better suited to dealing with specific issues.

12.7 This condition will be met more rarely in dealing with big countries than small ones. When the country is large, transport problems will be less likely to apply to its entire territory, and geographic disparities will be more likely to militate against a single-model approach. Such disparities can include differences in costs and flows induced by different weather conditions, differences in the levels and structures of economic development, and differences in transport needs and the means available for their satisfaction. In this regard, transport plans should take account of regional specifics in large countries. This can be accomplished by regionalizing certain parameters within the same model, or by constructing different models if the problems in question are very different in nature.

12.8 When statistical studies and information are abundantly available and of high quality, it is almost always preferable to handle each problem separately so as to make it easier to focus on its specific characteristics, but otherwise a comprehensive transport plan study may provide the necessary "nudge" to show up shortcomings in methodology and statistical information and serve as a point of departure for the training of competent transport planners.

12.9 Even when the requirements for the implementation of a transport plan have been met, the plan cannot provide answers to all questions. It is particularly suited to handling problems of a geographical nature that do not involve too much detail. Examples include the determination of funds for transport investment and their distribution by mode, by region or by major transport routes. A global study certainly provides more detailed results and permits a fuller enumeration of individualized operations, but the analysis of each one is likely to be less precise than what can be achieved by a lower level of aggregation.

12.10 The same models and the same procedure as the ones used for a national transport plan can also be used for studying a very important separate operation such as the crossing of international or inter-continental straits, or a tunnel through a major mountain range, or when the traffic concerned is likely to serve a large area. In such cases, traffic studies should be as far-reaching as transport plans and can be
conducted with the same methods, but the optimal investment sequence is easier to establish as there are fewer programs to be compared.

12.11 Another situation in which a national transport plan is useful arises when multimodal investment programs must be established comprising various small-scale operations of different kinds, such as road-surfacing, reinforcement of roads or runways or realignment of rail lines. In such cases, the direct evaluation of each basic operation (measured by, for instance, its rate of immediate return) provides a false picture of the marginal effect because between each of those basic operations one must look for effects of complementarity or competition which cannot be discerned when they are examined case by case. A national study covering the basic operations at an appropriate level brings out their interactions better and makes it easier to assess the consequences of particular policies; it therefore constitutes a good tool for estimating the amounts to be devoted to each operation. But the national transport plan is too crude an instrument for the precise programming of each basic operation, which requires conventional calculations of marginal return.

12.12 In any event, it is advisable that the investment programs growing out of the national plan should be followed up with more refined studies for a more precise determination of the nature of the operations and the time needed for their completion.

12.13 These studies should first be of a technical nature. One of the major causes of error in rate-of-return calculations lies in uncertainty concerning implementation costs, and such uncertainty can be resolved only by a more detailed technical study of the project.

12.14 Next, they must be relevant to traffic analysis, supplementing the general study with partial and localized traffic analyses in the form of studies of the history of traffic flows on the route under consideration, comparisons with the forecasts produced by the model, or special inquiries into the most important operations.

12.15 One matter, however, that can only be attended to at this juncture of the study is the analysis of the time profile of the traffic flows on the section under consideration. This is an important problem, for a single annual traffic flow can give rise to very different infrastructure needs depending on the way in which it is distributed over time. However, in the current state of traffic modeling, it can be resolved only by localized analyses based on specific inquiries and studies of the descriptive monograph type, and buttressed by common sense and experience.

12.16 With respect to the degree of formality and complexity of the models, the quality and availability of the data should be kept consistent with each other. Where there are shortcomings in the quality
of the data, more complex methods and models may be required; \(^8\) this is generally not the case with transport plan studies. But the model will be hampered especially by the absence of certain data.

12.17 In any event, it is important that the model should not function as a black box between input data and output results. This is prevented by splitting up the model and considering the modeling framework as a constellation of partial submodels linked to each other but independent and subjected to separate treatment. Each submodel will have to be evaluated separately. The plausibility of its results can often be judged by considering the elasticities of the results with respect to the most important causal variables. This type of test has the advantage of allowing easy comparisons among models, and especially of allowing international comparisons. Annex 4 contains, for purposes of general identification, a list of elasticities that can be calculated and the plausibility of which can be evaluated.

