

A FRAMEWORK FOR COMPUTER-BASED COST EVALUATION  
OF HIGHWAY PROJECTS  
IN DEVELOPING COUNTRIES

by

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Submitted to the Alfred P. Sloan School of Management  
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requirements for the degree of Master of Science.

This thesis is an attempt to explore the possibilities of computer utilization for highway project evaluation in less developed countries (LDC). It focuses primarily on the evaluation of tangible costs. Accordingly, costs are reduced to three areas: (a) construction costs, (b) maintenance costs and (c) vehicle operating costs. The two latter areas are particularly important in developing countries as opposed to industrialized nations.

All three areas must be considered from the very beginning of the highway planning cycle (cursorily described in the thesis), especially for cost evaluation. Moreover, funding (or loan) agencies, which subsidize most highway projects in LDC's used to require thorough evaluations of all types of costs. These costs must be examined simultaneously, insofar as trade-offs may occur within any given area (intra-area), as well as between all areas (inter-area). All costs, hence inter-area trade-offs, depend on the traffic present and future figures. Such figures, which link all areas together, constitute undoubtedly fundamental data for a highway department. Nevertheless, it is shown that their obtention raises many problems.

Whereas intra-area trade-offs may currently be supported with computer procedures (determination of "optimal" quantities and of their subsequent costs), inter-area trade-offs are not as easy to single out and formulate. The thesis presents a framework for development of data and of procedures able to significantly enhance highway projects cost evaluation. However, some aspects of the cost evaluation process, not presently fully structured, are still likely to evolve, along with the nature of procedures and their data requirements. Therefore, this framework makes some provisions for such a possible evolution. Moreover, it takes into account the eventual integration of a cost evaluation system into a broader Management Information System (MIS).

The following analysis also stresses the importance of the organizational structure in an LDC highway department, hence of individual actions and motivations (not only for managers) vis à vis a computer-based system. Such a system cannot be implemented without a strong human back-up involvement at all levels; "a fortiori" when this system does not only support well-structured decisions.

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It is customary, in this country, to dedicate theses; therefore, this study--though highly imperfect (which is only the author's responsibility)--must be dedicated to the memory of A.H.S. who accidentally lost his life on September 1, 1975.

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CHAPTER I: INTRODUCTION--SCOPE OF THE FRAMEWORK

1. HIGHWAY PROJECT COST EVALUATION IN DEVELOPING COUNTRIES

1.1 Importance of the Cost Criterion for Highway Project Evaluation  
in Developing Countries

Highway project cost estimates constitute the principal criterion for evaluation of highway projects in developing countries for two reasons:

(a)-Highway costs, by definition, are tangible hard figures. Not all highway aspects are pecuniarily reducible and, even if some are, there is no general consensus, especially in industrialized nations, how to account properly for them (e.g. speed, safety, environmental, political or socio-economic considerations, etc.). However as will be seen later, it may be noted that these intangible aspects are obviously quite relevant and must undoubtedly be considered.

(b)-Highway costs significantly outweigh all other evaluation criteria in developing countries. It may be assumed, though sometimes hard to justify, that in developing countries non-pecuniary aspects, may be neglected in a first approach as compared to pecuniary aspects due to the relative importance of some costs. This is in particular, the viewpoint of funding agencies which subsidize most highway projects in less developed countries (LDC) and are generally more interested in economically quantifiable impacts of projects than vague social considerations.

Point (b) explains why highway departments in LDC's are striving to develop sound methods of project cost evaluation in order to satisfy

requirements set up by the funding agencies.

This thesis examines how the introduction of computers into the cost evaluation process may contribute to solve effectively some of the problems, especially different types of trade-offs, related to this process.

The overall objective of the highway planning cycle is to minimize costs related to the highway project. More precisely, the objective is to render as much service as is possible with a given amount of resources or to use as few resources as possible to render a given amount of service.

The first trade-off to occur opposes supply costs to demand costs. Supply costs concern costs related to the highway department activities (construction and maintenance) whereas demand costs are costs related to the existence of the road as incurred outside the highway department. For the same reasons as exposed in point (a) above, demand costs are reduced here to vehicle operating costs. (1) Supply costs are two-fold: on the one hand, they are related to construction, and, on the other hand, to maintenance.

Maintenance is a very important activity for highway departments in LDC's since climatic conditions are more variable than in Western nations (seasonal patterns), subsequently earth or gravel roads are submitted to rough conditions. Trade-offs may concern (a) construction

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(1)-In general, other user aspects, eventually non-user aspects, may be embodied with demand costs, but this objection does not strongly hold in the case of LDC's.

vs. vehicle operation, (b) maintenance vs. vehicle operation. Other trade-offs concern construction vs. maintenance. All of these trade-offs will be called hereafter "inter-area" trade-offs.

### 1.2 Construction, Maintenance and Vehicle Operating Costs

"Inter-area" trade-offs are very important in LDC's. For example, as a possible consequence of unavailability of skilled labor for maintenance, or of construction grants preferred to increased maintenance taxes, etc. there might be more incentive for construction rather than for maintenance. The resolution of most "inter-area" trade-offs therefore rests upon a good evaluation of different cost categories, e.g., private vs. public costs, economic vs. financial costs, labor vs. capital costs, etc. For instance, criteria based on economic pricing have been set to take into account "real" cost values (considering resource depletion, etc.) instead of intrinsic market values.

Other trade-offs (called hereafter "intra-area" trade-offs) are trade-offs which may occur within each area (i.e. construction, maintenance, vehicle operation).

Since most LDC roadways are low-traffic roads, technical options, hence choices, for these roads are limited: they usually concern gravel or earth roads as opposed to bituminous roads. Possible technical (intra-area) trade-offs therefore only occur in small numbers. An example of construction trade-off may be provided by the substitutability of thicker pavement and of stronger sub-grade in pavement technology: both techniques being able to support the same maximum load. Similar

types of trade-offs may be formulated between drainage (number and type of pipes required to drain the road) and declivity (vertical profile and "slope" of the roadway), or between declivity and alignment (horizontal layout of the roadway), etc. Intra-area trade-offs generally occur when a decision is going to be made about a determined characteristic of the road. Given (a) some physical data (terrain, topography, soil quality, climate, etc.), (b) traffic forecasts and (c) a range of allowance design standards (declivity, bearing ratio, width, serviceability, etc.) the problem consists of determining the optimum (required and compatible) quantity of work, materials and equipment, hence their subsequent costs, for the road construction. Cost optimality may be defined as follows: for a given level of quality (deduced from standard setting), costs are as low as possible. Trade-off considerations are fundamental for this purpose, since it sometimes happens that higher quality is obtainable for the same cost (as aforesaid).

In the maintenance area, a typical intra-area trade-off concerns the trade-off between a policy of continuing light preventive maintenance and a policy of heavy (but occasional) after-the-fact repair maintenance.

In the vehicle operation area, trade-offs may occur between tire wear and fuel consumption (roughness versus declivity: speed), etc.

Intra-area trade-offs appear as rather limited and easy to formulate in technical terms; subsequently they may often be solved by computer procedures.

On the contrary, inter-area trade-offs are more complex. The most significant ones concern maintenance vs. construction and maintenance costs vs. vehicle operating costs. Inter-area trade-offs significantly impinge

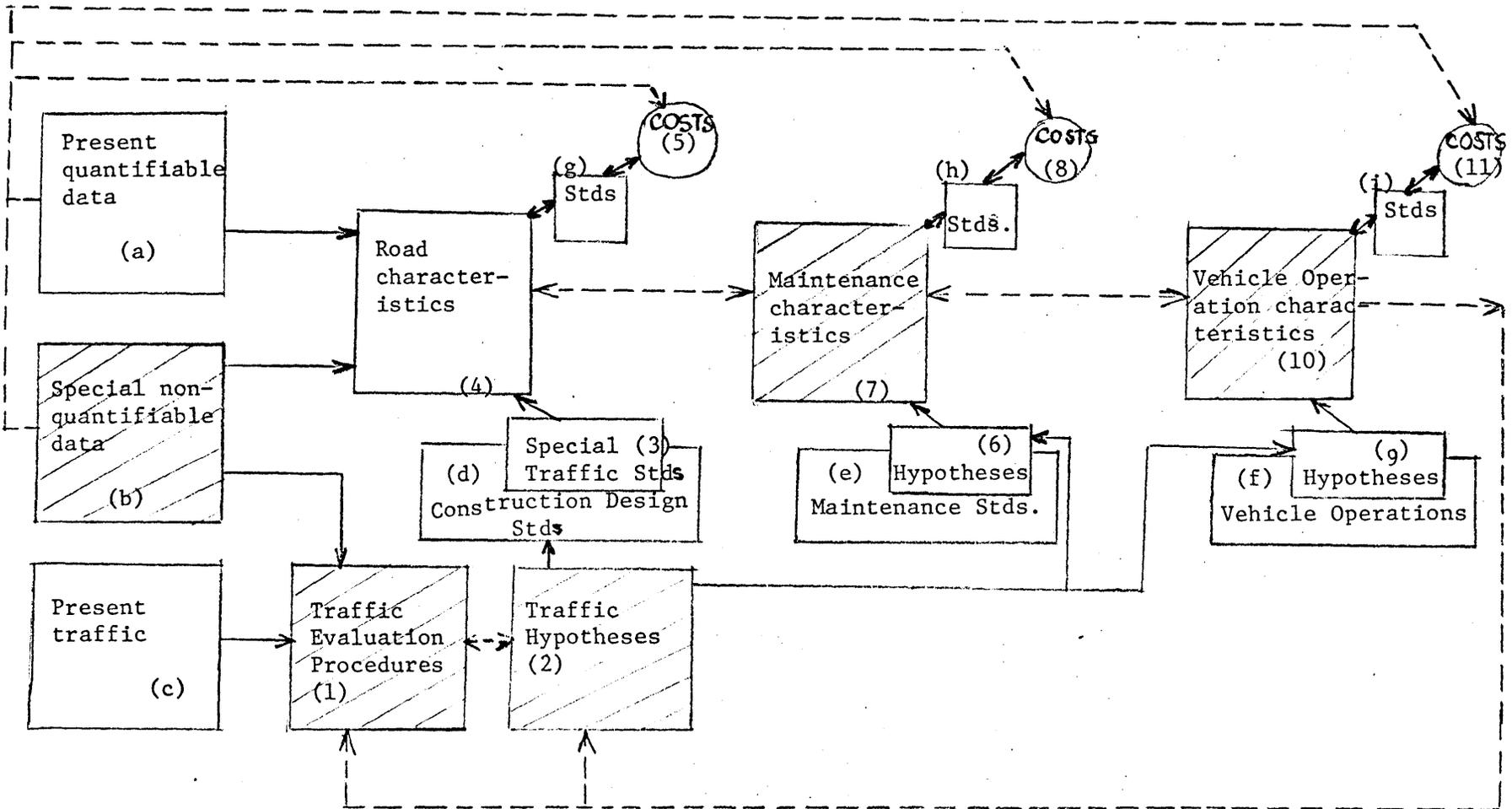
on such factors as volume and patterns of traffic about which relatively little is known. Inter-area trade-offs constitute the keystone of the cost evaluation process for it often happens that optimal solutions intrinsically determined for two or three areas do not necessarily coincide with the inter-area optimal solution (which is then to be chosen within certain limits).

### 1.3 Scope of the Thesis

Figure 1-1 depicts the highway cost evaluation process. The first operation to occur concerns traffic forecasting (boxes (c), (1) and (2) ). Then the road construction characteristics (4) are determined--subject to some standards (d) and hypotheses (3)--and their subsequent costs (5) computed by applying standards (g). In the same way, maintenance costs (8) and vehicle operating costs (11) may be estimated, respectively subject to (e), (6), (7) and (h), on the one hand, and (f), (9), (10) and (i), on the other. Boxes (3), (6) and (9) represent the respective "classes" of the project for construction, maintenance and vehicle operation.

Costs are first determined more or less independently by resolution of intra-area trade-offs. In a second stage, all three types of costs must be compared and eventually modified to reflect some compatibility and consistency between the three areas (inter-area tradeoff). The process is no longer very structured and mainly operates through "trial and error" modifications. These modifications may significantly alter the hypothesis underlying the classes of standards (3), (6) and (9).

Successive modifications occur until a final stable equilibrium is reached, admissible for all three areas. The "unstructured" aspect



-- Unstructured Relationships

▨ Significant Problems

Figure 1-1: Evaluation of Trade-Offs

of the inter-area trade-off derives first from the complex interactions between all areas and traffic (represented by discontinuous arrows in figure 1-1) and, secondly, from the relative lack of structure inherent to the content of box (b) (data not easily quantifiable as opposed to well-quantifiable data in (a) and (c) ). In their turn, data in (b) impact the structure of (1) and (2) which somewhat determines the nature of the relationship between the different areas. Therefore, part of the solution to a better-structured evaluation of inter-area trade-offs finally rests on box (b) (which also directly affects cost estimates).

Hatch-crossed areas highlight major "unstructured" areas where computer support cannot take into account all real factors impinging on the process. Hence, figure 1-1 implicitly assumes that traffic is principally a function of first, maintenance, itself depending on deterioration (function of the road characteristics and traffic figures) and secondly, vehicle operating costs (function of traffic, maintenance and road characteristics).

This thesis will explore first how computer functional procedures are able to support some relatively structured cost evaluation aspects of highway projects (e.g. boxes (4), (7), and (10) ). The framework developed here is an attempt to define the scope and the nature of such procedures (essentially related to intra-area trade-offs). A typology of data relevant to cost evaluation and based upon these procedures is also introduced. The study simultaneously concerns itself with less-structured aspects of the cost evaluation process, as shown in figure 1-1, and examines (a) how the present structure of some operations can be improved and (b) how managers may cope with various problems (not able to be taken into consideration by the machine).

It is assumed that only the three areas of construction, maintenance and vehicle operation intervene here, with some specifications due to the LDC special conditions. Nevertheless, the thesis does not focus on detailed consideration of procedure contents nor on data requirements for cost evaluation. The framework presented here is rather meant to provide some guidelines for the implementation of an effective cost evaluation system in terms of both rationalisation and overall control of operations within a given organizational context.

## 2. COMPUTER SUPPORT TO COST EVALUATION

### 2.1 General Characteristics of a Computer System

Computer capabilities may be seen as two-fold: (a) storage of data and (b) processing of information for decision-making. A computer system is often described as encompassing a data-bank, on the one hand, and functional "procedures", on the other.

The above capabilities may also explain why a distinction is sometimes made between data and information: data constitutes the "raw" material whereas information results from processing the data in a manner useful for decision-making. However, as will be shown below, both capabilities are strongly interrelated and this somewhat weakens the above distinction.

An important characteristic of computers is that they can only deal with relatively "structured" processes and elements (which are clearly defined and moreover, may easily be translated to be "understood" by the computer).

It is therefore necessary to break down the cost evaluation process

into such "structured" sub-elements to benefit from a computer's support. Such a segmentation must operate on and complement the previously mentioned distribution between the three areas (construction, maintenance and vehicle operating costs). It should allow better understanding of the cost evaluation of highway projects. Nevertheless, one must always bear in mind the fundamental relationship between the three above areas and a global overview of the process.

An immediate problem arises concerning the structure of each sub-element to the extent that the highway project evaluation process is only partially structured. Its elements cannot be totally structured, neither internally nor externally, according to typical models.

By structured, it is meant that every thing about the element may be explained in both an operational and normative fashion. In a systems analysis perspective, structure is concerned with both internal and external features.

It is the purpose of this thesis to delineate the implications of the relative lack of structure for each element, and eventually to present a viable alternative to a "total structure" (i.e. procedures) solution, viz multiform extended control, in a broad sense, which nevertheless allows effective use of computers.

## 2.2 Structured vs. Unstructured Decisions

It is now time to define precisely what the structured/unstructured terminology means and where it is applicable. Up to now, these attributes were purposely used in a loose sense and applied to "situations". In fact, they directly refer to a decision process underlying

the so-called situations. The <sup>-16-</sup>terminology was introduced by A. Gorry and M. Scott Morton (1971) whose definition will be adopted here. It is a prolongation of the traditional distinction between "programmable" and "non-programmable" (popularized by H. Simon) which in its turn is related to the algorithmic vs. heuristic decision-making processes, rational vs. intuitive cognitive styles, etc.

The attribute structured also applies to the global information process supporting the decision i.e.: (a) information and decision, (b) procedure(s) and (c) data. The attribute may concern (a) as well as (a) plus (b) or (a) plus (b) plus (c). However, as indicated in Section 2.1, such a categorization of the information process is far from being clear-cut and delimitation of each of the three categories depends on the degree of structurization of the decision. In theory, this categorization only really holds for totally structured decisions. For instance, as will be studied below, in the case of rather unstructured processes, there is no procedure per se but rather aggregation and/or comparison of different data; hence the frontier between data and information becomes hazy. Moreover, information may be assimilated to the procedure outcome, hence the procedure itself, etc.

It is contended here that most decisions related to highway project cost evaluation cannot be seen as totally "structured" in the same sense as routinized accounting procedures. Therefore, there is no way to represent the global cost evaluation process by a functional procedure model similar to ( (a), (b), (c) ): this simply does not work. On the other hand, few decisions in the highway evaluation process are totally "unstructured" and made on a purely intuitive basis.

This thesis, though it recognizes the importance of functional

procedures, is led to single out other resources for effective use of computer-based systems when a global procedure model cannot apply. The approach suggested is based on (a) systematic use of functional procedures when applicable to parts of the decision and (b) "control" assessment at every level within the process.

### 2.3 Implementation of Functional Procedures and Perspective for More Structured Decisions

The archetype of an elementary "totally" structured process is provided by the chain ( (c), (b), (a) ) described in Subsection 2.2 (see figure 1-2). Structured processes are made either of one procedure or several interrelated procedures. Procedures represent functions whose nature, of course, has to be known.

In such cases, managers have only to feed "raw" data, according to given input formats, into the procedure--black box--which produces information; hence, the decision may be made at the end of the chain.

There are very few cases, if any, of this type of totally structured situations in the highway project evaluation process. The above straightforward model, though it represents an idealistic management information system type, is far from representing the reality of most MIS's (Management Information Systems).

However, some limited aspects of the cost evaluation process may be somewhat depicted by a modified version of such a model. This is, for instance, the case of trade-off decisions within each of the construction, maintenance and vehicle operating costs area (intra-area trade-offs). It will be seen, nevertheless, in Chapter II that (a) the validity of the

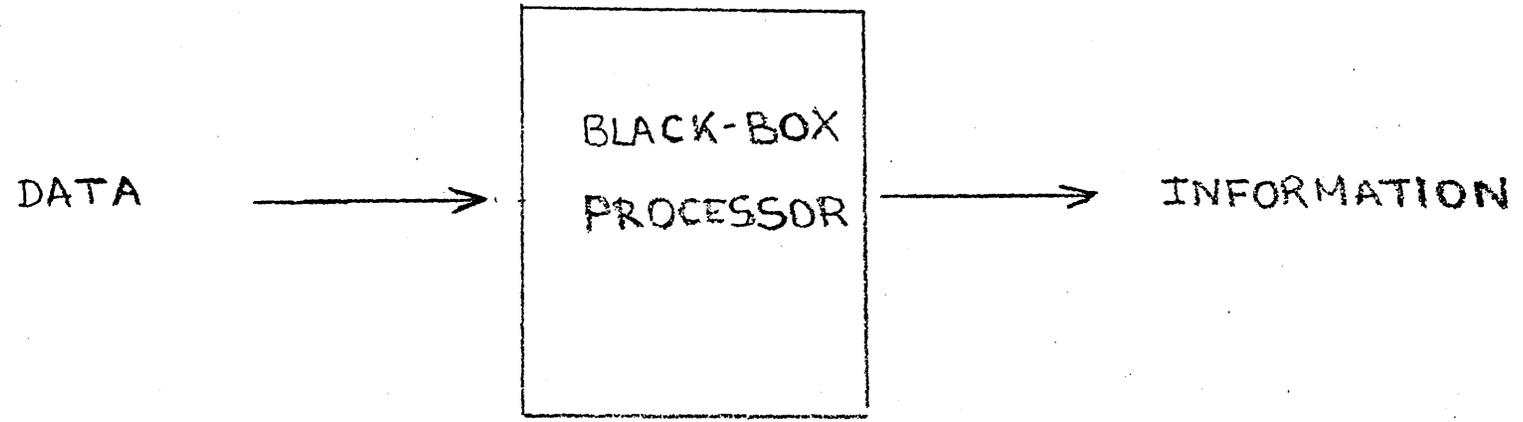


Figure 1 - 2: A Basic "Black Box" Procedure Model

model is heavily dependent upon some restrictive hypotheses; therefore, the mechanistic theory does not fully apply here. Moreover, (b) data have to be significantly adapted and sorted and (c) the degree of structure lowers when one moves from construction to the other two areas.

Chapter II is then an attempt to examine how the "black-box" model (functional procedures processing raw "data" into "information") may apply to some aspects of the cost evaluation process of highway projects in developing countries. Chapter II is led to introduce a classification of cost evaluation procedures into three categories: (a) core-procedures (quantity estimation and cost estimation); (b) traffic procedures (traffic trends and forecasting); (c) financial procedures (concerned with financial and economic pricing of projects). It is shown that such a model may apply for intra-area trade-off evaluation. However, a "black-box" type model cannot apply globally to inter-area trade-offs. These trade-offs presuppose too many complex links not all mastered at the present time (see figure 1-1). Due to the relative lack of structure characterizing, among other things, the category of traffic procedures, it is necessary to rely on ways other than functional procedures to allow effective cost evaluation enhanced by computers. This may be done, in the short-term, by implementing a solid coordination system based on different forms of control available to the highway department, as will be developed in Chapter V. Nevertheless, inter-area trade-off evaluation must rely as much as possible upon structured procedures.

As a direct by-product of its analysis of procedures, Chapter II also provides an overview of the highway project cost evaluation process (intra- and inter-area trade-off evaluation). It reviews as well some of the factors impinging on cost evaluation.

2.4 Control of Data and Information as a Prerequisite for Improved  
Structurization of the Cost Evaluation Process

Chapter II analysis highlights the roles of four categories of data, as related to the use of procedures: (a) standards (related to all procedures), (b) socio-economic data related to traffic forecasting procedures, (c) discount rates, interest rates, etc. related to financial procedures and (d) specific project data, especially related to core procedures (traffic, physical data, costs, etc.).

Chapter IV elaborates on the characteristics of these data and sets up a matrix typology based on two criteria: source of data (whether or not the data are collected or developed within the highway department) and scope of data (whether or not data concern a specific <sup>project</sup>). Chapter IV then attempts to present normative features for collection, storage conversion, updating and communication of data based upon the matrix typology.

Chapter V explores how highway department managers may use data to make decisions related to a non totally structured area such as project cost evaluation. What are the highway department information needs? However, though the purpose of Chapter V is to study how managers should interact with data, hence intervene in the data-processing cycle, no attempt is made here to characterize in detail the very nature of their decisions.

