A PROPOSAL FOR AN ENVIRONMENTAL DECISION SUPPORT SYSTEM AT THE REGIONAL LEVEL: CONCEPTS, SUPPORT METHODOLOGY, TOOLS AND THEIR TERMINOLOGY

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PREFACE

One of the goals of IIASA's research activities in the area of environmental quality modelling is the integration of data and models in a unified framework to assist decision makers with the management of complex environmental systems.

Building on IIASA's work undertaken within the WELMM (Water, Energy, Land, Materials and Manpower) project of the former Resources and Environment Area and the work on Decision Support Systems of the former Management and Technology Area, a conceptual framework for an environmental decision support system (EDSS) has been developed and is presented in this paper. The proposed EDSS has been developed with the interest and the financial support of the CSI, the Center for Information Systems of the Regional Government of Piemonte, Italy.

The main issue addressed by this paper is to devise a system assisting decision makers in tackling environmental problems at the regional level. These decisions are typically characterized by a combination of both *structured* (formalizable, described in a quantitative model) and *unstructured* elements (incomplete information, undefined cause-effect relationships, influence of political objectives, public perception, consideration of estethics, etc.).

The proposed EDSS enables the user to use models and data, of relevance to a particular task, which are embedded in the EDSS in the form of a process information system. The specific feature of this process information system is that it contains processes of anthropogenic nature (the socio-economic activities being the cause of environmental impacts like power plants, industrial production units, etc.) as well as natural processes determining the spatial/temporal distribution and the extent of environmental quality changes (like the dispersion and deposition of air pollutants and their effect on human population, vegetation and wildlife).

The system ensures that the data and models, which have been developed in the context of specific EDSS applications are documented right from the outset and become thus equally available for further use. This becomes especially important in view of the long-term effort to be put into the development of data and models dealing with the large number of environmental problems that governments, industry and academic institutions are confronted with at the regional level.

Dr. Eliodoro Runca
Impacts of Human Activities
on Environmental Systems

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1. INTRODUCTION

The objective of this paper is to propose a framework to assist decision makers in the management of environmental problems at the regional level. The framework is to be implemented within an organizational environment, characterized by a classical electronic data processing (EDP) background, in which the area of Decision Support Systems (DSS) is a relatively new field. Therefore, some emphasis will be devoted to the concepts of DSS, addressing *semi-structured* problems (typical within the environmental area), as well as how the DSS intervenes at the various phases of the decision making process. For reasons of clarity we have refrained from discussing in depth many of the concepts introduced in the paper. Instead, they are elaborated in the appendices , which also contain the references and literature sources, suggested for further reading. With respect to the tools proposed (as well as to the illustration of the proposed DSS to an applied study field), we would like to stress that the main purpose is illustrative. However, the examples given show that tools and methodologies supporting the proposed DSS, whether they come from traditional EDP, from economic theory or the applied natural resource analysis field do exist and can provide direct input to a DSS such as that outlined in the paper.

In summary, *the* paper's *principal purpose* is to define a *decision support methodology* and a *resulting system of data bases*, to be used by the decision maker's *support organization* (i.e. that of the CSI - see appendix 1), rather than by the decision maker himself. Thus, the design proposed was strongly influenced by the CSI's operational context (i.e. type of application areas addressed, methodologies and tools selected, etc.). Finally, we note that *the system is "ad hoc"* in that it was specifically tailored to the afore-mentioned operational context and (at present) is intended to support policy formulation, implementation and evaluation in the environmental area (hence, it is nominated an Environmental Decision Support System (EDSS)). However, *it is generalized* in that it aims to be relevant to (a) a wide range of sector specific environmental problems (each of which is characterized by its own "peculiar" context and content) and (b) the interrelationships between such sector specific problem areas. This feature in the context of an environmental DSS seems essential, as the end user (i.e. the public sector, decision makers, the administrators, politicians, etc.) is, often, as concerned with the credibility of his policies in areas outside of his immediate sphere of influence as with their efficacity in his "own" area. Further, environmental management at the regional scale (the scale discussed) often includes "global" decision making (e.g. to be banal, increase environmental exploitation to increase economic growth, improve social recreational facilities and decrease environmental degradation) that is, by definition, both horizontal (i.e. crosses sector specific areas) and vertical (i.e. entails the analysis of sector specific areas in the effort to resolve issues such as conflicting objectives, limited resources, etc.) in nature.

It follows from the above, that *the paper* is not addressed to DSS End Users. It *is primarily intended for technical support staff* who are interested in building DSS frameworks (in particular, in the application area discussed), but have little experience of the DSS field. It is assumed that the reader has a certain familiarity with areas such as EDP, PIS (Process Information Systems), MIS (Management Information Systems), OR (Operational Research), MS (Management Science), etc.

2. WHAT DO WE UNDERSTAND BY AN ENVIRONMENTAL DECISION SUPPORT SYSTEM (EDSS)?

By a decision support system (DSS) we understand an interactive computer based system to assist a particular (group of) decision maker(s) to use data and models for solving specific tasks relative to the management of environmental problems at the regional level.

We use the term environment in a wide sense, as the DSS operates (contains data and models) at three levels;

anthropogenic activities (i.e. the socio-economic activities changing the status of the environment, like industrial or energy production, agriculture or urbanization);

natural processes determining (a) the spatial and/or temporal evolution of environmental quality changes and possible transformations (e.g. chemical reactions in the air, water or soil) like the dispersion and deposition of air pollutants; and (b) determining the form and extent of their impacts (e.g. impacts on aquatic or terrestrial ecosystems or on human population);

societal/organizational structures within which the DSS operates; whose decision making processes it documents and aims to improve. It is at this level that formal (e.g. air quality standards) or judgemental (e.g. esthetics) criteria or societal values (e.g. public perception, political criteria) are formulated to assess and to evaluate the consequences and impacts described at the levels of anthropogenic activities and natural processes.

2.1. Decision Support Systems

The concept of DSS (appendix A2 provides a more detailed discussion of DSS than that provided here) and especially how it relates and differs to the characteristics of operational research or management science (OR/MS), management information systems (MIS) or classical electronic data processing (EDP) can best be illustrated by looking at DSS from the viewpoint of the decision makers/users[1]. DSS are thus characterized by operating in a *three-dimensional framework* defined by: (a) the *phases of the decision-making process;* (b) the *management level(s)* where the

[1]DSS from the viewpoint of the DSS designer/builder will be discussed in the later sections of the *DSS tools*. The third possible viewpoint, the so-called "toolsmith's" or programmer's viewpoint will not be discussed in detail in this paper.

decision is made and (c) the *type of tasks* to be performed in a decision-making process (see Figure 1).

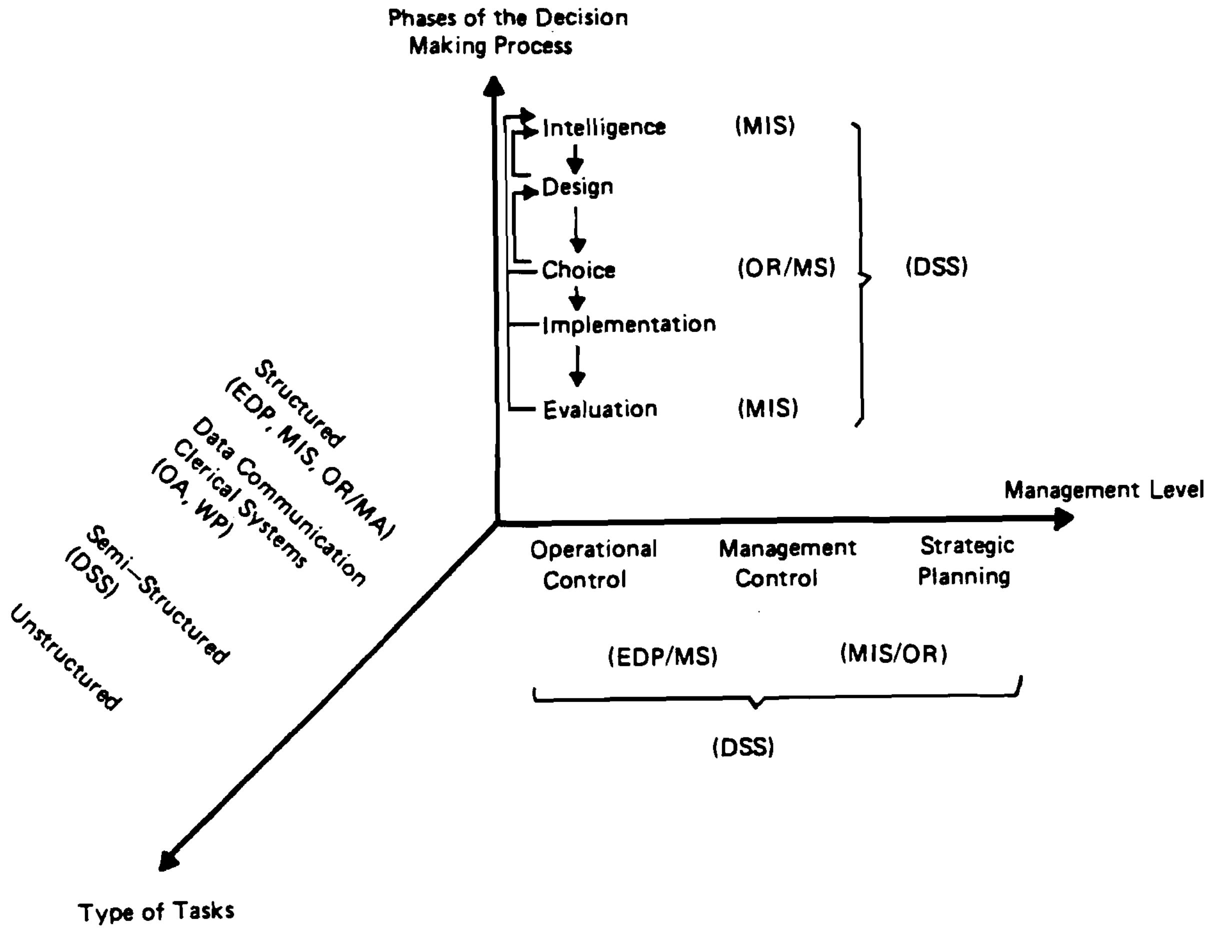
DSS are defined to assist decision makers in (a) all phases of the decision making process and (b) at all management levels based on a detailed understanding and description of the decision making process itself. Finally and most important, DSS are designed to support decision makers in the context of semi-structured tasks[2] (i.e. tasks which consist of structured (formalizable) and unstructured elements).

Of course, many of the concepts of DSS are also characteristics of MIS and the fields of OR/MS in general. *However, DSS represent a distinct field from at least two viewpoints. Firstly, in terms of approach;* in particular, that the effective design of management oriented information systems must be based on a detailed understanding of management decision processes *utilizing diagnostic and descriptive methodologies* rather than the prescriptive and/or normative methods typical of OR/MS. *Secondly, DSS are distinct in terms of their impact* on and relevance for managers/users. DSS imply the use of computer related technologies and sciences to:

1. support managers in relation to decision making in the context of semi-structured tasks;

2. aid managerial judgement rather than replace it;

[2]From the viewpoint of the decision maker/user we refer simply to hard or difficult problems, as the concept of structure is heavily dependent on the decision maker's perception and performance in the phases of the decision making process where the structured and unstructured elements of a task are defined.



Acronyms:

EDP : Electronic Data Processing
DSS : Decision Support Systems
MIS : Management Information Systems
MS : Management Science
OA : Office Automation
OR : Operational Research
WP : Word Processing

Figure 1. DSS as defined from the managers'/users' viewpoint.

3. improve the *effectiveness* of decision making as distinct from its *efficiency*. Here DSS are concerned with issues such as managerial cognitive processes, learning methods, etc., as opposed to cost or personal reduction or increase in turnaround times.

2.1.1. The Decision Making Process (Cycle)

Here we present a five level model of the *phases of the decision making process* to which diagnostic and descriptive methodologies[3] can be applied.

These five phases may be summarized as follows:

- *intelligence* (searching the environment for conditions calling for decisions). This phase is typically *characterized by unstructured search*[4] for raw data, its processing and analysis as well as other structured and unstructured inputs (e.g. organizational procedures, legal standards, political objectives, and the like);
- *design* (inventing, developing and analyzing possible courses of action). It is at this phase in the process to understand the problem that possible solutions are generated and tested and a first formulation of the structured and unstructured elements of the task is undertaken and fed back to the intelligence phase. The main emphasis of the EDSS in this phase will be on

[3] Here we refer the reader to the later sections of this paper dealing with the SADT structural analysis and design technique and its application to represent the decision making process and its phases.

[4] Note the relationship to EDSS tools like a system thesaurus, hierarchical data access and filtering software and data base management systems (DBMS).

documentation of how the user perceives possible solutions (alternatives) to the problem *using the same representation techniques* as deployed in the intelligence phase. In addition, the user should have access to previously generated solutions (especially of other user communities) and to already existing formalizations of relevant natural and/or socio-economic processes[5]. .

- *choice (selecting a particular course of action from those available).* In this phase, the traditional normative/prescriptive methods of MS/OR have their prime use and form part of the EDSS. In addition, the EDSS must allow the user to interactively introduce subjective choice criterion complementing or replacing structured (formal) choice criteria. The choice phase feeds back to the design and intelligence phases.
- *implementation:* In this phase, the EDSS should allow a user *to monitor the implementation* of the courses of action decided in the choice phase (budget spending, acquisitions, etc.,) providing thus a feedback concerning difficulties in the implementation and the formulation of additional problem areas for the intelligence phase.
- *evaluation:* This is - although up to now in the DSS literature not sufficiently recognized - a crucially important step[6]. *Evaluation improves, by learning from experience,* the

[5] Here we refer to the process and process model data base of the EDSS, discussed in more detail in the EDSS tools section.

[6] Note that only through evaluation the decision maker can learn more about his effectiveness in the earlier phases of the decision making cycle and is able to improve his performance in them. A typical problem area in environmental studies is for example, that the boundaries of the system analyzed are drawn in a too narrow way. Thus decisions solving one

execution and results of the four earlier phases in the decision making cycle. The main emphasis here is not on the EDSS as such (quality of access, speed of response, etc.,), but on the *improvement of the decision makers praxis* through use of the supportive tools forming the EDSS framework. Although many formal evaluation techniques (decision output tables, software records of user behaviour and the like) exist, the most important point to be considered is the EDSS seen as a *learning tool* enabling the user to improve his effectiveness in the various phases of his decision making process. This also results in specific EDSS design and implementation strategies facilitating user learning, feedbacks to modify his decision making model or the descriptive/functional models involved in the task, and enabling generally the improvement of his decisions. These strategies, referred to in the DSS literature as *"adaptive approaches"*, *"middle-out design"*, etc., will be discussed in more detail in the EDSS implementation strategy chapter.

2.1.2. Structured versus Unstructured Tasks in the Decision Making Process

Here the term structure refers to the distinction of programmed and non-programmed tasks used in Management Science, i.e., to their degree of formalization. Structured tasks can be automated or routinized, thus replacing judgement, whereas unstructured tasks are purely judgemental and defy automization. *Semi-structured tasks permit*

problem (e.g. reduction of air emissions through control devices) is creating another problem in a larger system (e.g. sludges and waste disposal, water pollution, economic impacts, etc.).

synthesis of human judgement and computer capabilities.

Another ***definition of structure*** lies in the ***differentiation*** between *observable* (like electricity consumption, stack height, etc.,) and ***subjective (non-observable)*** variables (e.g. esthetics) considered in a particular task, as for instance, the location of a power plant.

Typically, in a decision-making process the task starts as a structured one (in considering only "hard" economic or engineering type of criteria) with "soft" or subjective criteria being added successively until a final decision is reached. However, a task may start at the strategic planning level as an unstructured one (e.g. "do something about the public concern for environmental quality") and gets decomposed to a number of structured or semi-structured tasks involving the lower management levels in the phases of the decision making process.

However, we have to realize that it is not always immediately clear whether structure is simply perceptual or intrinsic to a particular task. Also, the degree of structure of a task may be socially defined as well as being perceptual to the decision maker. An objective of the EDSS is to assist the user in the structurization of his task(s) during the design phase of his decision making cycle (i.e. by way of the earlier mentioned documentation of his decision making process, access to earlier generated solutions, etc.), and through the constraints ("disciplines") imposed on him by the EDSS tools available, in particular SADT, the process and the process model data base, etc., as discussed later.

2.1.3. Management Levels

The last dimension of the EDSS are *the management level(s)* in which the decision is made. Here we distinguish three basic levels: *strategic planning*, i.e. the level of the relations of an organization with its environment (strategic planning of an organization); *management control* (i.e. management and coordination of different activities in view of the objectives defined at the strategic planning level); and *operational control* (i.e. the management of a specific activity or task).

2.1.4. EDSS User Community

The user community of the EDSS disaggregates into three basic classes:

(a) users/decision makers proper within the above defined three management levels and the previously mentioned three problem type categories (i.e. degree of formalization of task). These user types are *application oriented.*

(b) technicians/"toolsmiths", responsible for the EDSS development and maintenance. These are analysts, programmers, etc., developing and using EDSS tools in relation to specific case studies.

(c) consultants that interface (a) with (b). These consultants (referred to as "facilitators" "DSS builders" or "DSS *generators*")have the fundamental objective of creating specific applications and to assure proper user participation.

The DSS *generator* can be regarded as an additional level of DSS introduced when a *specific DSS application cannot be developed with existing DSS tools*. The DSS generator is of particular importance because of *the need for a flexible and adaptive design strategy* necessary in view of (a) organizational and environmental changes and (b) the users inability to define clearly in advance the functional requirements of the system. Thus, DSS are distinct from traditional system development strategies, which are *a posteriori* developments following the definition of the users' decision making process and the resulting software requirements.

The principal objectives for the DSS "facilitator" or coordinator are to:

- *enter* into the decision making process and create the possibility for the decision maker to use DSS.
- *implement* the DSS, control the project, handle the relationships with the users, the organizational details, etc.
- *evaluate* the results of the innovative solutions, and
- *educate* by using the results of his evaluation task, improving thus the general performance of the users and enhancing the possibilities available to them (see "enter" objective above) through DSS.

2.2. EDSS Implementation Strategies

The DSS system building approach *emphasizes* the use of *analytical methods that are diagnostic and descriptive in nature* (further discussed in appendix A2-2). Another feature is that of basing the EDSS system design on the structure, context and the *dynamics*[7] of a decision making process and the task it involves within the three-dimensional DSS framework outlined above (see Figure 1). As such, systems aim to be relevant to "the daily praxis" of specific decision making situations. Thus they have to be tailored to such situations and we cannot think of "typical designs". For example, the DSS discussed in this paper is an *ad hoc system* designed for dealing with certain classes of environmental problems.

It follows from the above, that the use of a label "support system" is meaningful only in situations where the "final" system emerges through an adaptive and interactive process of design and use! This point is of particular importance to us. It represents a large (cultural) difference with respect to the design and implementation strategies used in classic EDP or MIS. This requirement for flexible and adaptive design/implementation strategies is strongly emphasized (both by experience and) throughout the whole DSS literature independent from the particular nomenclature used (middle-out design, evolutionary approach, adaptive design etc. as further discussed in appendix A2-1).

[7] Let us illustrate this point again: A task may involve various types of management levels (either simultaneously or consecutively). The number of unstructured elements of a task determine the amount of effort to be put into the *understanding* of a particular problem (intelligence and design phases of the decision making process) and determine the methodologies to be used in the choice phase (e.g. optimization, multicriteria optimization, environmental impact assessment, etc.). At all these phases, formerly unstructured elements of a task may be translated into structured ones or additional unstructured elements influencing a particular decision may be introduced. Thus no *a priori design* of the EDSS is possible, in view of the dynamics of a particular task within the DSS framework.

The proposed EDSS has a design and implementation strategy based on the diagnosis, description and documentation of the decision making process *as well as* the tasks involved in its various phases. *This principle of representation prior to application is the main constraint for the EDSS user*. The tools proposed for this representation ((a) diagrams for the decision making process from the viewpoint of the decision maker and from the viewpoint of the EDSS builder; (b) process and process model diagrams to represent structured phenomena involved in a particular task) represent a constraint for the EDSS builder. They also provide *the necessary basis to link the EDSS with the other analysis and design techniques of classical EDP being used* (for other projects) in the organizational environment[8] in which the DSS operates. Thus, the proposed EDSS aims at integrating tools, languages, data base management systems, etc. with which the user community is already familiar, even though some of these, in their implementation within the EDSS might require hardware/software translation solutions.