B. Other Available Tools and Their Areas of Validity

12.18 Several other problems arise in conjunction with the development of a national transport policy. First there are investment problems pertaining to a smaller geographical scale, and there are also the other matters enumerated in the introductory chapter and recalled at the beginning of this chapter: evaluation of a rate-setting or regulation policy, and interactions between transport and economic policies.

12.19 Among investment problems on a scale smaller than country-wide, two that merit special attention are the opening-up and service of rural areas and the design of corridors and trunk lines. The opening-up and service of rural areas require a type of traffic that is not covered at all by the models used in transport plans (cf. 38 for descriptions of some methods). It involves travel over very short distances, often with very different vehicles which can use lighter infrastructure. It only overlaps with long-haul transport in that often it uses the same infrastructures and in that the funds earmarked for such investments are often included in the same packages as those for long-haul transport, and choices must then be made between the two.

12.20 When the design of trunk lines and corridors requires large investments and involves substantial traffic, it must rely on the same models and methods as national transport plan studies. It can be simplified, however, by focusing on the one-dimensional structure of the problem. Zoning can be simplified and so can the models. Future traffic growth can be inferred from past growth as there is little spill-over of traffic from other trunk lines; the magnitude of the results of certain parts of the modeling, especially the distribution of traffic over modes and itineraries, can also be evaluated more easily.

\(^8\) The typical case in econometrics is that of linear regressions: the existence of errors in the explanatory variables calls for more complex estimating methods than if they were not present.
Basic projects can be more easily combined to make up investment programs; the advantage of such groupings is that they reduce the number of elements and these can then be more conveniently assessed without detailed estimates.

12.21 Foremost among general transport policy problems that are nonspecific to geographical locations are traffic sensitivities to prices and to quality-of-service parameters such as time. Geographic models on a national scale generally lend themselves best to assessments of the effects of comprehensive modifications of service quality (e.g., time gains) on traffic. The same does not apply to the effects of tariffs: if the aim is to learn the change in ton-kms or passengers-kms that would result from a change in rates or fuel prices, it is generally preferable to undertake global econometric studies. These would be less costly, faster and better able to encompass all forms of traffic than a spatial study on a national scale -- the kind that aims to reproduce the origins and destinations of traffic flows -- which might overlook diffuse short-distance traffic and omit certain factors that can only be examined at the local level.

12.22 Another problem relating to transport policy lies in the evaluation of regulatory measures such as price controls (imposed rates) or quantity restrictions. There, too, a transport plan cannot cover and evaluate all the consequences, and specific econometric studies are necessary (cf. 18).

12.23 Finally, transport plans do not answer every question on the relations between transport policy and macroeconomic policy. Models exist for assessing the direct effects of an infrastructure investment on economic activity: effects on national production, the trade balance, public finance. These effects are generally measured through the workings of input-output matrices. A routine method for measuring those consequences is the "effects" method (cf. 7), which, though questionable when used to formulate decisions, is very much to be recommended for describing a situation. The same methods can also be applied in assessing the consequences of a rate-related measure or a productivity gain, but when used for that purpose the method must also allow for the response of demand to price changes (the price elasticity of demand for transport) and this introduces a complication absent from the simplest models for assessing the direct effects of investments which postulate rigid relations between quantity changes.

12.24 Lastly, the spatial effects of prices and transport service quality are considered in certain models of the relationship between transport and the location of activities, but such models are still in the research stage. Their usefulness is limited by the lack of adequate statistical data, and it is impossible to base decisions on their results.

\[2/\] i.e., pertaining to the carrying out of the investment and not to the consequences of resulting operations.
C.  Conclusion

12.25  The foregoing shows that transport plans deserve neither the excessive acclaim with which they were greeted some 15 years ago, when they were regarded as a panacea, nor the relative discredit into which they seem to have fallen more recently owing to some unfortunate experiences. They constitute a unique tool with which to handle certain problems, but they cannot answer all questions, and certain prerequisites must be met and precautions taken before they are run.