As contended throughout the thesis, information is nothing but data with associated meaning for decision-making, upon which managers have to evaluate different alternatives. Chapter V therefore shows (1) how information, generally developed through structured functional

procedures, may reflect these <sup>-21-</sup>possible alternatives (e.g. report context, responsibility associated with information and information flow, etc.), (2) how managers should interact with data and procedures to develop additional information relevant for effective project evaluation. This latter point is two-fold and concerned with the ways (2a) that managers tend to increase, if not the structure, at least the rationality of their decisions and (2b) that they cope with the problem of presently unstructured decisions or uncertainty assessment. As argued previously, the solution to these problems rests on increased control, extended rationality, and flexibility.

Chapter V is concerned first with the validity assessment of information stemming from structured procedures. It also considers the nature and the scope of control to be exerted by the highway department (1) on the different categories of data (pointed out in Chapter IV) and (2) on its information flow.

The structure of decisions is analyzed here from a more global perspective than in Chapter II. Chapter V is an attempt to isolate some necessary conditions for the long-range achievement of the quasi structurization of the cost evaluation process. Report characteristics and some technical considerations about file organization structures (as resulting also from the Chapter IV analysis) are subsequently viewed.

Chapter VI eventually examines how the evaluation of the global costs of highway projects is likely to be made at different levels in the light of the matrix typology introduced in Chapter IV. Chapter VI also surveys the perspectives of development and potential integration of the system suggested here into a broader computer-based system encompassing more aspects of the highway department activities.

## 2.5 Long-range Perspectives

The importance of the classic motto "not too far, not too fast" is stressed in the conclusion. An integration into a broader computer-based information system (CBIS) may only occur after managers are accustomed to a computer system. Extended rationalization, control and flexibility should have been previously implemented. The "adaptation" phase is of paramount importance and determines the success or failure of the system proposed here. Its success may result in a quasi-automatic transformation of all aspects of the cost evaluation process into structured functions. Therefore, integration into another broader system should not be done too fast, before ensuring of the success and the acceptance of the first system.

## 3. BACKGROUND CONSIDERATIONS AND FUTURE IMPLICATIONS FOR COMPUTER-BASED COST EVALUATION

### 3.1 Organizational Setting

It is impossible to study the implementation of a computer system without referring to the human organization setting around this computer. CBIS's are made of three components (a) computer technology and hardware, (b) data and software, and (c) people; people constitute undoubtedly the most important category. Therefore, the highway department organization, in the case of a LDC (not fundamentally different from any industrialized nation's case), and its implications on cost evaluation are studied in Chapter III.

Nevertheless, the thesis does not include the highway department organization as a specialized factor for the presentation of the follow-

ing framework. The basic reason for that is that the highway department structure fits relatively well in the presentation developed here.

It is argued that highway department top managers are in charge of rather unstructured decisions such as inter-area trade-offs whereas division managers are more concerned with structured decisions such as intra-area trade-offs. Decentralized districts are essentially in charge of data collection. The present task distribution is, by nature, dynamic, therefore, evolves to the extent structured decisions also evolve!

### 3.2 Project Planning

Another characteristic of the highway department concerns the evolution of project planning from the early stages of the pre-feasibility study to the final ones of the feasibility study.

This will also be reviewed in Chapter III. It is assumed that project planning does not really have an impact on the framework presented here, except for the degree of accuracy of data which is significantly increased. The different stages of the planning process when data are known (or assumed to be known, i. e. estimated) with more or less accuracy may be taken into account through specification of different options to the procedures as will be seen in Chapter II.

### 3.3 Other Computer-based Systems

As mentioned in Section 2, the cost evaluation system suggested here may be developed and integrated with some other CBIS module in order to

build a more extended CBIS. The appendix is devoted to a survey of the characteristics of other CBIS currently in use throughout U.S. highway departments. Chapter VI subsequently relies on this survey to explore some feasible perspectives for the development of a global modular CBIS in developing countries, based on the system examined here. Investment in a sophisticated file organization system may be amortized more quickly if such a realization ever occurs.

### 3.4 Implication for the Thesis Framework

This thesis is primarily an attempt to show some normative directions for better structurization of the cost evaluation process of highway projects in developing countries. As indicated previously, these directions are based upon (a) support allowed by computer capabilities (development of function procedures and data bank), and (2) multiform control, hence extended rationalization and flexibility of the process and of its computer-based procedures.

It is assumed that people involvement is a necessary, if not sufficient, (technological considerations also intervene) condition for the success of the system proposed here.

However, the analysis cannot focus equally on every aspect of this system. For example, it somewhat neglects detailed technical considerations in favor of more general analytical features inherent to the system (collection and development of data, structuration and utilization of procedures, information network, organizational setting, etc.).

Needless to say, rather than focusing on global perspectives for the implementation of a cost evaluation computer-based system, the present

analysis could also have been <sup>-25-</sup>expanded in other directions equally relevant for cost evaluation of highway projects. For instance, it could have (2) concerned itself with the very development of the computer-based procedures, the study of the nature of the decisions made about highway projects, more economic details about investment criteria, a deeper approach to the demand side of highway production (not necessarily based on users, nor on pecuniary terms), cost-benefit analysis, etc.

Since the objective of this thesis is not to build a system per se, it is difficult to evaluate the value of the following upbringings in terms of operationality. Moreover, such evaluation would necessitate definition of clear-cut goals not explicitly delineated here. Increased rationalization and accrued effectiveness undoubtedly result in some tangible benefits. However, different highway departments may seek different goals, hence, definitions of benefits from a computer-based cost evaluation system may vary from one case to another. It is therefore impossible to evaluate this thesis' upbringings without a preliminary agreement on a possible set of benefits.

Some possible benefits may concern eventual reduction of personnel needs, increased percentage of projects subsidized by funding agencies or more simply, better forecasts of costs and traffic---this latter point requiring significant lead time to be evaluated.

Another possible benefit associated with the thesis is its impact on "procedure builders". These latter usually tend to neglect some global

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(2) around which the system is built

albeit fundamental, aspects of the cost evaluation process in favor of more "nitty-gritty" details of FORTRAN programs. These programs may therefore be very efficient but totally ineffective to the extent the highway department (a) is unable to obtain the data necessary to feed them or (b) can only obtain very inaccurate data.

DECISIONS

1. STRUCTURED PROCEDURES AND THEIR IMPACT ON DATA AND INFORMATION

1.1 The Black-box Model Adapted to the Cost Evaluation Process

The degree of structure of any decision (hence of information supporting it), is in direct relationship with the ability to express the decision-making process through a series of sequential algorithmic or programmable operations, as seen in Chapter I. Each of these operations may be represented by a function upon which functional procedures (or black-boxes) are based (see figure 1-2). Black-boxes are meant to receive input data which are transformed into information according to the straightforward process (data → procedure → information) described in Chapter I.

The overall cost evaluation process cannot be represented by such a model, though some aspects of this process are more likely than others to be structured mechanistically. This is, for instance, the case of (a) the final cost processing when all quantities are known and the only thing to be done is to multiply the quantities by their unit costs; (b) traffic estimation procedures, to the extent that the forecasting function, hence its variables are known; (c) financial costs conversion into economic costs (social rate of discount, etc.). Nevertheless, such procedures are heavily dependent upon their environment and are rarely inputted with so-called "raw" data. They often deal with some elaborate form of information, which may be modified by the managers accordingly. (1)

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(1) It is argued throughout this thesis that information is associated with some intrinsic meaning for decision-making.

Moreover, the range of validity<sup>-28-</sup> applicable to most of the procedures studied here is very narrow and must be specified through some parameters (to be included in either the procedure calls or automatically determined by the value of the standards on which the procedures rest).

It is shown here that final cost estimates depend on (a) development and choice standard costs, (b) accuracy of quantity estimates, and (c) the way that procedures handle fixed costs or overhead which may occur: all computations are based upon unit costs (variable costs), and fixed or lump-sum costs have to be integrated to take into account all costs. So much for the well-structured aspects of procedures.

Another significant point about procedures concerns procedures based upon relatively unknown functions. For instance, traffic procedures cannot take into account all factors impinging traffic to the extent all of them have not been clearly isolated yet! Moreover, consideration of the numerous two-way relationships between construction, maintenance and vehicle operation on the one hand, and traffic determination on the other hand, is still far from being totally structured. This induces some restrictions to the validity of different forecasting procedures within each of the three areas.

An example of adaptation of the black-box procedure model to some intra-area aspects of the cost evaluation process is shown in figure 2-1. However, neither feedback loops nor complex interactions between procedures are represented there.

Figure 2-1 distinguishes between three types (or sets) of procedures. The core of the intra-area cost evaluation process consists in the two interrelated quantity estimation and cost processing procedures. Traffic or road deterioration forecasting procedures, though heavily related to

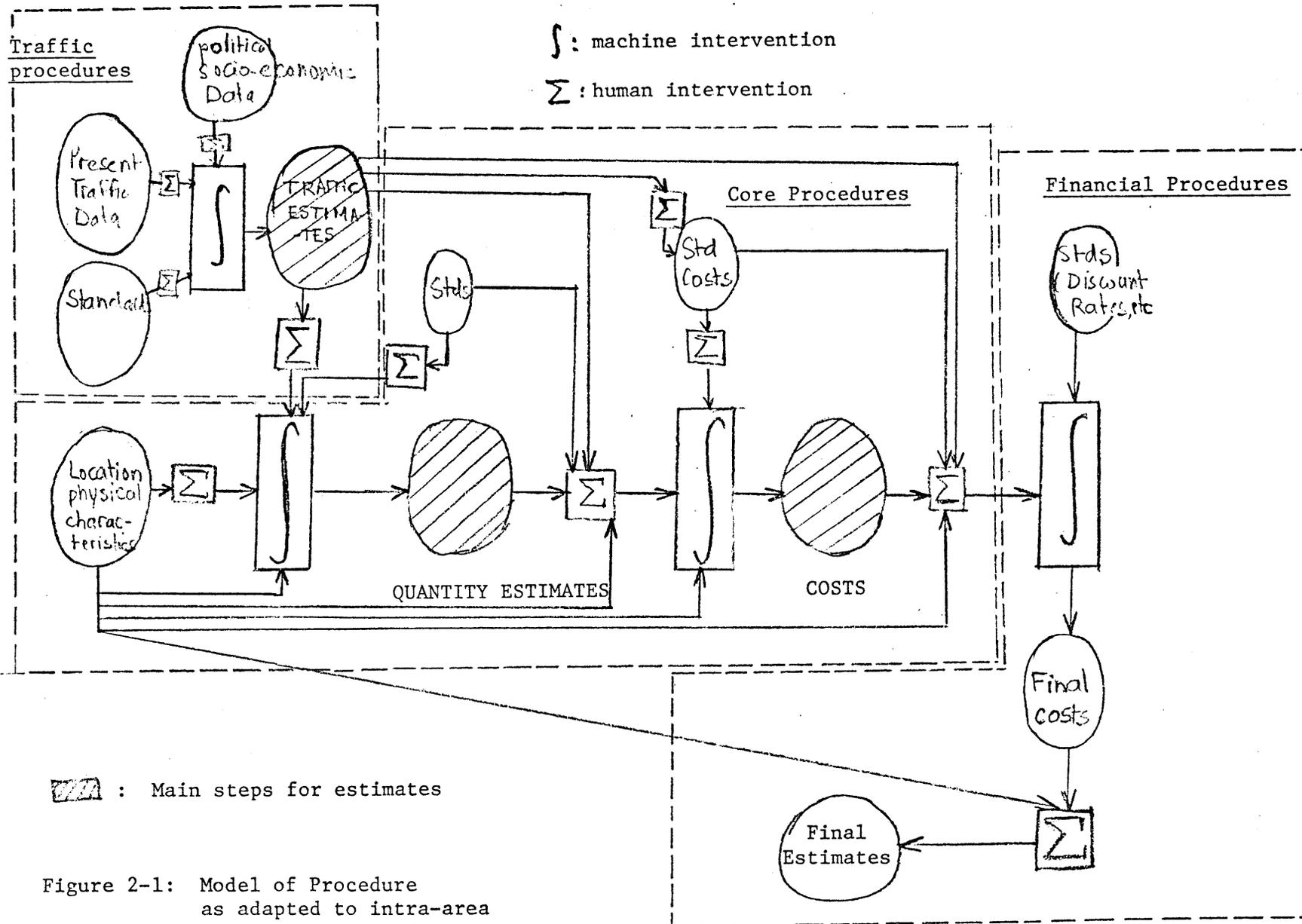


Figure 2-1: Model of Procedure as adapted to intra-area cost evaluation of highway projects

the previous "bloc" are considered apart, in the same way as cost conversion procedures (concerned with economic costing evaluation or integration of fixed costs to the previous estimates).

Whereas the core bloc is directly relevant to the activities and control exerted by the highway department, the two other blocs rely heavily upon external conditions and data; this problem will be studied in more detail in Chapter IV.

The model represented in figure 2-1 may apply as well for construction cost estimation as for maintenance or vehicle operating cost determination, under the obvious condition that some procedures are modified. For instance, the so-called traffic forecasting procedure considers different aspects whether applied to construction or maintenance or vehicle operations. Moreover, evaluation of maintenance or vehicle operating costs necessitates input of some construction data and, in the case of vehicle operating costs, some maintenance data.

Previous considerations are all based on intra-area trade-off decisions and on the application of figure 2-1 model. This model also applies to inter-area trade-off decisions, though, in this case it is less directly helpful because it cannot take into account all costs from the three areas simultaneously. Costs have then to be considered sequentially and the highway department is now faced with a relatively more unstructured situation (see figure 1-1). Managers must interact with all relevant data and significant information to determine satisfying solutions through simulations based on sequential utilizations of this model.

Figure 2-1 stresses the importance of input data, especially standards, vis-à-vis the validity of procedures: the next subsection is devoted to the study of interaction of data and information with procedures and focuses on standard definitions. Sections 2 and 3 are concerned with

the study of the "core bloc" of the model as it applies primarily to intra-area cost evaluation. Section 4 is concerned with the relations between the three areas whereas Section 5 deals with the "traffic bloc".

Detailed considerations about data availability and classification are not examined here and are postponed until Chapter IV, whereas Chapter V will concern itself with (a) managers' assessment of procedure validity and (b) utilization of procedures in the case of rather unstructured decisions.

### 1.2 Data and Information concerned with Procedure Utilization

Procedures are only valid to the extent they are fed with relevant data and/or information. For instance, in the case of the final cost evaluation procedures, the accuracy of output information depends as much on the accuracy of the quantity estimates and the relevance of standards inputted as on the context of the procedure itself.

There is no clear-cut boundary line between data and information and this thesis will often use data for information or vice-versa, without necessarily specifying "data (or information)". What can be considered as "information" at one level may be seen as "data" elsewhere. This essentially depends on the "subjective" context, viz the meaning which can be associated for direct decision-making purposes by the individual (or procedure) /to whom this data is presented. For instance, the physical characteristics of the roadway may constitute valuable information for a roadway surveyor, whereas it is only data for an accountant; on the contrary, a unit-cost may be considered as worthy information by the accountant but totally meaningless by the roadway surveyor.

Moreover, following the subjective framework just sketched for the definition of data and information, it may happen that an individual vaguely sees the utility of a given data for remote decision-making though he cannot use it under its present form and he must process, hence significantly transform, it, in order to be able to make a decision upon it. For instance, top management recognizes the importance of the road's physical characteristics, but in most cases cannot directly interact with these characteristics. They still have to be processed into quantities, costs, etc. in order that top management may make a decision. However, the surveyor may directly "react" to these characteristics, which have an intrinsic meaning for his decision-making process. Therefore the road's physical characteristics constitute information for the surveyor but are rather data for top managers.

Standards and standard setting methods constitute the most critical aspect of the cost evaluation process automation as depicted in figure 2-1. They determine costs essentially through (a) quantity estimation and (b) cost evaluation. They also intervene in the traffic forecasting procedures and in financial and economic conversions. Moreover, standards usually provide the way to link together different intra- or inter-area aspects (essentially through traffic assumptions) and allow determination of some features (which may still be unknown at some stages of the planning process). Examples of standardized hypotheses are given by assumptions concerning the class of the road (e.g. maximum declivity, minimum width, maximum traffic allowable, etc.) or the level of maintenance (frequency, importance, costs, etc.).

One can distinguish between two types of standards: the first type applies to core-procedures of figure 2-1 whereas the second type is

concerned with broader policy issues such as level of traffic and subsequent requirements for the roadway, maintenance policy or characterization of the different categories of vehicles using the road. This second type rather applies to traffic type procedures though its standards are used as input to the core procedures, under an aggregated form. In general, one can consider that some provision is made to take this type of standard into account; for instance, by specifying some parameters to the procedures. These parameters represent the "class" of the project.

The former type of standards, related to core procedures is meant to account for some variations of unit cost at a regional level (e.g. how do costs vary from one region to another?). The following analysis focuses on this type of standards and core procedures, though most of the analysis may be generalized to class standards. These latter, since they impact procedures, are also mentioned rapidly.

It is of the utmost importance to ensure that the categories of standards developed for each possible operation within any area are diversified--and flexible--enough to allow sensitive evaluations. Categories are divided into items; items are meant to reflect any possible available solution for a construction, maintenance or vehicle operation problem (regional cost, technical solutions, etc.). A good choice of the "class" of the project must be followed by a good determination and evaluation in every category of the required quantities and costs of each appropriate item.

Standard categories and subsequent items are developed statistically upon previously completed realizations or experiments. An example of standard item is provided by the average cost of a given operation the

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characteristics/<sup>of</sup> which are clearly specified (e.g. technical features of material, equipment and manpower allocation, etc.).

As indicated, items vary according first, to the class of the project (which is reflected by some parameter specification) and secondly, to other conditions such as the region, the techniques and manpower available, etc. These latter conditions must be embodied in the items themselves.

Standards, as will be seen in Chapter IV, are fairly stable over time, whereas data related to the location and technical features of the highway under study are more likely to vary, simultaneously with global cost information, especially during inter-area simulation evaluations ("trial and error" process). Input and output data will be studied in more detail in Chapters IV and V. The remaining part of this chapter is more concerned with the nature of the evaluation process, as characterized by definition and development of standards, on the one hand, and utilization of procedures (to the extent that it is possible), on the other hand.

## 2. TECHNICAL STANDARDS AND CHARACTERISTICS OF INTRA-AREA TRADE-OFF CORE PROCEDURES

Section 2 is an attempt to study the limitations of quantity estimates based on standard items, specific to each area under concern (i.e. construction, maintenance and vehicle operation). These estimates are automatically determined through figure 2-1 quantity estimation black-box procedures.

Standard item determination--hence quantity estimation--is heavily

dependent upon unit-cost considerations, though it must also reflect some technical features. Nonetheless, cost determination will be studied separately in the following section.

It must be noted that core procedures are more structured in the construction area than in the other two areas. Construction, as noted in Chapter I, has always been considered as the main activity of highway departments in industrialized nations, therefore, its evaluation process is better structured. Moreover, some aspects of maintenance and vehicle operation standards are similar to construction standards; this explains why the forthcoming analysis of the construction area is somewhat more detailed than the analysis of the other areas.

## 2.1 Construction

### .Definition of Items

Construction activities may be broken down into five separate categories:

- (1) preparation of site
- (2) earthwork
- (3) drainage structures
- (4) pavement
- (5) various structures (bridges, tunnels, etc.).

Category (5) depends too much on specific conditions to allow here estimation on a unit-cost basis. Estimations are generally made on a lump-sum basis.

Each of the four other categories may in its turn, be divided into items. Black-box procedures are to determine the relevant items for each project and to estimate their required quantities.

However, before this can be <sup>-36-</sup>done, it is necessary to specify the class of the project as determined by traffic-related considerations, and obviously to feed the specific project data into the black-box. The class of the project is used to determine the appropriate categories of algorithms and items. In each category, items have to be defined which may be expressed in a given unit of measurement.

(1) The preparation of site consists of clearing and grubbing. This activity may be estimated per hectare based on three basic assumptions: light, medium and heavy clearing and grubbing.

(2) Earthwork deals with the roadway excavation which encompasses rock excavation, common excavation, borrow material, formation of embankment, etc. In their turn, all these activities may be represented by various types of items according to the task characteristics. All items may be expressed here in cubic meters. Some of them, such as the ones concerned with borrow material, have to account for transportation of materials: where does the borrow material come from? This necessitates the development of new items.

(3) Drainage depends on the choice of pavement technology. Drainage activities encompass such activities as excavation for structures (which may be expressed in m<sup>3</sup>), concrete installation (m<sup>3</sup>) hand laid rock embankment (m<sup>3</sup>) and pipe installation (lm).

(4) Pavement items are concerned with specifications relative to materials used for the sub-base and surface treatment: pit run material (m<sup>3</sup>),

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(2) m<sup>3</sup>: cubic meter  
(3) lm: linear meter

crushed aggregate base coarse (<sup>-37-</sup>m<sup>3</sup>), etc., on the one hand, and gravel (m<sup>3</sup>) or crushed aggregate (tons) and lituminous asphalt (liters), etc., on the other hand.

The choice of items is only determined to a certain extent by the class of the project and by the nature of specific data. Sometimes managers must specify which items apply, especially at a regional level (e.g. region characteristics).

#### .Input of Specific Data

As shown in figure 2-1, data related to the project under study have to be inputted into the procedures after options have been indicated (class of project; stage of study, e.g. prefeasibility, feasibility, etc.). It is, however, necessary to convert on-field data in order to make them readable by procedures. Details of data conversion operations will be given in Chapter IV. Two types of specific data are inputted here, as represented in figures 2-1 and 2-2. They reflect constraints due to (a) physical features and (b) traffic characteristics (as determined by a traffic forecasting procedure).

Once all necessary data have been inputted, quantity estimation procedures may provide, through simulation, different feasible solutions related to the roadways physical characteristics: layout, declivity, width, subgrade, pavement, drainage and their required quantities of material and associated work.

The next task for the manager consists first of assessing the quality of the results given by the procedure. Do they or do they not reflect enough of the idiosyncratic features of the project under study? In the

case where the results are not <sup>-38-</sup>satisfactory, the manager should trace the origin of this and modify inputs (specific data and/or standards) accordingly. Well fitting of standards and class parameters to the project characteristics is of crucial importance for the validity and accuracy of output estimates. Satisfying information about quantities may then be transmitted to the cost estimation procedure, as will be seen in the next section. The cost estimation procedure allows the determination of the best possible alternative in terms of construction criteria. This alternative has then to be tested in terms of inter-area trade-off criteria.

#### . Content of Procedures

Though this thesis is not principally concerned with the details of procedures, it appears necessary to give here an idea of the content of their "black-boxes" and of the importance of cost consideration for quantity determination. The following passages will examine how the roadway characteristics may be optimally determined in function of (a) the physical features of the road and its traffic trends and (b) costs.

(a) Considering only one-dimensional technological attributes, it is easy to feature technical requirements through diagrams whose abscissas represent physical characteristics--converted into some measure--and whose ordinates represent the quantity of work and/or material required. For instance, the number or the diameter of drainage culverts, the volume of rock excavation, borrowed material, etc. may be graphed in function of the terrain topography (prefeasibility study) or of the roadway declivity (feasibility study), assuming some hypotheses about the roadway

surface. In the same way, the <sup>-39-</sup>thickness and strength of the pavement or drainage structures may be graphed as functions of the temperature or of the annual or seasonal rainfalls.

Requirements from traffic may also be pictured by diagrams showing the relationship between a given vehicle attribute: axle load, size of vehicle, and a given technical characteristic: strength of pavement, of the subgrade, depth of culverts, width, curvature, etc.