As stated above, the principle of representation results in the necessity to employ representational tools (i.e. pictorail/graphical techniques, languages, etc. - each of which is presented in detail later) for the analytical description and diagnosis of (a) the decision making process (cycle), its tasks, activities, etc. (the tool in question is nominated SADT) and (b) the socio-economic/natural phenomena considered in its ambit (the tools in question are nominated process topography and process documentation language). Also, *that their use* (and the inherent

[8] Note that the EDSS will be implemented in an environment with a principal mandate in classical EDP fields : budget and salaries accounting for the public sector, organization and storage of census data, organization of library systems, etc.

characteristics of the tools themselves) *is the main EDSS users constraint*. However, in the context discussed, we use the term "constraint" more in the sense of "system discipline" than in a constricted or repressive connotation. Further, it is fundamental to understand that *they are*, at the same time, a constraint, a system discipline and *the possibility* for (a) building frameworks such as that discussed and (b) regarded as a "language", a means for the user to coherently express, analyze and communicate his problems both vertically (i.e. between his management levels and with the EDSS framework support staff) and horizontally (i.e. with related application areas, study disciplines, organizations, etc.). Without pretending to discuss the matter exhaustively (such a debate is not the paper's purpose; however, for those interested, see the referenced literature sources), we would like to make the following points to clarify the above;

1. a prime purpose of their use is the analytical description and diagnosis of activities, processes, etc., according to *a standard methodology*. In the vertical plane, such a standard is "only" desirable (i.e. between management levels, with the EDSS support organization, etc.). But, horizontally (i.e. in the context of environmental DSS systems involving many application sectors, study disciplines, organizations, etc.) it is absolutely necessary. (This would not be the case for a single application area DSS absent of multi-disciplinary/multi-organizational characteristics.)

   Pragmatically, such a standard methodology is the basis for building certain essential components of a regional scale environmental EDSS (e.g. process data bases, process model data base, process information system, etc., as discussed in detail data), not to mention organizational, didactical and dissemination tasks (i.e. division of labour, clarity of communication, project control, etc.).

2. *a prime purpose* of any DSS *is to address* problems characterized by structured and *non-structured elements*. By implication (this subject matter is discussed in detail later), there are many problem areas, activities, tasks, etc., to be examined that, at first sight, appear to be totally "fuzzy". The use of structural graphical techniques is a means to identify what elements of the "fog" are in fact, or can be, structured, (i.e. they are a means for, where possible, moving that which was initially perceived as unstructured towards a structural state. This being valuable even if the resulting "structured state" simply evidences that it contains many semi and/or unstructured components indeed in the context of DSS, this would be the typical result.

3. At last initially, *the use of such techniques* will not be the decision maker (DM) as such, but *the DSS consultant* to whom the DM expresses his problem. In this context, the techniques represent an interactive tool between (a) the DM and the DSS consultant and (b) between the consultant and his support staff (also note that we have already mentioned their use as the basis to link the EDSS with the analysis and design techniques of the EDP area).

4. In summary, the prime responsibility for the integrity, maintenance, cataloguing and use of such tools will, necessarily be collocated within *the support organization* building the EDSS framework (e.g. in the case discussed, the CSI). Here, we reiterate the need for

standard methodologies. That is, the support organization cannot satisfactorily perform its supportive and "pooling" role without a coherent methodological strategy. We use the term "pooling" to emphasize the fact that an EDSS such as that proposed (and the methodologies discussed) has little sense if the support organization is not acting as an "aggregation point" for many decision makers, application types, information types and sources, etc.

2.3. Levels of the Tools of the EDSS

There are two main guiding principles concerning the tools of the proposed EDSS:

(a) to use diagnostic/descriptive techniques (and the resulting documentation) as the first step towards solution design, *prior to any implementation;*

(b) to provide logical consistency (equivalence) between specific methodological tools, *by applying the concept of process* in representing the decision making cycle, the activities to be performed in it, and the socio-economic and natural processes of relevance to a particular task.

Regarding (a), the first analytical activity to be pursued in a particular task will be to develop a map (or as we will call it later on, an *activigram* or a *topography)* of the task, activity or process, which is *descriptive*, not *prescriptive* in nature.

For this we propose the use of a structural analysis and design technique (SADT) (and the resulting "activigrams") for the representation of the users' viewpoint of a particular decision. That is, (a) the phases of a decision making cycle, the management levels involved and the task *structure* (i.e. structured versus unstructured elements of a task), and (b) the representation of the activities and the tools required to support the user's view of the decision making process, i.e., the *EDSS builder (coordinator) viewpoint*.

This approach finds an equivalence in the representational techniques proposed for the (a) definition and (b) description of socio-economic/natural phenomena or processes the decision process deals with, i.e. (a) the process topography and (b) the process model diagram.

This equivalence stems from:

(a) the correspondence of the analytical approach chosen. That is, *the principle of representative* whether we are dealing with (a) the decision making cycle as such (is, by way of SADT) or (b) the socio-economic/natural phenomena to which the decision making cycle refers (i.e. by way of a process topography and process model documentation language like that developed at Canada Statistics, and as discussed in detail later).

(b) the application of *the concept of process* in relation to both the decision making cycle as such and the socio-economic/natural phenomena to which it refers (appendix 4 provides a detailed discussion of process information systems).

In a general way a process may be conceived as a system:

- separated from its environment through a definitional boundary;
- connected to the same environment by way of input/output flows;
- which may, or may not have an internal structure determining (a) the relationship amongst these flows and/or (b) allowing the process to be disaggregated into a number of subprocesses;
- characterizing transformations of mass, service, energy or information flows into other flows (in the case of mass and energy of course subject to the laws of mass/energy conservation). These transformations (or activities in the case of a decision making process) are *controlled* by service or information flows or by properties (characteristics) of input flows going into the transformation.

From this general presentation of the concept of process it becomes apparent that we can describe both the decision making process and its related activities (e.g. introduction of abatement and control strategies) as well as socio-economic process (e.g. the operation of a power plant) and natural processes (e.g. diffusion of air pollutants) based on the above outlined concept.

The main differences, which call for two different analyses and documentation techniques are that:

(a) the decision making process is defined as a semi-structured one consisting of a combination of structured and unstructured flows, whereas socio-economic or natural processes are considered as entirely structured (i.e. having only ***observable*** input/output flows), and

(b) the decision making process is considered only descriptively. This means that the decision maker determines or controls the transformations or activities in it (e.g. through unstructured input or control flows) whereas the socio-economic/natural processes are considered both descriptively and ***explicatively***, in that a formal mathematical model is established to explain how input/output flows relate to each other (i.e. in the form of a process model dealing only with structured observable flows).

In Figure 2 we give an overview of the relationship of the various tools of the EDSS (discussed in more detail in Chapters 3 and 4) to the various phases of the decision making cycle and the activities pursued in it.

As a summary, the EDSS physically consists of a set of formalized procedures (or methodologies) to analyze, design and to document how a particular user views his problem and is assisted in tackling it by way of EDSS tools. By the tools of the EDSS we understand data bases for numerical, relational and bibliographic type of information, related interactive data access and analysis tools (software), as well as "off-the-shelf" mathematical models (e.g. using the linear programming technique and other appropriate mathematical models). These tools are ***applied in a flexible way*** to respond to the different task types in the phases of a decision making process as well as to the user requirements for choice, and evaluation methodologies.

However, *the above postulated flexibility* has to be regarded more as a *final goal* of the proposed system than its initial configuration. As it will be constructed (models developed and/or implemented, data collected, etc.,) on the basis of specific environmental "pilot" case studies (district heating system, air pollution, etc.). This implies that the type of models and data available will be oriented towards specific applications (or tasks) within the framework described. However, once developed, it will be easy to enlarge and enrich it to include more and more socio-economic and other criteria to respond to the dynamics of particular problem areas.

Let us put a final emphasis on the documentation tools. They are not solely techniques but also form "final products", (the "activigrams" and the process topography and the process model diagram), that become an integral part of the EDSS data bases. Thus, "decision rules", elements and activities of earlier decisions are documented and available to the EDSS user (i.e. the decision maker) and the EDSS builder. The same applies to the EDSS's process information system; earlier developed process descriptions and models may thus be used again within a completely different decision situation. Thus, another important "intrinsic" feature of the proposed EDSS is that it gets enriched more and more, the more and more it is used.

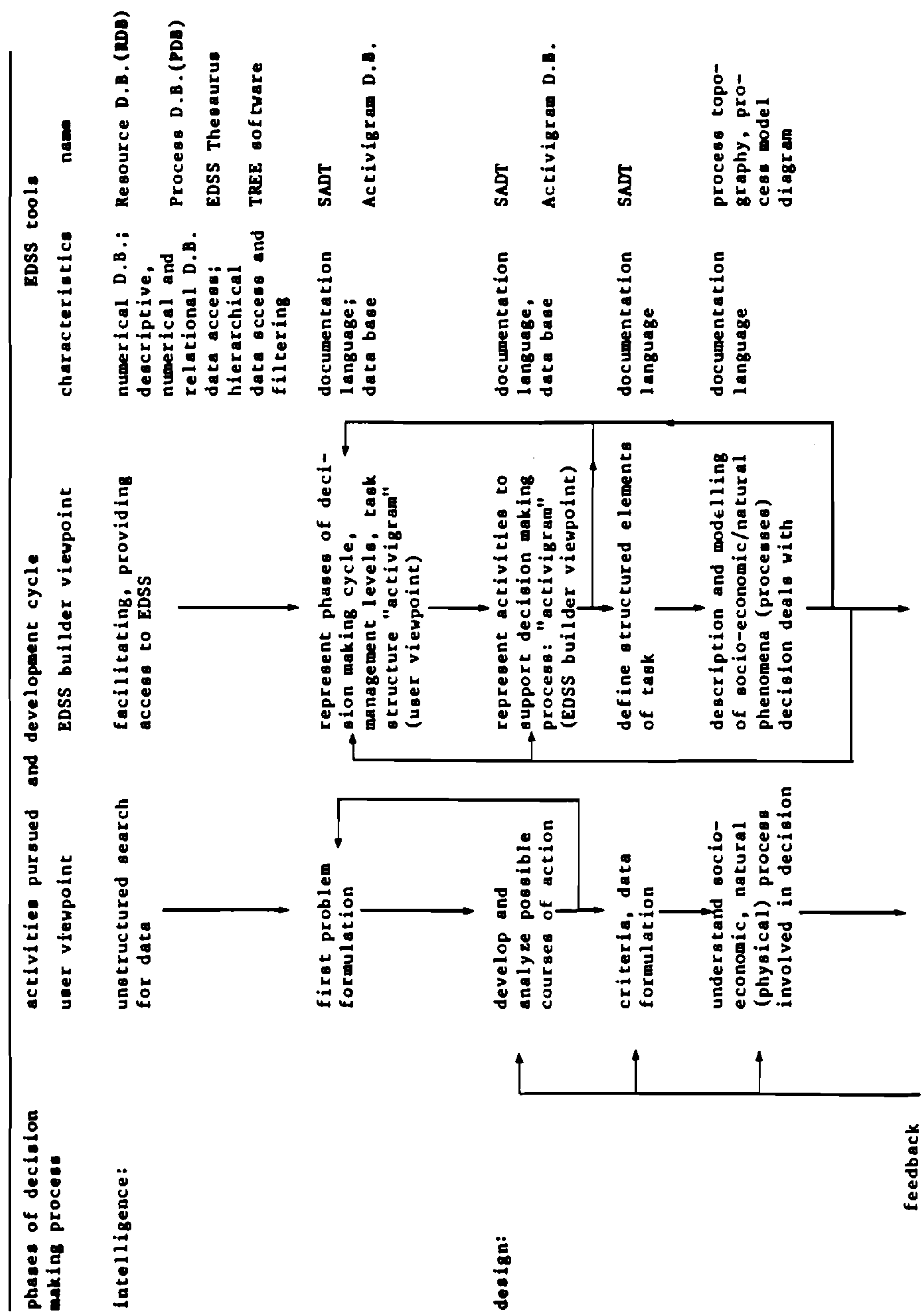


Figure 2. An overview of the tools of the EDSS and how they relate to the phases and activities of the decision making process

phases of decision making process	activities pursued and development cycle: user viewpoint	activities pursued and development cycle: EDSS builder viewpoint	EDSS tools: characteristics	EDSS tools: name
design:	first comparison, scenario generation, formulation of requests to EDSS; access to data, process data and models	develop process descriptions, implementation in PDB	documentation language	topography process model diagram
feedback		provide access linkage to programmer for implementation of models	software data bases	DBMS RDB, PDB
		prototype implementation of particular EDSS configuration: documentation:designer and programmer viewpoints	documentation language	SADT
		implementation (programmer)	software	"off-the-shelf" software
			data bases	RDB, PDB
	use/evaluate system	improve implementation		
		linkage to formal EDP documentation	documentation language	SADT (= functional analysis in e.g. DAFNE)

feedback feedback

Figure 2 (continued). An overview of the tools of the EDSS and how they relate to the phases and activities of the decision making process

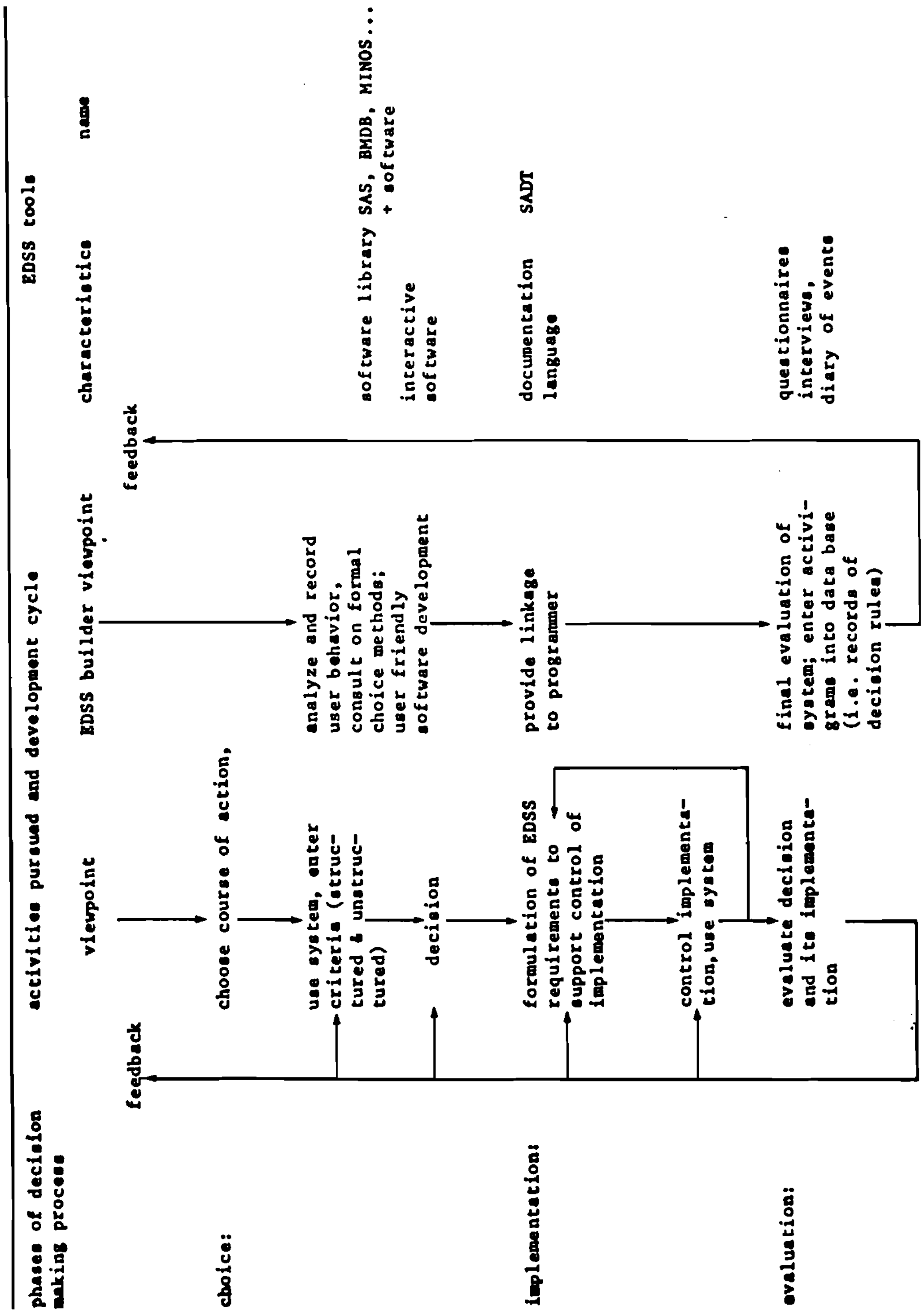


Figure 2 (continued). An overview of the tools of the EDSS and how they relate to the phases and activities of the decision making process

3. DOCUMENTATION LANGUAGE FOR THE DECISION MAKING PROCESS AND EDSS OPERATION

The proposed documentation language is based on a structural analysis and design technique (SADT), originally developed for functional analysis and system design. Some *modifications* in order to respond to the specific requirements within a DSS *have been introduced* (these are described in appendix A3-1). We can summarize the basic concepts underlying this documentation language as follows:

1. A particular problem (task or decision making process) *is described by building a model* or a representation of the problem. The model is *descriptive* (as opposed to prescriptive) in nature as it is based on the decision makers' perception (model) of the particular problem. In order to achieve full documentation, the decision makers' model of *what* the problem is, is supplemented by a second viewpoint of *how* the problem is tackled by the EDSS (i.e. the EDSS designers'/builders' viewpoint, ultimately also from the programmers' viewpoint) (see also point 3). The model is *comprehensive* in that it includes the different viewpoints of a particular problem and in that the boundary of the problem area is exactly described.[9]

2. The *description and analysis is top-down, modular, hierarchical and structured.* A particular decision is disaggregated into its various phases (intelligence, design, choice, etc.), which are then further broken down into the tasks involved in that phase.

[9] Recall here the definition of process as presented in Chapter 2 and as discussed in more detail in Chapter 4.

Tasks are composed of activities (e.g. transformations[9] of information flows) which are the "modules" for the description. The decision making process, its phases (and the activities performed in them) is described in a hierarchical decomposition (see Figure 3). Finally the description is called "structured" in that the connections between the various activities (see point 5) are complete, including the description of structured *and* unstructured data flows[9] into (or control[9] criteria on) the activities performed in a particular task.

3. In SADT we differentiate between the creation of first a *descriptive model* of the decision making process (i.e. the user's viewpoint) followed by a *functional model* of what functions the EDSS must perform (i.e. the EDSS builder's viewpoint) responding to the descriptive model and finally a *design model* of how the system will be implemented to perform these functions. The design model may be part of the SADT functional model, (when based on the EDSS builder's viewpoint), or form an independent SADT model (i.e. the programmer's, or "toolsmith's" viewpoint.

4. The SADT models describe both *things* (objects, documents, data) and *happenings* (activities) and how they are related. In analogy to the definition of process in Chapter 2 and the documentation language for the process data base (see Chapter 4), we state that the SADT models describe activities (to be performed by men, software, computers, etc.) which have input

[9] Recall here the definition of process as presented in Chapter 2 and as discussed in more detail in Chapter 4.

and output flows (data, etc.). Activities *transform* flows and are controlled by additional structured or unstructured control flows (choice criteria, constraints, data standards, etc.).

5. The *SADT* documentation language *is a diagramming technique using certain predefined graphic representation symbols* (see Figure 4[10]) to show component parts, the interrelationships between them and how they fit into a hierarchic structure (see Figure 3). The documentation is complete in that *it includes* both *structured and unstructured input/output or control flows and their proper relationships* to the components of the diagram (i.e. the activities pursued in a particular task).

It should be noted that *these SADT diagrams provide equally linkage to other formal EDP documentation tools (e.g. DAFNE* or the like). Once a particular decision making cycle is completed and the EDSS task gets transformed to a formal MIS system (documented and redesigned using classical EDP analysis and documentation methodologies) the SADT diagrams or "activigrams" (user, EDSS builder and equally programmer viewpoints) form part of the functional analysis of a particular MIS system. At the end of Chapter 4 we will give an overview of the conceptual and/or physical (tool) equivalance between (a) the documentation language SADT used for description of the EDSS operation, of (b) the documentation language used within the EDSS process data base and (c) classical EDP analysis and design techniques.