12.26  First of all, one must have an accurate idea of the questions to be answered and make sure that a transport plan is the best way to find the answers. One must in particular be mindful of the fact that investment policy, the usual target of transport plans, is not a goal in itself but that other instruments may be available for achieving the same objectives just as the bad use of those instruments will frustrate the plan objectives. The next point to keep in mind is that the methodology of the transport plan must be geared to the level of the available statistical information and transport know-how in the country. The methodology certainly constitutes an advance but it cannot operate when there are major gaps in information. The models used in that methodology should, if possible, be designed as separate stages of a plan that can each be tested and used in isolation. A constellation of separate submodels is preferable to an all-encompassing model acting as a black box. Finally, a transport plan must be judged as much by its educational value as by its initial results. It should be designed for frequent and regular review over several years, and suitable for amendment and improvement as experience is accumulated. It should serve as the medium for a dialogue between analysts and decisionmakers, and help to bring to light and correct gaps in the understanding of transport problems.

12.27  For all those reasons, transport planning may require the participation of foreign specialists but must above all involve the country's own analysts who will eventually have to run the model, and it must be supervised by persons with administrative responsibilities and persons with political authority. Meeting these conditions entails not only considerable financial expenditure but above all, a well-thought-out approach to inserting the transport plan into the decisionmaking process for transport, and a firm and continuing political determination to carry it out.
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DESCRIPTIONS OF STUDIES CONCERNING
SOME TRANSPORT PLANS


- Study of road corridor in Argentina; allocation among itineraries based on utilization costs (allocation to lowest-cost itinerary), followed by discounted profit estimate.


- Intended to plan over a 10-year period, 1968-1976 [sic].
- Covers not only investments but also operation and organization.
- Different stages:
  - selection of the principal network studied by conventional methods (traffic, development prospects, continuity);
  - determination of priorities (rate of immediate return > 10%, with sensitivity analyses);
  - verification of financial plausibility.
- Implementation:
  - survey of the network and its characteristics,
  - division of the country into centroids,
  - traffic count on each section,
  - OD (origin/destination) surveys on the road, in order to: determine the "lines of desire" (i.e., the OD matrix), and separate local and long-haul traffic,
  - all-or-nothing traffic allocation, based on the OD matrices,
  - growth by extrapolation based on income elasticity,
  - fleet trends by class of vehicle and use,
  - traffic growth differentiated by center in terms of changes in economic indicators.


- This book's main feature is a chapter on the application to Colombia of a large, experimental simulation model. This model calls for a large number of data and, in addition, the interpolation and extrapolation of missing data (a special program was created for that). It contains submodels that can be used separately. It connects the transport model to a model of general economic growth to test long-term development schemes.

- Basic work. Recommends treating air transport separately because of lack of intermodality, and offers a method for assessing road performance (Road Transportation Performance Model - RTPM), regarded as base model. The other modes stem from "modal splits" based on those early results. On the demand side, it proposes a "Commodity Flow Distribution Model" based on linear programming, to determine the rationality of current flows and forecast future flows. A "Commodity Flow Assignment Model" dealing with assignment on the road network is connected with it.

The Interregional Transport of Major Agricultural Commodities in Tanzania, Dar es Salaam, June 1979.

- Survey designed to participate in the transport planning process.
  - Detailed inventory of demand: surplus and deficit regions; traffic, compared with known traffic; modal distribution; cost analysis according to the different modes.
  - Proposals concerning rate-setting and its level of regulation.
  - Recommendations for management improvement in general, railroad operation and truck maintenance.
  - No discussion of infrastructure investments.


- Outside the general process defined by the detailed table of contents, the report discusses the "transportation model" used, on the basis of a gravity model:

\[ \text{Tab} = K \frac{F_a + F_b}{D_{ab}^n} \]

Central American Transport Study (1974-76).