Some of the foregoing diagrams are based on continuous properties whereas other are representing discrete possibilities. Though some properties may be more easily deduced by extrapolations in the case of continuous curves, this does not have much importance for the standard classification setting based upon these diagrams.

(b) Once the technical characteristics (resulting from the physical constraints and the traffic conditions) have been determined on a one-dimensional basis for each attribute, costs may be brought into consideration. All the technical requirements are then reviewed together to highlight possible trade-offs. Isoquant curves are computed which show the level of traffic and/or the physical conditions able to be met by a given combination of technical attributes. Isocost curves are also drawn: according to optimization theory and microeconomic principles, the points of tangency between the isocost and isoquant curves yield the optimal combinations (expansion path) for a given level of traffic and/or physical conditions. These points represent the final figures which should come out from the quantity and cost estimation procedures.

## 2.2 Maintenance

Maintenance forecasting is linked to determination of the roadway deterioration. The set of maintenance standard characteristics to apply depends on the roadway construction and users' actions. Therefore, maintenance quantities cannot be computed without some hypothesis about the roadway characteristics to be entered into the quantity estimation procedure. Traffic figures (potentially related to the roadway deterioration) have also to be considered here, though they are computed outside the core procedure area, in the traffic procedure area of figure 2-1.

In the same way as in the construction area, it is possible to distinguish different categories of maintenance tasks. Their frequency and content depends on the class of maintenance actions to be deduced from the traffic procedure output. The choice of a class of maintenance is based upon answers to questions such as: "When should maintenance be done?", "At what level?", "How?". It is related to the determination of a given policy at the highway department level and sometimes also, at a national or regional administrative level (e.g. intervention of users). There are two basic and extreme approaches to maintenance problems. The first type of approach consists of setting up a policy of continuing maintenance which does not usually consider the actual state of the roadway but rather relies on forecasting. It may be called "preventive" maintenance and is rather costly. The other type of approach to be called "after-deterioration" repair policy consists of intervening only "after-the-fact" when the road is seriously damaged and users may begin to complain. An optimal policy lies somewhere between these extremes.

In both types of approaches, however, unit costs, albeit different, roughly correspond to the same categorization of basic items, some of which are very similar to construction items.

Items may be grouped into four categories:

- (1) maintenance of the riding surface of paved and unpaved roads
- (2) shoulder maintenance on paved and surfaced shoulders
- (3) drainage control
- (4) vegetation control.

The maintenance of major structures not being considered here, the major aspect of maintenance concerns the surface maintenance, i.e., (1) and to a lesser extent, (2).

Item determination is based upon cost and class characteristics and the overall item list is quite comparable to construction item inventory. Examples of maintenance items related to (1) and (2): surface grading of earth roads; surface grading of gravel roads expressed in gradings per month for both the dry and wet season; spot regravelling of gravel roads (m<sup>3</sup>/km/year); resurfacing of shoulders (m<sup>3</sup>/km/year) etc.

- items related to  
/(3): culverts and ditch cleaning (times/year);  
items related to  
/(4): brush and vegetation control (times/year).

These items obviously depend on the class of maintenance adopted and on the mix of policies considered. Maintenance may be done (a) on a routine basis (e.g. brushing or grass cutting, minor patching, ditch cleaning, etc.), or (b) on a periodic basis (e.g. resealing, resurfacing, etc.) whereas some more important actions concern (c) repairs (the non-occurrence of which may imply serious road damage or failure) or (d) improvements (road upgrading).

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Specific data to be inputted into maintenance simulation procedures are traffic data and data related to the highway department maintenance policy strategy on the one hand, and construction data (roadway characteristics) on the other hand. Procedures are meant to compute (a) the resulting maintenance operations likely to intervene and (b) the state of deterioration of the road as a function of the level of maintenance done and of the traffic. This obviously depends on the road construction characteristics. However, maintenance estimation procedures are far from being as developed at the present time as construction procedures.

### 2.3 Vehicle Operations

The approach to vehicle operation quantity determination is identical to construction and maintenance determination.

Basic standard items are determined upon considerations of <sup>repairs</sup> and consumption, eventually of cost. They may be grouped into two categories, where cost importance appears clearly: (1) variable costs (also called running costs or, more improperly, operating costs), (2) fixed costs.

Category (1) embodies fuel and oil consumption (expressed in liters/km), tire wear (unit/km), maintenance parts (several items) and maintenance labor (several items), etc.

Category (2) embodies depreciation, overhead, insurance, registration and licensing, driver wages, etc. Category (2) is not to be considered directly here.

In the case of vehicle operating cost estimation, the two core procedures are heavily interrelated to such an extent that they may even be assimilated into a single one. It must also be noted here that vehicle costs only intervene through comparison of the project-induced new

costs with the previously existing costs. The significant decision variable here consists of the cost difference (savings) implied by the highway construction.

Variable costs are directly related to the road characteristics, in proportion with vehicle utilization. Fuel consumption is clearly a function, first, of the type of fuel utilized and the weight power requirements, and secondly, of the declivity and roughness of the road as well as of the speed. Speed, in its turn, is a function of the declivity, width, roughness, curvature, etc. of the road. In the same way, tire wear heavily depends on the vehicle characteristics and on the surface roughness. Some types of relationships may be developed for maintenance parts and maintenance labor. It is precisely the attribution of the quantity estimation procedure to compute these variables.

Classes of vehicle operation are established upon the traffic determination figures computed outside the core-procedure area. Fuel consumption is different for tourism vehicles and heavy trailers! The level of maintenance is also assumed to impact evaluation of vehicle operating costs and must be reflected in the procedure parameters. Specific input data concern the road characteristics, on the one hand, and traffic data on the other hand. As seen, procedures have to compute the quantities related to variable costs.

The influence of cost upon quantity evaluation procedures is fundamental. This is due to the fact that different categories may be chosen which all satisfy the same "quantity" conditions; their choice is determined by costs.

### 3. COST EVALUATION PROCEDURES

#### 3.1 Variable vs. Fixed Costs

Given quantity estimates, cost evaluation procedures operate straightforward on a multiplicative basis. Quantities determined previously (by the quantity estimation procedures) have only to be multiplied by a standard unit cost. This standard unit cost is associated with items previously determined, according to the project characteristics (class, location, etc.). However, this way of operating does not explicitly account for fixed costs--as opposed to variable costs which vary according to the quantities required.

Fixed costs are costs which occur as a total and cannot a priori be divided into smaller components, relative to the importance of the task done. Moreover, fixed costs do generally pertain to only one task and occur indirectly, as will be seen below.

On the contrary, variable costs are proportional to the importance of a task, of its material requirements, etc. and rest on unit-costs.

Most costs belong to the continuum between fixed and variable costs and it is difficult to make a clear-cut distinction, though a distinction is of the utmost importance for managerial evaluation of costs and subsequent decision-making. Fixed costs may be considered as costs which necessarily appear at a given time, independently of the level of activity and the use of a facility. They must therefore be taken into account somewhere, on as clear as possible a basis. This explains why some supervision costs, for instance, are often included as a percentage of unit-costs.

For vehicle operating costs, the distinction is straightforward and fixed costs are easy to keep track of. This is not the case for supply

costs where the boundary between fixed and variable is much hazier. Examples of irreducible fixed costs, to be taken into account through lump-sum estimates, and not directly depending on the project importance concern the costs of the construction camp, the engineer's vehicle supply, external supervision, preliminary studies, etc. In the case of contractors' prices, the number of fixed costs is generally insignificant. This is not true for maintenance costs since maintenance is usually performed by the highway department and its accounting is not presently so well structured.

### 3.2 Direct vs. Indirect Costs

Direct costs are directly related to a given activity, the results of which are tangible (e.g. costs materials used for the road, fuel consumption, earthwork, etc.). Indirect costs are generally concerned with necessary background activities (not necessarily productive) such as administration, research and development, etc. In highway projects, indirect cost examples are associated with prefeasibility and feasibility studies, construction camp facilities, engineering control, laboratory experiments, food services, transportation. Some of them are reducible to variable costs (food services, lodging, vehicle operations, etc.) on a daily basis or on any other unit, whereas most of them are fixed costs (construction camp, supervision, laboratory, etc.).

### 3.3 Labor and Capital Costs

According to elementary economic principles, the two basic inputs

to any type of production are labor and capital. Some "goods" are said more labor-intensive whereas some others are more capital-intensive. It is possible, however, according to the particular market conditions prevailing, to partially substitute one input factor for the other. The distinction between labor and capital is thus fundamental in LDC's where labor may be easier to obtain than capital. Capital represents funds necessary to acquire materials and equipment. Construction is generally considered as a capital intensive activity and maintenance as more labor-oriented. Another more refined distinction must be made between skilled and unskilled labor, the second type of labor being more easily available in LDC's. Comparisons between the different types of labor and capital outputs are based upon productivity analyses and constitute a basic criterion for decision at a funding-agency level (outside the highway department). Therefore unit-costs (and global costs associated with it) must account for this classification. The cost of each elementary item has thus to be broken into the cost of (a) skilled and (b) unskilled labor on the one hand, and of (c) equipment, (d) materials and (e) overhead profit, on the other hand.

This classification is very important for the final decision and resource allocation between different projects at a national or international level. "Is it better to have more personnel assigned to this task or on the contrary to use mechanical devices for such purposes, etc.?" are samples of questions, the answer to which may significantly be facilitated by the above cost typology.

Moreover, the distinction between labor and capital costs determines the application of social discount rates, meant to take into consideration some specific market peculiarities of the concerned LDC.

### 3.4 Financial and Economic Costs

Financial criteria and resulting cost evaluation are used to appraise the value of an investment in terms of intrinsic market trends. The value of a given investment is assessed upon different methods, e.g. rate of discount (interest), internal rate of return, capital recovery factors, etc. Each of these methods is meant to determine whether or not a project is worth its investment in the long run. All methods may be used simultaneously (as is generally done). However, the underlying evaluation of costs and benefits (assumed to be as accurate as possible) is only made at market prices. Accuracy of estimates depends on the validity of the procedures used, of input data<sup>and</sup> of the forecasted traffic figures. This is one of the thesis's global concerns, whereas the following passage highlights the problem of economic evaluation of the project.

Economic costing rests upon "shadow prices" (also called social or accounting prices). Instead of evaluating the different costs at their market prices--only representative of a narrow and specific situation--economic costing computes the "real" price of each factor (involved in the highway project) based upon unit shadow prices that reflect worldwide dominating conditions. Shadow prices are heavily dependent upon a long-range overview of <sup>resources utilization and depletion.</sup> investment analysis is carried out the same way as previously described, taking real prices instead of market prices.

"Shadow prices" or discount rates are determined outside the highway department at a governmental or international level and are imposed on the highway department for project evaluation.

Financial and economic figures of the project are provided by the

the financial procedure(s) (see figure 2-1) which operate(s) on final cost estimates (after addition of lump-sum fixed costs or any other modification due to the specific features of the project under study). Computation of economic and financial cost does not raise any particular problem since costs are already supposed to be broken down into skilled and unskilled labor costs, equipment, material and overhead costs. The procedure has only to apply the appropriate rates to produce the final figures.

#### 4. INTER-AREA TRADE-OFFS AND UTILIZATION OF PROCEDURES

The process of inter-area trade-off cost evaluation is much less structured than that of intra-area cost evaluation, and may not be supported by a global procedure similar to the model developed in figure 2-1. It must therefore rely on the existing intra-area procedures. Managers have to introduce new hypotheses and see what the consequences are both for global costs and for intra-area costs. This no longer leads to optimal intra-area solutions. Global costs are then minimized in accordance with the objectives of the funding agency and of the country. In so doing, managers have to ensure that the hypotheses initially established in each area are still respected and that the final solution reached remains feasible for each area (stability of hypotheses within a certain range). However, the process of inter-area trade-off cost evaluation is likely to evolve toward a more structured form. This structured form will allow some of the inter-area trade-offs' aspects to be taken into account by a functional procedure similar to the one determined earlier. The key to this evolution rests on the increased

human understanding and quantification of the inter-area relationships. Traffic trends evaluations and projections seem to be presently the only data accounting for this interaction, as well be seen in Section 5. Section 4 is an attempt to suggest some direct normative approaches to this problem.

#### 4.1 Trade-offs Between Maintenance and Construction Costs

A typical trade-off between construction and maintenance concerns the importance of the construction costs as compared to the resulting quality of the roadway. Asphalt roads necessitate less maintenance than earth roads but in the short-run are more expensive to build. Consideration of time incidence on costs is fundamental here. Maintenance costs are often viewed as "variable" costs (occurring in the future with some uncertainty) whereas construction costs, occurring in the short-run, are assimilated to "fixed" costs.

This differentiation is very important especially in LDC's where maintenance may often be very costly to perform due to the relative lack of skilled manpower. However, this fact should not result in the construction of overmeasured highways not justified by the existing traffic nor <sup>by</sup> its future trends; the highway department has thus to make some commitments about its future maintenance policy and consider maintenance costs as fixed within certain conditions. This does not mean that maintenance should be done on a strictly scheduled basis (not accounting for the actual state of the road), hence ineffective and costly, as described in Sub-section 2.2.

The best criterion for deciding upon supply costs often rests, to

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some extent, on demand costs. In this case, vehicle operating costs must determine the limits--eventually the equilibrium condition--of costs supported by both sides (see figure 2-2).

#### 4.2 The Trade-off Between Construction and Vehicle Operating Costs

Users' costs depend primarily on the state of the road as initially built (see Sub-section 3.3). For example, variable costs are functions of the surface quality (roughness, e.g. asphalt vs. gravel or earth), of the steepness of the road's vertical profile, etc. Moreover, they also depend on the road's horizontal alignment, on its width, its all-weather practicability, etc., but these elements may not all be expressed in the framework adopted here which does not explicitly account for time saving, safety, etc.

In general, however, users are more sensitive to maintenance than to construction activities except in the case of penetration roads (i.e. roads built "out of the blue" where there was no previously existing road).

#### 4.3 The Trade-off Between Maintenance and Vehicle Operating Costs

Trade-off between maintenance and vehicle operating costs often constitutes the crux of the strategic choices made by the highway department (maintenance policy setting).

One can distinguish two thresholds below in which roads cannot be left without maintenance intervention. The first one concerns the psychological critical level below in which users are likely to react vigorously (see figure 2-2), whereas the second critical level is related

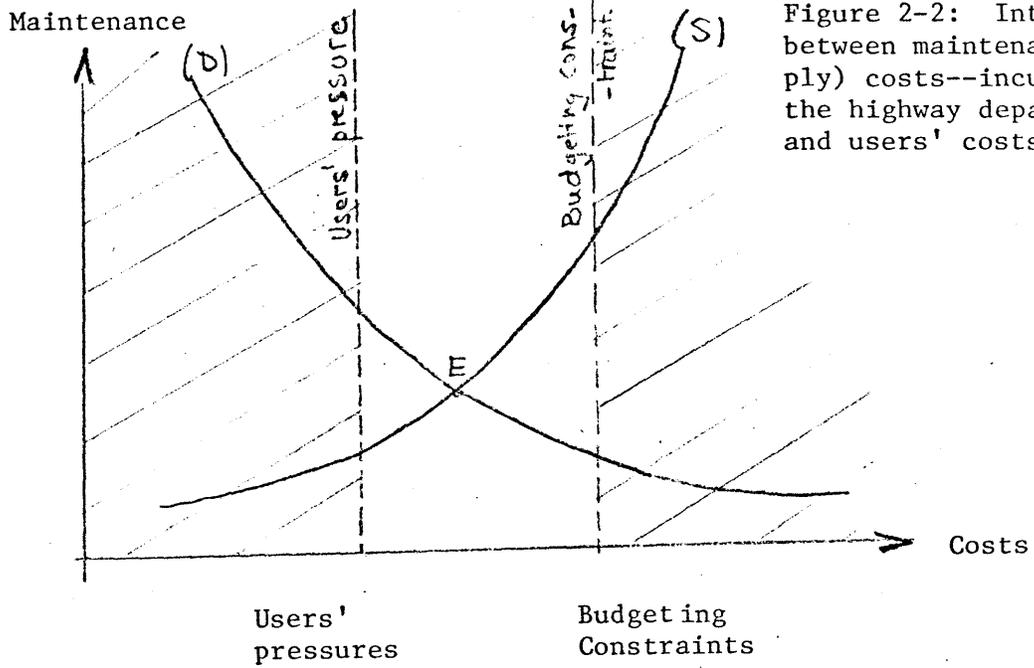
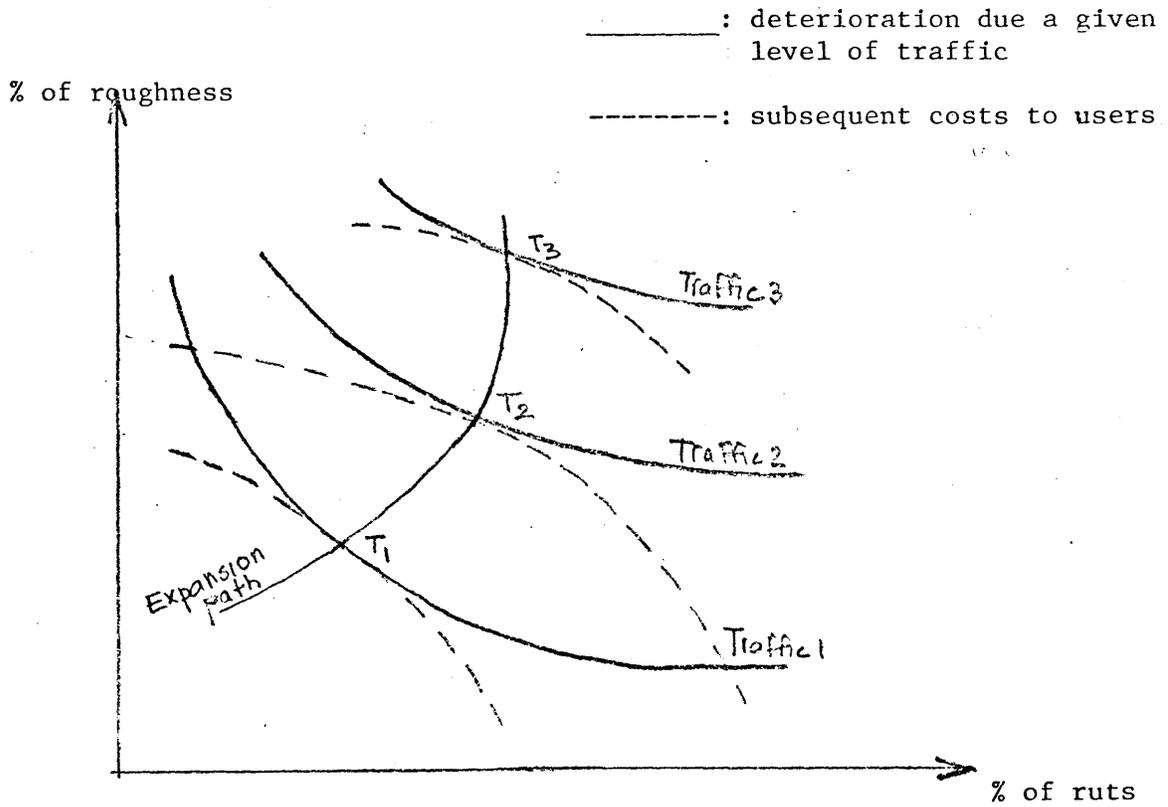


Figure 2-2: Interaction between maintenance (supply) costs--incurring to the highway department--and users' costs.

Figure 2-3: Determination of minimum vehicle operating costs..



to the complete deterioration and failure of the road under concern. In addition to these two levels, the highway department has to determine its own criteria of maintenance intervention; e.g. critical level of deterioration. Figure 2-3 suggests such a type of criterion based on "optimization" of users' costs and deterioration. Furthermore, highway departments must choose a strategy lying between the two extreme maintenance strategies described in Sub-section 3.2 (routinized vs. after-the-fact maintenance).

Once this choice is made, the next important point of a maintenance policy concerns the level of intervention. What is the optimal level of the roadway surface to be restored? The deterioration of a given level has a sensitive impact on vehicle operating costs, hence on traffic evolution. It may result in traffic boost or, on the contrary, in a relatively decreasing traffic trend. The intervention level must therefore be chosen efficiently in order to keep traffic within the interval where it was first estimated to move.

Another relevant issue of maintenance policies deals with labor aspects: what kind of human skills are available to the highway organization? Skilled and unskilled labor distribution heavily impacts construction standards in the trade-off decisions and the periodicity and importance of the maintenance action.

## 5. TRAFFIC DETERMINATION

Traffic constitutes the cornerstone of any project evaluation. As shown in figure 2-1, it determines (through its forecasted trends, which also impact the choice of a given class for the project) quantity

estimates, hence costs in every area. Traffic may accordingly be considered as the major data resource of a highway department. Unfortunately, operations related to traffic evaluation are not now very well structured and do not allow a satisfying overview of the highway cost evaluation process, especially of its inter-area trade-offs. This unstructured aspect is due in large part to the fact that traffic depends on external socio-economic conditions, which cannot be controlled by the highway department.

Traffic intervenes in every area of the highway department activities and its action is often two-sided (direct and feedback). For instance, traffic impacts deterioration, reciprocally, deterioration impacts traffic. The more traffic on a given roadway, the more deterioration occurs; whereas the more deterioration, the more vehicle operating costs, hence the less traffic. It is therefore important for highway departments to have policies which allow them to control traffic within certain limits.

The following subsection depicts the present existing type of traffic analysis.

#### 5.1 Qualitative Analysis of Traffic

All vehicles using a road do not have the same impact on the roadway. It appears necessary to distinguish them in terms of load and of the somewhat related aspect, size. In developing countries, there are generally five categories of vehicles (a) motor cars, (b) light trucks (including land rovers), (c) buses, (d) (medium) trucks, (e) heavy trucks and trailers. Sometimes categories (c) and (d) buses and trucks are

combined.

Other important characteristics to intervene in cost computations concern the fuel type (gasoline or diesel) and the actual loading of vehicles considered. This latter characteristic is often different from the nominal figure allowed either by the type of vehicle considered or by the law on the roadway under study. It often happens that trucks are overloaded: this constitutes an important factor for highway pavement and subgrade technical design.

### 5.2 Quantitative Features of Traffic Evolution

The first step to determine traffic trends is to know what the actual traffic is. This may be somewhat problematic in the case of penetration (i.e. nonpreviously existing) roads. Present traffic figures may be supplied in three different and complementary ways: (a) compilation and examination of existing data sources, (b) direct generation through field traffic surveys (traffic counts, O/D surveys<sup>(4)</sup>), and (c) inference from sector or industry studies. Field traffic surveys are generally fundamental and done under the responsibility of operating decentralized districts.

Future traffic trends are usually separated into four categories (a) traffic regular projections, (b) diverted traffic, (c) generated (or induced) traffic and (d) development traffic.

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(4) O/D: origin-destination

(a) traffic regular projections are determined independently of the new roadway construction. They take into account regional economic developmental trends. Therefore they encompass more than single traffic growth extrapolation and must rest on a thorough study of the present economy. Seasonal patterns may have a significant impact on them.

(b) Diverted traffic concerns existing traffic and projected future traffic (on other roads and determined independently of the project realization), which are likely to use the new roadway as a consequence of advantages to be found by using it, instead of roads previously used. Such a switch may essentially be explained in terms of cost or time saving; concerns of increased speed or improved safety may also intervene here.