[10] Note the modifications and additions to the original SADT graphic conventions introduced in order to respond to the specific documentation requirements of the EDSS.

Ultimately, the *SADT diagrams will form a special data base*[11] (being equally part of the EDSS) *documenting the decision rules*, task structure, etc. of decisions in earlier addressed problem areas. This will enable the user (as well as the DSS builder) to access and analyze earlier generated solutions in similar problem areas, forming thus a learning tool to improve the effectiveness and performance of the decision maker and the EDSS.

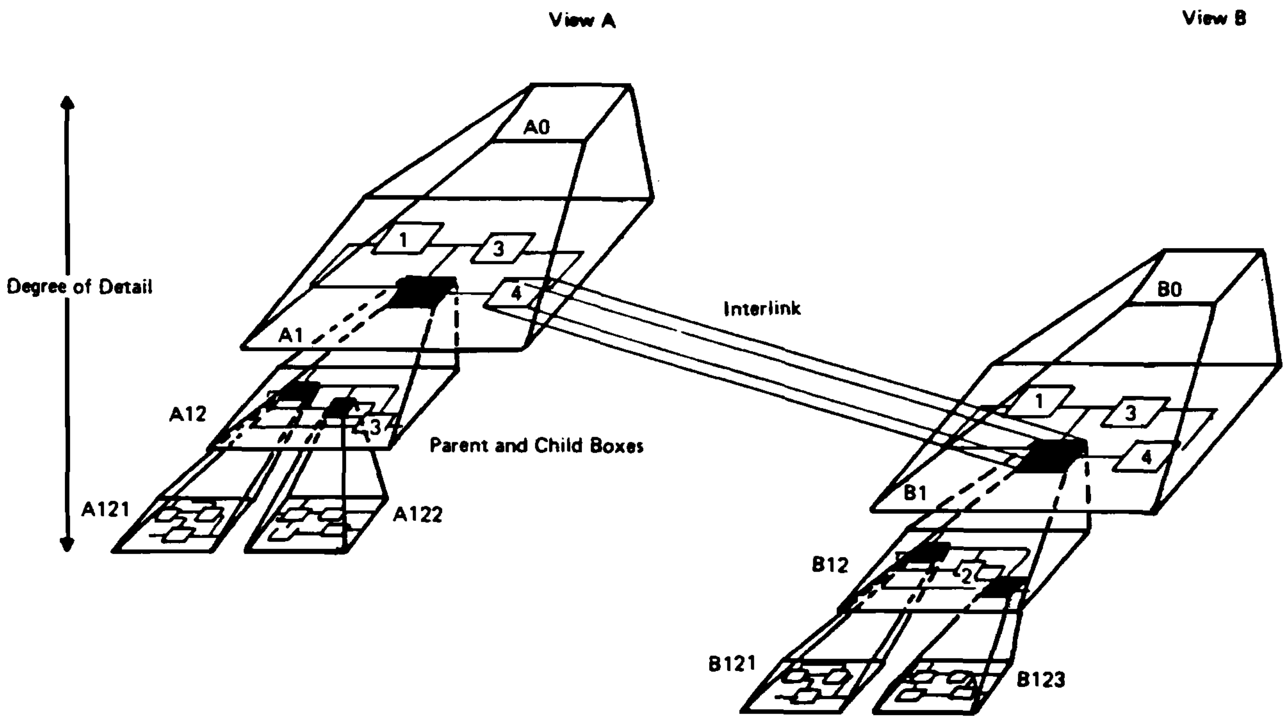


Figure 3. SADT structured decomposition

[11] We note however, that this type of data base will be developed at a later step of the EDSS implementation, once a number of EDSS applications to different classes of environmental problems have been completed.

In order to illustrate better the potential applications of a documentation language like SADT for case studies using the proposed EDSS, Figures 5 to 7 present examples of case study documentations on the basis of a past IIASA study, aiming to develop a tool to assist decision makers in an indepth analysis of the consequences and impacts of the application of centralized versus decentralized solar electric systems at the regional level. The complete set of SADT diagrams illustrating the EDSS builder's viewpoint of such a study is presented in Appendix 3, along with a brief introduction to the problem area and the case study application performed at IIASA. Examples for process descripions according to the proposed EDSS process data base conventions are presented in Appendix 4.

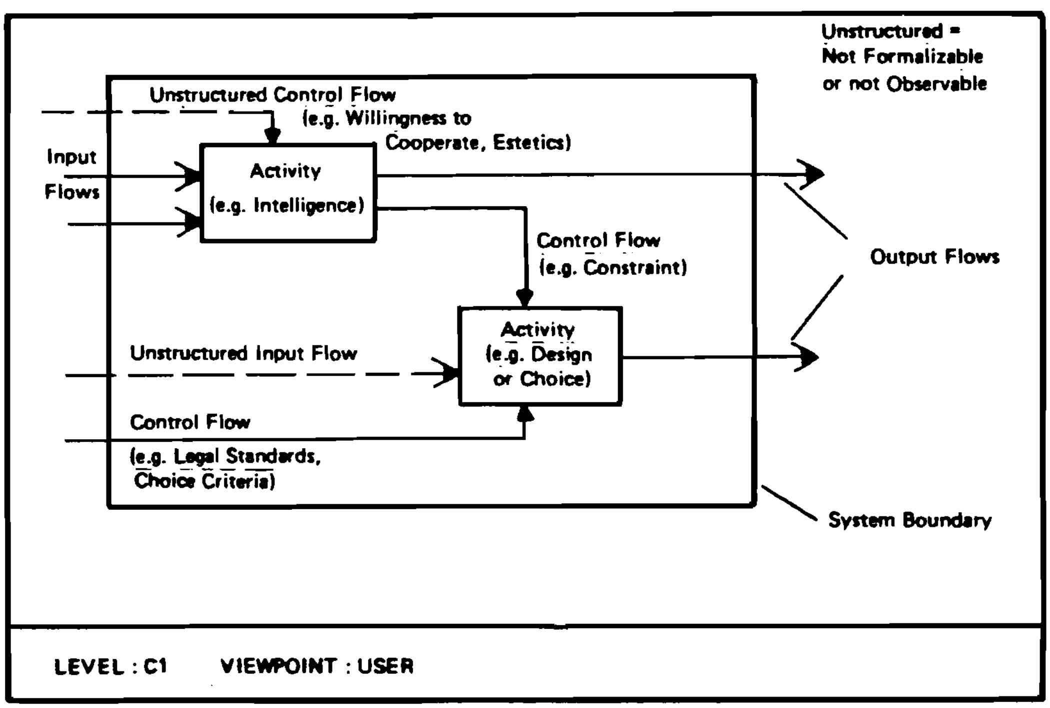


Figure 4. Proposed SADT graphical conventions

For the purposes of our discussion of a documentation tool like SADT for the representation of decision making cycles, we would like to draw particular attention *to the representation of unstructured (control) flows* going into the activities involved in a decision. The case study illustrates that in the objective to achieve higher regional energy self-sufficiency, there are a larger number of unstructured inputs to be considered, resulting in specific requirements (options) on the EDSS systems configuration.

Questions like the reduction of political dependence from energy imports, creation of local jobs through decentralized energy systems, reduction of environmental pollution through development of renewable local energy resources are additional inputs to the structured (technical) elements of the task (system configuration, energy production having to meet the quantitative and qualitative (energy services) requirements of the consumers, systems optimization, etc.). Thus, for instance, the user has to have the possibility to design and to assess the impacts of such a regional energy system, with a variety of EDSS options (including maximization of energy autonomy, systems cost optimization, sensitivity analysis, choosing alternative models describing[12] the conversion technologies, etc.).

[12] Note that this is especially important in considering technologies not yet introduced on a large commercial scale.

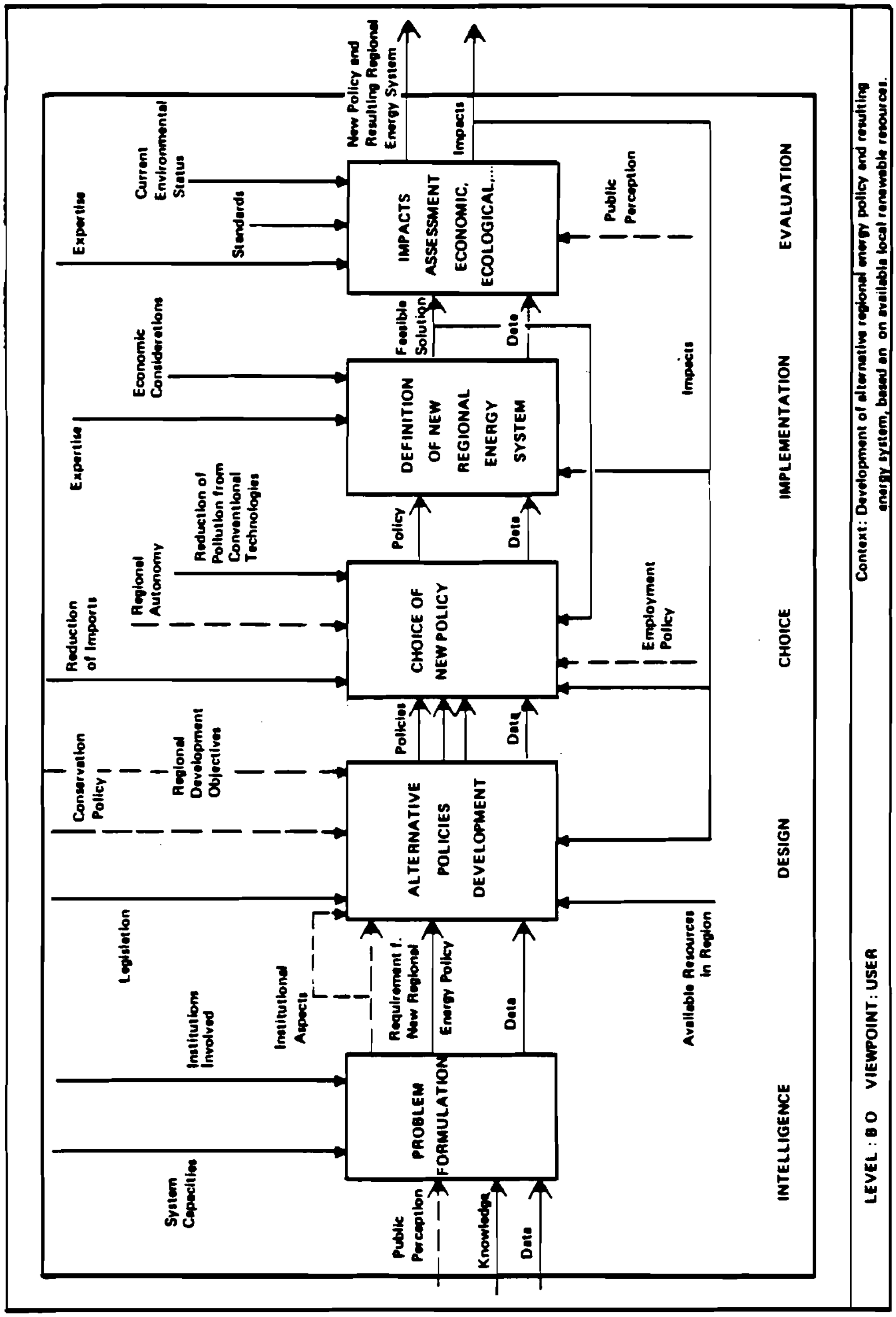


Figure 5. SADT illustration: user viewpoint of a particular decision (centralized versus decentralized solar energy systems at the regional level)

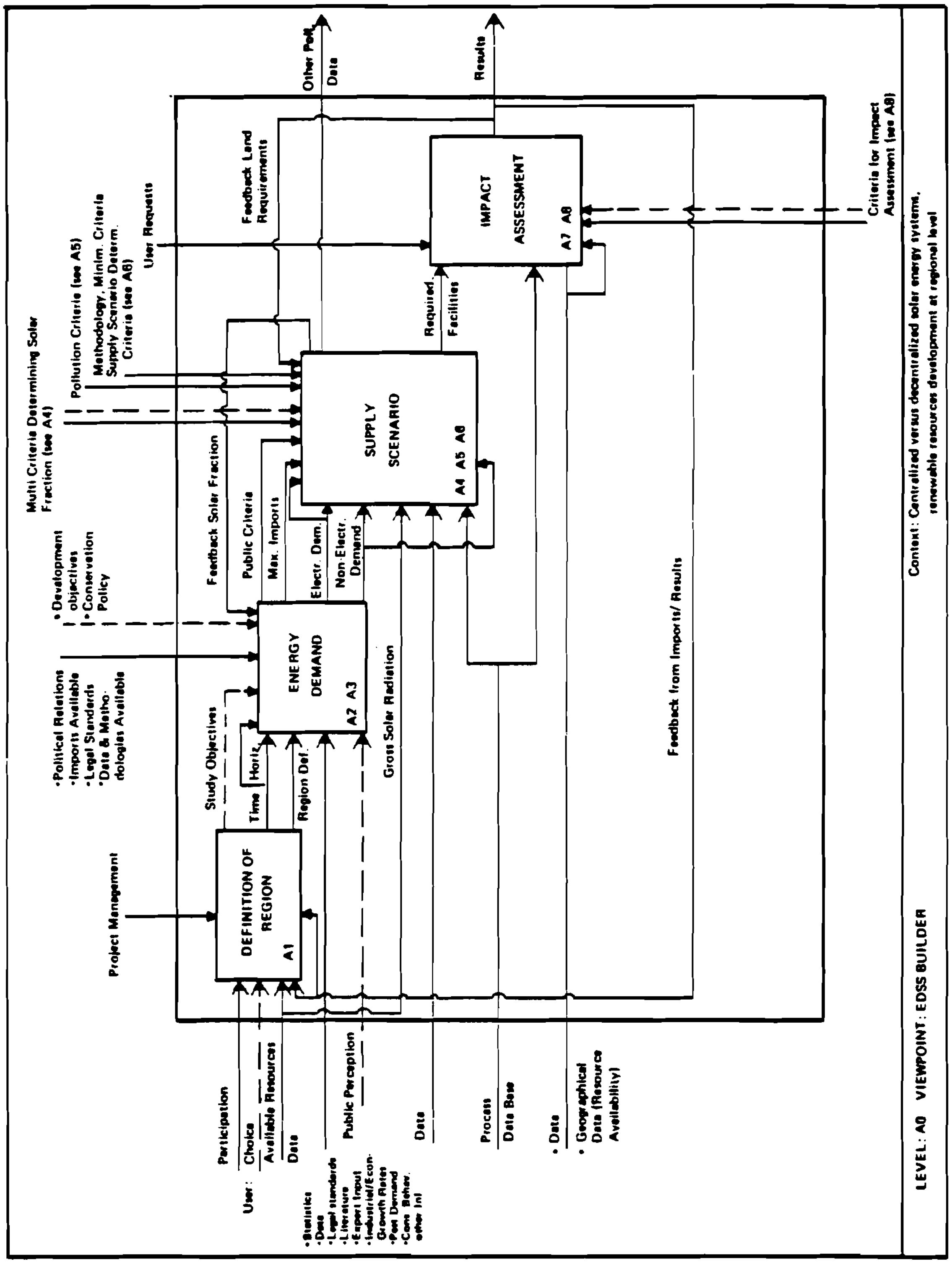


Figure 6. SADT illustration : EDSS builder's viewpoint of a particular decision (centralized versus decentralized solar energy systems at the regional level) complementing user's viewpoint (Figure 5).

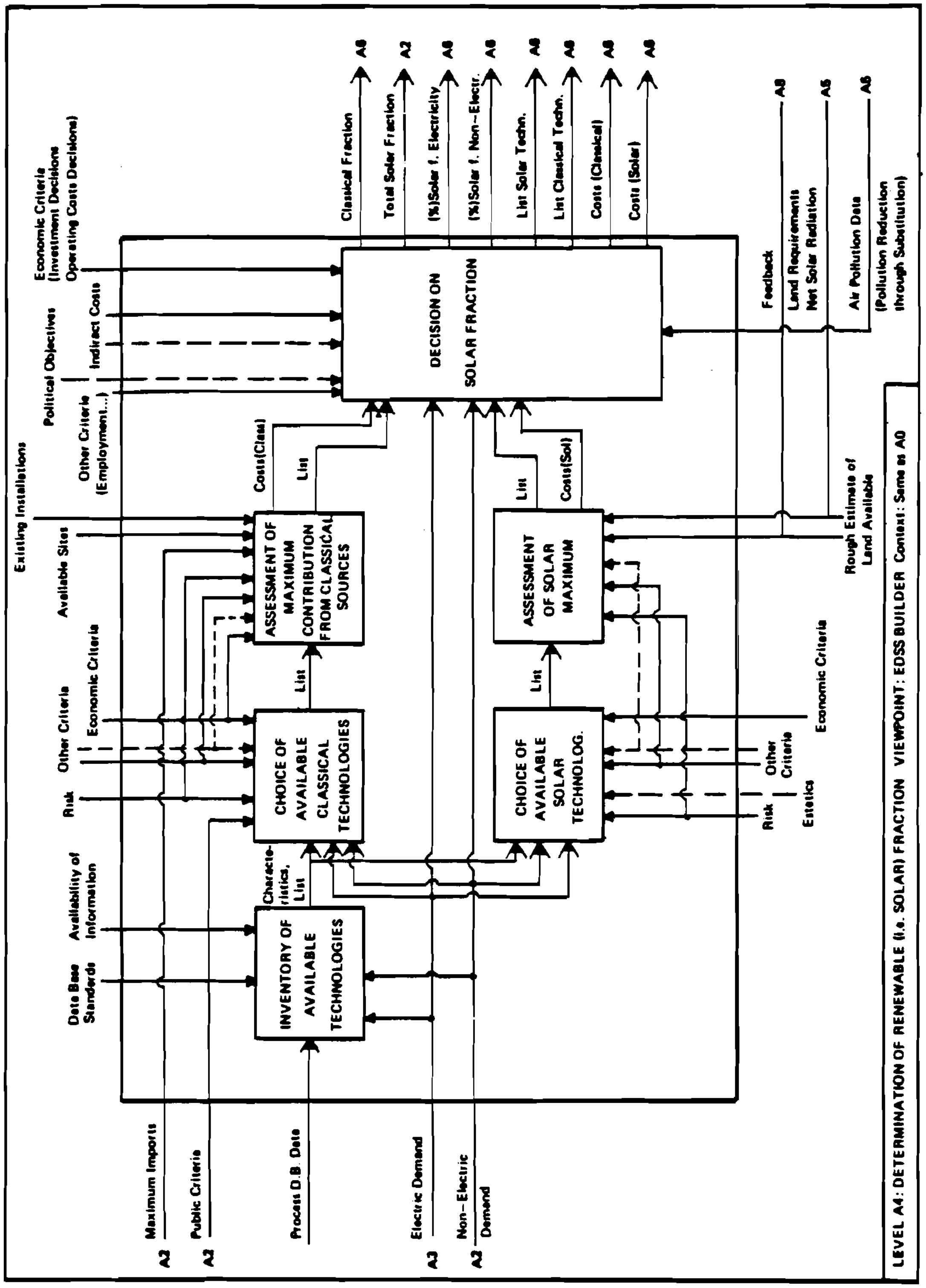


Figure 7. SADT illustration: example of disaggregated EDSS builder's viewpoint (Figure 6).

4. TOOLS OF THE EDSS: DATA BASES

4.1. Types of Information in the EDSS

Conceptually, we can summarize the sequence of information development for the EDSS as consisting of three phases: (a) *intelligence:* identification of phenomena of relevance to a particular task (provided by the user's viewpoint "activigram"). (b) *definition* of data required and socio-economic and natural processes involved (user viewpoint "activigram" and access to information already contained in the Process Data Base of the EDSS). (c) *description* of data and systems (processes) analyzed, including structural (system boundaries internal system's structure) and functional (relational - i.e. development of a model of the system) descriptions.