- Covers the five countries of Central America.\(^1\)
- Investment plan with 79-90 horizon.
- Time span: 3 years.
- Very thorough and detailed study that goes over same ground as 64-65 study.
- Specifically defines investments by main road and by five-year period.

\(^{1/}\) Guatemala, El Salvador, Honduras, Nicaragua, Costa Rica.

- Horizon 1995.
- Four sections: I. resume, II. economic trends and outlook, projection of demand, sector development strategies, modal distribution, III., IV. modal reports and final program.

- Demand analysis:
  - country divided into 64 zones and 22 regions,
  - 50 categories of merchandise,
  - development projections by product and by region,
  - very qualitative intermodal coordination (railroads must cover their cost, road must specialize in short and medium haul, etc.),
  - intermodal distribution defined in qualitative and subjective fashion (e.g., two assumptions: one that actual mode distribution is maintained; the other that measures are taken affecting rail use).

Zimbabwe National Transport Study 1985.

- Division into 56 zones.
- Very descriptive presentation of the current transport network, recent growth rates.
- Little emphasis on modeling.
- Traffic forecast: passengers on the basis of price and income elasticity for three income classes.
- Passenger and freight increase on the basis of two economic development scenarios for each zone.
- Automobile-aircraft distribution by passenger, based on a logit model.

\[ Z_{\text{car}} = \frac{1}{1 + \exp \left( 0.11(C_{\text{car}} - C_{\text{air}}) \right)} \]

\[ C = (\text{price } \$ + 11.70 \text{ (travel time hours)}) \]

(N.B.: There was an OD survey with questions on the reasons for the mode selections and an elasticity inference for passengers as well as freight.)

- Curves showing freight cost variation by distance for road and rail.
- Conclusion of the intermodal freight study: difficult to measure total costs and mode distribution.
- For the establishment of investment programs, preparation of a multi-criteria analysis including, inter alia, the immediate return rate.
- Comparison of rail and road costs and rates.
- Preparation of an individualized investment program for railroads, national and regional roads, airports. [also showing] overall estimates for maintenance costs.
- Recommendations regarding management and operation.
EGYPT NATIONAL TRANSPORT STUDY, PHASE II.

- Study for a program of transport investments and policy guidelines to the year 2000.
- Demand forecast: passenger and freight OD surveys; use of existing statistics; passenger survey on the modal split between Cairo and Alexandria.
- Number of separate commodities: 30 consolidated into 5.
- It seems that the freight traffic projection was based not on formal methods but rather on monographic analyses, both for growth and mode distribution on the various routes.
- Number of zones: 30 for goods, 150 for passengers.
- Preparation of passenger traffic scenarios.

SOUTH EAST ASIAN REGIONAL TRANSPORT SURVEY, 1972 (RTS).

- Covers seven countries: Indonesia, Singapore, Laos, Philippines, Vietnam (South), Thailand, Malaysia.
- Focuses on the international trade of those countries.
- Methodology: projects economic development and external trade until 1990 overall and by geographic currents, then analyzes bottlenecks (by a projected traffic/capacity report) and remedies in investment, 2/ operation, organization and rate-setting. Topics covered: sea, road, urban traffic (general recommendations), air.


- Covers: Burkina Faso, Chad, Gambia, Mali, Mauritania, Niger, Senegal.
- A part dealing with supply describes current infrastructures.
- A part dealing with demand defines a goods and passengers matrix of 121 nodes and 245 arcs, with 31 centers.