(c) Generated traffic is the new traffic generated by the facility presently under study. It is independent of the new activities that the new roadway may create and is directly related to the roadway quality. Costs to be considered here are no longer relative variation costs (increased savings or improved safety) but absolute global costs (e.g. cost justifying the purchase of a truck to operate on this roadway).

(d) Development traffic depends on the road impact vis à vis new activities (industry, agriculture, urbanization, etc.) and must be distinguished from generated traffic. The road is no longer considered as a passive communication device between two points, but on the contrary, is assumed to promote and create new activities on its sides, which, in their turn, increase traffic (i.e. development traffic) along the road and at its extremities and nodes. The growth of traffic outside of certain limits obviously results from development traffic creation.

However, development traffic heavily depends on conditions external

to the highway department concern, namely socio-economic conditions.

Clear assumptions must be made about the above four categories of traffic, but the present state-of-the-art of traffic evaluation is essentially concerned with the first two categories (the evolution of which may be explained by vehicle operating costs). Though cost considerations are crucial for traffic evolution trends (especially in developing countries where safety, speed or time considerations are relatively less stringent than in industrialized nations), it may be assumed that traffic elasticity also depends on other factors, which still remain to be isolated.

### 5.3 Directions for Improved Structurization of Traffic Procedures

The most unstructured aspects of the highway project cost evaluation are related to traffic evolution and determination, e.g. feedback on traffic from maintenance policy from variations in vehicle operating costs, etc.

Such an assertion often constitutes an easy way to locate some unstructured aspects. However, it is true that traffic procedures are less structured than core procedures for the reason traffic procedures interface with more intangible external socio-economic or political aspects, as indicated throughout this section.

Figure 2-4 is an attempt to illustrate how the inter-area trade-off evaluation process occurs and how the different types of procedures studied above may support it. The left hand side is concerned with the intra-area core-procedures. The right hand side represents "traffic procedures" where forecasts and possible feedbacks as well as the

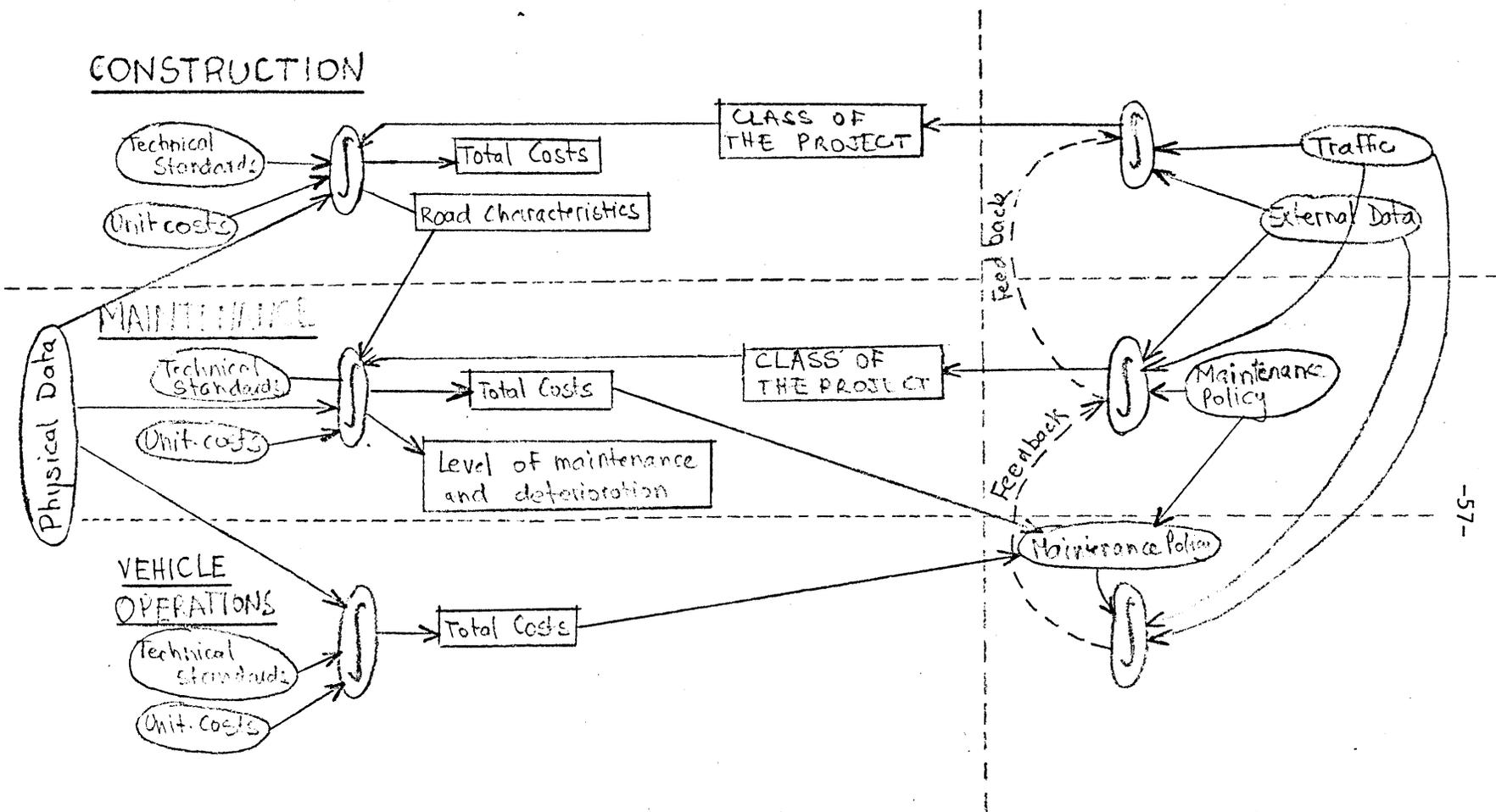


Figure 2-4: Interdependence of Traffic & Core Procedures

project class are determined to be entered into the core procedures. Figure 2-4 also depicts the information (and data) flow between (a) the different areas and (b) their related procedures. It is contended in it that a prerequisite for effective inter-area trade-off cost evaluation rests on hypotheses stability: this is represented by the arrows on the right-hand side.

The foregoing schema only provided a cursory illustration of the problems which arise from inter-area trade-off cost evaluation. They are related to the structure of traffic procedures. It is argued here that a short-term solution to cope with these problems consists in accrued control of data (and information) at all levels, hence first in a better control and eventual improvement of procedures and secondly on a good human environment and information flow. These aspects are going to be developed in Chapter IV and V after a rapid survey of the organizational setting of highway planning in Chapter III.

CHAPTER III: THE ORGANIZATIONAL FRAMEWORK: STRUCTURE OF THE HIGHWAY  
DEPARTMENT AND THE HIGHWAY PLANNING PROCESS

1. ORGANIZATIONAL SETTING: THE THREE LEVELS OF MANAGEMENT

Highway departments may be viewed as three-level hierarchical organizations. Figure 3-1 schematically represents the structure of a typical highway department in a LDC (adapted from the Ethiopian Highway Authority organizational chart). It makes the distinction between (a) top management which reports to a given ministry or directly to the government or eventually funding agencies. Top managers are the General Manager (or Commissioner of the department), his assistants, the Chief Engineer and his assistants, the Director of Planning and Development, the Administrative Director, the Heads of important divisions or clusters of divisions, etc. Official titles are likely to vary from one highway department to another.

(b) headquarters divisions, in charge of limited and well-defined tasks e.g. accounting (fiscal services), legal affairs (contracts), management services (EDP<sup>(1)</sup>, standard procedures), equipment, inventories, technical design, etc.

(c) decentralized districts essentially responsible for maintenance and direct labor construction administration.

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(1) EDP: Electronic Data Processing sometimes also  
ADP: Automated Data Processing

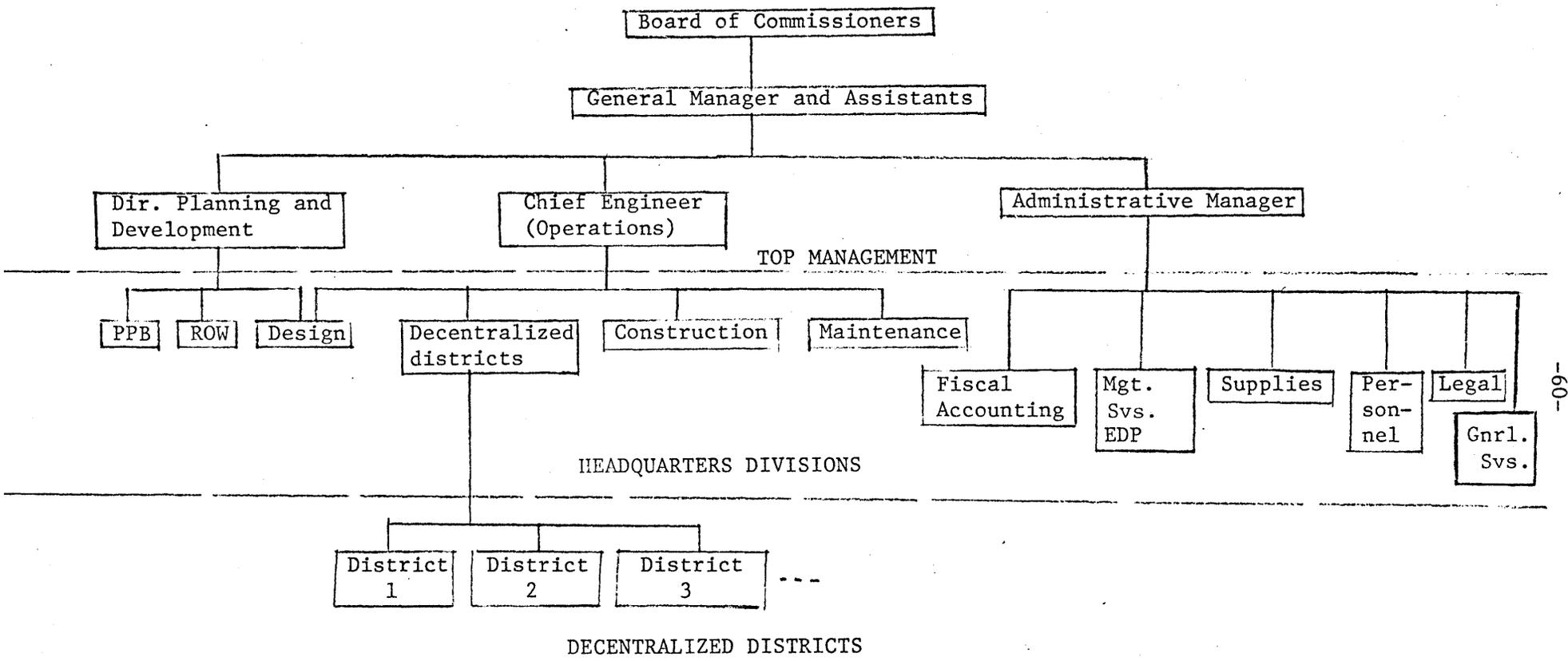


Figure 3-1: Organizational Structure of a LDC Highway Department  
 (adapted from the EHA flow chart in Road Maintenance Study,  
 Fredrich R. Harris Inc. Consulting Engineers, NY, June, 1973)

### 1.1 Top Management and Funding Agencies

Top management is required to have a good overview of activities performed in the divisions, especially as related to projects. For instance, the Director of Planning and Development must coordinate the activities of the Planning, Programming and Budgeting (PPB) Division with the Management, Legal, Personnel, Fiscal, etc. Services Divisions and, especially with the technical divisions (design, operations and contract)--all three of them depending on the Office of the Chief Engineer.

In terms of project responsibility, top management has to evaluate projects from a global standpoint by having a good overview of all projects' characteristics (e.g. financial, technical, material and personnel available etc.).

After a project (or particular program) has been favorably reviewed by the highway department top management, it may be transmitted to the government and/or the funding agency for further evaluation and decision making. These organizations have then to decide whether or not the project is worth being carried on (or, on the contrary, discontinued) and funded. Accordingly, the project file is transmitted back to the highway department for further action.

### 1.2 Divisions

There are basically two types of divisions: on the one hand, administrative divisions such as financial, personnel, supplies and equipment, legal, etc. services; on the other hand, technical divisions such as design operations, contract construction divisions (usually

under the supervision of the Chief<sup>62</sup> Engineer). The boundary line between the two types of divisions is not very clear-cut and some activities such as EDP or ROW (Right of Way ) infringe on both types. Furthermore, such a division such as the PPB Division has to be located at the interface of both types. Similar to the Administrative Director and the Chief Engineer, the Director of Planning and Development is considered a top manager.

Divisions are in charge of specific and well-defined tasks and may be broken down into branches divided in their turn into sections. Examples of branches are provided by the EDP branch (Management Services), the warehousing branch (Supplies and Equipment), the cost accounting branch (Financial Services), the bridge design branch (Design), etc. Similarly, examples of sections are given by the projects section, the advance planning section (both preceding sections belonging to the PPB Planning and Projects Branch), the drainage section, the pavement section (Design Branch) etc.

As stated earlier, divisions activities may overlap and a good coordination between functional units is essential for effective performance. For instance, the PPB Division has to be in relationship with all the divisions or more directly, branches or sections concerned with project planning, programming or budgeting, namely almost all technical and administrative divisions: e.g. legal (ROW, contracts, etc.), management services (EDP), design (road location and design).

### 1.3 Decentralized Districts

Decentralized districts--under the direct supervision of the Operations Division--are essentially in charge of direct labor

construction, maintenance and administration of the existing roadway network. Moreover, decentralized districts may sometimes act as decentralized agencies of the headquarters and of the headquarters' divisions, especially for on-field surveys, data collection at a local level, check-up operations, etc. as will be seen below. Decentralized districts generally have power over an extended territory, which does not always coincide with other administrative entities such as regions, departments, provinces, etc. This may be at the origin of some discrepancies in the data collecting process. Data collected by the highway department may sometimes not be consistent and vary in function--basic administrative territory they cover--as compared to data from other agencies.

## 2. THE HIGHWAY PLANNING PROCESS

### 2.1 A General Framework for the Highway Project Cycle

A typical highway project cycle consists of five phases:

(1) prefeasibility or macrostudy: this first step must take into account the:

(a) situational setting (descriptive): location of the road, resources allowable (from the highway department standpoint), previous actions related to this road and/or project, other past and present supply and demand features, etc.

(b) future trends and forecastings (predictive model): "natural" evolution (demand and supply, major foreseeable changes (demand), etc.

(c) goals, objectives and resources (normative model): possible and necessary interventions.

The prefeasibility study must provide a first idea of the scale and the implications of the project. It rests principally upon data, totally out of the control of the highway department and external to its direct activities, e.g. socio-economic, environmental, political data (use of land, travel patterns, modes of transportation, population, industries, etc.).

The major output of this phase concerns the determination of, first, a possible "corridor" for the highway location and, secondly, of a fiscal plan, at the local, regional, national (possible international) level--to check whether adequate resources are available for implementation of the recommended plans.

Prefeasibility ends with a "go-no go" type of decision-making; the chosen optimum plan may eventually be transferred to the feasibility study phase.

(2) feasibility or microstudy: this step deals mainly with the in-depth study of the previously determined "optimum" plan: precise location, technical options available, detailed aspects of budgeting, improved scheduling, better evaluation of impacts, etc. The feasibility study principally focuses on the estimation of the project impact, essentially as seen in Chapter I, cost evaluation from both the supply and demand standpoints. Their costs constitute the criteria upon which the final "go-no go" decision of the microstudy is made at the funding agency level.

(3) precise engineering design: whereas the microstudy was still mainly management oriented, the engineering design phase is heavily technically oriented. A precise technical proposal must be submitted at its completion: this usually allows to refine again significantly

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cost estimates upon which the project construction may be advertised, after preliminary agreement from the funding agencies. At the same time, acquisition negotiations may start.

(4) construction: Construction is generally performed by an outside contractor (after contract award) under the supervision of the highway department at the decentralized headquarter level.

(5) maintenance: This phase deals with the day-to-day administration of the previously built highway. Maintenance is usually done at the decentralized headquarter level, on the basis of criteria set up by headquarters.

The development of a highway project is not strictly linear and sequential and the above phases are all interrelated--especially in terms of information needed for decision-making during each phase. Feedback often appears from one phase to another, sometimes triggering new basic insights to the project. For example, during construction, the feasibility scheduling or financial forecasts may happen to be reviewed. Moreover, the maintenance phase of a particular project may have some impact--through modification of standards--on the evaluation criteria of other projects then in the planning "pipeline".

Projects may often remain in the planning pipeline for several years before eventual construction though prefeasibility or feasibility studies may each be realized within a couple of months.

In a traditional engineering terminology, only the first three phases are considered as part of the planning process. The more the project moves forward in the process, the more technical and structured the types of decisions and operations to be made become. The prefeasibility study is almost, by definition, an unstructured activity,

quite difficult to automate (traffic procedures, see Chapter II). On the contrary, engineering design is much more routine and may easily be supported by computer procedures. This fact results from the constant and gradual narrowing down (of the number of options to be considered) during each of the first three phases. In the traditional management terminology, the prefeasibility study corresponds to planning, the feasibility study to programming and engineering design to budgeting. Highway planning does not involve only financial variables. Nevertheless, similar to classical business-like situations, highway projects are essentially evaluated on a final cost basis (see Chapter I).

One must note here that this thesis only concerns itself with cost estimation during the prefeasibility and especially the feasibility studies.

## 2.2 The Prefeasibility Study

The major upbringing of the prefeasibility study concerns the determination of an optimal corridor. Prefeasibility essentially deals with reconnaissance and advance planning. It is during the prefeasibility study that user costs (implied by the present situation) are computed as well as data collected about traffic, topography, climate, soil (suitability, strength, composition for drainage purposes, hydrology), population, etc. Meanwhile, traffic trends are forecasted and managers have to evaluate the adaptability of given standards (pavement, width, maintenance policy, declivity, etc.) likely to be applied to the road insofar as real characteristics cannot be ascertained (maximum or minimum criteria, choice of standardized technologies, etc.).

The first quantity estimates, hence cost estimates, may thus

be developed on such a basis. <sup>-67-</sup> A financial schedule may therefore be set up. Subsequently, highway department top management may recommend or disapprove the project. They may also ask for further (preliminary) analysis and/or modification. The project may then eventually be communicated to the funding agency before being transferred into the feasibility study (though the funding agency's approval is not compulsory at this stage). Prefeasibility and feasibility studies only concern the highway department's internal activities and do not generally imply as large amounts of money as construction or maintenance. This is why the prefeasibility study need not be submitted to the funding agency, especially--in case of insufficient back-up--for proper evaluation.

### 2.3 The Feasibility Study

The feasibility study may be broken down into three successive phases.

The first phase concerns the determination of the roadway's horizontal alignment. Different alignment alternates are generated and evaluated in light of the real--or supposed--characteristics of the road. This latter is then divided into segments based on horizontal alignment alternates. Physical data may be refined and new on-field collection initiated to the extent that the roadway's exact location is known precisely.

Better estimation of earthwork and drainage quantities may also take place during this phase, along with more accurate evaluation of vehicle operating costs based on the actual layout (e.g. mileage). In turn, these new vehicle operating costs may somewhat modify traffic projections.

The second significant phase of the feasibility study deals with vertical profile determination, provided the previously chosen horizontal alignment. All new physical data are now supposed to have been collected. Vehicle operating costs, earthwork, drainage, declivity and width data may thus be ascertained under given pavement assumptions and maintenance policy characteristics.

The last degree of liberty to be removed (by attributing to it a real value) concerns the pavement characteristics and some final technical details based on the choice of pavement (though subgrade features may have already been more or less determined earlier)

The impact of pavement characteristics on maintenance policy options must also be assessed at this stage.

Once here, it is important to stress that the feasibility does not always occur as linearly and sequentially as suggested by the above analysis. Some characteristics, such as sub-grade materials--especially if there is no possibility of borrowing material on site-- may have been ascertained from the very beginning of the study, independently of the actual setting of the road.

Trade-offs--either intra-area or inter-area--are likely to occur at each phase of the prefeasibility or feasibility study as far as all (real or assumed) characteristics are known. However, the final cost estimates (upon which the significant trade-offs--especially inter-area trade-offs--are based) are only developed at the final stage of the feasibility study, when all real characteristics are known with enough accuracy. These costs (and their justifications through trade-offs) constitute the ultimate criterion upon which top management and thereafter the funding agencies are making their decision.

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3. COORDINATION OF THE DIFFERENT PLANNING PHASES AND ASSIGNMENT OF  
FUNCTIONAL RESPONSIBILITIES

3.1 Decision-making and the Planning Process

Each phase of significant decision (corridor, horizontal alignment, vertical profile, technical details, etc.) is essentially made--on the same basic pattern-- through consideration of intra-area trade-offs in a first approach, and of inter-area trade-offs thereafter. Though data are continuously refined throughout the planning process, all significant data are supposed to be known at any time, either through their real value or temporary estimation based upon standards.

All levels of responsibility within the highway department are involved to some extent in this decision-making process, either through the collection of information (or data) or information processing whether or not a decision which directly affects the final cost estimates is made at this level. Since information is nothing but data with intrinsic subjective meaning for decision-making, it often occurs that some data have more meaning at lower organizational levels than at higher ones. Subsequently, operating decentralized districts and divisions may act on data (therefore information for them). For example, during the prefeasibility collection process, surveyors may decide not to collect physical data related to a location which they do not deem appropriate for the highway. Analogously, division employees modify data before and after machine processing to better reflect the project characteristics, etc. Moreover, divisions are primarily responsible for presenting top management with feasible alternatives that have been studied along with their recommendations. It is thus of the utmost

importance to have a good coordination of the different activities related to a project, especially of the information flow, as stressed below.

The final decision for every phase of the planning process is usually made by top management which evaluates the different alternatives proposed by divisions. These alternatives generally reflect mainly intra-area trade-offs. It is top management's responsibility to delineate the effects of inter-area trade-offs, especially from a supply viewpoint, though the demand perspective must not be neglected. Governmental and funding agencies require sensible assessment of vehicle operating costs as related to the choice of alternatives for construction and/or maintenance. Furthermore, projects must not be evaluated in intrinsic terms, i.e. they also have to be assigned priorities in comparison with other projects. Sound project evaluation and formulation of clear-cut trade-offs (especially inter-area trade-offs) are of the utmost importance for this purpose. In particular, evaluation of traffic projections is crucial at this point. Highway departments must thus concentrate heavily on this problem of traffic forecasting procedures in order to structure them more significantly.

Whereas the project file is transmitted to top management at the end of every significant phase of the prefeasibility and feasibility studies, other governmental organizations and funding agencies only intervene at the end of the prefeasibility study (depending on the importance of the project) and especially of the feasibility studies (when final cost estimates have been developed). These agencies focus primarily on the demand side of project evaluation and, in general, thoroughly examine inter-area trade-off formulation.

Project priority is subsequently assigned in direct relationship with the clear-cut formulations of these trade-offs. Highway departments must therefore strive to meet funding agencies requirements.