From the data viewpoint the EDSS data bases contain three types of information: *numerical* (e.g. statistics on population, air emissions, etc.), *relational* (a model data base on the functional relationship between variables) and *bibliographic* (on data sources, references, etc.). The data bases may be accessed independently by users through a special user friendly data access and Data Base Management program (especially in the intelligence phase of the decision making cycle) or be accessed inside the EDSS in the course of a task (requiring additional access software). The data of interest within an EDSS may be characterized as follows: first the data refer to phenomena *within defined (spatial or definitional) boundaries* of a system (the population of a given region, i.e. an administrative boundary; or the emissions from a power plant; a boundary defining a technological system (i.e. the power plant, but excluding electricity transport and distribution); second, the data are defined either for *a specific point in time* (population as of a given date, emissions of a power plant at a given date and hour) *or for a specific time interval* (i.e. a plant requiring defined input flows between the time interval t_{-5} to t_3 and producing output flows between t_0 and t_5). Third, of interest are not only the input/output variables (e.g. quantity of coal as input and electricity and emissions as output) but equally their *functional relationship*, which is recorded in a special model data base. Finally as we deal mainly with physical phenomena (electricity production in a power plant, diffusion of air pollutants into the atmosphere) the principal emphasis will be that the *data collected/stored will be in physical units*. To achieve these data requirements, the principal data base of the proposed EDSS will be based on the concept of "process", as elaborated in the next subchapter and (in a straightforward analogy to the way in which it is employed in the representation of the decision making cycle as described in 2.2).

4.2. What is a Process?

The concept of process is elementary to the proposed EDSS. Not only for the representation of the decision making cycle but also for the description of anthropogenic activities causing environmental impacts as well as naturally occurring processes of, for instance, biological or climatological nature of relevance to environmental quality.

A process is defined first of all by a (definitional) boundary separating the system to be studied from its environment. The definition of this boundary follows, of course, the requirements for detail considered necessary to a particular study. The definition of a process boundary then allows the most *complete identification* of everything that *crosses the boundary* either as input or as output, i.e. the flows of a process, connecting the process to the environment. The temporal definition of the process is either done by the time interval the process operates in (similarly to an operation factor in a power plant) or by recording the temporal evolution of the process flows (especially important in cases of variations of the flows during a given time interval). Process flows may be mass, energy, service or information flows.

Inside a process we distinguish between *the proper mass or energy flows* (of course subject to the physical laws of mass and energy conservation) *and "funds"* being (physical) structures or systems, which have to be in existence prior to any transformation of mass and energy flows. Funds thus provide control[13] to physical processes: in the representation of a process these funds are represented as providing a service flow as input to the transformation. In the case of a production process these funds include the work force, the plant buildings and equipment[14] and land. This concept of fund can be extended to include in the process descriptions systems (e.g. the athmosphere) providing a "free" service (e.g. the diffusion of air pollutants) to the socio-economic system.

The concept of a fund can also be applied to describe the exploitation of non-renewable resources: the fund in this case represents a stock of a given resource (say, for instance, a coal deposit) which after some initial investment (exploration, infrastructure, etc.) provides (a service)

[13] Properties of flows can provide equally control on physical processes, e.g. steam pressure and/or temperature "control" whether/how a particular chemical reaction takes place.

[14] Funds as in the case of buildings and equipment may be subject to depreciation.

input to the mining process, until the stock is depleted.

Thus far, we have described a process by its boundary, its input/output flows, its funds and the transformation of flows occurring inside a process. This represents a *definitional structure* of a process. In addition a process may have an *internal* process structure (i.e. a sequence of internal transformations connected by internal process flows). Internal process structure enables the *disaggregation* of a process into various subprocesses (i.e. the transformations of a process would become (sub) processes themselves, with internal process structure, etc.).

Finally, the concept of process as deployed in the context of the proposed EDSS, entails yet another meaning of "structure": in that (a) only observable process flows and their characteristics are recorded and (b) that a *functional (relational) model* exists explaining how input and output flows relate to each other. *This forms the process model data base of the EDSS* and in its mathematical and computer code form a set of process models to be linked with addtional mathematical off-the-shelf packages (MINOS and the like).

4.3. Process Data Base versus Resource Data Base

The application of the concept of process in a data base requires, (a) that the boundaries of a system described have to be defined (e.g. in a spatial or temporal context) and (b) that the system has to be defined in terms of the functional relationship between the variables (i.e. the process model). However, the EDSS will also contain data where the system boundaries are either ill-defined or a functional model of the relation between input-output flows is not available and/or cannot be developed within a given task.

Numerous examples for this can be found, particularly in the area of natural resources: whereas statistical data on the available groundwater resources may be available, based on measurement data, the system boundaries (e.g. the delimitation of the aquifer) or the input flows to the process, (which we would call groundwater formation), are poorly defined. Even if the process description in terms of its boundary and input-output flows were complete, one would still require a complete process description and a functional model of the process. But, such a development would often be beyond the scope of a specific task where, for instance, the availability of groundwater is just one of the many constraints in the task of siting a production plant.

Whereas, in principle, it would be possible to store the type of information discussed inside the Process Data Base, as a process where the process definition would be incomplete and the process model would be in the form of a "black box" it does not appear desirable for reasons of consistency (required for instance, in the aggregation of various processes to a bigger system). It would also be contradictory with the top-down conception/definition (process boundary, complete list of input/output flows) and bottom-up verification/implementation (estimation of parameters for process models through analysis of process observations) strategy adopted for the PDB (Process Data Base) development.

Therefore, we propose that the EDSS contains a second type of data base, *called the Resource Data Base*, containing the information where the process is badly defined in terms of its boundary, flows, or their functional relationship. The Resource Data Base (RDB) will contain mainly data on the availability of natural resources, on population, climate, etc., providing either supplementary background information for a particular decision or allowing the identification of the constraints or impacts related to the phenomena described within the process data base[15].

4.4. The EDSS Process Data Base

4.4.1. Concepts and Conventions for Development and Implementation of Process Descriptions

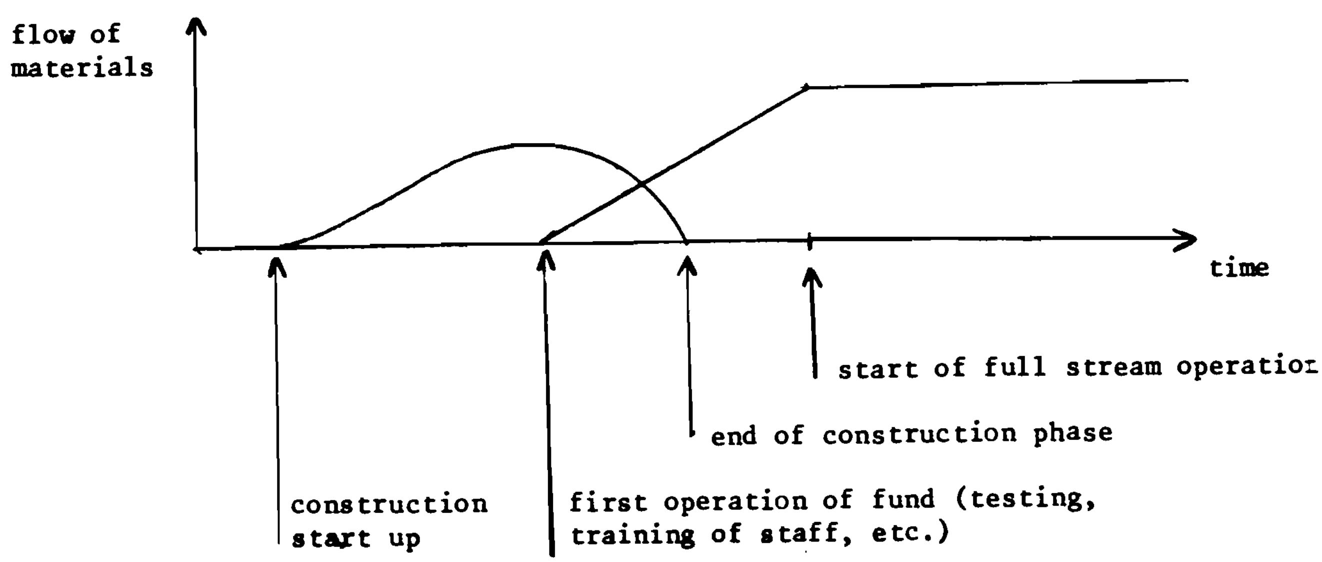
We have defined above the principal components of a process description: the process boundary, the process input/output (and internal) flows, differentiated into mass, energy, service and information flows. The description of the process boundary and of the process flows is straightforward (see Figure 8). The temporal evolution of a given flow is considered as just another characteristic of that particular flow recorded in the PDB. We consider a given flow as *an entity, having a number of attributes* associated to it like name, unit, absolute and/or relative flow quantities at different points in time, flow *properties* (like temperature, pressure, etc.), flow *composition* (mass flows consisting of a certain combination of chemical compounds, etc.) and so on.

However for the representation of the funds of a process, (in terms of its description as well as in the quantitative data relative to it) there exist two possibilities to record information on funds. First funds may just be represented with the input and output flows during the operation

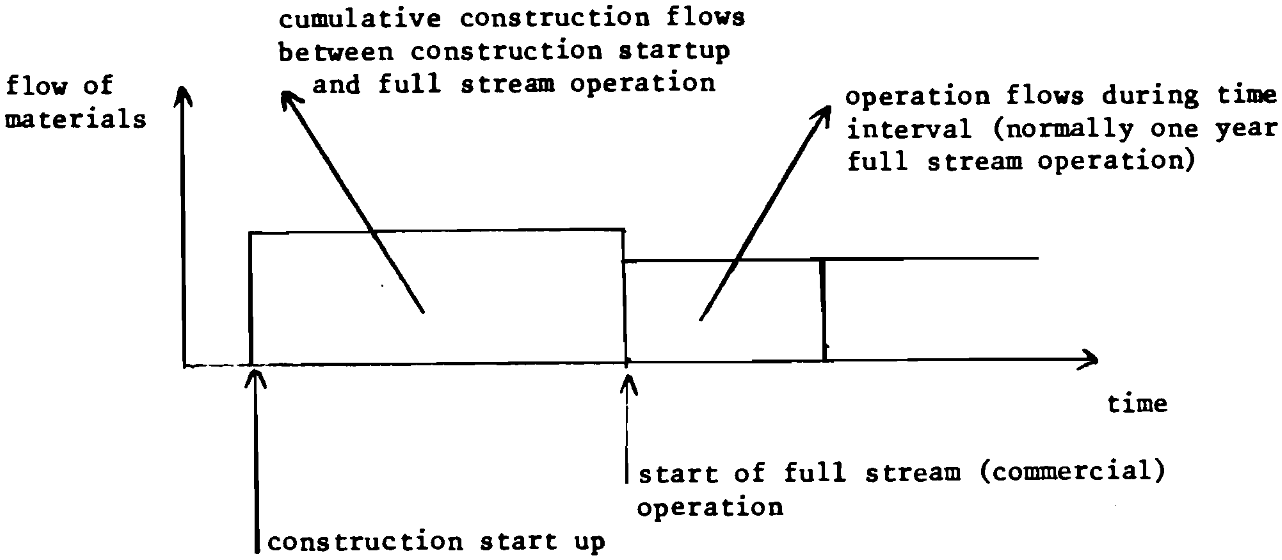
[15] The data recorded in the RDB become, once a process description and process model for a particular area (e.g. population, availability of groundwater, etc.) is being developed, part of the Process Data Base as observations on that particular process.

of the process. For instance, spare parts and repair materials as input to an equipment fund and the service flow as output. The flows which are going into the construction or establishment of such a fund (production, transport and installation of the equipment) would then be described by an own process (e.g. construction of a power plant). This being the approach taken for instance in the Process Encyclopedia Data Base developed by Statistics Canada (see appendix 4).

The second approach considers the flows going into the construction of the funds as part of the same process, as they are in fact nothing more than necessary input flows to a particular process, at a different time interval. In many cases there is even a time overlap between the various flows into a partiular fund. Consider the following simplified example of the material flows going into an equipment fund: materials for its construction (raw materials like construction material, processed materials in the form of steel, equipment parts, etc.) and materials for its maintenance and repair (spare parts, etc.):



Or in a simplified form, one can assume all flows prior to the full stream (commercial) operation of a process as being part of the construction phase, with an abrupt switch to the operation phase, as for instance the convention used in the WELMM Facility Data Base developed at IIASA (see appendix 4):



However, the key element in the components of the process concept discussed thus far and as illustrated in Figure 8 is in fact, the transformation taking place inside a process, as represented in the transformation node. The transformation of resource flows into flows of a higher degree of utility (e.g. the transformation of mass to energy, or energy to service flows), which is the objective of activities in the socio-economic system and the subsequent transformation of byproducts or wastes from economic processes in the biosphere are the issues to be addressed by the EDSS. This leads us to a discussion of the question of process hierarchy and process structure.

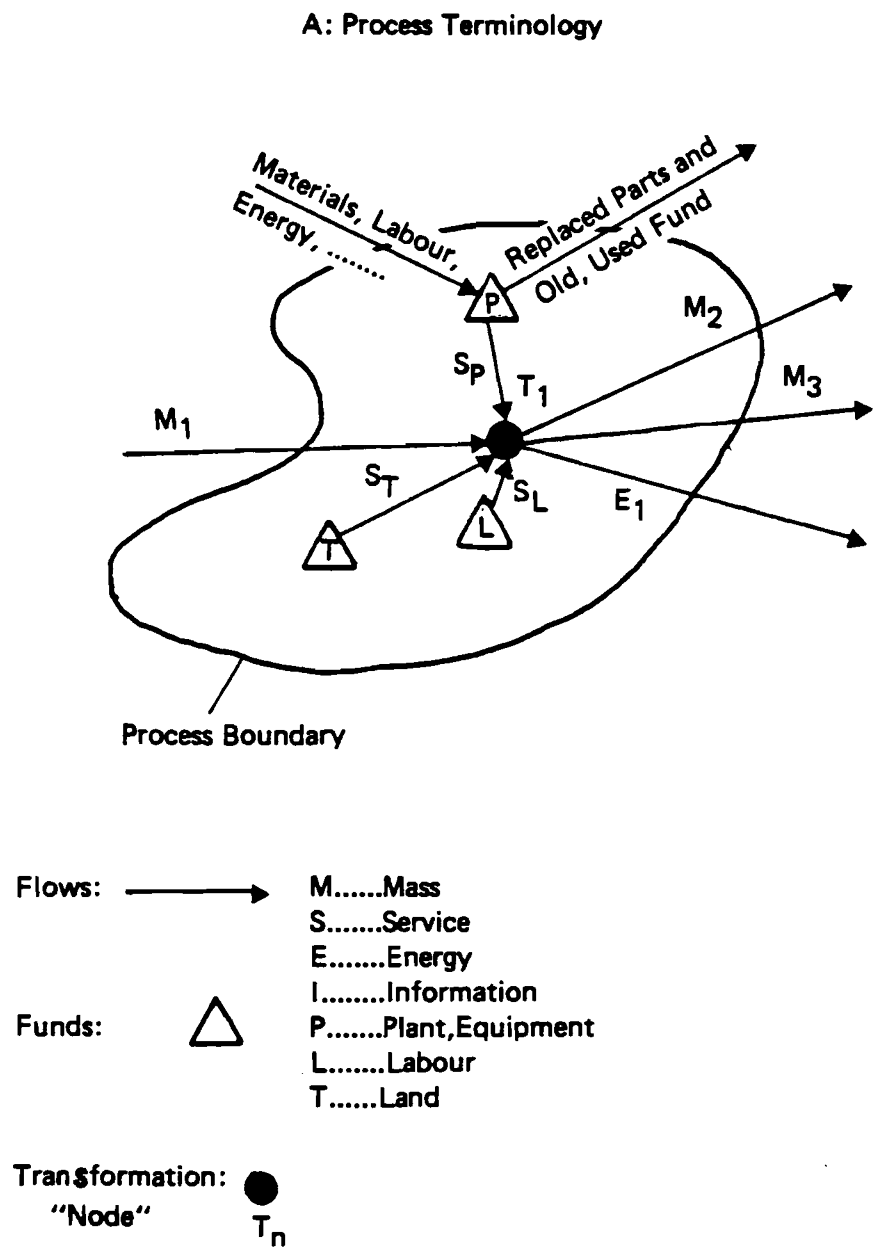


Figure 8. The concept of process (A) and a simplified example for energy production, consumption and environmental impact (B)

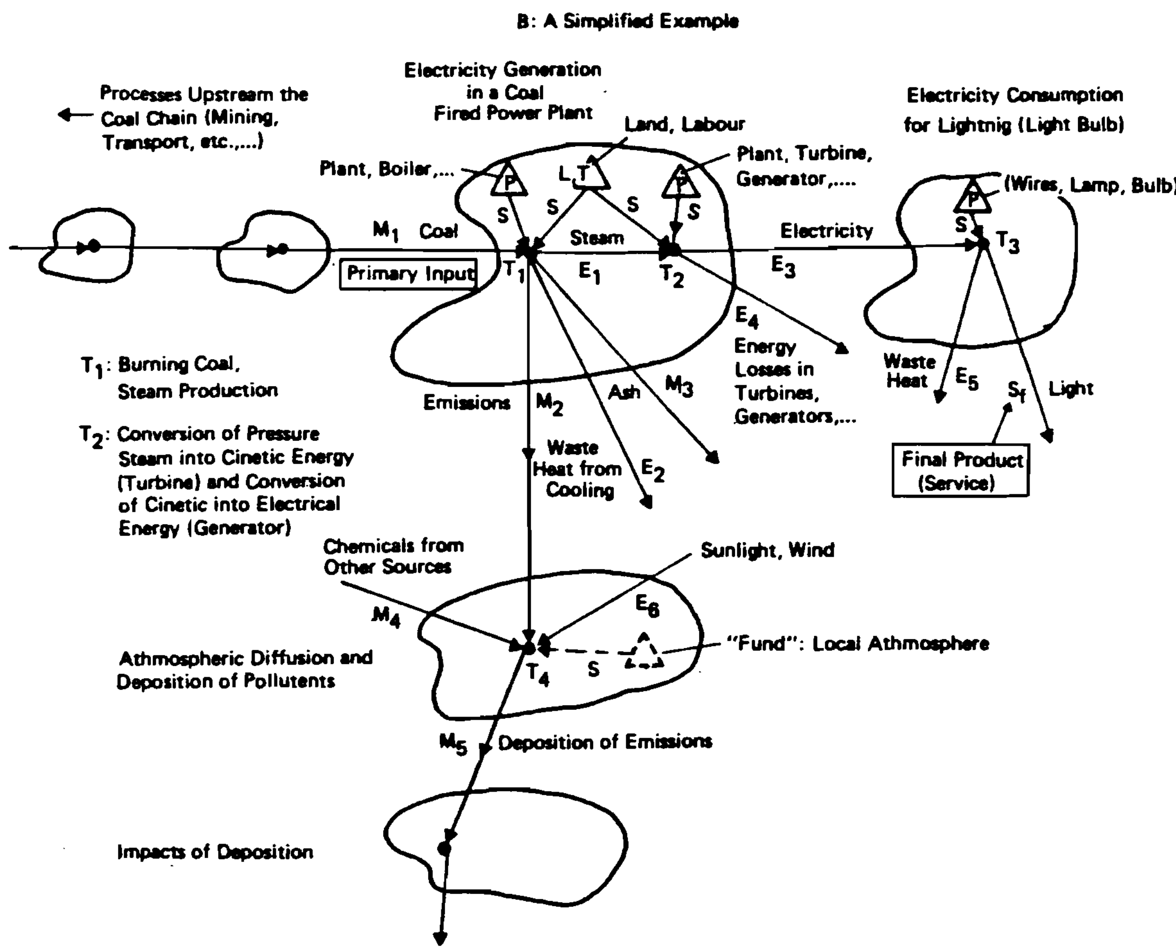


Figure 8 (continued). The concept of process (A) and a simplified example for energy production, consumption and environmental impact (B)

4.4.2. Process Hierarchy and Process Aggregation and Disaggregation

Note that by the term hierarchy we refer to the aggregation or disaggregation of processes and not to their simple linkage in terms of balancing the output flows of a process with the input flows of another one, or to their time sequence. *The hierarchy of processes relates to their definition*, in the sense of how the process boundaries are drawn in between the two extremes of basic physical or chemical processes and the whole environment (see Figure 9). For a production process the process lies in the hierarchy between a unit operation process (e.g., the opening or closing of a valve) and the whole economy. Any process at a higher level of this hierarchy consists in fact as an aggregate of processes at a lower level. For obvious reasons it is impossible, however, to define the processes for a process data base at the very bottom of the process hierarchy and describe all subsequent processes consisting of a (sheer) huge amount of unit operation processes. So any process definition adopted will always be a compromise between the amount of detail anticipated at the beginning of a study, available time and resources, availability of data, etc.