- Two horizons: medium term and year 2000.
- Focus: defines a time value by a price/time model applied to the road-or-air choice, time value controlled by an hourly wage estimate (discretionary time values governed by value of work time).
- Mode assignment:
  - for goods, all or nothing for bulk shipments; Abraham's law for miscellaneous shipments.
  - for passengers, Abraham's formula with generalized cost.
- For each region: distribution: Fratar method

2/ Individualized projects.
\[ T_{k+1}^{ij} = (T_k^{ij} + F_k^{ij}) F_k^{j} \]

\[ F_k^j = \frac{T_j}{\sum_i T_k^{ij}} \]

\[ F_k^i = \frac{T_i}{\sum_j T_k^{ij} F_k^{ij}} \]

- \( k \): number of the iteration.
- \( T_j \): desired total \( T + 1 \) at destination \( j \).
- \( T_i \): desired total in \( T + 1 \) at origin \( j \).

**Senegal - Transport Plan (1978-1981).**

- This study, conducted by the Office of Research and Programming of the Ministry of Public Works of Senegal, included:
  - study of traffic perspectives and vehicle operation costs,
  - development of geometric norms, a schedule of average prices and representative costs of work by type of road and geographic section,
  - preparation of a transport plan,
  - programming of road investments to be made during the next 10 years.

- Simultaneously, studies were conducted on the improvement of the peanut storage and distribution system and the development of agricultural earth roads.
SHORT-TERM AND LONG-TERM MARGINAL COST
AND DEVELOPMENT COST IN TRANSPORT

1. Marginal costs present peculiarities because of the existence of externalities and non-trade goods. Social costs and congestion costs appear next to operating costs. Furthermore, infrastructure is characterized by indivisibilities. In their absence one could define a long-term marginal cost which is the mathematical derivative of the function of long-term expenditure which represents the envelope of short-term expenditure functions when capital varies. According to a classic result, optimum adjustment of capacity assures equality between long-term marginal cost and short-term marginal cost. Obviously, when there is indivisibility, no smooth envelope of short-term expenditure functions will appear so that the long-term marginal cost cannot be calculated. One is then compelled to introduce the notion of development cost.

2. This annex presents, first, the conditions for equality between long- and short-term marginal cost, and then the notion of development cost.

A. Equality between short-term and long-term marginal cost in the case of transport infrastructure

3. Assume an economy in which consumers are all alike and have the utility function \( U(q, T, C) \), where

- \( C \): is the only staple consumer good,
- \( T \): is the transport quantity (the number of journeys completed per unit of time),
- \( q \): is a parameter indicative of service quality, for example the time taken by a journey (note that this indicator relates negatively to the quality of the service),
- \( C_0 \): is the economy's original endowment with the staple good,
- \( K \): the amount of infrastructure capital,
- \( r \): the annual capital cost per unit of infrastructure,
- \( R \): the income of the consumers.

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1 Directly based on Alain Bernard (cf. 1).
v the monetary private cost of transport,

μ the user charge (to be determined) for the infrastructure,

To simplify the argument, all the "monetary" variables -- r, R, v, μ -- are expressed in terms of C, the general consumption good.

4. The problem is to determine the conditions for optimal management of the economy. Mathematically, that involves a maximization of the utility function (U) subject to constraints:

\[
\text{max } U(q, T, C)
\]

subject to:

\[q = f(T, K), \text{ a technical relation that expresses the performance of the infrastructure, and } vT + C + rK = C_0, \text{ which is a condition of equilibrium of the economy, indicating full use of all resources.}\]

5. From the Lagrangean

\[U(q, T, C) - \lambda [q - f(T, K)] - P(vT + C + rK - C_0)\]

one derives the first-order conditions for a maximum:

\[
\begin{align*}
\frac{\partial U}{\partial C} - p &= 0 \\
\frac{\partial U}{\partial T} + \lambda \frac{\partial f}{\partial T} - pv &= 0 \\
\frac{\partial U}{\partial q} - \lambda &= 0 \\
\lambda \frac{\partial f}{\partial K} - pr &= 0
\end{align*}
\]

6. The user charge for infrastructure, u, must now be set so as to ensure that users seeking to maximize their utility subject to their budget constraint will attain the quantities of transport T and staple good C, that emerge from the solution of the preceding program. In other words, there is a second program to solve, that of consumer behavior:

\[
\text{max } U(q^*, T, C)
\]

with \((μ + v)T + C = R\). q is the quality of service resulting from the preceding program, on which users are assumed to have no influence. The solution T, C of this second program must be the same as that of the preceding program.