### 3.2 Top Management vs. Divisions; Unstructured vs. Structured

#### Decisions

Assessment of the project impact and costs estimates are developed by divisions in cooperation with decentralized districts, according to general directives and perspectives from the highway department top management. Top managers, after having assigned (initiation of the prefeasibility study) objectives and goals<sup>(2)</sup> to the projects must evaluate the conclusions and possible recommendations from the divisions. As stated in Sub-section 3.1, this process occurs at least four times: once after the prefeasibility and three times during the feasibility study.

Top management intervention is two-fold; first, it must allow increased operational control (a) of the project evolution and (b) of divisional activities. Moreover, it is meant to provide top management with a better grasp of the different available alternatives (inter-area trade-offs), hence a broader overview of the possible implications of a project than divisions.

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(2) The terminology adopted here takes "objectives" as vague entities whereas "goals" are more quantifiable entities (able to measure the realization degree of the previously determined objectives). In public policy studies, the definitions of these terms are often inverted on a "quid pro quod" basis.

Though divisions may have to interface directly with partially unstable variables such as costs (changes in productivity or in the cost of materials) they essentially work on short-term stable and limited assumptions. Top management has therefore to provide them with directives to allow reduction of some unstable and uncertain highway planning aspects into more stable entities (e.g. hypotheses about projection or level of maintenance, and to a lesser extent, standard costs). Given these hypotheses, division activities and decisions are mainly structured and may rely easily on computer procedures such as the ones studied in II.1. These activities and decisions principally rest upon raw data gathered on-field by decentralized districts and other administrations.

On the contrary, top managers' work is based on information coming from divisions. This information--developed by divisions upon top management-induced hypotheses--is essentially "static", i.e. it does not consider dynamic trends likely to impact the roadway. For instance, physical aspects related to the roadway (e.g. location and segmentation of the road) and construction design quantity estimations do not vary over the road's life-time as do maintenance costs or traffic trends. Though maintenance costs and traffic trends have some impact on the division activities, it was seen that they are either determined by top management or computed by divisions on the deterministic basis of assumptions externally given (development of such assumptions is clearly out of the scope of division activities).

Top management must (a) evaluate the validity of procedures used by divisions and (b) check the effectiveness of division activities according to the project characteristics, on the one hand, and the

initial set of assumptions, on the other hand. This concern may be expressed as follows: How are standards applied? What is the validity of the traffic determination methodology used? Are further cost squeezes possible through increased productivity?

The above control and evaluation is primarily "static". Top management must also weigh each of the different alternatives proposed by the divisions and make a final decision about a policy choice. This is the crucial aspect of top management intervention, concerned with "dynamic" information. Now most of the aspects considered as "absolute" (given fixed figures in accordance with top management directions) by divisions are taken as variable, e.g. traffic hypotheses, deterioration conditions, etc. All assumptions related to possible time evolution and upon which divisions have been working, are successively removed to have their validity checked. Top managers focus on long-term considerations, considering simultaneously intra- and inter-area trade-offs. The key to sound dynamic evaluation of trade-offs lies under the heavy interdependence between traffic and maintenance, one of the principal stumbling blocks in any highway department. Which socio-economic factors enter this relationship? In what ways? No decision can be made without preliminary exploration of this important issue.

Dynamic evaluation of projects by top management is essentially heuristic and therefore not as well-structured as top management operational control of division activities. As stated in Chapter II, no "mechanical" standard procedure generally exist to support this dynamic evaluation. In a first approach, top managers have to check up on the consistency of all the solutions resulting from intra-area

trade-offs in the light of inter-area trade-offs. All figures must remain as stable as possible.

Top managers must also be imaginative and induce likely trends concerned with the project realization. Newly developed hypotheses which may concern only one area as well as many, have to be transmitted--based on structured procedures--to the divisions and new computations made. Determination of an optimal--or feasible--solution rests on successive "trial and error" loop tentatives until a stable and consistent equilibrium for the three areas is found, i.e. minimization of highway department overall costs for a given service to users. The level of this service is a function of the demand characteristics, and is generally imposed from outside to the highway department (government, funding agencies).

Dynamic project evaluation uses intra-area trade-off procedures, but there is no global procedure that is presently able to encompass this type of evaluation, which therefore depends on top managers.

It may be argued here that there is a clear separation of roles between operating decentralized districts, headquarter divisions and highway department top management. The former ones are essentially in charge of collecting data on-field, whereas divisions may be considered as in charge of structured decisions (e.g. intra-area trade-offs) and top management concerned with unstructured aspects of the process such as inter-area trade-off evaluation. This is of course a bit oversimplified. For instance, it was indicated that decentralized districts may have to make some decisions by themselves--based upon their understanding of the data they have to collect, which therefore presents some characteristics of information. Divisions are also concerned to

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some extent with relatively unstructured decisions (e.g. choice of standards or conversion of data). It was seen that top management has to check-up on the effectiveness and validity of structured procedures used at the divisional level. Moreover, the border between structured and unstructured is continuously moving so that fixed roles may not really be attributed on such a basis.

#### 4. THE INFORMATION NETWORK

Availability of information plays a crucial role in the soundness of final cost estimates. Moreover, some data are extensively updated during the planning process and its successive evaluations of the different trade-offs at each phase. This section devotes itself to the study of the information network necessary to support project cost estimation. It first examines how the basic data (and information) may be obtained both from decentralized districts and units internal or external to the highway department. Some normative features for the internal information network of the highway department are introduced thereafter which stress the fundamental role devoted to individuals in charge of some data or information. Subsequent chapters will somewhat elaborate on this aspect.

##### 4.1 Collection of Basic Data

Basic data may come from three types of sources (a) on-field data collected by decentralized districts (e.g. physical location data, traffic), (b) data collected, developed or stored in a unit within the

highway department (e.g. standards) (c) data collected, developed or stored outside the highway department (e.g. demographic data). In the first two cases, the highway department may control data collection whereas in the last case, it has to require data from outside, hence the highway department does not have any control of the transmission of the information needed.

This scope of control often impacts time-lead between initiation of a request for data and its fulfillment. As will be seen in the following chapter, one must first know where the data are located and secondly, ensure that they are available in as optimal way as possible. Therefore, the highway department has to set up a formal system for data collection. This system must integrate multicontrol criteria (e.g. status reports with date of request, name of individual contacted, expected date of data transmission, eventual problems, etc.). Moreover, this system must single out the different procedures available and individual responsibilities for request initiation, etc. This can be done through procedures manuals. For instance, if the planning division needs some external data at a local level (e.g. demographic data), assuming that these data are stored in a local decentralized branch of the Ministry of Interior, the planning division may eventually obtain these data through three different ways.

- (a) It may directly contact the decentralized branch of the Ministry of the Interior which is concerned (no intermediary);
- (b) It may contact the Ministry of Interior headquarters and ask them to get the data from their branch (one intermediary);
- (c) It may ask the highway department decentralized district which is closer to the concerned branch to provide the data from this latter.

(one intermediary).

Case (a) constitutes the more direct procedure to obtain the data. However, it often happens that because of administrative rules and bureaucratic red-tape, such a procedure is not possible. Analogously, the request may sometimes not directly be handled by the division itself, and preliminarily have to travel through highway department top management! Some highway departments have solved this problem of interface by creating a special unit in charge of handling all contacts with other external administrations. This unit has a role similar to that of service bureaus in charge of collecting unpaid receivables for corporations.

Collection of data within the highway department should be easier since divisions may directly intervene to somewhat activate the process and reduce time-leads. However, the appointment of individuals responsible for data collection is, here also, a crucial feature not to be neglected. In general, this task is performed by a project manager--eventually along with other projects--in charge of a given project from the beginning of the prefeasibility study until the completion of the feasibility study. This project manager usually belongs to the PPB division (Projects Section) and is responsible for coordination of any aspect related to the project study (e.g. interface with data sources and with top management, technical or financial divisions).

#### 4.2 Internal Flow of Information

The internal flow of information, which includes some basic data collection activities, must be organized on the same grounds as

collection of basic data. <sup>78-</sup>The flow of information relative to a given project is also coordinated by its project managers. Responsibility should also be decentralized on a human scale, whenever possible and according to procedures manual specifications. Therefore, managers should be able to locate and control data effectively. Moreover, all refinements and modifications of data should be properly handled and transmitted, (after appropriate screening or transformation) to every concerned actor of the cost evaluation process.

The objective of such a formal information system is, among other things, to act as a catalyst for cooperation of all individuals involved in the cost evaluation process. A minimum understanding of the process by participants and their subsequent active involvement in it is a prerequisite to any effective use and eventual future improvement (i.e. accrued rationalization and structuralization) of the process. All the existing procedures must be linked together: for instance, people in charge of the cost estimation procedures must know the limitations of the quantity estimation procedure output before entering them into "their" procedures. The inter-area trade-off evaluation process can only be added some structure when this is done.

Individuals should be designated who are in charge of information processing, of data collection, storage, etc. A schedule should be imposed determining what the life-cycle of data is. Their retention cycle, etc., when they are likely to be updated, to whom and when they should be transmitted, how? etc. When specific conditions apply, the responsible individuals would have to write them down and dispatch them, so that anyone can be aware of them, if necessary. Managers will thus be able to know where data are located and whom to ask for them. This may

concern new or previously non-transmitted data as well as more detailed ones, e.g. to assess the consequences of a change in options. Such aspects are fundamental for unstructured evaluation purposes when top managers may induce some modifications requiring retrieval of particular data. Moreover, this organization of the information flow must allow better control (of data themselves and of assumptions underlying them).

The previous requirements characterize specific project data (e.g. traffic trends, technical characteristics) as well as the standards mentioned in Chapter II, though evaluation of inter-area trade-offs generally relies more on critical application of a given set of standards.

A sensitive issue of an information network finally rests on the nature of data retrieval hence the problem of direct on-line access to data. This may be a relevant issue in the future but cannot reasonably apply in the present situation. Highway departments have first to get progressively accustomed to computer utilization rather than being contaminated by the automation plague--which often occurs simultaneously with on-line processing. The next chapters explore how data may be structured from the very inception of the planning process and how top managers must interact with them to make unstructured decisions.

CHAPTER IV: BASIC DATA REQUIREMENTS FOR ESTIMATION OF HIGHWAY COSTS

As indicated in Chapter II, one can differentiate three types of procedures (a) core procedures (quantity and cost evaluation), (b) traffic forecasting and (c) financial and economic procedures. All these procedures operate on standards, on the one hand, and particular data, on the other hand. It is the purpose of this chapter to characterize the different types of data required for each type of procedure.

The content of this chapter stems from a matrix-typology considering, first, the source(s) of data and secondly, the characteristics of their scope. Data are differentiated according to whether it is the primary responsibility of the highway department either to directly collect them on-field (internal data) or to require them from another external administrative (external data) source.

Similarly, project specific data are separated from general data such as standards, overall budgeting constraints, etc. External general data are used for financial and economic procedures, external specific data for traffic procedures, whereas most standards may be considered as internal general data and data related to the project as internal-specific (traffic figures, roadway characteristics, etc.).

It will be shown that each of the four categories of data induced by the above typology (the attributes of which are commutative) has specific homogeneous characteristics, especially in terms of conversion and updating, in addition to collection attributes (upon which the terminology is partly based). These characteristics subsequently impact storage and communication features for each category of data.

Effective project cost evaluation rests primarily upon collection and development of both general and specific data within and outside the highway organization. The best procedures without data are totally useless. It is of the utmost importance to have every piece of necessary data available and, at the same time, to avoid collecting or developing too much irrelevant data. This chapter, therefore, deduces from the above typology, some normative requirements for data collection and development, on the one hand, and for the internal data communication network on the other hand.

In accordance with what has been seen in Chapter II, data conversions (necessary to take into account the characteristics of a given project) are examined. How should specific "raw" data be modified and entered into functional procedures in order to fully reflect the project idiosyncrasy? How should standards be selected to evaluate costs as accurately as possible? etc. Similarly, updating requirements are analyzed in the light of the four categories of data.

The chapter focuses finally on data structuring and storage, which constitute the backbone of any information system.

Though this study is meant to present some normative features for (a) collection (b) conversion, (c) storage, (d) updating and (e) communication of data relevant to cost evaluation, it does not give detailed recommendations about data or input devices (e.g. cards), technical coding formats <sup>or data</sup> transmission; the proposed computer system being assumed to work on a batch basis.

However, data structuring and storage depends primarily on information needs and frequency of data access and/or modification. Therefore, the following study will analyze how data updating and conversion requirements--to be determined--should be met by a normative system.

## 1. TYPOLOGY PRESENTATION

### 1.1 Scope of Data: General Data vs. Project Specific Data

"General" data may not be directly related to activities concerned with projects, and even if so, they are meant to apply to any project--their development generally relies upon statistical methods: aggregation, means, variances, etc. and represent "average" conditions. They may be broken down into determined classes or categories (as seen in Chapter II) when content is stable over time; on the average they are updated once or twice a year. General data may either be directly related to the highway organization concerns and its collecting power viz may be internal or external (see 1.2). General data encompass indicators and data about regional or national population, economy, geology, geography, etc. as well as technical standards and their associated costs (e.g. quantity of earthwork required in a given situation, average cost of a cubic meter of earthwork applying then in a given region or on a nationwide basis), average national traffic figures, discount rates, highway department budget constraints, manpower and equipment availability, fund allotments for a region (broken down into road maintenance, new construction and upgrading), etc.

Standards, or particular types of general-internal data, are obtain-

ed and developed from data of previously completed projects. Thus they may periodically be modified. However, general data never directly concern a specific project under study and are used as reference bases for project evaluation at all levels. For instance, Chapter II showed that standards serve as such for structured evaluation procedures of project characteristics.

"Specific" data, on the contrary, only apply to a given project and have to be collected or developed for a special purpose, linked to a project under study. They concern physical, geological, economic, demographic, etc. figures as well as traffic data and forecasts, project segmentation, technical design and cost features. Specific data, as opposed to general data, are not all developed and processed. Some of them are "raw" data collected directly on-field by decentralized districts. Independently of the internal-external dimension, two types of specific data may therefore be distinguished: (a) "raw" data (e.g. topography, soil characteristics, socio-economic figures of region(s) concerned by the project, present traffic survey etc.), (b) "elaborated" specific data (e.g. road technical characteristics: segmentation, alignment, vertical profile, costs, etc; traffic and demographic trends, etc).

Specific data evolve during the planning process while the project goes from the early phases of prefeasibility to the last ones of feasibility. It is precisely the concern of the highway project evaluation process to develop--or to trigger the development of--"elaborated" specific data. This activity implies continuous revision and refinement, hence updating of data. "Raw" specific data may also vary; for instance, when the roadway exact location is determined, new, more accurate, physical data are needed for detailed engineering studies.

However, past a given stage, specific data often become stable (end of the feasibility study). As seen in Chapter II, raw specific data serve (jointly with standards) to determine elaborated specific data, some of which may be called information.

### 1.2 Internal vs. External Data

Internal data collection and development is under the responsibility of the highway department. Internal data are therefore closely related to the highway department operational activities. Examples of internal data are provided by traffic surveys and forecasts, road profiles, road segmentation, technical characteristics, geological survey, material depreciation, accounting methods, highway department budget, manpower resources, etc., figures.

It is the primary responsibility of the highway department to manage internal data and, eventually, to make them available in as optimal way as possible (timeliness, accuracy, structure, etc.) to any interested individual or organization, both within and outside the highway department.

On the contrary, external data are obtained through other organizations. They are as necessary as internal data for project cost evaluation but do not originate from the highway department operational activities. Population, agricultural, meteorological figures, economic indicators (rate of discount, shadow prices, etc.) or price of gasoline are examples of external data.

Many problems arise from the needs for (and the subsequent collection of) external data. First, external data may not be straightforward to locate, to the extent that the highway organization may not

know whether or not data exist and/or where to obtain them. Additionally, the highway department has less control of time-lags between a data request and its fulfillment. The request may even not be fulfilled because data, though collected, sometimes cannot be retrieved by the external organization(s).

Moreover, there is no certainty that external data are available according to the format desired by the highway department. Some data may also have been collected twice and not be consistent, etc. Therefore, the highway department has to know what data resources are available and adjust the evaluation process to these data, in the short-run (formats, accuracy, estimation, time-lags). Long-term activities to improve the situation should be discussed with the organization(s) concerned. These latter may also have some input upon the way the highway department collects and develops its own internal data. Subsequently this may lead to an agreement on data structure criteria and on accuracy, timeliness, etc.

However, in the short term, the highway department has to ensure that:

- (a) all data, both internal and external, specific or general are transmitted as accurately and rapidly as possible to the agent(s) or group(s) responsible for their processing. (see Chapter III). Control of the decentralized district activities is crucial for this purpose.
- (b) all data resources stored within the organization, whatever their provenance is, are easily available upon any user request.

The distinction between internal and external data has been set up here to reflect given data conditions of availability. Therefore,

this is not a strict distinction and it may vary according to the type of highway organization in different LDC's. For instance, some departments may have to develop their own economic indicators. It also happens that external data have to be either collected or induced internally to the highway department due to outside constraints.

It must be noted that the above distinction does not take into account the highway department's control of data values (e.g. possibility of impacting the data). Though the technical characteristics of a roadway may be entirely dependent upon the highway department engineers, such a control obviously does not apply for the highway department budget, present traffic data, contractors' prices or geological features of the soil, sub-grade of the road, etc. The present definition of internal and external data therefore differs significantly from definitions which may be found elsewhere.

For instance, A. Gorry and M. Scott Morton (1971), though they do not really elaborate on this concept, implicitly assimilate internal and external data to controllable and non-controllable data respectively. Elsewhere, E. Hearle and R. Mason (1963, p.47) consider external data as "environmental" data whereas internal data

"relate to the internal operation of the agencies themselves. Internal data pertain to the resources actually owned or controlled by government agencies and used by them in performing their functions. These resources consist of dollars, employees, equipment, and facilities. Internal data are used primarily to account for these resources and to describe the activities in which they are used."

It is argued here that internal data encompass more than this aspect, e.g. traffic forecasts, physical characteristics of the highway (soil, horizontal alignment, vertical profile) or prices charged by external contractors likely to work for the highway department.

Control of data by the highway<sup>-87-</sup> department (mostly of internal data) will be discussed in the next chapter since it deals more with information requirements.

### 1.3 Implications for Data Collection, Development and Reliability

Table 4-1 is an illustration of data distribution between the different matrix typology categories.

There are many links and relationships between every category of data. For instance, some internal-specific data are initially developed from internal-general data: as long as the exact characteristics (internal specific data) of a project are not known, they must be estimated. This is done through application of standards (internal-general data, project class) which are substituted to real characteristics for the time being (declivity, pavement, etc.).

Analogously, internal-specific data have to reflect, to a certain extent, external-specific data (socio-economic, political factors, etc.). This is principally done through computation of traffic forecasts (traffic procedures) and vehicle operating costs. However, it was seen in Chapter II that "demand" aspects are somewhat unstructured and that up until now they have rather been neglected in favor of more supply-oriented development (e.g. construction technical standards). One of the first procedures to be applied to "raw" specific internal data concerns traffic data. Traffic procedures compute future traffic trends (quantity and quality). Therefore, such procedures must integrate internal (e.g. present traffic) and external (e.g. socio-economic indicators) specific data with internal general data (standards).

	INTERNAL		EXTERNAL
SPECIFIC	<u>Road-related data</u> -Segments -Horizontal alignment -Vertical profile -Pavement -Drainage	<u>Non-road-related data</u> (construction, maintenance, vehicle operating costs) -costs -Fixed/Variable -Direct/Indirect -Capital/Labor -Skilled/Unskilled (labor) -Quantities -Traffic	<u>Socio-economic data for the project area</u> -Population, demographic data -Industries -Agriculture -Resources  <u>Physical features</u> -Climate -Land Use -Zoning -Environment  <u>Travel patterns</u> -Traffic elasticity
	GENERAL	<u>Unit-costs and technical standards</u> <u>Construction</u> -Brushing/Cleaning -Pavement -Drainage -Earthwork  <u>Maintenance</u> -Mowing -Patching  <u>Vehicle and traffic</u> -Categories -Fuel consumption	<u>Class criteria</u> -Traffic classification -Road classification -Maintenance classification -Budget -Manpower -Equipment  <u>Road backlog inventory</u> -Previous projects completed -Projects in the planning pipeline -Road inventory -National traffic data
			<u>Rates of discount</u>  <u>General socio-economic data</u> -GNP, Nation's Budget -Average income -Investments planned -Growth objectives -Population rate of growth

Table 4-1: Data Classification for Highway Project Cost Evaluation

Traffic projections determined ~~thus~~<sup>80</sup> are thereafter combined with other internal specific data. This leads to computation of quantity estimates for road construction, maintenance and vehicle operations.

Traffic projections also impact the choice of parameters to be used in these estimation procedures.

General-external data intervene on determination of specific-internal data, for instance, global cost economic evaluation.

Usually, any missing specific data may be estimated from general data and consistency between all categories of data constitutes a basic criterion for project evaluation.

Chapter III contended that highway project prefeasibility and feasibility studies depend heavily on the control of data collection and development, as much as on control of data values per se.

As indicated, in the case of external data, project managers have to know what data are needed in each category. Moreover, they must be aware whether or not these data exist. When these data do not exist, other solutions must be found, e.g. substitution or estimation of data. The same problem occurs when either internal or external data cannot be retrieved or transmitted quickly enough. A good control of data communication channels is therefore of the utmost importance. Such control may be obtained through such devices as periodic status reports of (a) requests initiated, fulfilled, etc., (b) estimated time-lag, (c) exception signals, etc.

The case in which specific data are missing or relatively inaccurate presents a cumbersome problem. It occurs sometimes during the initial phases of the prefeasibility and feasibility studies. The road exact location is not yet known and it may be necessary to substitute

"average" general data to the real figures; in this case inaccurate or obsolete specific data may be considered as general data. Analogously, internal specific data may be estimated from internal general data; this usually may be done easily because the highway department is familiar with the characteristics of the data it is dealing with (internal data). On the other hand, induction of external specific data from external general data may be more nettlesome because the highway department does not necessarily have the expertise to develop such external data accurately, e.g. population characteristics and evolution, climate, economic features of the region concerned with the projects.

As opposed to other categories of data which are fairly stable, internal-specific data tend to be more unstable (i.e. modified more often). This is due to the fact that internal-specific data include many processed data (estimates) continuously handled and somewhat refined during the highway planning process. It is argued below that this greater instability constitutes a major reason to store internal specific data separately from other data.

In accordance with Chapter II's description of procedures organization, one can distinguish several types of internal specific data, e.g. "raw" specific data (topography, traffic, length of the road, etc.), "first order" processed specific data (road segmentation, traffic forecasts, etc.), "second order" processed specific data (quantity of equipment, material, manpower necessary for the roadway construction and maintenance, road effect on vehicles, etc.), "third order" processed specific data (costs of each of the previous "second order" data), etc., up to the project global economic cost evaluation. Each of these

successive types of internal specific data is used as input along with other external specific or general data in order to determine the next type of internal specific data in the above chain (see figure 2-1). Moreover, each type is refined while the project study progresses.

## 2. CONVERSION, UPDATING AND COMMUNICATION OF DATA

### 2.1 A Priori Conversions and A Posteriori Conversions

The "transformation" or "adaptation", through which either specific or general data have to go in order to match procedure requirements and/or to reflect the particular conditions of the project under study will be designated here under "conversion" of data.