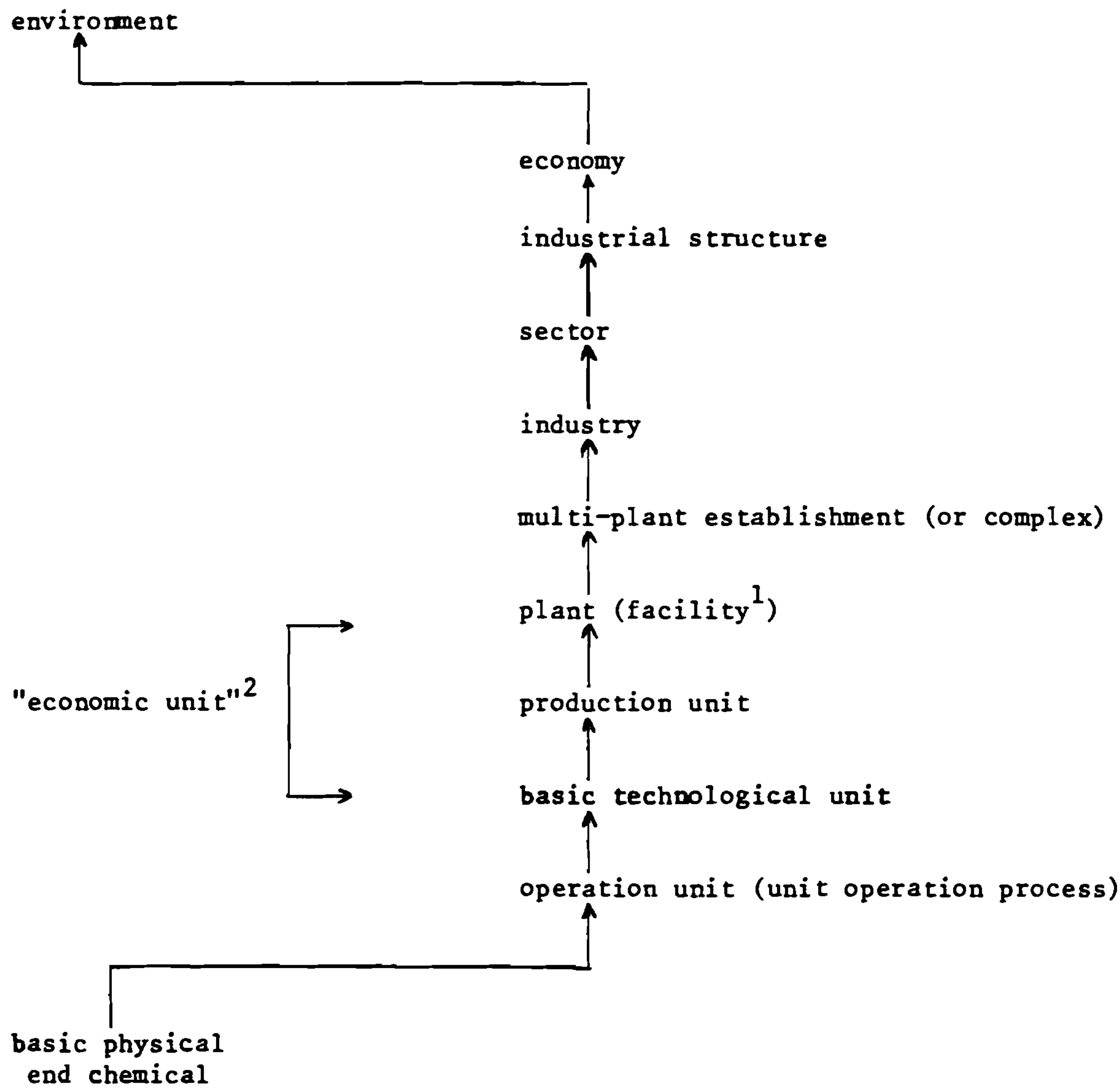
A second type of hierarchy of processes can be established in the form of a classification of the process flows. Energy flows are classified according to primary, secondary, tertiary, final and useful energy[16] or according to the different energy end uses. The service flows provided by the labour fund can be classified according to a classification of labour

[16] Useful energy in fact is both an energy and service flow. In the example of the light bulb in Figure 8, the transformation of final energy (electricity) to useful energy (light) takes place in an end use appliance (light bulb). The useful energy is providing a service to the consumer in terms of enabling him to read a newspaper in a dark room.

skill; with respect to the mass flows, one can use an international classification system like SIC or others. This hierarchy in terms of the commodities required/provided by a process is mainly an additional tool for data structuring. Processes can be aggregated both upwards along the process hierarchy (Figure 9) or along the above discussed commodity hierarchy. In the example provided in Figure 8 one could for instance aggregate all processes upstream of the coal chain to a single coal aggregate in the ground-electricity production process.

However, the *disaggregation* of processes into subprocesses requires that the process description *has an (internal) structure*. In the examples of the process "lightning" and "atmospheric diffusion and deposition", the process descriptions do not entail any internal structure (apart from the service flows provided by funds). No information is given about the internal flows and transformations. Note that this does not imply that we cannot develop a process model describing how the input and output relate to each other depending on external control variables. In such a "black box" type of process description, a simple list of input and output flows (mass, service, etc.) would suffice and representation of transformation "nodes" and funds would in fact be redundant.

However, a process may also have an internal structure (as indicated in the coal-fired power plant example in Figure 8). The various intermediate transformations and the internal process flows may be represented with their nodes, mass, energy or service flows, etc. Each of these transformation nodes represents nothing more than a process at a lower level of the process hierarchy. Thus, *internal process structure*



[1]Level of process definition in the WELMM FDB
[2]Level of process definition in the PE (Statistics Canada)

Figure 9. The hierarchy of processes

enables process disagregation. The description of a process in terms of its internal structure is, in a first phase, only necessary at the process definition and description level (i.e. at the topography level, similarly to the example in Figure 8). The quantification of the internal process flows (and their inclusion in the process model) can be entered into the data base at a later date, if a process disaggregation becomes necessary.

4.5. Process Description in the EDSS Process Data Base

The Process Data base contains three types of information:

- *descriptive/definitional* (i.e. the process definition and description in terms of a process diagram similarly to that presented in Figure 8 and as represented in the process topography);
- *relational* (i.e. the process description in terms of a process model, describing how the input and output flows relate to each other, their dependence on external control variables, etc.); and as represented in the model diagram.
- *numerical (i.e. quantification of the flows of the process as* well as the variables and parameters, of the process model).

Finally, related to the descriptive information, the data base will also contain extensive text material (relating also to the process model and the numerical data base) giving additional information about the process, references, data origin and analysts, etc. The main objective of this documentation is to present to the user not one predefined "paradigm" representation of a process, but rather to facilitate his own critical assessment of data and model credibility. To enable him to check references, to understand how data have been collected and analyzed, process models developed, etc. Figure 10 summarizes the elements of the process data base and their development cycle.

The collection of a Topography, a process model and a complete set of the parameters and variables of that model in the Process Model Data Base constitute a "process paradigm" to be used as system's units to build models of physical systems to support the analysis of a particular problem. "Paradigm" means that the process description in terms of its definition (i.e. the process topography) and in terms of its functional relationship is complete and internally consistent. This entails also the calibration of the model on the basis of process observations. A process (defined in its topography) may have many process models associated with it, varying in the degree of detail, the mathematical algorithms used or the particular aspects addressed by the model. For instance, the process termed "coal-fired power plant" may have a process model specifically addressing the question of air emissions and another one dealing with cooling water circulation. Both models in relation with their complete parameters and variables and the topography common to them are "paradigms" of the same process.

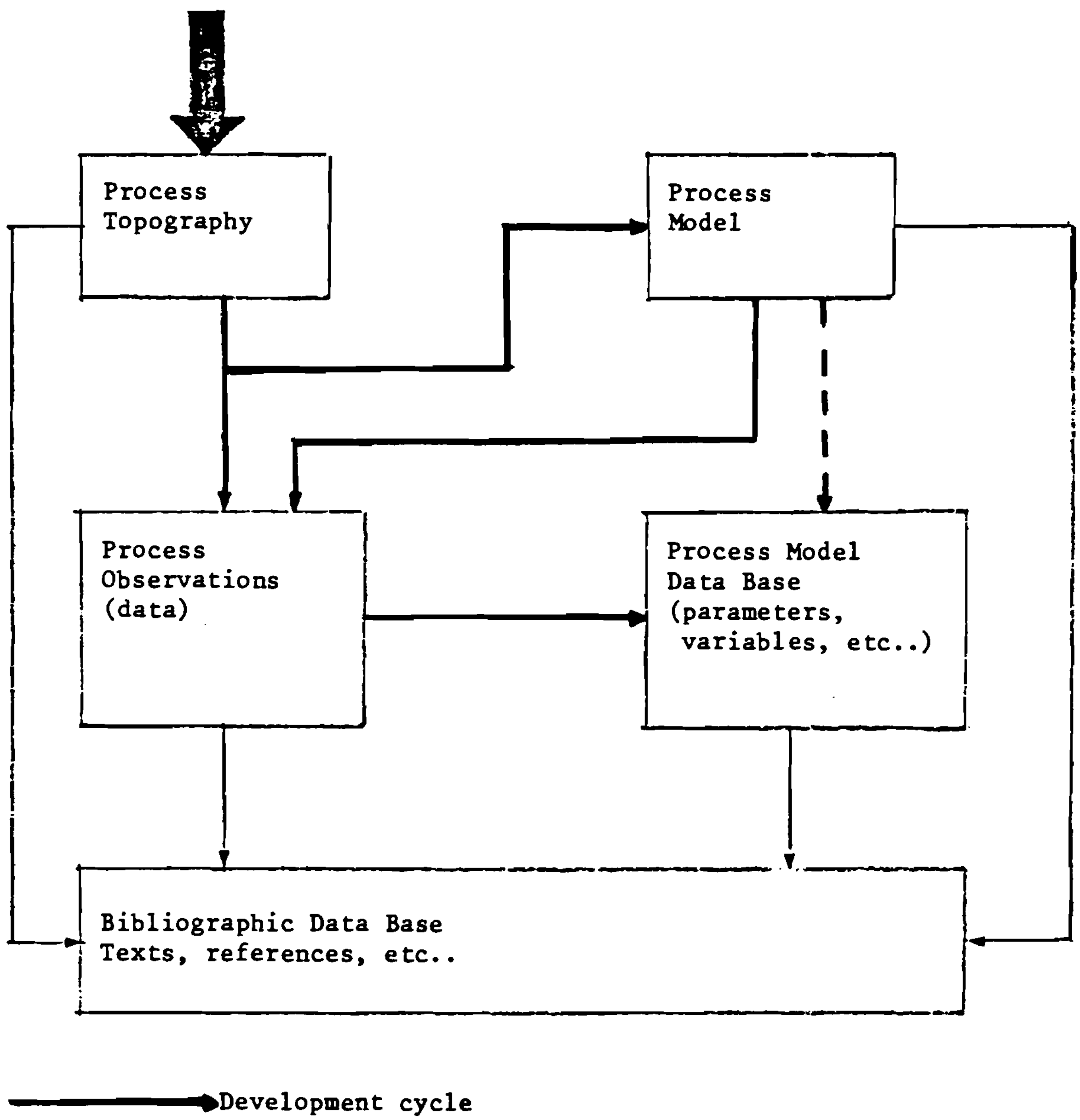


Figure 10. Elements of process data base

4.5.1. The Process Topography

The process topography, (i.e. the description of a process) has to be developed prior to any other information on a process. Each topography is unique and describes a process in terms of its boundary, flows, funds, and transformations. The topography consists of:

- list of transformations;
- list of funds;
- list of flows (input, output and internal process flows);
- text material on process description, references, analyst, etc., (stored in bibliographic data base[17]);
- process topography graphic.

The topography lists provide a structure to link with the other blocks of the process data base, where numerical or relational data relative to the topography lists are stored. Graphically the topography is represented using a software based on the symbolic representation of a process as outlined in Figure 8 (for examples see Appendix 4).

Once data on the process flows are recorded in the process observations the process topography graphic may be redrawn displaying not only descriptive but also numerical information.

In the topography, provisions has to be made to capture information about the composition and/or important properties of the process flows or funds. This is especially important in relation to the process models.

[17] providing an additional tool for the identification of processes in the data base (i.e. forming part of a process thesaurus)

In fact, we can consider any process flow or fund as an *entity* having a number of *attributes* describing the name, unit etc., of a flow or fund. The flow attributes form four major classes;

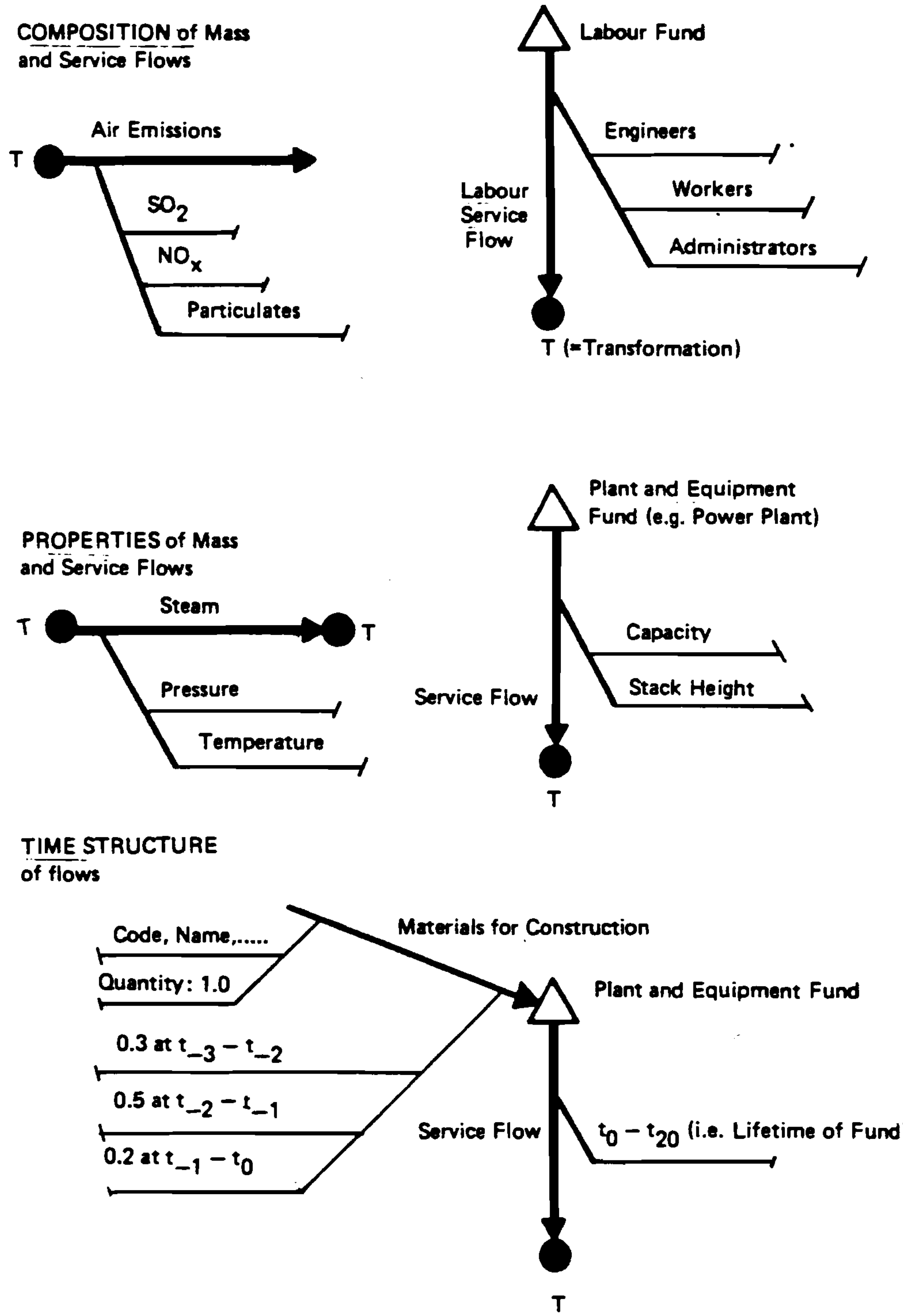
(a) *flow identification* attributes (code, internally chosen or based on an international classification scheme; name and definition; units; etc.);

(b) *flow composition* attributes (disaggregating a flow into its various compounds: chemical elements; type of personnel, etc..);

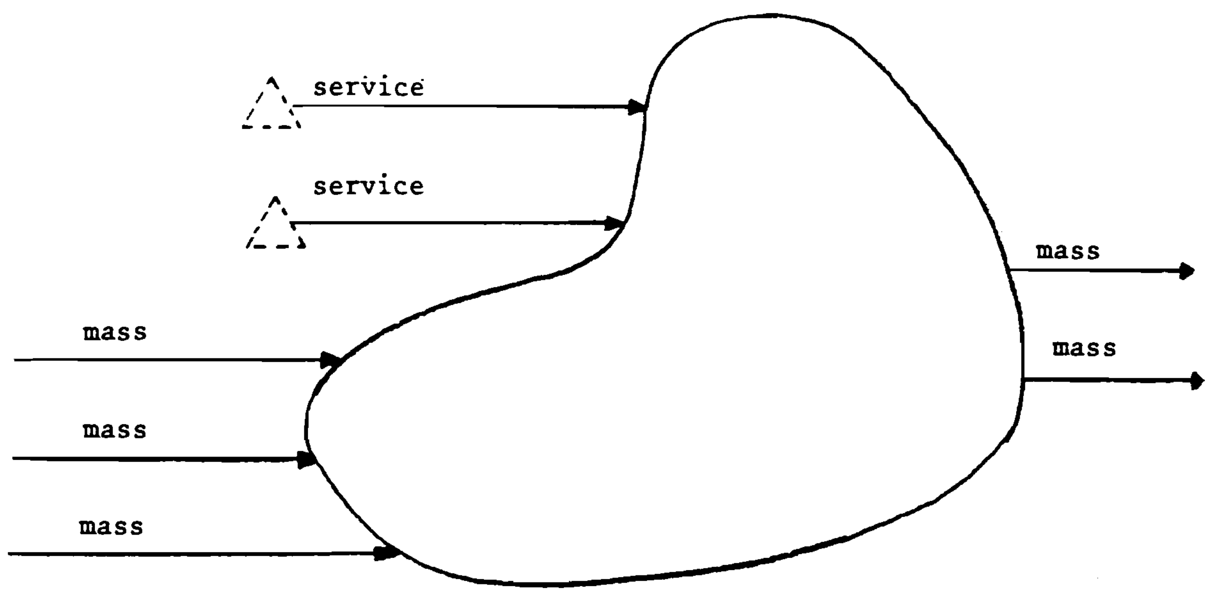
(c) *flow properties* attributes (qualitative flow characteristics like temperature, pressure, energy content, etc..);

(d) *flow time structure* attributes (recording the time intervals a flow is going into/originating a transformation or a fund; this can be combined with process composition attributes: for instance consider the material input to the construction of a fund; 30 percent may be used in the first year of construction, 50 percent in the second and 20 percent in the third year, etc.).