7. The Lagrangean of the second program is

\[U(q^*, T, C) - a[(μ + v)T + C - R]\]
yielding:
\[
\frac{\partial U}{\partial t} \mu + \nu = 0
\]
\[
\frac{\partial U}{\partial c} a = 0
\]
from which:
\[
\frac{\partial U}{\partial t} = (\mu + \nu) \frac{\partial U}{\partial c}
\]  \hspace{1cm} (5)
and, by combining (5), (2) and (1):
\[
\mu = -\lambda \frac{\partial \xi}{\partial t}
\]  \hspace{1cm} (5a)

which, combined with (4), yields
\[
\mu = -r(\frac{\partial \xi}{\partial t})
\]
But, according to the implicit functions theorem,
\[
(\frac{\partial \xi}{\partial t}) (\frac{\partial \xi}{\partial \xi}) = - (\frac{\partial \xi}{\partial K})
\]
therefore
\[
\mu = r(\frac{\partial K}{\partial t})
\]  \hspace{1cm} (6)
Furthermore, by combining (3) and (4) one obtains
\[
\frac{1}{P} \cdot \frac{\partial U}{\partial q} \cdot a = r
\]  \hspace{1cm} (7)
(6) is interpreted as follows:

"The optimal user charge is the long-term marginal cost." In fact
(\frac{\partial K}{\partial t}) is the infrastructure variation that must be achieved to
(\frac{\partial t}{\partial t}) respond, at a constant quality of service, to a unit variation
in traffic, and r(\frac{\partial K}{\partial t}) is the appropriate annual monetary charge.

(7) supplies the rule for establishing the size of the infrastructure,
which can be interpreted as follows: "The marginal utility of the
infrastructure, measured in monetary terms, must equal $r$, the annual capital cost per unit of infrastructure.\(^2\)

8. Let us now introduce the notion of social cost. The value of service quality equals $\lambda$, according to the conventional meaning of the Lagrangean multipliers.\(^3\) For each unit of traffic, $T$, it is therefore

$$\Pi = -\frac{\lambda}{PT}$$

and the social cost is

$$\Gamma = \pi T q$$

so that

$$\frac{\partial \Gamma}{\partial T} = \pi q + \pi T \frac{\partial q}{\partial T}$$

$$= \Gamma \pi T + \pi T \frac{\partial q}{\partial T}$$

$$= \Gamma \pi T - \lambda \frac{\partial q}{\partial T}$$

whence, with (5a)

$$\mu = \frac{\partial \Gamma}{\partial T} - \frac{\Gamma}{T}$$

9. For the optimal user charge we thus return to the traditional formula: it corresponds to the time losses caused to other users (when the marginal user appears, he occasions a total additional time loss $\partial T$, but himself only suffers,$\frac{\Gamma}{T}$)

\(^2\) Note that (7) is in terms of marginal utility, $P$ - a Lagrangean multiplier - being interpreted as the marginal utility of money.

\(^3\) The - sign reflects the fact that, since $q$ is the time spent. $\frac{\partial u}{\partial q} = \lambda<0$. According to the usual interpretation of Lagrangean multipliers, $\lambda$ is the total value assigned by users to a marginal increment in service quality $q$, total traffic being $T$. Per unit of traffic, this marginal value or utility is therefore $-\lambda T$, designated $\pi$. Social cost, by definition, is therefore the product of $\pi$ (unit value of service quality per unit of traffic) and $T$ and $q$: $\Gamma = \pi T q$. 
with a given quantity of infrastructure, which corresponds to short-term marginal cost.