"Conversions" may occur either "a priori", i.e. before any automatic processing of data is done (through the concerned procedure) or "a posteriori", i.e. after some results have been provided by the procedure. In the latter case, data may already be considered as information to some extent (see Chapter II).

Before being fed into procedures for estimation, "raw" specific internal and external data must be adapted to the procedures themselves. For instance, the projected roadway has to be segmented in homogeneous sections whose determination may be based on population, topography, economic conditions (i.e. both internal and external criteria). Consideration of all relevant available data in every category of the matrix is a prerequisite to any a priori conversion. At this stage, some data have to be aggregated while others are split.

A priori conversion is also concerned (a) with the choice of

parameters for the procedures to be applied and (b) with the related problem of the project class determination (see Chapter II), concerned with the subsequent use of standard items. This is a fundamental aspect to the extent that procedures rely on or embody parameters (e.g. planning stage indications, traffic or topography conditions, etc.). These parameters are only valid under certain assumptions. Subsequently, the choice of these parameters impinges significantly on the accuracy of the estimates.

Some changes or variations of standards and/or specific data may also occur after processing when results are judged to be abnormal or inconsistent with some benchmark measure. For instance, after having applied some criteria similar to those described in Chapter II (optimal intra-area trade-offs based on isoquant and isocost curves), a division manager may find that he did not obtain the best possible solution. Therefore, he may decide to somewhat alter the category of the project in order to obtain a better set of characteristics from the procedure. Similarly, the road segmentation may be modified if it does not reflect enough the nature of the project, etc.

Another type of conversion, intermediate between a priori and a posteriori conversion concerns modifications manually made on estimates to take into account specific characteristics such as fixed or lump-sum costs, etc. This type of conversion is made on outputs from a procedure before entering them into the other procedures of the process, e.g. final cost evaluation before computation of the shadow prices (see figure 2-1).

Most of the time, conversions cannot be made by the machine itself and require human intervention as will be seen in Sub-section 2.3.

## 2.2 Refinement of Elaborated Estimates and Introduction of New Data

New sets of given data often happen to be introduced into the middle of the evaluation process. At a general level, this may imply a revision of all estimates. For instance, during the very cost evaluation process of the highway project under study, some other projects may just have been completed. Operating results from these projects may modify general standards, therefore cost estimates of the project under study are based on these standards. In the same way, contractors may modify their prices whereas technological progresses may result in increased savings, etc. Though these changes of internal-general data are not likely to happen very frequently, they may significantly impact some estimates, as will be studied in more detail in Chapter V.

Another example of new data introduction is also given by collection of new more detailed specific data (either internal or external) while the planning process progresses. Therefore, previous "raw" specific data have to be updated as well as the subsequent estimates based on them. This, however, only occurs two or three times during the project cost evaluation.

Modification of data also occurs continuously during the planning process, as applied to "elaborated" specific data. Then the changes result from successive determination of the roadway corridor, horizontal alignment, vertical profile, pavement characteristics, etc. (see Chapter III).

Another type of change is due to variations of the basic hypotheses and of the standard classification of the project. Highway departments may decide to squeeze some costs, necessitating therefore new estimate

computations.

In sum, updating may be considered as relatively high for internal specific data and significantly lower for external-specific data (2-3 updateings during the evaluation study cycle) whereas there is practically no updating of general data. Consequences of updating frequency of the data will be depicted in Section 3.

### 2.3 Human Intervention and Communication of Data

The best possible data structure may be totally ineffective if updating, collection and development of data is not properly handled, i.e. suffers some delay in communication or effective modification. An effective solution to this problem, suggested in Chapter III, consists of ensuring that every piece of data, whatever its characteristics may be, is under the responsibility of an individual. This individual must be in charge of everything concerned with the existence of this piece of data in the highway department data-bank, not only collection development and updating, but also communication and control of utilization. For practical reasons it is generally the project manager's task to be in charge of specific data related to the project under his responsibility. However, this latter may sometimes delegate his responsibilities to technical divisions or decentralized districts.

A crucial aspect of the data communication network concerns transmission of data (or information) from one procedure to another along the evaluation process chain until a final stable and satisfying inter-area trade-off is reached. An effective solution to the problem raised here,

complementary to the previous one, may again rest on the formal setting of individual responsibilities for data conversion and communication. Responsibility attribution may be defined in a procedures manual.

Responsibility attribution to designated individuals as related to collection, development and updating of data, should significantly improve the system responsiveness. For example, when a piece of data is needed at a supervision or top decision level, and nobody is directly in charge of this piece of data, there may be problems (a) in retrieving this information and (b) in figuring out the conditions how and when it was developed. On the contrary, with formal responsibility attribution, someone must necessarily be in charge, among other things, of this piece of data. Moreover, such attributions of responsibility generally attenuate the feeling of frustration induced by the introduction of a computer. They also facilitate the necessary involvement of individuals into the overall evaluation process: this is a very important point because the machine cannot do everything by itself, and therefore, effective cost evaluation needs important human support.

### 3. DATA STORAGE IMPLICATIONS

#### 3.1 Specific Internal Data

The category of specific internal data consists of all relevant data upon which cost is eventually determined. Therefore, these data are the most consulted data during the cost evaluation process. Moreover, due to the progress of the prefeasibility and feasibility studies, on the one hand, and to the different operations taking place at the end of each significant phase of the planning process (evaluation of trade-

offs) on the other hand, these data are, as previously indicated, the least stable data in the highway department data-bank. Specific internal data constitute the second and most numerous category of data kept in a highway department (about 10,000 bytes ).

At each trade-off evaluation, whether the process is structured or made on a heuristic "trial and error" basis, new quantities and associated costs may appear whereas during each phase of the planning process (i.e. of the prefeasibility and feasibility studies) basic estimates are refined, hence modified.

It therefore seems useful to store specific internal data separately from other data. Specific internal data structure needs to be easily accessible or modifiable. A highway department is relatively free to choose any structure for these data since their definition, if not their content, is primarily under the highway department's control. However, any structure has to consider some special relationships such as the one between quantities and their associated cost estimates. Additionally, some other characteristics, analyzed below, must also be taken into account.

Specific internal data may be separated into two classes, whether or not they are directly related to the roadway's physical layout.

The first class of data, is concerned with the roadway's physical features (physical layout, i.e. horizontal alignment, vertical profile, drainage, sub-grade, pavement, etc.). To the extent that some of these characteristics are relatively homogeneous along some lengths, road-related data can be organized according to the roadway segmentation. A hierarchical network structure organization encompassing segments seems to be particularly adapted for the data-bank internal storage.

The structure must consist (1) of the road (2) of some reference points and (3) of road-path points. Reference points may precisely delineate segments and/or they may represent geographical or administrative references (intersection with a road, a river, administrative limit, etc.).

Road-path points are located by their coordinates and their distance to the closer reference point. Length data (segments, sub-grade and surface type, width, etc.) and point data (drainage culverts, cross-section, shoulders, right of way, etc.) may therefore be easily included in such a structure. Moreover, some other subsequent details relative to future maintenance, operations conditions (speed limit, accidents, posted signs, traffic) are also able to enter this structure.

It may also be useful to connect roadway-related data (identified through a set of coordinates) with an interactive engineering graphics system. Such a system could be helpful for technical division estimates not only during the project planning phase but also during construction and subsequent maintenance operations, for check-up purposes. It is important to note <sup>that</sup> road-related data are meant to be retained in the future and periodically used. The road-related data bank may, however, have to go through some restructurization, it may eventually be squeezed or transferred to an other storage device (with slower access characteristics since access to data will occur on a less frequent and less pressing basis), when the project is completed. It may also have then to be merged with other projects' data in a common road inventory (back-log) file.

The road-related data are not concerned at all with estimates of quantity and of their subsequent cost. These latter data are directly related to the project study (and to a much lesser extent, to the road

itself and its future utilization): they may be kept apart. Since the above estimates are nevertheless related to some of the road's physical aspects, one may conceive of a system of indexing references from the non-road-related data to the corresponding road-related data (point-items and length-items).

The non-road-related data set embodies quality estimates (e.g. manpower, material and equipment requirements for the project realization) as well as traffic figures, weather conditions, etc. and other internal data such as supervisors' names, construction or financial schedules, etc.

The content of this set has a high probability of being extensively modified during the construction phase but it is unlikely to be consulted frequently after the project completion (except for occasional audits or statistical computations) whereas the road-related data still has an operational value.

Non-roadway-related data present characteristics similar to the category of external specific data (demographic, socio-economic, political, etc. data) though external specific data are not likely to be modified as extensively as internal specific data. However, at the end of the project planning process, when internal data have become more stable, specific external and non-road-related data may be kept together.

The structure of internal specific data, especially of road-related data should allow some "buffer" space to receive "raw" specific data before they are converted hence, transferred either to road-related data banks or are included in the non-road-related files (which may sometimes occur without previous storage in a buffer).

### 3.2 Specific-External Data

In the present state-of-the-art, little is known about analytic methods that would account for the impact of specific-external data upon traffic trends. Highway department managers are aware that this is one of the most nettlesome problems that they have to deal with. Therefore, rather than focusing heavily on this unstructured aspect <sup>and</sup> on numerous "trial and error" attempts, they prefer to take some already structured traffic assumptions as given (on the basis of initial traffic computations obtained through traffic procedures). Specific-external data are thus rarely used more than once and modified. Research on specific-external data is often delegated to special "staff" units, and based upon "trial and error" methods but "line" managers, concerned with real projects, generally do not extensively rely on specific-external data during the planning process.

Moreover, only a relatively small amount of specific-external data is actually collected and stored to be ultimately entered in the (elementary) procedures presently developed. However, traffic procedures are likely to be significantly developed in the future, and to require then much more input data. The present storage of specific external data should eventually be able to provide some extra capacity for this purpose. This should not raise any problems because the present space occupied by specific-external data is insignificant; additionally, it is situated in a slow-access region of the data-bank so that extra space provision should not be too costly.

In sum, specific-external data are rarely taken into account by the highway managers, i.e., accessed or modified during the project's

life-time. Managers prefer to consider given, already developed traffic assumptions either (a) close to the assumptions resulting from initial processing through the elementary traffic procedures or (b) extreme assumptions (low traffic, high traffic). The only changes of specific-external data able to occur concern variations of external hypotheses about socio-economic, environmental, etc. data. These changes cannot be explained directly by highway department managers who prefer to ignore them. Attempts to provide better structures to traffic procedures are however done in special units of the highway department and these procedures are likely to be more effective soon. They will also require more specific-external data. Provision should therefore already be made for these data, which may have to be accessed frequently and quickly.

In the present situation, specific external data may be stored in files characterized by slow and infrequent access. Specific-external data are meant to be kept after project completion for assessment of the initial forecast validity or for some other project use (in the same area). As indicated in Sub-section 3.1, at this stage, specific external data may be kept together with the non-road-related/<sup>specific internal</sup> data, especially with traffic data and estimates which were developed upon specific-external data.

### 3.3 General-Internal Data

General-internal data, mostly technical standards and unit costs, constitute the most numerically important category of data (around 4000 bytes for vehicle operations, 5000 bytes for maintenance and 7500 bytes

for construction).

General-internal data are more stable during the planning process than specific data. Changes in general-internal data only occur once or twice a year; they may be caused by completion of new projects whose figures do not coincide with former standards, and/or new technical or technological conditions (e.g. increased productivity, new materials, new technological progresses, etc.) or inflationary trends (also reflected by general-external data changes; e.g. new contractors' prices).

Standards are statistically developed from data of projects already completed and from maintenance operations. Three types of technical (or technological) standards are considered here: construction design standards, road deterioration and related maintenance standards, and vehicle deterioration standards. Each of these types of standards is related to standard costs (see Chapter II). Standards are broken down into categories, and in turn divided into elementary items.

Technical construction design standard items give the characteristics of materials, equipment and manpower for optimum construction operations. These items reflect varying conditions and it is the responsibility of the project manager to take into account the right items. He has to specify the project class which selects the relevant parameters and the items which apply to the project. Moreover, through a priori and a posteriori conversions, project managers may modify some assumptions in order to better reflect the very nature of the project.

Road deterioration and related maintenance standard items have the same basic structure as construction items. However, vehicle standards

are different; they give such characteristics as tire-wear , fuel consumption, part maintenance, etc. for the principal categories of vehicles in use in the country (e.g., heavy, medium size, light trucks, buses, tourism cars, etc.). These characteristics also vary in function of the particular features of the project (e.g. altitude, humidity of the region, etc) and this variation is generally taken into account through the available set of items.

Technical standard items are combined with specific data to give quantity estimates. Managerial decisions, once the choice of the corridor has been made (prefeasibility study), are more often concerned with the evaluation of a given set of standards than of specific internal physical highway data, as will be seen in Chapter V.

Standard items are usually developed in a particular unit of the highway department (generally connected with the PPB Division, e.g. the Programming and Budget Branch). This branch is essentially in charge of providing fast updating of the standard data-bank once or twice a year. Standards are developed in coordination with all divisions, especially technical, legal (Right of Way), accounting (budget, unit costs) divisions.

Though some categories of standards, especially in maintenance and construction, are overlapping (e.g. materials and pavement characteristics), it does not seem efficient to avoid redundancy by storing them together. On the contrary, a highway department should keep its three sets of technical data separately. Therefore, these three sets should be able to be managed by different knowledgeable individuals in each field. However, some necessary connections have to be established between the three sets of standards. For example, certain categories

of vehicles impact more roadway deterioration than others, therefore there should be some links between different items in the construction and maintenance sets on the one hand and vehicle operation sets on the other hand.

However, a fundamental characteristic of technical standards sets rests on their relationships with their corresponding unit-costs, stored separately. Unit costs are likely to vary more often than technical standards, therefore it may be effective to store them apart, provided that their linkage with their corresponding technical standard items are satisfying. Standard unit costs are also developed on a statistical basis by highway departments to reflect direct internal operations costs (essentially maintenance) and external operations costs (essentially construction, vehicle operation). Due to external constraints, as indicated, unit costs are more likely to change than technical standards and their change is less predictable. It is necessary to keep extensive cost data lists for each major contractor. Prices may vary according to the activities considered; therefore, a contractor's prices may be lower than another one's for certain activities, but not all. Of course, this type of cost storage must be done in a slow and infrequent access zone.

However, the sets of present optimal standard unit-costs must be kept in a relatively fast and frequent access zone because (a) of the occasional updating mentioned above and (b) of the frequent access to the standard unit-costs in relation to the technical standard items (less often updated). Combination of both types of data gives cost estimates for each of the three areas. First, quantity estimates (internal-specific data) are estimated from technical standards and

specific data. They are then eventually modified or reprocessed and stored. Each of these quantity estimates refers to a standard-unit cost which in turn is retrieved from the data-bank and combined with the quantity estimate to give a cost estimate (multiplicative operation). All cost estimates are then modified, if necessary, and added up to give global cost estimates. However, this method does not account directly for "fixed" or lump-sum costs which cannot be broken down into unit costs, e.g. construction camp, supervision, planning costs, etc. (see Chapter II). It may be useful to store some data related to these costs in the cost sets of the highway department data-bank. These data would give managers an idea of the magnitude of fixed costs to be integrated with final global estimates in order to properly reflect all project costs. In the case of prices charged by contractors, most of the fixed costs are already included in unit costs and there is no real problem there.

General-internal data do not only encompass the previously described technical standards and unit costs used in core-procedures. A second type of standards (mentioned in II-1.2) also intervenes in traffic procedures and in the determination of the project class or of maintenance policy, etc. However, in such cases, their utilization is much less well-structured and practically does not allow storage in a data-bank in the present situation. For instance, there may be some rules asserting that if some conditions are met (state of the road, volume of traffic, etc.) the road must be classified in such or such a category for maintenance, construction, etc. according to prescribed policy criteria. Highway departments are now striving to clarify these still relatively structureless issues so that such standards will soon

be able to be integrated into the highway data-bank.

Independently of future considerations, general internal data already need large storage space. Since there are different categories of general-internal data, these latter can be stored separately and divided into sets (e.g. construction technical standards, vehicle operating unit costs, class standards, etc.). Sets must be able to be easily linked together. Some sets are likely to be more often updated than others; this is one of the reasons why it may be useful to store them separately. Nevertheless, all types of general-internal data are very frequently accessed during the planning process of a highway project, especially during cost estimation and heuristic inter-area trade-offs appraisals. Their structure must therefore allow easy access. Moreover, it must be noted that general-internal data may be used by any unit of the highway department and applied to any project under study, hence one should pay careful attention to their structure.

#### 3.4 General-External Data

General-external data only intervene at the top management and more particularly at the governmental or funding agency level. They are used to assess the value of a project as compared to financial and economic criteria (rates of discount, general economic conditions, etc.). They are only applied to project estimates once these latter reflect stable characteristics and inter-area trade-offs. However, general-external data are not considered at all in divisional operations.

This category of data does not need extensive storage space. Moreover, it does not enter sophisticated procedures--subsequently able to

be deeply modified--and its updating or access requirements are rather limited. Therefore, general-external data may be stored in a relatively remote and slow-access area of the data-bank.

General-external data, similar to any general data are meant to be kept for future uses and applied to any project within the highway department, eventually outside of it, under any request. Subsequently, their structure has to be carefully designed when the system is built.

CHAPTER V: TOP MANAGEMENT INTERVENTION, CONTROL AND EFFECTIVE INFORMATION  
NEEDS

1. CONTROL OF PROCEDURES AND ACCURACY OF INFORMATION

As seen in the foregoing chapters, effectiveness of the cost evaluation structure can be considered as resulting from two principal factors. The way that the different evaluation procedures and modules are interrelated constitutes a fundamental determinant of effectiveness. At a lower level, the internal structure of procedures, e.g. forecasting and simulation techniques, standard definitions of elementary items and classes of projects are as relevant. Some obvious limitations stem from the quality of procedures and of input data that sometimes cannot be improved because they are totally out of the control of the highway department. Thus, this latter has no power at all on them, e.g. influence on socio-economic data or determination of the exogenous rates of discount, etc.

1.1 Interdependence of the Procedures in the Overall Inter-Area  
Trade-Off Cost Evaluation Process

As signaled by J. Emery (1969), interdependence and types of relationships between procedures is a fundamental factor for the effectiveness of the global system. Segmentation in individual specific procedures is only relevant to the extent that the "globalness" of the process

is still properly taken into account (by the links between the different procedures).

Chapter II showed how all the intra-area trade-off core procedures are related; maintenance costs can only be determined to the extent that roadway characteristics are known, whereas vehicle operating costs determination rests upon the choice of a maintenance policy and roadway characteristics figures. However, the main problem concerned the so-called traffic procedures and their connection with the core procedures. This nexus is of crucial importance especially for inter-area trade-offs; unfortunately, little is known about it. During inter-area trade-offs, highway managers are faced with considerable risk of suboptimality and instability of initial hypotheses in each area (construction, maintenance, vehicle operation). It may happen that an optimal or feasible set for the construction area, based upon given traffic assumptions, has to be modified at the maintenance estimation stage and/or at the vehicle operation estimation stage. This often completely changes the initial traffic hypotheses of the construction phase, subsequently, the optimality of the determined construction characteristics, etc. Highway managers have therefore to check the stability of hypotheses by continuous feedback control loops between the different areas. Objectives must be clearly set, e.g. a given traffic level in the long-range. Simultaneously, consistent alternative actions should be evaluated. For example, they may be based on the chain (road characteristics plus traffic pattern → determination of maintenance → stability of traffic) where the last stage is meant to check the stability of the objective traffic pattern. On the contrary, the objective may be a given level of maintenance. It is then necessary to

install a chain such as (road characteristics plus maintenance forecasted → traffic evolution trends → stability of deterioration of the road--hence maintenance).

Another important aspect of procedure interdependence is concerned with "a priori" evaluation of standard characteristics for the roadway under study. This occurs (a) at the prefeasibility stage and at the early stages of the feasibility study, and (b) as just showing in each area before inter-area trade-off evaluation takes place. Highway managers must induce a set of given characteristics for cost evaluation before any detailed real evaluation is possible. For instance, the prefeasibility has often to assume that the road under study is to be paved or, on the contrary, that it is to be an earth road. Such assumptions are only made for clarification purposes and are meant to be replaced by real characteristics while the study progresses. In the short term, however, standard criteria must be developed, able to buttress the choice of a hypothesis versus another one. These may be included among classification criteria of roadways, as described in Chapter II, and therefore deduced from the traffic procedures.

The last aspect related to procedure interdependence deals with the information network itself and its relationship with the organizational structure described in Chapter III. Human intervention is a fundamental characteristic of any computer-based system effectiveness as underlined in Chapters III and IV and should not be neglected in any sense. As a prerequisite to the system effectiveness, specific individuals must be in charge of specific procedures and/or specific information availability.

1.2 Output Information and its Limitations

Any basic criterion for effectiveness of cost evaluation is a direct function of the final information output and relevance of this information for decision-making. As stated in Chapters II and III, information is modified at each organizational level and each of these levels are used as a stepping stone for final information development. The effectiveness of every piece of information or procedure must be judged in the light of this final output.

Management intervention is based upon the global cost characteristics described in Chapter II (e.g. fixed vs. variable, labor vs. capital, financial vs. economic, etc.). Managers must be able to trace from the final reports the origin of these costs down to the quantity estimates and eventually decide on modifications at this basic level.

Such an intervention assumes relative accuracy of quantity estimates, hence a good reliability of procedures, standards and specific input data. This is not always the case and managers have therefore to check carefully every assumption before making any decision. Insertions of some "indicators" or "benchmarks" in reports may significantly facilitate this task. Development of "management by exception" criteria is very important for this purpose. Such criteria should enable managers to screen report contents at a glance and locate immediately any anomaly in them.

Another important feature of reports concerns their limitations which in turn often result from procedure or input data limitations. For instance, procedures cannot take into account some changes in costs

which will occur exogenously <sup>-111-</sup> to the highway department during the project realization. In the same way, the algorithms may not be sensitive enough to make the difference between two close but distinct technical solutions and their resulting costs. Subsequently, managers have to be aware of such limitations and be able to somewhat overcome them, as will be shown in Section 2.

## 2. UNSTRUCTURED ASPECTS OF INFORMATION PROCESSING

Section 2 examines how managers have to directly interact with data and information when no direct structured procedure is able to provide them with straightforward, relevant information, i.e. (a) when procedures exist but may not handle some problems (therefore under managers' direct responsibility, e.g. charge of exogenous prices); (b) when procedures present some known weaknesses (e.g. sensitivity, aggregation, etc.); (c) when there is no procedure and no chance in the short-term to install one able to cope directly with the managers' problems (unstructured decisions). In this latter case, managers must proceed by "trial and error" methods, as seen in Chapter III.

### 2.1 Local Controllability of Data Values

This sub-section is concerned with the control of data values by the highway department. Such control should not be confused with (the scope of) control of data collection and the development discussed in Chapter IV. Though external data (i.e. data whose collection and development do not incur directly to the highway organization) are

generally not controllable by the highway department; controllable data cannot be combined with external data: internal data are not all controllable by the highway department. In some cases, however, this organization has some discretionary power on these data, from a monopoly viewpoint. An example of the foregoing distinction is provided by contractors' prices, usually not controllable by highway departments. However, the highway department may exert some pressure on contractors, keeping their prices under a given critical level.

The same case occurs with the roadway location physical data; engineers may, to some extent, impact on physical constraints by moving the highway location to another corridor.