Compositions and/or properties may be graphically represented as a "bundle" of associated flows, as in the following example:


COMPOSITION of Mass and Service Flows
Air Emissions
T
SO_2
NO_x
Particulates
Labour Fund
Engineers
Workers
Administrators
Labour Service Flow
T (=Transformation)
PROPERTIES of Mass and Service Flows
Steam
T
T
Pressure
Temperature
Plant and Equipment Fund (e.g. Power Plant)
Capacity
Stack Height
Service Flow
T
TIME STRUCTURE of flows
Code, Name,.....
Quantity: 1.0
0.3 at $t_{-3} - t_{-2}$
0.5 at $t_{-2} - t_{-1}$
0.2 at $t_{-1} - t_0$
Materials for Construction
Plant and Equipment Fund
Service Flow
$t_0 - t_{20}$ (i.e. Lifetime of Fund)
T

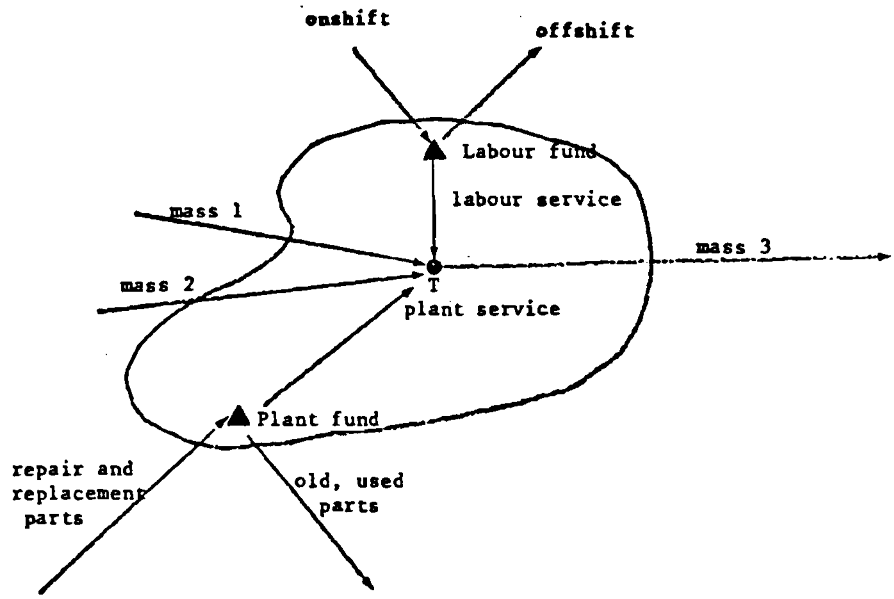
Properties of flows, typically constitute control variables in the process models. Within the topography, all process flows are originating or designating a transformation. However, in order to provide a means to represent incomplete information (i.e. the most usual case) process flows may also originate or terminate at the boundary of a process with their internal connection not shown. In an extreme case, for instance, as in many industrial census data the process description would look like :



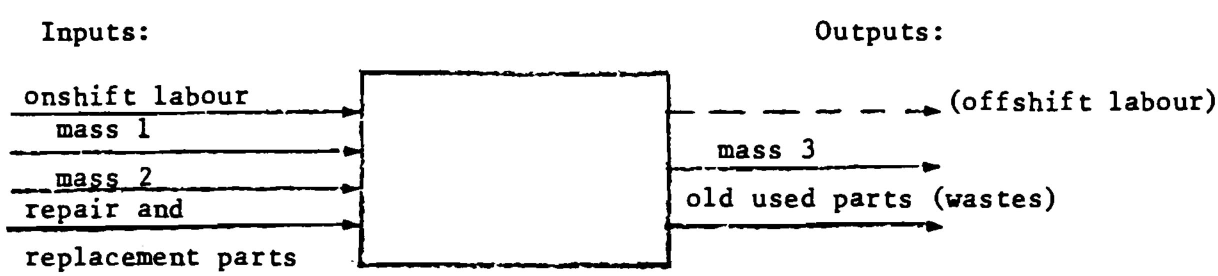
Hence for the process topography it would suffice to develop only a list of flows, including the service flows from funds, which may or may not be defined. A similar simplification of the process topography in a tabular form can be done, in the case that a process has no internal, or just a "pseudo-internal" structure[18].

18 "pseudo-internal" in the sense that a process is defined in terms of its funds and their associated service flows, but is only disaggregated into one transformation.

So instead of a topography of the type:



one could simply reduce the topography to a tabular form:



4.5.2. Process Models

Once the process is defined through the process topography, the next step consists in the description of the functional relationship between the input and output flows of a process. This is achieved by *developing process models in relation to a topography.*

Each process (i.e. process topography) may have a number of process models associated with it, depending on the amount of detail addressed by the model, its purpose and its mathematical structure, etc. A process model consists of:

- general model description (source, analyst, purpose of model, etc.) stored in the bibliographic data base,
- list of procedures (equations),
- list of variables[19] (definition, symbols used,...),
- list of parameters[19] (definition, symbols used, ...),
- model diagram.

The process model uses *two fundamental concepts: variables and procedures.* Variables represent information about objects defined by the model. Procedures represent the relationship (expressed in terms of an equation) between the objects taking the values of variables as input and estimated new values of variables as output. The process model is completely defined once the general model description and the lists of the model's procedures, variables and parameters are recorded.

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[19] In their numerical form stored in the Process Model Data Base

Note that up to now the process model is still in the design and documentation phase. This phase should in any case be prior to any implementation. To ensure consistency the process model descriptions will be based on a structural diagramming technique that allows to:

- clearly partition the design and documentation from the implementation phase;
- documents the model in a graphic form (i.e. the model diagram) for a better overview;
- allows to systematically document the definition and meaning of all variables and parameters associated with it.

A description of this structural diagramming technique, developed at Statistics Canada is provided in Appendix 4.

Finally, it is important to note that the above outlined concept of process models is equally providing a mechanism *to establish and to document* the aggregation of processes to a higher level in the process or commodity hierarchy.

4.5.3. Process Model Data Base

Associated with the Process Models where the variables, the procedures (i.e. the functional relationship between variables) and the parameters relative to the procedures are defined, the Process Model Data Base contains the quantification of the variables and parameters of the process model. These parameters can be estimated[20] using various statistical analysis techniques on the basis of actual observations on a

[20] Usually denoted as model verification or calibration.

process (stored in the process observation file), or they may be entered directly into the file from literature sources.

As discussed earlier each process, defined in its topography, may have a number of process models associated with it. Similarly each process model may have also various parameter sets associated with it, depending on the statistical methods used for their calculation, the available data base or the references used. The Process Model Data Base therefore may contain for each particular model, a range of parameters enabling the user to choose between different parameter sets or to perform sensitivity analysis. In the ideal case, the Data Base would contain for each parameter the uncertainty ranges or probability values associated with it. As in the other blocks of the Process Information System, the Model Data Base requires extensive text material on the parameters stored (origin and reliability of data used for their estimation, methods deployed, applicability and range of variation of the parameters, etc.,) which is recorded in the bibliographic data base.

4.5.4. Process Observations

The Process Observations contain factual, observed or measured data relative to a particular process defined in the topography and the process model(s). The observations may contain either raw data (which have to be further analyzed and their consistency checked[21]) or data which have been collected and already analyzed for other purposes (an example of this is the WELMM Facility Data Base). The latter type of data facilitate, of course, the evaluation or verification of the parameters of

[21] For instance through mass and/or energy balances

the process model. Whereas data in the Process Model Data Base are recalculated in view of the underlying process model (e.g. all variables normalized per unit of output or throughput), the Process Observations are recorded in their original units, or in the case that transformations on these data have been performed (e.g. conversion into metric units), these are documented (conversion factors used, etc.). This documentation (including equally data sources, date when data have been recorded, etc.) forms an integral part of the data base.

Again an individual process topography may "own" a number of observations about it. For instance, observations relative to a process called "coal-fired power plant" may come from data of different power plants, of different size/capacity, different location, etc. However, these data refer to the same process definition as outlined in the topography (with respect to the technology deployed, equal internal process structure, etc.).

Process observations include quantitative data on all constituencies of the process data base discussed earlier, and in particular, on the process flows, i.e. input, output and internal process flows; their differentiation into mass, energy or service flows as well as their composition; and also on the funds of the process and their properties. With respect to the Process Model(s) and the associated Process Model Data Base the Process Observation Module is more rich in information, as it includes data on process flows or funds which are not considered as variables in the Process Model(s), but which are referred to in the process topography.

Figure 11 summarizes the various blocks of the Process Data Base's structure. Going top-down, there are one to many types of relationships: one topography can "own" many process models and observations, one process model can "own" many parameter sets. Bottom-up we have a one-to-one type of relationships, i.e. each observation belongs only to one topography, etc.

In Figure 11, the relationships to the bibliographic data base (shown already in Figure 10) containing references, text footnotes, etc., are not shown. The bibliographic data base has three types of relationships: (a) one-to-one: a literature or text note refers only to one topography, one observation; one observation holds only one literature or text note, etc., (b) one-to-many: each topography, process model, process parameter set or process observation holds many literatures/text notes (this would be the normal case in the EDSS); (c) many-to-many: a literature/text note may refer to a number of records in the topography, process model, process model data base or process observation.

4.6. Resource Data Base (RDB)

As already noted, the Resource Data Base records information of relevance to issues being addressed by the EDSS, where process descriptions cannot be developed within a specific task. Data of this type are, for instance, in the areas of resource availability (water availability, availability of non renewable and renewable energy resources, etc.), land cover and land utilization, climatological data (temperature, precipitation, wind, ...), existing air quality measurement data, population data, to name just a few main topics.

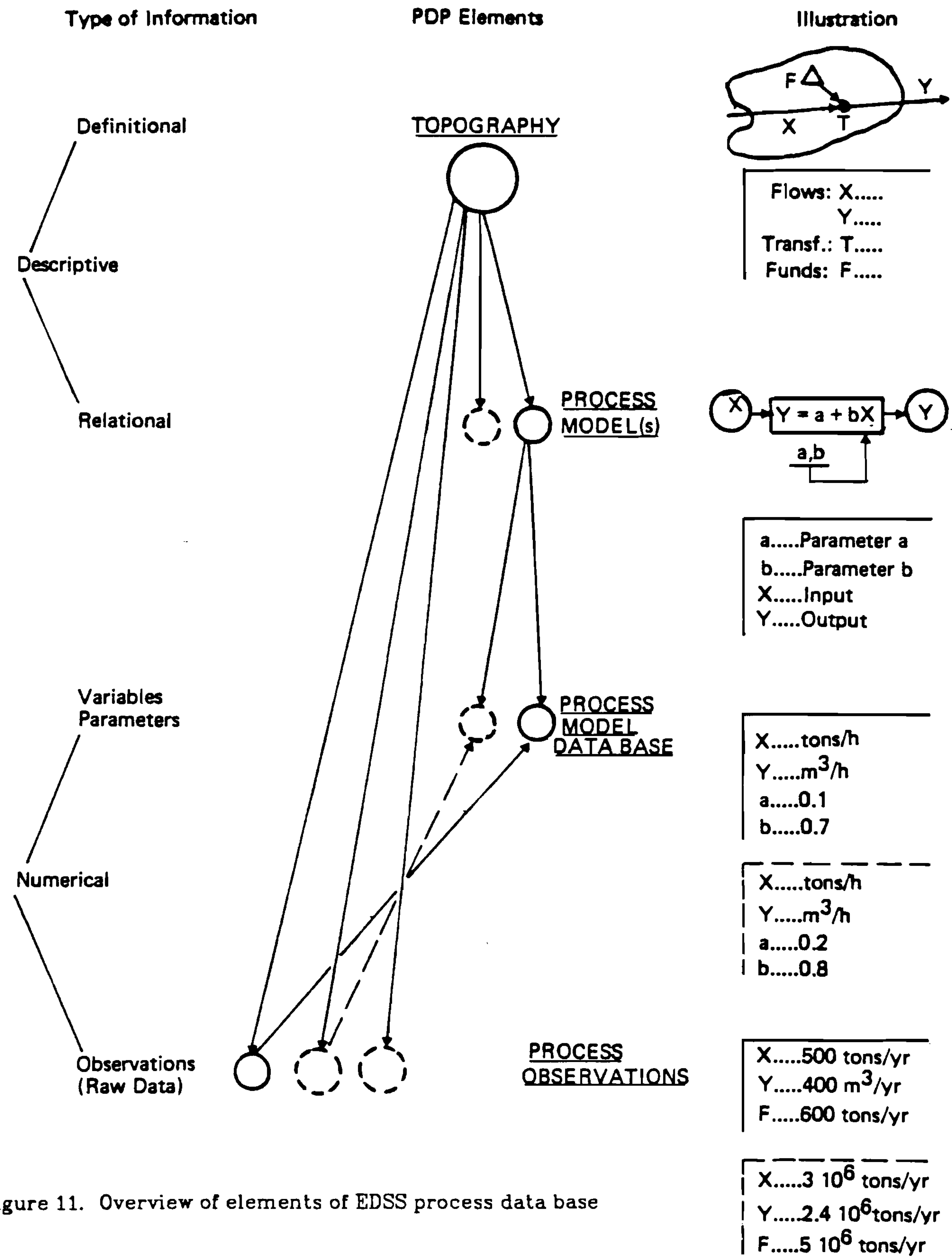


Figure 11. Overview of elements of EDSS process data base

There are two possibilities to define a region about which the RDB records information. Each imply different accounting methods and types of data:

(1) One can start with a given natural deposit and draw around it the region which would be affected by eventual exploitation, for instance, an energy deposit or an aquifer. Similarly, a region might also be defined not on the basis of the production of a natural resource, but on its conversion and/or consumption and the area where (environmental) impacts occur, like a power plant and the zone around it affected by its emissions. For this type of data base it is, of course, necessary to develop first a complete process description of the process causing (environmental) impacts and/or defining the region. The RDB then records additional data, which are not part of the proper process descriptions but are nevertheless of importance (e.g. data on existing air quality, population, etc.).

(2) The second possibility consists of taking the ethnical, geographical, political or administrative determinants into account and to define a region according to them. For instance, the administrative/juristic definition of a region and its sub-entities. Data may then refer either to the whole region or to its defined sub-entities (e.g. the population of the whole region, its communities, etc.). This is the level at which most national or regional statistical offices collect data on. Or the data collected refer to precise geographical locations inside the defined region (measurement stations for climatological,

environmental data, etc.) or refer to data describing spatial coverage or the topography (soil quality, land cover, etc.).

The first type of data, referring to the whole administrative entity and its sub-entities can be stored easily in files, which are particularly apted to a powerful hierarchical data access software (e.g. the TREE software[22] developed at IIASA and presented in more detail in Appendix 4).

The second type of data (geographical point observations and spatial coverage) call for, what is usually denoted as a geographical data base. Two main techniques exist for storing geographical data (see Figure 12). The first describes the contours (polygons) delimiting each parameter. The files contain a series of coordinates, which give, once they are related to form boundaries, the surface covered or the extension of a particular parameter. This delimitation of the boundaries may also be achieved by interpolation programs starting from point observations creating isolines (as opposed to "pseudo-isolines", i.e. contours of non continuous variables, where the polygons describing points of equal variable values are approximated in connecting the stored coordinates and no further interpolation between these "pseudo-isolines" is possible). The second technique for storing geographical data consists of assigning each variable to unit cells, within a grid (which may then be further subdivided) covering the whole region. The files then contain three types of data: presence indicators, recording the major characteristic of a cell;

[22] In the applications at IIASA the software enables the user in an interactive session to access and retrieve information at various levels of aggregation moving along on tree-like shape geographical hierarchy starting on top with the world total, and then going down to world regions and then to countries (and in a further extension down to states, departments or provinces, counties, communities, etc.).

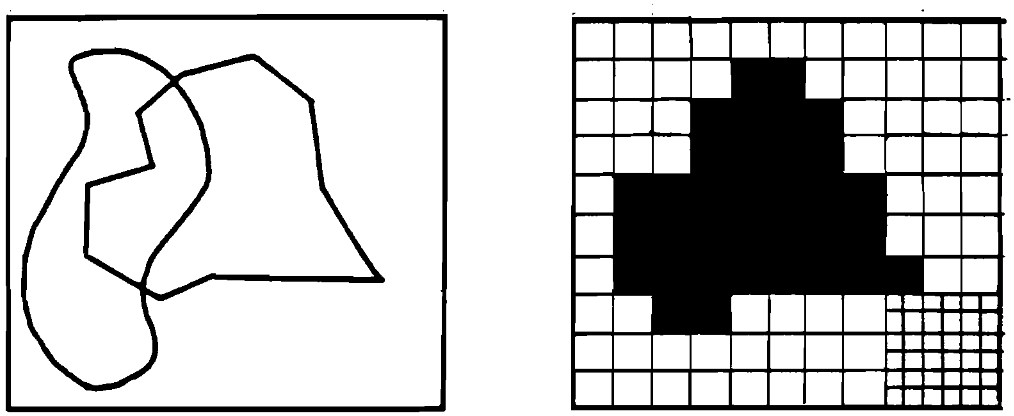
percentages or forks (part of a cell covered by one or another parameter) and integers for sample observations (e.g. population, solar radiation, air quality, etc.).

Both types of approaches will be required to record information of relevance to the EDSS.

4.7. Bibliographic Data Bases

The Bibliographic Data Base has four main objectives:

- first, *to allow a user to assess the contents of the EDSS:* available data in the form of process descriptions, data contained in the Resource Data Base, available data analysis tools, etc. This might be called *the thesaurus function*, providing a catalogue of the EDSS, on the basis of which a user may then access the parts of the data bases where the information is physically stored. This function *is especially important to support the unstructured search for data during the intelligence phase* of the decision making process.
- secondly, to provide a means *to store the references of the source documents, used in the development of the EDSS:* data sources, model documentations, general literature on methodological aspects or providing basic information on the processes recorded in the Process Data Base.
- thirdly, in relation to the Process and Resource Data Bases, to provide a means to store extensive text material, process and model descriptions, comments and discussions about recorded data.



POLYGONS
(Contours)

CELLS AND
"ZOOM EFFECT"

Figure 12. Two ways of storing geographical data. What we call the "zoom effect" is the possibility, for a specified part of the region under study, to split the cells into 4, 16 (or even more) smaller cells, so that the analysis of the region may be more precise.

- fourth, in analogy to the Process and Resource Data bases, the Bibliographic Data Base should (at a later step of the EDSS implementation however) *equally record the SADT "activigrams"* (i.e. the analogue of the decision making process documentation to the process topographies and process model diagrams) *of earlier EDSS applications. Thus earlier decisions on the management of environmental problems, decision rules involved, etc., are documented and may be used for other applications.* In this context, the Bibliographic Data Base should also contain user manuals and program documentation of the available software of the EDSS to facilitate the ad hoc development of a new EDSS configuration for a new case study application. This will facilitate especially, the development of "activigrams" of the EDSS builder's and the programmer's viewpoints and the subsequent computer implementation of the software for a specific EDSS configuration.

Points two and three above are an integral part of the layout of the EDSS and have to be developed right from the very beginning (in parallel to the other components[23] of the EDSS). However, the implementation of the system's thesaurus, the activigram data base and on line manuals will follow a stepwise procedure after the completion of various case studies (air pollution, district heating and others) when the system is getting accessed by a large user community (this might apply first to the Resource Data Base and only after to the Process Data Base).

[23] Note the emphasis in the subchapter about the process models on model documentation prior to implementation.

4.8. Some Thoughts on Other Tools of the EDSS

Besides the tools (and their associated software) and the elements of the EDSS discussed thus far, (SADT for the activigrams (user, EDSS builder, programmer viewpoint), pictorial software of process topography and process model representation and the obvious requirement for appropriate Data Base Management software inside the data bases of the EDSS), there is the need for additional user-friendly, interactive data access and manipulation tools, which make the system truly a Decision Support System[24]. This software will have to provide a framework in which the user can select, (i.e. through the systems thesaurus) retrieve, (e.g. through a relational DBMS or one based on the Entity Relationship Approach) project (printouts, plots, maps, (colour) graphics, etc.) and manipulate and analyze (e.g. through an interaction with SAS statistical packages) information contained in the EDSS and link this information to process and mathematical models.

The development process is continuous and cannot be defined completely at the present state of the EDSS, as the software has to respond to specific user needs (note our earlier emphasis on adaptive or "evolutionary" EDSS design and implementation strategies). Once a number of case studies are described within the EDSS methodology (i.e. the system's activigrams), the requirements of the users on the system's access software will be documented and can be analyzed and corresponding software developed. Still we can identify certain areas, which will have priority (however not necessarily in the order listed below):

[24] The EDSS as outlined in chapters one to four of this paper consists essentially of a decision support methodology and a system of data bases which are adopted more to be used inside the support organization (i.e. CSI) than by the actual decision maker.