10. In addition, \( \frac{\partial \pi}{\partial K} = \pi T \frac{\partial \pi}{\partial T} = T \frac{\partial \gamma}{\partial K} = r \), according to (4)

hence

\[
(- \frac{\partial \pi}{\partial K}) = r
\]

11. This gives a further form of the rule for determining the scale of infrastructure in terms of social cost: "The capital cost for the marginal investment is to be made equal to the reduction of social cost resulting from the investment, for a given level of traffic."

B. Development Cost

12. If infrastructure is marked by large indivisibilities one cannot form a smooth envelope of the short-run expenditure functions and long-run marginal cost cannot be derived. On the other hand, if there are many indivisibilities but none of them particularly large, one can still construct the short-run expenditure functions and draw a smoothed envelope. One then obtains a long-run marginal cost which will equal an average over time of short-run marginal cost, varying quite significantly with capacity utilization.

13. One may thus approximate long-run marginal cost by a process of averaging or smoothing over time. This is the method of Development Cost,

\[
DC = \frac{\sum_{t=0}^{T_t} \delta D(T_t) \delta T_t \left[ \frac{\delta D(T_t)}{\delta T} \right] (1+i)^{t} + \sum_{t=0}^{T_t} \delta I(t) \delta T_t \left[ \frac{\delta I(t)}{\delta T} \right] (1+i)^{t}}{\sum_{t=0}^{T_t} (1+i)^{t}}
\]

where

- \( \theta \) - Length of period for smoothing out long-run marginal cost
- \( D(T) \) - Operating expenses when traffic is at level \( T \)
- \( I(t) \) - Investment in period \( t \), a function of the expected traffic in that period, \( T_t \)
- \( \delta T_t \) - Differential change in traffic at \( t \)
- \( \delta T_T \) - Change in investment resulting from the change, \( \delta T_t \), in the traffic series
- \( i \) - Discount rate
C. Problems of Introducing Transport Cost into Traffic Models and into Cost-Benefit Calculations

14. A rigorous calculation of Development Cost is not possible, but it can be approximated:

\[
ADC = \frac{n}{\sum_{t=0}^{n} \frac{T_t - T_0}{(1+i)^t}}
\]

where

- \( D_t(T) \) Current expense, year \( t \), corresponding to traffic level \( T \)
- \( I_t(T) \) Investment, year \( t \), corresponding to traffic series, \( T \)
- \( i \) Rate of interest
- \( S_n(I_t) \) Terminal value of investment \( I_t \) in the assumed final year \( n \), the horizon of the program

This expression approximates marginal transport cost, averaged over the period 0 to \( n \). The value obtained should be the more reliable the less it depends on the process \( T_t \), the development of traffic over time. It is intended to yield the cost that ought to be charged to users if optimal pricing was to prevail at the final date of the exercise. As such it may be introduced into the traffic models. Total transport cost over the entire period, after discounting, equals

\[
r = \sum_{t=0}^{n} \frac{D_t(T_t) + I_t(T_0) - S_n(I_t) x (1+i)^{t-n}}{(1+i)^t}
\]

It is then easily seen that

\[
r = ADC \sum_{t=0}^{n} \frac{T_t}{(1+i)^t} + \sum_{t=0}^{n} \frac{D_t(T_0) - ADC x T_0}{(1+i)^t}
\]

Except for the last term in (10), ADC is thus the average unit cost of transport in the period from 0 to \( n \).

15. Written in this way, the relation allows one to judge the conditions in which ADC will yield a good approximation of transport cost when entered into traffic models or into economic calculations. First among these is the condition of constant returns which, when prevailing, reduces the final term in (10) to zero. The general view is that returns
are indeed constant for vehicle operations, though slightly rising for expenses on infrastructure. Next, one requires that the series of investments, \( I(T_g) \), should be reasonably regular. If it is not, the value of ADC will vary significantly with the choice of \( n \), that is, with the total length of the period over which the calculation is extended. One can then no longer rely on equality between long-run and short-run marginal cost. A special case of variations in the investment series arises when there are major indivisibilities and that occurs rather frequently in infrastructure.