It is of the utmost importance for the accuracy of estimates that highway department managers assess the uncertainty of internal data values not directly under their control, and of external data values. This uncertainty assessment, as opposed to assessment of procedure uncertainty or of validity scope, cannot be handled through use of procedures and must therefore be analyzed separately of procedures.

As previously indicated, it is necessary to distinguish data which can somewhat be influenced by the highway department from data totally imposed to it. The separation between the two categories of data is cursorily given by the separation between the external-general data category (totally exogenous) and the remaining parts of Chapter IV matrix.

External-general data are determined at a national, even international level and thus less can be done by the highway department to impact them. Examples of these exogenous data are inflation rate, shadow prices, discount rates, national budget of the LDC, political conditions, etc. In an extreme case, however, it may be assumed that

there is some interdependence since a boosted public works policy requiring much labor is a classical way to fight unemployment. Highway departments have to assess carefully any uncertainty related to external-general data and to their evolution. This assessment generally occurs at the final stage of financial procedure processing and uncertainty is accounted for through a percentage discount of the final cost evaluation. It may be noted that a variation of external-general data, pertaining to the highway department's operations, is also likely to affect the whole economy of the country. Therefore such a variation does not have an important impact per se on the global nation budget as every other cost varies simultaneously.

On the contrary, external-specific data variations are much more sensitive per se at the level of global cost estimates. They are concerned with political or socio-economic, etc. changes directly related to the project under study or the roadway location and directly impact traffic trend determination for instance. The key to a better structurization of traffic procedures, hence of cost evaluation rests on these data. It is only when these data are properly taken into account by quantitative functions that regular traffic projections and diverted traffic forecasting procedures may be considered as relatively well structured. These procedures do not presently take into consideration much of the external specific data and principally rest on vehicle operating costs, as opposed to the other factors directly impinging on generated traffic and development traffic. Managers must therefore be able to assess "roughly" how changes in external-specific data are likely to affect traffic projections: this is a crucial point for the road classification. It often happens that roads are built whose

class is not in relationship with the actual traffic the road is going to support (under or over-estimation). A good control of such hypotheses can be obtained through simulation processing of two extreme hypotheses and choice of a middle-range solution when stability is ascertained.

Internal data uncertainty has also to be carefully assessed, e.g.

(a) impact of a variation in the cost of materials or in the prices of contractors (b) impact of an optimal intra-area solution on other intra-area (hence on inter-area) aspects (c) impact of a variation in roadway steepness on vehicle operating costs, etc. Some of the above features such as the ones raised by points (b) and (c) concern standards and may more or less be handled through procedures. On the contrary, variations in contractors' prices, in productivity or technology, cannot be integrated into procedures and have to be directly treated by managers at a "manual" level. Consideration of these latter features is often crucial to the quality of the cost estimates and allows accrued control of the project's subsequent operations. Though they are not able to be reduced to procedure-treatment, such actions may be facilitated by the report formats and flexibility as will be seen below in Sections 3 and 4. Distinction between fixed and variable costs is also important for this purpose: control is easier to exert in the case of variable costs (when managers know how variations are likely to apply) than of fixed costs.

A last--and extreme--type of control mentioned earlier is concerned with monopoly bargaining and regulation enforcement as applied to internal data. The highway department is able to impose conditions on contractors' prices in the same way as it may, to a certain extent, control traffic evolution on a road by setting some regulations,

e.g. systematic control of truck<sup>-115-</sup> loading, tolls, or on the contrary upgrading of maintenance, exemption from taxes for industries settling along the road, favoring this development traffic, etc.

## 2.2 Use of Procedures for Unstructured Decisions

To make unstructured decisions, top managers have also to rely on existing procedures. However, this should be done very carefully. First, managers have to be aware of the flaws of the procedures (which cannot be improved) for instance, external uncertainty of data as seen in Sub-section 2.1 or lack of sensitivity, etc. Subsequently, managers should not try to submit two close sets of data to a procedure when it is likely that the procedure is unable to single out the difference between the two sets in terms of trade-offs. Secondly, managers have to use procedures for unstructured decisions as rationally as possible. In so doing, they should always consider the human aspects of data processing and information communication. Rather than extensively processing different hypotheses through imperfect and non-connected procedures, managers have to better rely, to some extent, on the organizational structure and the advantages it may offer.

The basic method for unstructured decision-making consists of successive heuristic "trial and error" tentatives, as seen in Chapter III. Managers try a solution, then another, etc. until they obtain a "stable"--if not optimal at least feasible--trade-off. Needless to say, the different solutions induced are not completely intuitive and correspond to some rational process (small variations of a hypothesis, observation of the results provided by the procedure, then new hypothesis

if still unstable results, etc.). However, during this "unstructured" process, managers may need any type of data if they suddenly deem it necessary. Therefore, the information system should be ready (a) to provide managers with this data and (b) to run the procedures as indicated by top management (choice of data, hypotheses, etc.).

The next section shows that a prerequisite for improvement of unstructured decisions consists, for a large part, of an effective information network, based upon decentralized responsibility, as seen in Chapter III.

### 3. DEVELOPMENT OF INFORMATION FOR TOP MANAGEMENT

#### 3.1 Control of the Information Flow

Reports constitute the basic tool used by top management and link all units to highway department top management. Reports must be organized in order to facilitate top managers' intervention by drawing their attention to sensitive points (management by exception, "benchmarks" providing background information).

Flexibility of reports is crucial to the extent that top managers' decision-making process is essentially unstructured and may evolve, as foreseen, requiring some other information needs. This particular aspect of report flexibility will be studied in more detail below, along with its technical implications.

A primary concern of highway department top officials, as related to the information network, rests on information consistency at each level (organizational structure) and stage (planning cycle) of data processing. As applied to cost estimation, consistency is two-fold. First,

technical solutions developed by the highway department (hence the resulting information) should reflect--i.e. be consistent with--the project idiosyncrasy. Secondly, technical solutions should be compared to each other (intra-and inter-area trade-offs). Moreover, some conflicts impacting transmission and consistency, may arise from personal situations.

Continuous checking of information consistency and attenuation of conflicts, hence increased stability of information is a prerequisite to effective cost estimation. It may precisely be obtained through responsibility decentralization and good overview, through effective reports, of the global information flow at a top management level.

Initial hypotheses suggested initially by top management to divisions at the beginning of the study must remain as stable as possible. Furthermore, hypotheses concerned with a given area should not conflict with hypotheses holding for another area (stability of inter-area trade-offs).

At a basic organizational level, individuals in charge of a given processing operation must ensure of the consistency of the results which they are responsible for (a priori and a posteriori conversion of data to reflect the project idiosyncrasy on the one hand and intra-area trade-off consistency on the other hand).

Another important feature related to the control of the information flow in a highway department concerns the location of information. It is a particularly important feature for unstructured decisions when some piece of information may have to be retrieved "out of the blue", because it is needed by top management independently of the regularly scheduled information flow specifications. It is fundamental for

managers to know where and how the information is stored. This knowledge is also crucial for fulfillment of requests external to the highway department, which may concern any type of internal data (see Chapter IV). With a decentralized organization of the information flow where each piece of information, among others, is under the control of an individual, managers should be able to easily find the extra data they might need to test a given alternative. Moreover, they should be able to discuss the implication of this variation with a knowledgeable individual who is precisely responsible for this piece of information.

Implementation of decentralized information flow (a) somewhat suppresses information overflowing at the top level (through screening and aggregation of information) and (b) allows good control of information consistency and storage at every level. Therefore the overall "globalness" of the system (as dubbed by D. Carroll, 1967) is preserved and top managers may evaluate inter-area trade-offs in favorable conditions.

### 3.2 Aggregation and Screening of Data: Content of Reports

Reports transmitted to top managers must simultaneously include specific-external, specific-internal and general-internal data. However, general-external data need not be inserted to the extent that managers cannot really act on them. Most information in the reports should be able to be modified by managers making decisions which impact data. To prepare these decisions, lower hierarchical levels (acting as stepping stones for information) have to screen and aggregate internal data: managers are not concerned with details about the road profile or declivity, nor with all standard items as described in Chapter II.

Technical details about the roadway, transmitted to top managers, may consist of general characteristics such as nature of pavement, maximum declivity, width, maintenance policy adopted, etc.

Traffic data should appear in relation to a set of external-specific data (socio-economic indicators, political features, etc.) so that managers may somewhat ensure of the consistency of the induced hypotheses.

Finally, costs should be indicated: quantities, unit-costs and global costs separated into labor (skilled and unskilled), and capital (material, equipment, overhead and profits) eventually overhaul costs. This should be done for each area (construction, maintenance and vehicle operation). Each standard item and its characteristics, as described in Chapter II, must also be specified on this list. Moreover, the reports must also reflect the prevailing hypotheses (determination of the project class, in accordance with the traffic procedure results).

Reports addressed to top managers are developed from the reports received by the project manager. Though top management reports are not as detailed as the project managers' ones, the former reports may also contain some information about names of individuals responsible for each significant stage of the evaluation process in case some extra information is directly needed by top management (without going through the project manager). Moreover, top management reports refer to the project manager's report. In turn, these reports either contain the information needed, refer to the other reports at a lower level or to project files. It is therefore possible by "transitive closure" to trace every possible information. Though reports addressed to the project manager constitute the key-tool for such a search, their

importance may vary in function of the structure of top management reports. Therefore, the form of these reports has some strong implications on the scope of control exerted by top managers as opposed to the project manager.

#### 4. FLEXIBILITY OF THE INFORMATION FLOW

This section explores how the highway department may adapt its overall information flow (communication network: data-bank and reports) to new conditions resulting either from improved structurization of the cost evaluation process or from exogenous constraints.

##### 4.1 New Activities and New Data

Since the nature of the evaluation process is meant to evolve over time towards a more structured form, e.g. traffic procedures, class of projects, etc., the computer-based system supporting its information needs must be able to adapt to the process changes and existing procedures must therefore be structured in order to allow as much flexibility as possible. This may be realized by utilization of a sophisticated file organization structure (more elaborated than the traditional file organization structures such as sequential organization) which would allow eventual extension of some categories of data (standards or external data). It does not seem necessary to increase the capacity of storage of internal specific data. However, procedures may have to be modified or somewhat extended. Therefore, their different interfaces must be left as loose as possible. Changes likely to be

affected by the computer-based system in the future essentially concern upgraded traffic procedures and extended maintenance aspects. Moreover, some new activities may be added, dealing with more refined analyses of users' costs and benefits.

#### 4.2 "Ad-hoc" Reports

Management may happen to realize that some current approach to a given problem is no longer satisfying and therefore has to be replaced or buttressed by a more appropriate and effective approach. Subsequently, some modifications may have to be brought to the existing computer algorithms and data-handling methods if such an approach has to be instituted. In the short-run, it was shown above that managers may always refer to the specific individual in charge of the data under concern and therefore directly get the information needed by such an approach.

In the cost evaluation process, such issues generally result in the need for ad-hoc reports at the managerial level. For instance, these reports may have to contain new indicators upon which a better "management by exception" may be based. It may also happen that some erroneous procedures have to be totally revised, e.g. evaluation of traffic volume, maintenance policy impact on vehicle operating costs or search for optimal design standards (due to new technology introduction), etc. In both cases, the data-bank should be able to adapt to the new requirements without any major problem.

An elaborate file organization structure similar to the ones upon which proprietary softwares such as "file management systems" are

based may constitute a good solution to this type of problem, without going to an overall data-bank management system (DBMS). The DBMS solution would require extensive programming and does not seem necessary here: a file management system appears to provide enough flexibility for the highway department's present needs. Moreover, it was seen in Chapter IV that the updating requirements of the project data-bank are fairly limited and the data-bank itself is not voluminous enough to justify an overall DBMS and its "overhead".

#### 4.3 Exogenous Constraints

Highway departments are public organizations, submitted to the control of the government bodies, on the one hand, and to the public (e.g. through pressures, public hearings, etc.) on the other hand. The extent to which this control is achieved varies. Analogously, the span and the condition of this control may evolve. The highway department must be prepared to handle any of the new constraints which could be imposed either by government bodies or directly by the public, in general.

In Western countries a typical example of a new constraint stems from environmental considerations which significantly impacted highway administrations in the early Seventies. These latter were required to work on new procedures, and most CBIS's in use then, i.e. relatively few, had to be completely reorganized. It is important that CBIS's implemented in LDC's should be able to handle similar issues as satisfactorily as possible (e.g. right of way, safety, noise, landscape,

etc.). However, such constraints are basically unable to be forecasted specifically.

The flexibility which would be allowed by an elaborated file organization / <sup>system</sup> appears therefore to be a fundamental requirement to the implementation of any CBIS module. Too many organizations, using only pure sequential access to their files, are realizing painfully, as depicted in a well-known paper by R. Nolan (1973), that any change in their reports requires a preliminary time-consuming reorganization of their data-bank.

Another point, concerned with exogenous constraints, refers to internal data which, as specified in Chapter IV, may be requested by any outside organization (e.g. agriculture agency, telephone company, etc.). It is thus necessary for the highway department to fulfill these demands as efficiently as possible. Such efficiency is considerably enhanced by a good file organization such as the one provided by a "file management system".

A final point related to the system flexibility concerns its integration into an overall CBIS encompassing all the activities of a highway department, from project planning to inventory management, accounting or construction status reports. This point is going to be discussed in the following chapters.

#### 4.4 Future Perspectives

Flexibility undoubtedly constitutes an essential prerequisite for any further step towards accrued structurization of the cost evaluation

process, hence increased rationalization and overall control in the short-run of the process. Needless to say, flexibility should be modeled in function of the organizational setting and vice-versa.

Short-term progress (to be accounted for by the flexibility provisions of the system) are essentially likely to focus on upgrading of already well-structured procedures (e.g. core procedures or economic procedures). Such progress will tend to increase sensitivity of procedures, for example, by taking into consideration more standards (internal-general data) or relevant, controllable, internal-specific data. Simultaneously, management by exception will probably evolve considerably, e.g. development of new reference criteria and directions to handle "abnormal" situations such as incompatibility between two "optimal" intra-area sets of solutions, etc. In the same way, managers will have to learn how to assess limitations inherent to procedures, more generally to automation (e.g. uncontrollable internal data).

In a broader perspective, the system may benefit from accrued structurization of two "externally" oriented ways. Valid traffic procedures may be developed, based on a better understanding of the complex interaction singled out in the foregoing chapters, whereas one may rather think of integrating the cost evaluation system previously implemented into a global CBIS. This solution will also allow, among other things, the development of traffic procedures (interface with other modules concerned with specific-external data). However, this latter perspective is quite ambitious. To be fruitful, such an integration should be progressive and, in a first stage, should limit itself to a coordination with some well-defined MIS modules (e.g. accounting, personnel management, inventory, etc.) or engineering computer systems.

CHAPTER VI : PERSPECTIVES FOR A COST EVALUATION SYSTEM

1. THE BASIC ISSUE: DEVELOPMENT OF SOUND COST FIGURES

This thesis endeavored to suggest some concepts to support effective cost evaluation of highway project costs in LDC's. Its objective was to show how to improve the validity--both in terms of intrinsic content (value) and range--of cost figures and related data upon which the evaluation decisions are made. Though implementation of a computer system may imply dollar-savings in the long-range (better decisions, personnel reductions, accrued timeliness, etc.), it is not obvious that such savings occur in the short-run, to the extent that the automated system suggested here encompasses more aspects--hence, is more developed and requires more attention for decision-making--than the previously existing process.

Validity of final estimates depends (a) on "primitive" data entered into the process and (b) on the structure of the procedures and on the alternatives they may generate. Both aspects are interrelated and may be cemented through a third one, viz., human intervention, as will be stressed again below. The foregoing analysis argued that the organizational structure of the highway department, its methods of project management and development constitutes a fundamental factor for structurization of the cost evaluation process, hence, its rationalization and overall validity (involvement and participation of all concerned individuals).

Similarly, this thesis demonstrated that there is no clear-cut difference between data and information. It singled out the role played by human intervention and the resulting importance of the highway department structure. Though the study was led, for practical reasons, to develop a general

data/information analysis, it is made clear that the traditional data/information concept must be superseded by a more useful and powerful approach.

### 1.1 Human Participation

A computer system without any human input or support would be totally useless (definition and collection of data, procedure implementation, etc.). Moreover, computers are essentially meant to enhance human decisions (based upon report analyses): the most sophisticated technology, if not used properly, is totally ineffective. It is therefore of the utmost importance to define ("manually") the problem(s) under concern, to state them correctly and to give them some structure.... Once this is done, it is always possible to find a given technology that applies satisfactorily to the problem.

Some aspects of the evaluation process of highway projects may subsequently be "structured" and transferred from the top-management level-- which cannot cope with all decisions related to trade-offs and therefore only acts directly on the less structured (inter-area trade-offs)--to lower levels (e.g., divisions, eventually decentralized districts), as presently the case for most intra-area trade-offs. It is thus necessary to ensure a good coordination between all the levels involved in the process (two-way communication, relevant control of data collection and screening, etc.). Top managers must also ensure that the results which are to be transferred to them may be easily controlled.

A good communication network also favors generation of informal information which plays an often underestimated role in decision-making (for example, see H. Mintzberg 1973). Though it is sometimes argued

that rationality and human style are conflicting, this thesis contends that on the contrary, both factors complement each other to a certain extent and that any computer-based system designer should account simultaneously for both of them.

Another aspect--related to human considerations--concerns the design of procedures--should they be built on a "top-down" or "bottom-up" basis, i.e., should they consider primarily the lower-level method of decision-making or the top-management ones? Though each of these types of approach was adopted in the past, it is contended here that these two approaches must constantly balance themselves. This may precisely be done through permanent coordination within the highway department (intra-area vs. inter-area trade-offs standards, direct intervention, etc.). For example, it was suggested that if a top manager needs some information (e.g., given physical characteristics of the roadway), he may directly ask for it at a lower level. Eventually he may then evaluate the consequences of any change in the value of this indicator with the most knowledgeable person about it (who precisely is the person to contact to obtain the information). Reciprocally, if a lower-level employee has any significant problem, he should always be able to refer, if necessary, to top managers.

Since some human decision-making power, or, at least, human presentation of alternatives, may be displaced by machine simulation, decision-making improvement is always made at the expense of some individual(s) in the organization. The system designer must therefore ensure that the potential users of the system do not feel frustrated by it. A good man-machine dialogue has to be implemented. Every individual should have the feeling that he is indispensable to the good working of the system. This may be realized through nominal attribution

of responsibility (data conversion, storage, development, etc.) as contended throughout this thesis. Such aspects seriously impact the success or failure of the system. Control and definition of responsibility may explain the implementation of a hierarchical system.

At a personnel level, additionally to rationalization and speed gains, the system implies some gains too. In the short-term, it may require some extra technical skills (e.g., acquaintance with the system operation). However, in the long-range, affectation of employees to other tasks--where they are more useful--is likely to occur and hence to be beneficial since an automated system does not need as much manpower as a manual one. Highway departments in LDC's seem to lack skilled labor; moreover, there is a large turnover among their employees. Introduction of computer devices should therefore allow to train unskilled workers to use the system. On the other hand, computer introduction is likely to reduce somewhat the turnover impact on the information network: data location, methods of development and processing are supposed to be widely known and the shock due to the disparition of the individual in charge of these data is somewhat amortized.

## 1.2 The Data Resource

The thesis showed that the careful definition of "primitive" data is an essential ingredient to the development of relevant information. For example, what are the external-specific data to be considered in traffic procedures? What should be the milestone references for processed information evaluation?, etc. Some aspects of highway project evaluation are not quantifiable and therefore may be quite difficult to handle, to the extent that they can be isolated (which is not always the case). However,

in general, all data implying costs seem to be more or less quantifiable, though the differentiation between variable and fixed (or between direct and indirect) costs may be quite nettlesome.

At another level, collection and development of data may also be complex. An important problem is concerned with uncertainty assessment of data. Uncertainty not only occurs as a consequence of change or variations of data themselves but also of error and negligence in data collection, conversion or coding. Therefore, a good control resting on an effective organizational structure is necessary to ensure data reliability. The next relevant problem concerns definition and application of standards. Parameters have to be properly defined, i.e., they must be able to account for every foreseeable case and be as representative of the reality as possible. On the other hand, their application (class of projects) must be carefully "typified" and regulated in order that they do not pertain to erroneous estimates. Two types of standards may be distinguished. The first type is concerned with regulations setting whereas the second type is related to resource allocation and therefore encompasses less structured applications, as seen from Chapter II. Examples of the first type are provided by the technical standards for trade-offs (e.g., intersection of isoquant and isocost curves, see Chapter II). On the contrary, resource allocation standards are not as straightforward to handle. They must take into account project <sup>particularities</sup> for inter-area trade-off determinations (e.g., class parameters of a project) and therefore must apply regulation standards. They subsequently impact the whole evaluation process, as argued throughout the thesis.

Reports (or computer outputs) must allow an as-good-as-possible grasp of all costs related to trade-offs and of the necessary decisions these

costs may induce (presentation of all possible alternatives). Simultaneously, reports must be structured in order to allow effective control, first, of data collection, development and processing and, second, of the evaluation process content itself. For this purpose, reports integrate signals (e.g., standards) enabling managers to react as soon as something has to be modified ("management by exception", development of standard references). Reports must also trigger "what if"-types of questions. They generally provide--on a regular time-basis (day, week, month, year, etc.) unless otherwise specified--the estimated cost distribution between labor and capital, skilled and unskilled labor, direct and indirect expenses, etc. This information is meant to be compared with regulation standards, the highway department present situation and its objectives, etc. to make the soundest possible definitions.

Consistency of different reports between themselves is an important feature for decision-making as well as consistency between report figures and the values of the different categories of data shown in Table 4-1. For example, report traffic trends must be well correlated with the population development figures, in the same way as the breaking down of project costs must reflect the general economic variables expressed by external-general data, etc.

### 1.3 Structures and Procedures for Cost Evaluation

The previous subsections singled out the importance of a structurization of the cost evaluation process. This may essentially be done by dividing the process into many "structurable" subsystems, the responsibility of which may be delegated to a designated individual. However, a global process overview should never be given up. Procedures manuals are very

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important for this purpose. They mention how every action should be practically handled: for instance, who must be in charge (collection, updating, etc.) of such data, how such other data is processed, to whom it must be transmitted, where it is stored, etc. Moreover, procedures manuals also account for possible changes of data and the way they are handled, as well as specifying the formats and frequencies of reports, etc.

Functional procedures may be designed to account for rather structured aspects of the cost evaluation process. However, it was seen that most aspects of this process may still be augmented with some structure. For instance, managers are still trying to define the impact of "external-specific" data on traffic trends (traffic procedures) to strengthen traffic procedures: what are the relevant variables? In the same way, before assessing any maintenance activity, one must define a valid road deterioration model, the class of the road should be realistically determined, etc. Even when these procedures are significantly "structured," managers must be aware of their intrinsic limits (quality of data imputed, quality of output, sensitivity, etc.).

More unstructured aspects, occurring especially during the inter-area trade-off evaluation by top managers, require an important discretionary human intervention (e.g., comparison with standards, assessment of positive and negative effects of data variation, feasible vs. optimal figures, etc.). An effective "management by objectives" (MBO) system must be set up for this purpose, based on the organizational structure and responsibility attributions. Combination of all efforts is a requirement for the quick obtaining of valid results.