- *natural language* Data Base Management Systems (DBMS) program including graphic capabilities *to access primarily numerical data* in the Process and Resource Data Bases and related interactive data entry and analysis programs enabling the user to interact with statistical packages like SAS, BMDB or the like;
- *interactive software* on top of the above mentioned DBMS allowing the user *to* quickly *scan, access and retrieve* (listings, graphics, etc.) data recorded in the data bases. Here we mention the interactive hierarchical data access and filtering program TREE developed at IIASA, particularly for the Resource Data Bases. The TREE program also provides a "dictionary" function of data recorded in the Data Bases (see also Appendix 4);
- *interactive software* to allow the user *to use* "off the shelf" packages of formal *mathematical tools* (as for instance the MINOS linear programming package);
- software allowing the user to locate processes involving spatial phenomena (e.g. distribution of air emissions) in relation to production processes and the generation of the associated geographical location and distribution patterns (e.g. isolines of equal concentration of pollutants) and their linkages to the geographical data base (e.g. retrieving equally the population density or the existing air quality);
- for the process data base, software to retrieve paradigm representations of a particular process and associated process

observations and all text and source material (i.e. a complete retrieval of all contents of the EDSS relative to a particular process). This in addition to the software accessing the individual parts of the Process Data Base: topography and process model graphics generation and display, access to the data of the Process Model Data Base and Process Observations and the references and text material relative to a process;

- software enabling the user (or together with the EDSS builder) to link various process models together, to access the Process Data Base interactively, to change certain Process Model parameters and to *run* the interlinked process models;
- finally, a mechanism enabling the user to aggregate[25] processes to processes at higher levels of the process or commodity hierarchy along the lines outlined for the process model documentation methodology (process model diagram) However, a truly interactive, user friendly system, without going to a predefined higher level topography[26] (whose transformations are the processes recorded in the Data Base) will be developed only in a more long-term effort.

Additional EDSS tools to the above mentioned, will be developed within specific applications of the EDSS following the requirements of the different users or user communities. It is not reasonable to define

[25] Let us recall that the disaggregation of a process depends entirely on the existence of an internal process structure. If this is not entered at least in the process topography no disaggregation is possible.
[26] Note that even without the requirements to link ad hoc through a program a large number of input/output flows of processes and their composition/properties, the program still has to recalculate (conversion to common units, etc.) and then to aggregate the data stored in the various parts of the Process Data Base.

beforehand these requirements and the resulting software characteristics, apart from some general requests for a powerful, yet simple to use user-friendly interface offering a wide variety of systems capabilities and ways of communication to the user starting from non-cryptic error messages, "help" commands and retrieval of software manuals and ending with a wide range of possible outputs (report generator, color graphics for maps, plots and diagrams, three-dimensional graphics, etc.).

4.9. A Summary of EDSS Documentation Tools and their Conceptual/ Physical Equivalences and Relation to Formal EDP Documentaton

After the presentation of the main guiding concepts underlying the proposed EDSS and the resulting principal EDSS tools, let us briefly summarize the conceptual and/or physical equivalences between these tools and in the case of conceptual equivalence why we propose[27] nevertheless *different* tools.

Right from the beginning of the conceptualization of the proposed EDSS and its tools *the concept of process was recognized as the key element*. Although, this concept is applied to describe the decision making cycle *as well as* the socio-economic and natural processes the decision deals with, there is a principal difference between them resulting in *different documentation* tools: SADT for analysis of the decision making cycle, and with respect to the socio-economic/natural processes the pictorial languages for the process topography and the process model documentation language.

[27] Note that this section reflects long discussions followed by final agreement from the side of the IIASA and the CSI authors of the present paper.

This difference stems from the different ways the term "*structure*", is used within the context of decision making cycles (processes) and the models of socio-economic and natural processes.

SADT is the EDSS tool to analyze, design and document the decision making cycle (or process) from different viewpoints[28]. However, not from a vigorous time sequence or functional point of view, *but from an entirely descriptive one* (responding to the user requirements on the EDSS). Inside the SADT methodology the term "structure" refers only to the hierarchical aggregation and disaggregation of the activities in a decision making cycle and to the completeness in documentation of the input/output and control flows connecting these activities. Most important, these flows described with SADT *represent also nonstructured* (non observable, not measurable) *elements in the decision making process* like (political) values, expectations, etc. In the design phase of the decision making cycle SADT provides a tool to link (structured) elements recorded in the Process Data Base (Data, Models, etc.) or outside it (i.e. what we termed the Resource Data Base) as well as to integrate non-structured user input (this is documented in the EDSS builder viewpoint SADT activigram).

The process topography and the process model however, address only those processes where a model (as documented in the proposed structural modelling language dealing with observable variables and parameters) has been developed. *This employs the use of the term structure in a much more rigorous sense than inside SADT* (including

[28] We might say these viewpoints, that of the user, the EDSS builder, etc., are different "paradigms" of the same decision making process.

equally the time dimension of flows, not considered in the SADT methodology), i.e. from the descriptive *and explicative* viewpoints. Thus, only structured elements (i.e. measurable observations and parameters) are considered.

Clearly the anology between *SADT* and a *process topography* is correct in that both define a process with its boundary and transformations (activities in SADT) and input/output flows. However, their principal difference is in the way they employ the term *structure*. Decision cycles as described by SADT include unstructured (non observable) input or control flows and describe the cycle in a non-time structured model. From the data flows viewpoint[29], SADT descriptions include information not considered in the process data base and the process models.

In the *design phase* of the decision making cycle the SADT diagrams[29] include finally also the third type of EDSS tools, namely formal mathematical models (statistics, optimization, etc.) as opposed to the descriptive models contained in the PDB topography and the process model data base.

Thus, despite our initial inclination to apply the concept of process "universally", and to develop a common documentation tool, the present proposal to use two different tools (SADT and the Process Data Base documentation languages) reflects nothing more than the "structural" differences between decision making processes (with all human and political externalities) and socio-economic/natural processes.

[29] EDSS builder and programmers viewpoints.

Finally, as we address this paper primarily to persons familiar with systems where the problem is well defined, including only structured elements, let us make some observations on the relationship of the proposed EDSS documentation tools to formal EDP documentation tools. As an illustrative example we will consider here the DAFNE[30] methodology (used at the CSI).

The common feature of the EDSS and EDP (DAFNE) documentation tools is the idea of documentation *prior* to implementation. However, the EDSS tools aim at a documentation responsive to the (changing) user requirements on the system, following a "middle-out" or adaptive design and implementation strategy (see appendix A2-1) for a particular case study. This is radically different to the cumbersome and lengthy analysis, design and documentation tools characteristic of the EDP, MIS field, where the problem area and the resulting system requirements are clearly defined beforehand, and the principal goal is "system efficiency".

This difference is especially important as we perceive the EDSS as a *learning tool* where the documentation (including the development of the process data base) of past case studies enrich the EDSS and provide input for further case study applications.

Nevertheless, there are many conceptual equivalences between the documentation of structured elements inside the EDSS and EDP/DAFNE documentation. This is presented in Figure 13. The structured elements of the EDSS builder's viewpoint (SADT activigram) and its resulting programmers viewpoint SADT diagram have their conceptual equivalence

[30] Sof Tech Inc., and ITALSIEL, 1976, DAFNE: Metodologia integrata di sviluppo dei sistemi.

not only with the documentation language used inside the Process Data Base (process topography, process model diagram), but equally with the functional analysis part of DAFNE. Moreover the use of (although modified version of) the SADT documentation language in the EDSS provides a direct input to the SADT diagrams used in the functional analysis of DAFNE. Also there exists an equivalence between the numerical part of the process data base (topography lists, process model data and process observations) and the Resource Data Base of the EDSS as both will be developed based on a similar methodology (Entity Relationship Approach[31]) as the conceptual scheme for the DAFNE data analysis. Thus any particular EDSS application configuration can be translated into a formal EDP/MIS system, when required and then be redesigned in order to improve its efficiency[32] based on formal EDP analysis and design methodologies like DAFNE.

5. CONCLUSIONS

The present EDSS proposal was designed to be applied within a governmental agency (CSI) to provide a framework assisting decision makers/users at the government level, but equally within industry and academy, in the management of environmental problems.

The reason, why we propose an implementation within a governmental agency such as CSI is related to the integrative aspects involved in the EDSS implementation (in particular in the collection, organization and use of process information). That is the EDSS implies standard

[31] Recall here the discussion of flow attributes (flow properties, composition and time structure).

[32] Note that systems (software) efficiency is no prime concern for the EDSS.

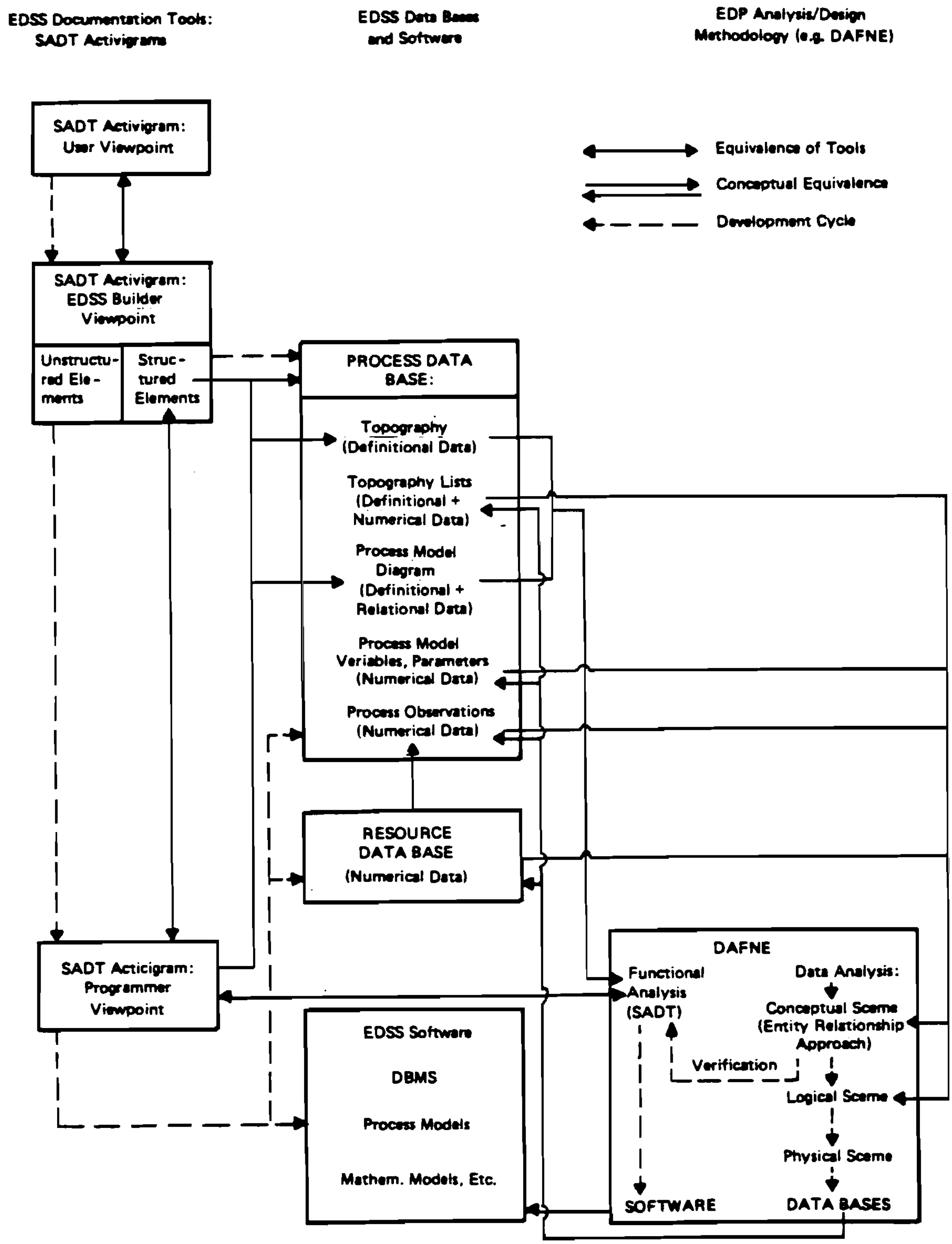


Figure 13. Conceptual and/or physical equivalences between EDSS operation documentation language SADT, EDSS process data base documentation and formal EDP analysis and design techniques (DAFNE).

methodologies (for cataloguing, documenting, analysis, etc.) across sectors (i.e. socio-economic *and* environmental such as air, water, energy, etc.), across organizations (government, governmental agencies, private/public industries, academic institutions, etc.) and finally across study disciplines.

The CSI as a governmental agency, has an explicit mandate to perform a task such as that described above. However, it is lacking the necessary methodological apparatus to integrate an ensemble of various activities already performed at the institute and to valorize them better. This paper is intended as an attempt to improve this situation.

We consider that the proposed EDSS methodological (and conceptual) apparatus respects the real differences in problem context and content (i.e. different activity levels, structured versus unstructured tasks, different problem contents, etc.) whilst still providing logical consistency (equivalence) betwen the specific methodological tools proposed (e.g. both SADT and the process description methodology (Topography, Process Model) are based on the concept of, and the representation of, an activity, a process).

The logical consistency of the proposed system is provided by a common analytical approach; in the use of diagnostic/descriptive techniques as the first step towards solution design. The first analytical activity proposed is to make a map, (activigram, topography) of the task, (activity, process) starting from the user's viewpoint instead of using normative/prescriptive techniques. This is especially important as the EDSS addresses *semi-structured* tasks. Also, once the importance of unstructured elements in decisions (political objectives, public opposition, etc.) is recognized, there follows logically, the request for *flexible* tools responding to the changing perceptions and requirements of decision makers. Thus, the proposed EDSS is conceived as a *learning tool*, i.e. the system, through its existence and ease of access enables the user to learn from experience rather than *forcing him, from the beginning into a normative/prescriptive framework.* This of course does not preclude the use of normative/prescriptive techniques (in particular, during the choice phase of the decision making cycle) in the EDSS, but the overall design of the system allows the use of *many* techniques and models (for instance, a process may have many paradigms, etc.). The choice of the most appropriate one is seen as a function or product of the decision making cycle itself.

The EDSS will only improve the performnce of the decision makers if it is a LEARNING tool for him in respect to his decision tasks. A tool which will be enriched (process information, quality of information, range of alternatives considered history of decision rules, i.e. activigram data base and so on) the more it is used. The stepwise implementation procedure of the EDSS aims to respond to this "user learning process" as well as to the dynamics of a particular task within the decision support framework (i.e. the phases of the decision making process, management levels involved, changing combination of structured and unstructured elements involved in (a) task).

The principle of seeing the system as a learning tool (implying thus evolving "paradigms" of a particular decison making cycle) and the documentation followed throughout the EDSS operation, enables users to expand their *"bounded rationality" vis-a-vis* the management of (particular) environmental problems. *This should be the criteria used in judging the systems' success.*

The technical problems involved by the proposed EDSS implementation are considered relatively minor when compared to the organizational and educational problems involved.

These technical problem areas include:

- verifying the integrity of the specific EDSS methodologies proposed, through a number of pilot case studies.
- developing "translating" software to ensure that tools already in existence in different operating environments (and with which the user may already be familiar) can communicate with the EDSS;
- ensuring that the practical *system design is* not a function of technological problems but *a function of the user requirements* on the system (i.e. the system being a function of how the user looks at the world, how *he* perceives the decision making process). This includes the possibility to combine centralized solutions (e.g. the implementation of the process data base) and decentalized solutions (e.g. access to data and models through user friendly, interactive access languages and/or decentralized implementations on personal computers).

Of course there are many technical points not developed in the paper or just have touched upon. In particular, conceptual and technical developments in the context of man-machine interface:

- handling (from a software viewpoint) of the representational languages within the system, in particular a software implementation of SADT. *Note that the process data base documentation languages software (developed by Statistics Canada) already exists.*
- system access languages (powerful, natural language DBMS, interactive data retrieval/analysis languages, etc.). Here we note that desired flexibility in this domain might be complicated by the decision to deploy the Entity Relationship Approach of DAFNE for data analysis as already in use at the CSI. We note further the existence of the interactive, hierarchical data access and filtering software TREE (implemented on top of a DBMS) developed at IIASA.
- related to the first point above, *we note the possibility* of recording historical decision rules and *to make interferences about future decision paradigms* from an analysis of the information recorded (however we consider this as a more long-term project).

Finally we consider the area of evaluation methodologies including ensuring sufficient feedback to system design and system capabilities, as a field requiring further development. However, this should run in parallel to EDSS application studies (see appendix A2-1 for a more detailed discussion).

The authors recommend that the next step in the EDSS implementaton is to consider as quickly as possible pilot applications involving a mixture of work groups (different management levels at the governmental and the industrial level, academic institutions, and CSI staff) and tasks involving a combination of structured and unstructured elements (e.g. district heating systems, air pollution, substitution of coal for oil in power generation and related environmental problems, questions of introduction of renewable, decentralized energy systems, etc.).

In addition, we recommend a further collaborative outreach activity from the side of the CSI (similarly to the one which lead to this paper) in order to learn from other experiences and to acquire software outside of the CSI organization. This is important in order to avoid duplicate efforts and "reinventing the wheel" both for the EDSS design (here, we note that the area of Decision Support Systems and its ancillary subjects, i.e. handling structured *and unstructured problems*, the use of representational techniques, AI, etc., promises much, but is still relatively new) and in the area of the EDSS test case studies.

APPENDICES: BACKGROUND MATERIAL, REFERENCES AND SYNONYMS RELATIVE TO THE EDSS

APPENDIX 1: AN INTRODUCTION TO THE REGION OF PIEMONTE AND THE ORGANIZATIONAL ENVIRONMENT IN WHICH THE EDSS WILL BE IMPLEMENTED

A1-1. THE REGION OF PIEMONTE

The Region of Piemonte[33] is geographically located in North-West Italy. To the North, the Region is enclosed by the Arc of European Alps (explaining the literal translation of "Piedmont" - "at the foot of the mountains"). To the West it is bordered by France, to the North by Switzerland and the Italian Region of "the Valley of Aosta", to the East by the Regions of Lombardia and Emilia and to the South by the Region of Liguria. The territory consists of 25,397 km^2. of which 10,990 (43%) is mountainous, 7,700 km^2. (30.3%) is hilly and 6,710 km^2 is lowland. In the lowland runs the Po river which, has formed the famous "Plain of the Po". Located along the Po is the largest city in Piemonte, Torino (Turin) which is the centre of the Region's industrial activity with 1,143,200 inhabitants.

In Piemonte reside approximately 4,457,000 inhabitants. Piemonte has a long industrial history and this is reflected in the distribution of its working population. Of a total of 1,719,000; 975,000 (56,7%) are employed in industry, 220,000 (12,79%) in commerce, 183,000 (10,0%) in agriculture, 172,000 (9,95%) in tertiary services, 67,000 (3,8%) in public administration and 102,000 (5,9%) in other activities.

Economically, the Region is highly developed and characterized by a diversity of income generating activities. The industrial sector includes the most important automobilistic industry in Italy, the major electronic industry, an important aero-space sector, and it is world renown for machine tools. In the agricultural sector, beef stock breeding, rice pro-

[33] See also Wooding, 1982.

duction (highest productivity per hectare in the world) and wine production are major income sources. Finally, the mountainous areas in the arc of the European Alps furnish Piemonte with a thriving tourist industry throughout the seasons of the year.

A1-2: THE PUBLIC ADMINISTRATION

The constituion of the Italian repubic, decreeds that the Italian public administration be divided into local (Comuni), provincial (Province), and regional governments (Regioni). There are 20 regions in all and as from 1970 a process of devolution (decentralization) of power from the State affords the regions with a notable degree of autonomy. Each region has its own elected parliament and (in certain areas) it has the power to legislate for which its legislation, within its administrative boundaries, has the same value as legislation deriving from the national parliament. The autonomy at the regional level means that each region has the power to devise its own socio-economic plans and in Piemonte these plans are formulated on a five-year basis.

The local government (Comune) is the smallest administrative unit in the Italian public administration. In Piemonte there are 1209 such local governments and their basic function is the administration of the public services available to the private citizen. At the head of each local Government is a Mayor who is elected by a board of governors which, in turn, is appointed by public elections.

The administrative unit between the regional and local levels is the Province and in Piemonte there are six such administrative units. Also the Provinces have the function of administrating a number of public services, but where such services involve a territory including several local governments (Comuni).

Beside this traditional (territorial) sub-division the Region of Piemonte has further divided the Region into 15 development areas (called Comprensori). Each area has homogenic characteristics from the socio-economic viewpoint and the purpose of the sub-division is to aid in the development of an appropriate socio-economic policy specific to the special needs of each development area.

The local governments located in the mountainous areas (in Piemonte there are 44 such governments) are, in accord with national legislation, grouped into an administrative unit literally called "Mountain Community" (Comunita' Montane) which has the primary task of administering agricultural, urban and recreational development in the territorial area covered by the "Community".

Following the introduction of the national legislation which laid the foundation for the development of an Italian National Health System, activity in the area of health is entrusted to an administrative unit nominated "Local Health Unit" (Unita' Sanitarie Locali, or, more simply, U.S.L.) which have the function of co-ordinating the health services, including hospitals, at the local scale. In Piemonte there are 76 such units.