16. When ADC fails to yield a good approximation of transport costs one can still consider it a first iteration from which one may calculate the traffic volume and the investment requirement, proceeding from there to a new value of ADC. But there is no guarantee that these iterations will converge, quite apart from their high cost in terms of computer time.

17. The error in the ADC may arise from the occurrence of one large indivisible investment. In that case, one may simply run the model twice over: once without that investment and once with it. In each case the relevant transport cost will be the short-run marginal cost, equal in practice to the average cost of vehicle operations, to the marginal cost of infrastructure operations and to marginal social cost. Traffic will be distributed in very different ways in these different situations.

18. The method can be further explained by specifying the series of model runs required for the choice of one single project. For simplicity we assume that traffic generation is independent of transport cost and that the projects are intended primarily to increase capacity. The choice process will vary according to the characteristics of the expenses function. The simplest case occurs with constant returns and in the absence of indivisibilities. The choice criterion -- call it Generalized Cost of Transport on the Network, or GCTN -- is then simply:

\[
GCTN = \sum \left( \frac{CDA_w \times I_{w_c} \times \left(\frac{L}{(1+i)^t}\right)}{w} \right)
\]

where \( w \) represents the links in the network.

19. One then proceeds as follows:

- compute ADC on each link for what seems a realistic traffic series of traffic;
- run the traffic models;
- compare computed traffic volumes with the capacity on each link, arriving thus at the capacity requirements;
- examine alternative projects to provide for the traffic and select those with the lowest cost of implementation; and
- check the initial values taken by ADC by computing the new ADC with traffic volume and expenses as computed.

20. The initial assumptions may, however, fail to be fulfilled, for instance, if major indivisibilities affect investments on link \( w_0 \).
In that case, the traffic models are to be run twice, with short-run marginal cost on link \( w_0 \), the first time before the investment and then again after investment. One furthermore imposes constraints on the capacity of \( w_0 \), the excess being diverted to other modes or routes.

21. The choice criterion will always be minimization of GCTN but this magnitude now takes a different form:

\[
GCTN = \sum_{t, w \neq w_0} ADC_w \times T_{w,t} \times \frac{1}{(1+i)^t} + \sum_{t < t_0} \frac{1}{w_0} \times (srmc) \times T \times \frac{1}{(1+i)^t} + \sum_{t > t_0} \frac{1}{w_0} \times (srmc) \times T \times \frac{1}{(1+i)^t} + \frac{1}{(1+i)^0}
\]

In this formula,

- \( srmc \) - short-run marginal cost
- index 0 - before the project
- index 1 - after the project
- \( I \) - cost of investment
- \( t_0 \) - time of investment
- \( t_0 \), the date of the investment, then solves the equation

\[
A = \frac{i}{I}
\]

where

\[
A = [(srmc)_0 - (srmc)_1]T_{t_0}w_0 + (S - srmc_1)\Delta T_{w_0t_0}
\]

and \( \Delta T_{w_0t_0} \) is diverted traffic, while \( S \) stands for transport cost on the diversion mode or the diversion route.
CHARACTERISTIC ELASTICITIES AND MULTIPLIERS

The following are among the elasticities and multipliers that can be calculated on the basis of the general models used in transport plans:

- with respect to goods:
  - the elasticity of total traffic in GDP.
  - the direct and crossed elasticities of the traffic of each mode given the prices of each mode and the quality of service (transport time).

- with respect to passengers:
  - the elasticity of total traffic, broken down into segments of distance (a distinction is currently made between short, medium and long haul), at transport revenues and prices.
  - the direct and crossed elasticities of the traffic of each mode at transport prices and at service quality factors (principally time).

These elasticities could also be calculated, not at the national aggregate level but at that of a characteristic link.

- with respect to the macroeconomic effects of transport measures, the multipliers define:
  - the direct consequences of a transport investment on GDP and the use of external trade, possibly by distinguishing according to the types of investment (infrastructure or vehicles) and according to their means of financing (loan, taxes, tolls, etc.).
  - possibly the consequences of a transport price change on the same aggregates.