These factors also explain why the system to be implemented must be easy to understand (comprehensive) as well as visible to gain support

from the whole highway organization and therefore be allowed potential further development.

## 2. CONDITIONS STEMMING FROM THE LDC SITUATION

The particular situation of LDC's allowed some simplifications for the thesis (e.g., consideration of only three cost areas). Moreover, funding agencies impose certain requirements. This section examines what the future perspectives for the system development are in terms of evaluation refinement (e.g., integration of non-pecuniary variables) and in terms of integration of this system into a broader one. However, before discussing these aspects, the importance of a computer-based cost evaluation system vis à vis funding agencies must be stressed once more, along with funding agencies' project evaluation methods.

Funding agencies usually pay attention to the same factors as the highway department top managers. Moreover, they are especially concerned with the consistency between external-general data and the project figures (rate of discount, distribution of costs, etc.). Funding agencies also pay more attention to users' costs evaluation and to the overall impact of the project under study. This explains why highway department managers have to develop methods which carefully reflect external data and the table 4-1 "border" between external and internal data. Hence, consistencies between project figures and external national or international indicators should be respected.

### 2.1 Future Perspectives: Development of the Cost Evaluation System

Once the system suggested here will be working on a limited but satisfactory basis, it will be possible, and only then, to upgrade it (development of more powerful procedures) and eventually--if some consensus is reached on these points--to integrate some aspects not very well quantifiable presently (e.g., large scale benefits such as agricultural ones, other users' costs and demand costs, etc.). Some assumptions relative to LDC's will then be able to be removed, whereas some others will be stressed or added (e.g., maintenance, environment, etc.).

#### 2.2 Development of an Overall MIS

A global MIS (or rather CBIS, since it would also encompass technical engineering modules) may be implemented in the long-range by integrating together several modules--each being in charge of different processes. For example, in a first stage, a "Project Control System" embodying the present module could be set up in connection with administrative macromanagement finance or backlog inventory systems, etc. (see Appendix). In a second stage, it is conceivable to link explicitly this system with other similar large-scale systems (e.g., engineering system) and to integrate these two (or more) systems into an overall CBIS.

It is, however, necessary to proceed here little by little, on a "customized" basis. One should therefore avoid some stumbling blocks related to the development of totally disconnected procedures or an irrelevant integrated "total" system. As in many other domains related to project evaluation, compatibility with other modules should be emphasized at every level of development of a computer-based module. In the same

way as (a) supply and demand aspects have to match consistently or (b) technical and economic arguments must balance themselves, or (c) human, hence political, and national considerations must complement each other, etc., any computer-based module must account for other module(s) existing (or to be developed) in the highway department ..

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APPENDIX: APPLICATION AREAS FOR MIS'S IN U.S. HIGHWAY DEPARTMENTS

As suggested by its title, this appendix attempts to develop a taxonomy of some typical MIS modules presently in use throughout the U.S. highway departments. However, it does not concern itself with engineering computer-based systems, though these latter are undoubtedly part of any highway department CBIS and directly impact more management-oriented modules of the overall system.

The appendix is also meant to single out some perspectives for the upgrading and possible integration (into a broader MIS or CBIS)<sup>(1)</sup> of the cost-evaluation system whose main requirements and features are developed in this thesis. There are many links between "micro-management" (essentially concerned with projects and performed on a decentralized operational basis) and "macro-management" (performed at the headquarters, essentially administration and coordination of the overall activities, e.g. strategy: objectives and goals of the highway department). Computer-based modules supporting macro and micro management are complementary and mutually enhance each other. For example, they may use the same data-bank and data necessary for one module may be developed in another one (e.g., standards). Moreover, criteria for the design and implementation of both types of systems are analogous. Therefore, highway departments should be able to benefit from any previous experience with computers when developing a

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(1) MIS is understood here as more applied to management, whereas the scope of CBIS's is more general and may encompass any automated information processing operation (e.g., technical information for engineering). This study does not explicitly make the difference between MIS (routinized and structured applications) and DSS (Decision Support Systems: less structured applications), as it was introduced by A. GORRY and M. SCOTT MORTON (1971).

new module. Nonetheless, implementation of new modules should be done gradually only once existing systems are working well.

The present taxonomy makes the distinction between three types of systems: (a) administrative systems (principally macromanagement activities), (b) operational control systems (principally micromanagement- or project-activities) and (c) planning systems. These latter systems encompass both macro and micro-activities and may be viewed as a nexus between the two other types of systems. For example, planning of construction or of maintenance is made by the planning systems in accordance with specification of technical and financial constraints (engineering standards and macromanagement CBIS modules), on the one hand, and of control (micro-management modules), on the other hand. This taxonomy somewhat overlaps with R. Anthony's (1965, pp. 17-18) classical typology (strategic planning/management control/operational control), especially when applied to management control and operational control.

Computer-based systems for cost evaluation of highway projects belong to the category of planning systems which, needless to say, is the less structured category - the structure of systems decreases from type (a) to type (c) systems. Nonetheless, cost-evaluation systems may be developed without too many problems and independently of other systems to the extent that, first, they are rather limited and, second, that core procedures are reasonably structured. Subsequently, cost evaluation systems constitute an excellent first test for introduction of computers into relatively unstructured activities of a highway department - such systems should single out problems likely to occur in the development of any other module and therefore should allow managers to dominate them (e.g., collection and transmission of data, validity of procedures, importance of external data, etc.).

1. ADMINISTRATIVE SYSTEMS

Administrative computer-based systems may be classified into three broad categories: (a) accounting and finance, (b) payroll and personnel, and (c) inventories.

Most highway departments developed accounting and payroll systems first, whereas personnel and inventories systems were subsequently added. This is due to the fact that the accounting and payroll processing rules are imposed in each state, therefore well structured and that all that highway departments have to do is to automate such processes without (re)evaluating them. Data requirements are imposed, as well as reports. On the contrary, there is no compulsory approach to management of personnel and inventory. Each highway department is thus allowed to design and implement its own type of system, provided that it is compatible with the accounting and payroll state broad specifications; this is a far less structured problem. Data availability, however, should not be a bottleneck for any administrative system since these systems deal with internal data. However, significant problems lie under the choice of the adequate data to be collected, their degree of processing (screening, aggregation, analysis) and subsequently the relevance of the final management reports. Reports must allow proper planning and control of the highway department, i.e., meet the traditional management literature criteria of efficiency and effectiveness, which are still unclearly defined in the case of highway departments. Definition or narrowing down of these criteria should therefore be a prerequisite to the evaluation or design of any MIS segment.

Characteristic features of administrative systems will now be described

in terms of each system's objectives and goals, functional operation and impact (capabilities, limitations, data requirements, level and acceptance of utilization) and foreseen developments.

### 1.1 Accounting and Finance Systems

The initial concern of this category of systems was the automation of the general ledger accounting process, i.e., record-keeping (e.g., accounts receivable, accounts payable, cash liquidity, deposits, etc. and processing of vouchers). Logical extensions of this process are concerned with statistical analyses (distribution of federal expenditures, federal aid and grants, progress payment), billing, invoices and final allotments systems, etc.

Another component of this category of systems, which probably constitutes the most important requirement from any state legislature, is concerned with budgeting considerations. It is meant to keep track of any expenditures or receipt in accordance with a preformulated and predefined classification. One of this component's goals consists of setting up, one period of time ahead, standards to be met during the following period and recording and of analyzing the deviations which may occur. General ledger and budget systems must follow prescribed rules and allow legislative or any external type of control, such as audits of the highway department activities. Efforts have subsequently been made to upgrade cost and responsibility computer-based systems, able to allocate costs and resources to jobs (projects or maintenance operation) and administrative units on an individual basis. Such systems, through development of standards, considerably impact the highway department organization. However, they can only be implemented after completion of detailed project management systems

(e.g., operational control, financial scheduling, etc.)

In the same way, other finance oriented systems (e.g., capital budgeting and cash-flow, forecasting) which rest upon operational needs rather than imposed rules must wait for the implementation of such micro-management-type systems.

One of the problems encountered in accounting and finance systems concerns the flow of data and the data input process. Though data are internally generated (i.e., one is sure that they do exist and may be collected) one must make sure that the basic input forms are properly filled and that they are sent and processed quickly enough to be still significant for management, in the case of a batch system. Additionally to numerical data, some codes may also appear; thus, software procedures and output format must not be too sophisticated. On a technical level, accounting and finance systems, based upon the computer data-handling capabilities, often require a lot of flexibility--not always obtained. Management may often be led to ask for "ad-hoc" reports (to change report formats or to test different types of indicators--most of them not usually processed--as that is quite frequent in cost accounting and performance evaluation). That is why the previous systems are often built upon sophisticated file organizations such as data base management or file management systems and give highway department a first exposure to data management systems, which can be of use for other purposes especially in project micromanagement (see Chapter V).

Accounting and finance systems have even a greater organizational impact: they constitute the organization's backbone. Almost every other type of system within the highway department is connected with them one way or another since it is more or less concerned with financial resource allocation and use, i.e., a global process under the control

of the accounting and finance systems.

The principal limitation of accounting and finance systems lies under the data reliability and timeliness, on the one hand, and more seriously, on the other hand, under the value and use of information generated; does it really allow significant management action? Development of accounting and finance systems (cost accounting, capital-budgeting, cash-flow forecasting, etc.) pertain to such goals. However, design of such systems must rely on a "bottom-up" approach, i.e., preliminary implementation of micromanagement systems which will also ensure more accuracy to input data and participation of lower organizational levels to the process.

### 1.2 Payroll and Personnel Systems

The payroll process is a fairly routinized and imposed process. Payroll computer-based systems thus exist in all highway departments where they handle activities different in scope--from basic production of payrolls to the writing of checks. They encompass statements of earnings, tax, insurance, social security (FICA), union, retirement, etc., deductions. Production of W2s annual report is also handled. Input is done by the employees themselves, when they first accept the job and through time-cards; the input process is generally carefully performed due to the employee interest in the output! However, there is a problem concerning the updating of the files supporting the system (retirement, promotion, death, leaves).

Personnel management is quite similar to cost and responsibility accounting, where operational needs have to be isolated. Some segments of the personnel subsystems are imposed or thought to be imposed, e.g., employee record file or procedures for computation of the different ratios ensuring

fulfillment of the Equal Opportunity Employment Act. In some cases, statistical packages or analyses and reports are developed (e.g., salaries distribution, overtime, personnel projections, budget vacancies, status change notices, personnel requisition, etc.). Some highway departments built sophisticated systems producing seniority, skills, job specifications, etc., listings to support promotions and affectations. One can doubt the real utility of these systems; isn't promotion or affectation rather made through other channels? This kind of sorting algorithms is only relevant if it supports a clearly defined management process instead of being a pure computational and data-handling game. Elsewhere, attempts have been made (a) to build a personnel safety system which records all accidents where highway department employees are involved, or (b) to set up standards for affecting employees in responsibility centers (comparison of budgeted and actual affectations, job profiles, etc.). They prove to be very effective if proper back-up management action is ensured.

A characteristic of payroll and personnel systems, compared to the first category of administrative systems, is that they also handle non-numeric data and thus give a good exposure to codification problems which is to be useful for micromanagement systems.

### 1.3 Inventories Systems

This category encompasses, if not the less structured range of administrative activities, at least the one where there is no general operating rule and where design of a computer-based system depends only on definition of the highway department operational needs. Many classifications of inventories systems are possible and vary from state to state.

In general, it is possible to distinguish between three types of systems; (a) materials systems organized upon storage room units, (b) equipment systems (fixed assets, building, land, etc; other assets: vehicles, graders, tools, ....., EDP, office supplies, spare parts, etc.) and (c) the roads and structures inventories systems.

Materials inventory systems are concerned with highway related materials (gravel, sand, paintings, etc.). They generally also encompass a test subsystem which gives relevant characteristics for all materials. The main requirements of materials inventory systems is, first, to handle inquiries about the level of stock, the delay time, possibly the qualities of materials (these functions have more significance with an on-line installation) and, secondly, to initiate automatic replenishment of commodities (definition of maximum and minimum levels and of procedures for reordering. Material inventory modules have necessary interfaces with the accounting system (vouchers, vendors' file, etc.....) A very sensitive issue of materials inventory systems rest on updating so that most systems are based upon an on-line installation.

A category of equipment inventory systems is concerned with fixed assets management. It presents relatively few data to manage (less maintenance and less planning or control). This type of module mainly deals with depreciation and value of the assets, to a lesser extent with maintenance repairs. A more interesting category of equipment inventory systems is constituted by the non-fixed assets such as vehicles. Some highway departments make the distinction between propelled and non-propelled equipment. Such equipment as vehicles, spare parts, computers, or office supplies often require a separate management system by themselves. They are similar resources to manpower, which is a system by itself.

The last category of systems support roads and structures inventories.

Since there is no similar system existing in the private sector, this type of system has required full attention from highway departments and has only been able to be implemented through careful "bottom-up" studies. It is concerned with a lot of data, technical as well as purely administrative (periodic controls, last operations to date) and sometimes even traffic or safety data. Highways and structures inventory systems are often considered as part of the maintenance system which impinges on both the administrative macromanagement and the operational control--mostly project (or micro) management--systems.

Other computer-based systems may also be considered as related to administrative management (e.g., contracts, interproject, bidletting, maintenance, etc... management systems). Some of them (or their components) were mentioned above but all of them can be classified in one of the three previous categories of administrative systems. They were not explicitly described here, since they rather result from traditional macromanagement activities.

## 2. OPERATIONAL CONTROL SYSTEMS

Operational control rests on the generation, storage and analysis of detailed internal data relevant to a highway department activities. It stands at the interface of two clear-cut types of processes: pure administrative management and engineering, whereas planning activities are primarily concerned with the development and record-keeping (stemming from operational control) of standards. Planning activities are thus not directly connected with internal activities actual accomplishment. External

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data collection screening, analysis and storage also plays a large role in planning activities.

Operational control is generally based upon the functional project or task unit and does not only deal with the narrow highway construction cycle (systems development) but may be concerned also with specific maintenance activities (systems service) such as maintenance planning, design (re)construction, inspection, repairs or betterment (not necessarily construction: mowing, drainage, pothole patching, crack seal, guard rails, etc. ). A characteristic of specific maintenance activities is that they may be initiated independently of a determined cycle, such as the highway construction cycle, for instance, (re)construction may be initiated without previous "design" or "planning" phases.

A CBIS operational control segment has to gather, on a detailed basis, two types of internal data according to relevance criteria determined by management (general and specific data). Estimates and forecasts are related to the first type, whereas data that keep track of work accomplishment constitute the second type. Because constant adjustment of estimates and forecasts results from accomplishment performance (data of the second type are continuously collected by the system), an operational information system must work on a dynamic basis (constant updating, production of new outputs, assimilation of new inputs, etc. ). Outputs are made of reports and comparison analyses of "normative" and actual data meant to provide management with guidance for effective decision-making (management by exception).

The above system is representative of the basic two strengths of a computer, data storage and processing. The system principal characteristic probably rests on its coordination and communication capability. All relevant data must be gathered in a minimum time span between, before and after

screening, aggregation and summary. Relevant reports and analyses (exception, scheduling, funding, etc.) have to be quickly dispatched at different levels. The main impact of such a system obviously rests on improved control of project operations (better and faster coordination, availability and timeliness of information, relevance of feedback control, rationalization of operational procedures, etc.). Another significant impact concerns the improved transmission of aggregated data through exception reports, rescheduling analyses or financial summaries to the department top officials and to administrative control and planning managers. This may apply within the department as well as outside: a good CBIS operational control segment should enable highway department officials, at any level, to answer any kind of external requests about any project or task present status.

### 2.1 Project Status Report Systems

Project status reports systems, on use in most highway departments, have been essentially designed to provide top management with summaries of each project status. They require an extended data-base for each project and frequent updating. Several levels of aggregation are generally possible, which depend on the sophistication and the environmental use of the project status report system. It must be noted that a project status report system is of little use to line management (for instance, the project manager) except very casually (project managers are working on more detailed documents, e.g., project file). A status report system is used first for overall control purposes at high hierarchical managerial levels, and, secondly, for setting of standards in the department planning and administrative management control branches.

Status reports are mainly concerned with responsibility and task assignments on the one hand, and work accomplishment, on the other hand, in terms of time (start and/or completion time, delays, coordination, etc....) and funding (amounts budgeted, authorized, expended, etc.). Reports do not contend such project data as engineering profile coordinates, cost-benefit analyses, etc. However, they refer to individual(s) who know(s) where these data are stored.

Reports may either be entirely printed by computer (according to specifications of an eventual standard format) or produced on a preprinted standard form, where the computer printer has only to fill slots. Standard preprinted formats, when possible, are easier to handle: first, they are more readable (because everything is not printed the same way by the computer) and secondly, the reader has some milestones to refer to in the format, which both allows faster understanding (managers are accustomed to the print) and allows further actions which can be supported by the implementation of a computerized system.

The first part of any report concerns the project identification section where general characteristics of the project, such as location, code number, project manager name, cursory project description, etc. are mentioned. Each significant task of the process (it might be the whole highway cycle as well as only the preconstruction phase or the (re)construction (repair) phase--is then mentioned. For example, a typical formal for each phase may be:

Task name:	Task leader	
	Contact(s)	if other administration(s) or consultants involved
	Last Updating of data	
Milestones:		Start date, date requested, date expected, level of completion (state of advancement in %)

Finance:	Budgeted \$, \$ spent to date, estimated total \$
Other Resources:	Personnel, materials and equipment
Exception data:	Problems encountered, problems foreseen, special....

In addition to these individual task slots, there is usually recapitulative tables of the global financial estimates and actual figures as well as of an overall schedule showing the project state of advancement. There is also provision for some exception data.

Of course, the above description considered a complete cycle--type projects (preconstruction and construction) status report, though most highway departments generally have two different systems (hence two different formats) for these two phases. As previously stated, many other types and degrees of aggregation of these reports do exist. Explicit mention should be made of the information flow around the status report production and of the type of action the report may have to trigger; otherwise, as it often seems to be the case, the whole system is quite ineffective.

In several highway departments, a status report system often constitutes the first step to the development of an overall "Project Control System" meant to address itself to the full range of problems related with operational control viz. scheduling, programming or more specifically, right of way (ROW) management and contracts management. These modules generally rely, after a few modifications, upon the extensive data-bank of the status report system. As it is the case for scheduling and programming, they essentially are more concerned with "pure" data processing and handling than analyses. Moreover, they rely heavily on sophisticated OR (Operations Research) methods. The operational control CBIS segment (sometimes called as aforesaid when completed, "Project

Control System") constitutes a fundamental management tool for highway departments.

## 2.2 Scheduling Systems

Whereas projects status reports are mainly "passive" data displays, scheduling systems have been brought along in highway departments to process these data into relevant information able to trigger immediate management actions. Scheduling systems are mainly based upon such OR algorithms as CPM (Critical Path Method) or PERT (Program Evaluation and Review Technique). One of the first assignments for such a system is an a priori scheduling of the project tasks (estimates). Scheduling systems are then concerned with updating and performance reports consequences, i.e., comparisons of actual accomplishments against forecasted schedules, viz. rescheduling and production of "hot lists " (significant delays or exception reports).

## 2.3 Programming and Budgeting Systems

The same way that scheduling systems deal with time related project data, programming and budgeting systems pertain to process and analyze costs related data. They rely on the same basic OR methods as the previous category of systems and produce the same type of reports.

In order to be really effective, the three previous categories of systems must be carefully coordinated together into an integrated "Project Control (or Management) System." Project control systems significantly impact comparisons of projects and rational allocation of priorities and funding resources, it is one of the reasons why, though they do not provide any direct solution to planning in any way; they give better structurization to the information flow; highway departments tend to

devote more and more efforts to these systems.

#### 2.4 Other Types of Operational Control Systems

Most highway departments also developed computerized systems to favor a better grip on a few fundamental highway cycle procedures, such as Right of Way or contract management. These procedures integrate both managerial and engineering aspects and are sometimes considered (as for ROW) as engineering EDP applications.

ROW systems have to evaluate "a good optimal" (if not the best) route layout and to back up the possible acquisition process with data about previous ROW operations and regulations. It has been necessary to develop special systems for ROW management, due to the emphasis on these problems in the U.S.

Contract management systems are quite similar to ROW systems and also include several different components (statistics, bid letting advertising schedules, etc.). Some other systems, related to manpower use or federal aid grants, etc., have also been implemented lately. A common attribute of these systems is that they, more or less, all infringe on both the administrative and planning aspects of macromanagement. Therefore they should significantly facilitate communication between the three different management areas of a highway department.

Administrative and operational control systems may be characterized by an organizational multi-level involvement (headquarters, divisions and decentralized districts). Therefore, they all partly rely on production and dispatching of reports on a scheduled basis (e.g., daily, weekly, monthly, yearly, etc.). These two features are generally representative of every type of MIS module likely to be developed in a highway department.

### 3. PLANNING SYSTEMS

#### 3.1 Specific Features

Planning is one of the least structured activities in a highway department. Subsequently, as indicated earlier, it is one area where computer applications are not very numerous. This explains why a lot of normative thinking is done to allow better structurization of this area activities. The first direction of thinking concerns data e.g., (a) definition and classification of data needed for individual project planning (specific-internal data), (b) development of criteria and procedures to structure the process (general-internal data-standards), and (c) other data resources (external data).

"Development of criteria and procedures" implicitly concerns the building of forecasting models and simulation methods to analyze other types of data (second direction of thinking). These features explain why CBIS planning segments are often assimilated to data-banks with only few relevant processing and analyzing capabilities...since reports are not as developed in this area as in operational control.

A last issue, related to planning modules, concerns their structure: should it be "vertical" or "horizontal"? Answers to such questions depend on the organizational structure of the highway department. By "vertical" structure, it is meant that planning modules are developed independently of other modules which they are going to be connected to (e.g., control of construction and maintenance). Moreover, these modules are then only concerned with planning activities per se. On the contrary, a horizontal planning module is integrated into a broader system which totally accounts for a given aspect of the highway cycle (e.g., ROW, maintenance, construction, etc.). Needless to say, the choice of one strategy--rather than another--has important consequences for the coordination of activities within the highway department and must be assessed in terms of the specific setting of the organization.

### 3.2 Examples of Planning Systems

A good example of existing computer-based planning systems is provided by the maintenance planning system which tries to support preventive and corrective activities with a good utilization of inventory data, acquired from previously completed projects status report data-banks. This example shows the relevance of the vertical/horizontal structure issue just raised. Should highway departments implement general planning systems (vertical structure) or on the contrary should planning modules be integrated with specific operational modules?

Another type of planning module is undoubtedly provided by the cost-evaluation system suggested in the present framework. As seen throughout this thesis, all specific features mentioned in subsection 3.1 apply to this type of system, as well as other features characterizing

administrative or operational control systems. Therefore, it is thought that the implementation of such a system in an LDC highway department should be helpful to draw managers' attention upon some solutions to planning problems, hence should allow them to get accustomed to computer capabilities in highway-related areas. The organizational structure is strongly stressed here; it is thought that when technology cannot appropriately apply (unstructured situations), solutions must be provided by human capabilities. This can only be done through collective efforts such as the "stepping-stone" processing of information which was presented in the foregoing chapters and which is singled out once more, in Chapter VI .