This schematic and by no means complete description of the administrative structure in the regions of Italy, and in particular Piemonte, give some idea of the complexity of the Italian public structure; a complexity no doubt augmented by the process of devolution (decentralization) started in 1970. Also, from this arises the need to equip the public sector with the computing technologies and methods necessary for the correct and efficient functioning of the sector itself, and this explains one of the motivations for the creation of the CSI-Piemonte by the Regional Government in 1975.

A1-3. THE CENTER FOR INFORMATION SYSTEMS (CSI)

In 1975, for the first time in Italy, the regional parliament of Piemonte, decided to entrust to a single regional authority - the CSI-Piemonte - the coordination of all activities with respect to the utilization of informatics related methodologies and sciences within the region's administrative and academic structures. This policy was effected through a common accord between the Regional Government itself and the University and the Polytechnic of Torino. The CSI's specific objectives can be usefully summarized as follows:

- to provide the region's administrative structure with an "information base" and appropriate planning instruments oriented at the tasks of defining and implementing correctly conceived socio-economic policies. Such policies have to be balanced in the sense that they must be compatible and integrated with the region's cultural, ecological and environmental welfare;
- to ensure that the Piemontese public administrations, with respect to their informatics related methods, procedures and equipments are adequately structured, in the attempt to continually improve the services offered to the private citizens;

- to furnish the University and the Polytechnic of Torino and the Region's different research institutes with a scientific computing capacity adequate to their needs whilst also realizing the economies of scale attributable to an efficient management and coordinated utilization of the computing resources made available in the Region in this regard;
- to promote a cultural and didactic activity with respect to informatics related methodologies and sciences with the scope of ensuring that the region's various social, educative, economic and administrative structures are adequately informed and prepared in this respect.

The CSI's major role in the Region's effort to satisfy the previously noted objectives is the organization, management and diffusion of data, information and appropriate analytical methods and instruments. Such activity is undertaken according to two guiding principles. Firstly, to develop information systems which are directly relevant to sector specific applications problems and policies. Secondly, to do so through the employment of practices, techniques, concepts and methods (deriving from the science of applied systems analysis), that are sufficiently general to be common to each sector specific area. *The purpose being the development of a unified framework composed of many sector specific applications.* (i.e. along the lines of the EDSS proposed in this paper). The framework is to be used by the regional government and its various ministries as an instrument in the definition, implementation and verification of policies. In particular, in the evaluation of the significance of the relationship and interactions between sector specific policies.

The CSI is directly responsible to the regional government for the development of such a unified framework and in the provision of informatics capacity with respect to the development of sector specific information systems. However, the development of the latter necessitates the pooling of skills and resources outside of the immediate sphere of influence of the CSI. Operatively, this is achieved through the organization of multi-organizational, multi-disciplinary work groups (such work groups are conceptually analogous to those described by Holling (1980) in Adaptive Environmental Assessment and Management) delegated with specific objectives and targets. Such work groups enable the CSI to develop sector specific applications by building on conceptual, methodological and operative contributions from:

- the interested regional ministries and local administrations;
- the relevant academic structures both within and outside of Piemonte, and
- industry

With respect to the latter point it is important to note that each sector specific system is directed at a defined policy objective. Hence, any research activity to be conducted in the development of such systems is applied in nature.

The CSI employs presently a staff of around 240 persons with an annual budget of 18.75 billion Italian Lires (around 11.5 million US Dollars). Its computer configuration (see Figure A-1-1) include two main Hitachi computers running on IBM operating systems (MVS, TSO) and a number of Digital Equipment Computers (DEC 10s being currently replaced with VAXs) mainly used by the universities located in Torino and for graphics applications (Kongsberg system). The main intervention areas of the CSI are in the following areas (for more details see CSI, 1983b and CSI, 1983c and other references in reference list):

- Consultancy and systems development for Piemontese local, provincial and regional administrations - covers everything from public accounts to salaries.
- Regional health system.
- Regional library systems,
- Air pollution and energy (CSI, 1983a; CSI, 1982a; 1982b;)
- Agriculture,
- Transport planning,
- Meteorology (Bacci *et al*, 1982; Collo and Wooding 1982)
- Territorial planning,
- Productive activities and labour market,
- Commerce and small businesses,
- Artificial intelligence,
- Office automation.

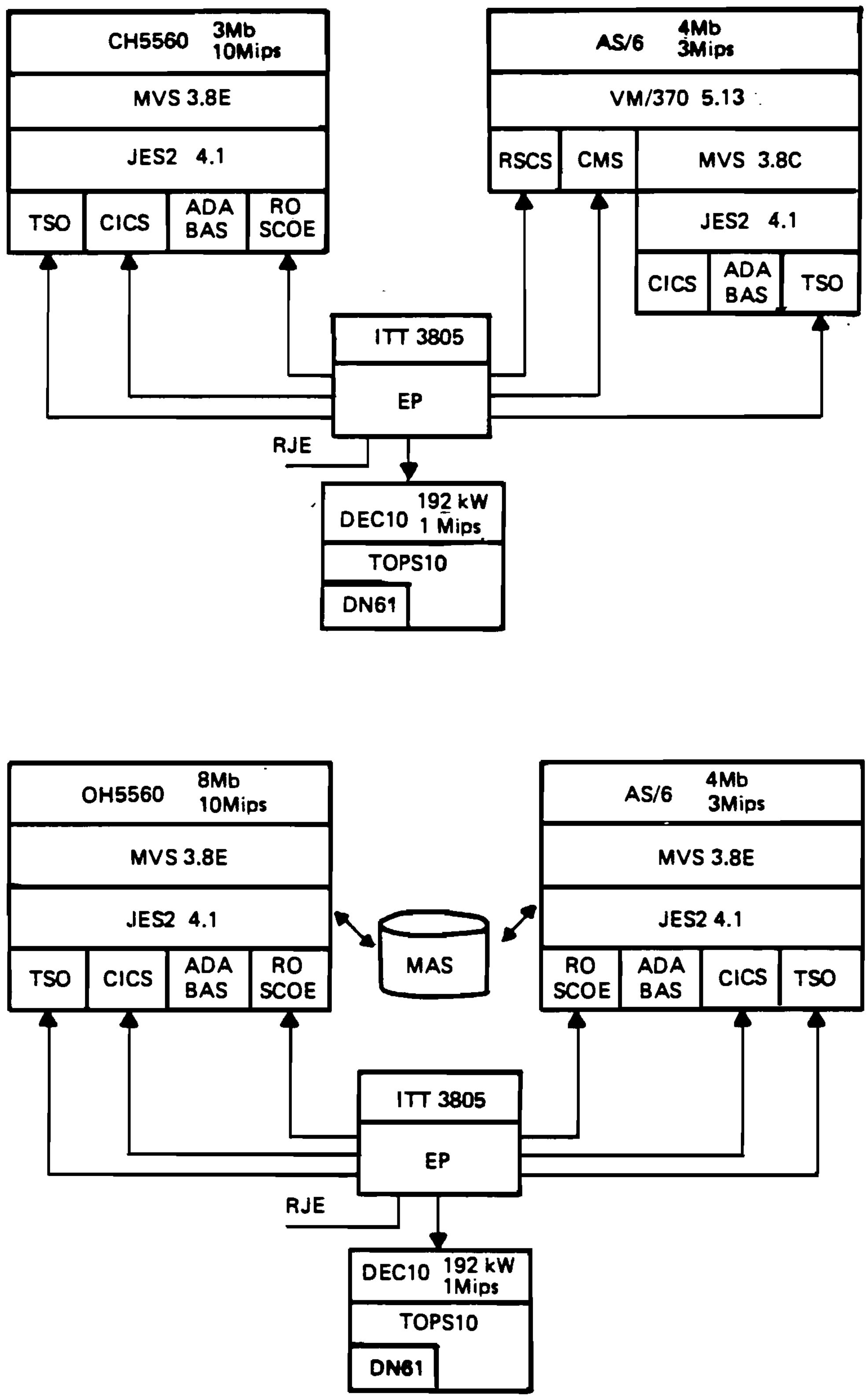


Figure A-1-1. An overview of the CSI computer configuration (DEC 10s currently being replaced by Vaxs)

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APPENDIX 2: DECISION MAKING CYCLES AND DECISION SUPPORT SYSTEMS

A2-1: AN INTRODUCTION TO DECISION SUPPORT SYSTEMS (DSS)

The concept of DSS and especially how it relates and differs from traditional electronic data processing and so-called Management Information Systems will not be discussed in detail. We just refer to a number of basic references. In particular, to W. Keen and M. Scott Morton (1978), W. Keen (1980), and the articles contained in the Decision Support Systems proceedings volume, G. Fick and R. Sprague, Editors (1980), where the concept of DSS and the various views and applications of it are adequately discussed. It also provides a good overview of the (abundant) literature relative to the topic.

For the purpose of our EDSS we will follow the definition of DSS, as proposed by R. Sprague (1980) as an: *interactive* computer-based system, *helping* decision makers to use *data* and *models* to solve mostly *semi-structured* problems. The DSS is defined within a framework having as its axis, the management level and the degree of formalization (structure) of a particular task, as illustrated in Figure A-2-1.

The third dimension of the framework are the phases of the decision making process as discussed for instance by W. Haseman and M.Kellner, (1977); C. Kriebel; M. Simon, (1960), and R. Gerritsen, (1975).

We have discussed already in detail in the text the various phases of the decision making cycle (or process). Let us summarize them again here briefly:

- intelligence (problem identification);
- design (development and analysis of possible solutions);
- choice (selection of particular courses of action);
- implementation (control of implementation of decisions taken);
- evaluation.

Evaluation, within the context of DSS *has two dimensions*. The first deals with improving, by *learning* from past experience the performance and execution of the other phases of the decision making cycle. The second is to improve the "daily praxis" of the decison maker. Evaluation provides both the opportunity of and the material for learning and provides a *feedback mechanism* ensuring *continuity*. However, that to be evaluated is not the DSS as such, but rather the effectiveness of the decision makers *praxis*, which is by definition something wider and more complex than the DSS understood as a combination of methodologies and resulting tools (i.e. the DSS data bases and software).

More specifically we understand by evaluation:

- (formal) methodologies for
- comparative analysis in time
- of a decision making process (praxis) which is evolving in time and complicated, by the fact that,
- the organizational *context* is also changing in time, due to factors which are completely outside of the DSS's control.

Any evaluation methodology must be characterized by:

- feedback mechanisms in order that *evaluation* is not seen as something to do *after* an event, but as something to initiate from the beginning - as a praxis of the implementation phase of the decision making cycle.
- flexibility in that it should be capable of *capturing* many viewpoints of the same praxis (i.e. many "paradigms" of the same decision making process) according to the nature of the specific praxis studied and the real actors involved.

Thus, evaluation methodology means a scheme characterizing the prior definition of improvements expected by the user; evaluation criteria; formal procedures or techniques (based on the evaluation criteria) planned in time (e.g. interviews, questionnaires, etc.); control of implementation and a feedback to the earlier mentioned evaluation methodology characteristics.

Regarding the evaluation procedures (techniques) and the criteria they contain, we are not advocating any particular technique but advocating evaluation as:

- *implementation praxis* and
- the decision making cycle's "self-contained" *learning feedback mechanism*.

The particular technique to be used will be chosen (or devised) during the design phase of specific EDSS applications as a function of the peculiarities of the specific praxis considered.

Specific evaluation techniques that come to mind are:

1. Decision output tables

   - the "ideal" measure but often not sufficient.

2. Changes in the decision making praxis

   - measure the plausibility that changes have resulted in benefits.
   - disaggregate praxis into distinct functions, establish ***traces*** (including software traces), "map" user behaviour in time, etc.

3. Changes in user concepts and evaluation of user perception of system:

   - considering the EDSS as a learning tool expanding the "bounded rationality" of the user.
   - assessment of quality of information, number of alternatives considered, etc.
   - using questionnaires, structural interviews with the user, etc.

Note that these techniques are closely interrelated. Also, that they are mainly concerned with the *effectiveness* of the *decision maker*. *Those that follow, are more oriented towards efficiency* but are complementary to the above listed techniques.

4. Procedural changes. Concerns everything which is physical rather than "mental" but can be important as effectiveness is also the "speed of response" of the decision making pro-

cess to a particular situation.

5. Cost/benefit analysis

6. Measures of service including:

   - flexibility of EDSS

   - access to computer (ease of use, protection from computer crashes).

   - quality of information of the EDSS, reliability of data, data quality indicators etc.

   - quality of documentation, access languages, education, etc.

   - capital and operating costs.

7. User evaluation

   - Structured interviews

   - Questionaires

   - Using information from other techniques.

8. Keep a "daily" diary of events.

These are just some thoughts concerning the evaluation phase of the decision making cycle (process), which we have dealt with in some detail here, as it was hardly touched upon in the proper text of this paper. However, it is a highly important topic implying a radically different approach to that typical of areas such as EDP, OR/MS, etc.(i.e. in the area of DSS, evaluaton is *an ante, a post and continuous activity*, not simply a post). Still, it is evident that the requirements for these evaluation techniques will become apparent only at a later step of the EDSS design and implementation (i.e. after the first experimental pilot implementations based on a number of case studies).

Let us now return to the discussion of the DSS framework. The third dimension is the decision making cycle (whose phases - as a final point on this subject - should not be considered as a linear time sequence without overlaps, feedbacks, etc. The second dimension of the DSS framework is the management levels involved in a particular task. We can briefly summarize these within the three categories as proposed by R. Anthony (1975), and discussed by A. Barbarie (1981), and W. Haseman and M. Kellner, (1977):

- Strategic planning: in a simplified form we may say that decisions at this level deal with the relations of an organization with its environment. In Anthony's classification it is the process of deciding the objectives of an organization, the resources used to attain these objectives and the policies for the acquisition, use, disposition and allocation of these resources.
- Management control: this involves the management and coordination between the different activities pursued by the various entities of an organization given the objectives defined at the strategic planning level. Anthony speaks of the process by which managers assure that resources are obtained and used effectively and efficiently in the accomplishment of the organization's objectives.

- Operational control: this activity does not involve coordination between different tasks or organizational entities, but deals with the management of a specific task or problem inside organizational entities in order to assure that "specific tasks are carried out effectively and efficiently" (R. Anthony, 1975).

Finally, the last dimension of the DSS framework is the degree of formalization of a particular task between the extremes of completely structured (or programmed) and completely unstructured (non-programmed) tasks (based on M. Simon's (1960) distinction between programmed and non-programmed decisions (see also R. Anthony, 1975 and G. Gorry and M. Scott Morton, 1971)). Here the terms formalizable, structured or programmed are used interchangeably when referring to decisions which are repetitive and routine to the extent that a precise procedure has been elaborated, which, in principle, is automizable. This implies also that the decision is based on observable variables. Non-programmed or unstructured decisions are novel or involve non-observble variables. However, the concept of "structure" or "unstructured" in decision making is heavily dependent on the decision makers perception of the decision making process. Thus, even when a decision in principle appears structured or completely formalizable (in an ideal scenario where there is no insufficient information) the particular decision maker (i.e. the user of the EDSS) may perceive the decision involving (value) judgements, politics, etc. Hence, the DSS has to respond to the perception of the decision making process of the user and not vice versa! Semistructured decisions (i.e. the main area addressed by a DSS) in fact combine elements from the above outlined extremes. G. Gorry and M. Scott Morton (1971) define semi-structured decisions as decisions where one of the several phases of the decision making process involve unstructured elements or are nonprogrammed.

The combination of the two dimensions management level and structure of the decision task yields the framework of information systems activity, proposed by G. Gorry and M. Scott Morton (1971) and as illustrated in Figure A-2-1. We have expanded the two-dimensional DSS framework to a three-dimensional one to include the decision making process phases. There is, of course, a relation between the axes of this framework. Decisions at the operational control level are rather structured, whereas at the strategic planning level they are rather unstructured. Intelligence and choice are more related to the upper management levels whereas implementation is more related to operational/management control, with supervision from the strategic planning level. The EDSS addresses mainly structured and semi-structured decisions or tasks and to a certain extent also unstructured ones. The arrows around the decision of power plant location in Figure A-2-1 indicate the dynamics of a particular problem within the framework:

- the decision can be located at the management level alone. In case illustrated, only the planning department of an electricity company would make the decision. It moves to the strategic

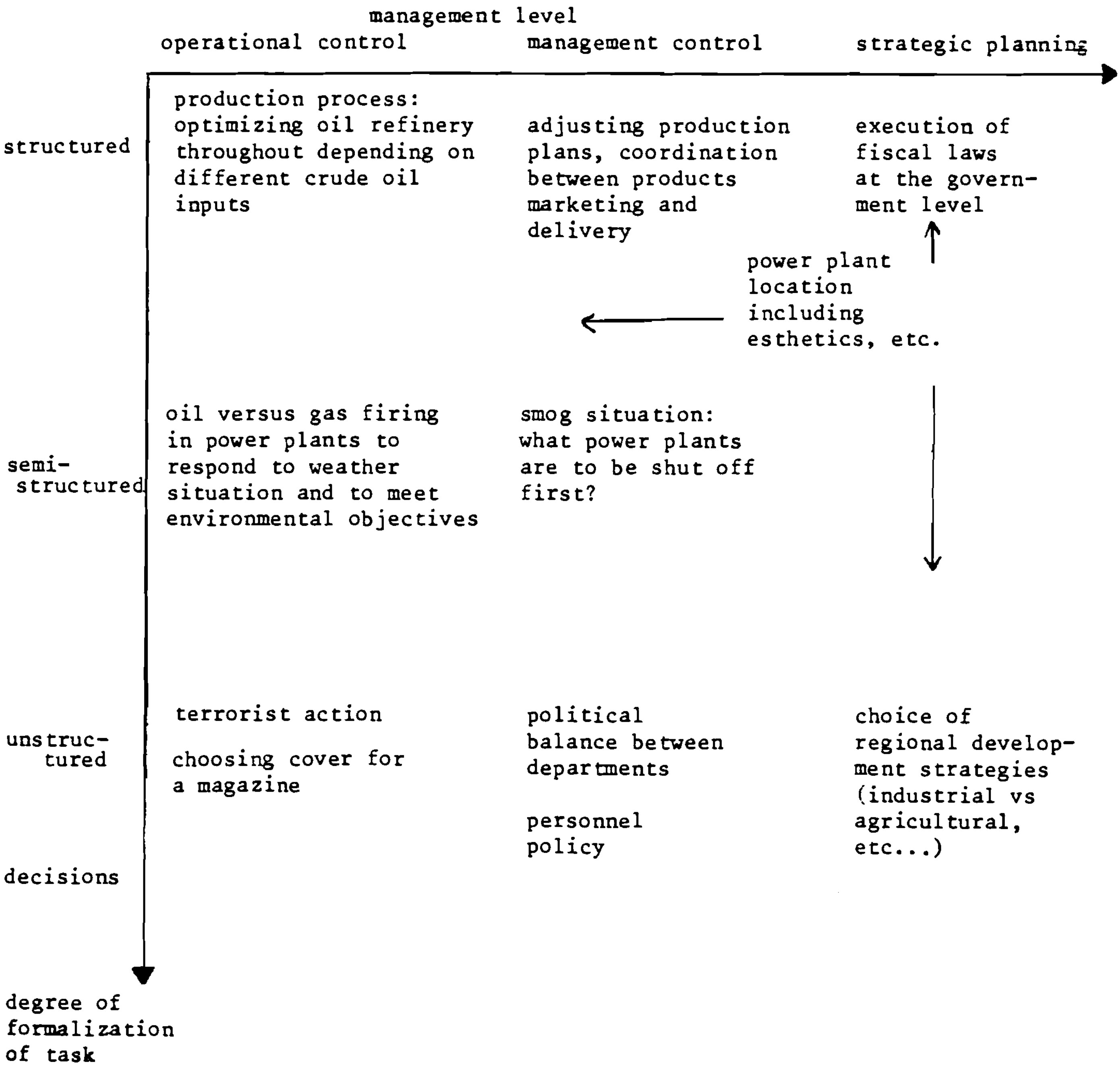

Figure A-2-1. Information systems framework with illustrations planning level when the decision involves negotiations with government bodies, etc. Similarly the decision might take into account only technological logistics (required additional capacity, optimal location for transportation grid, available cooling water, etc.), i.e. the decision is a structured one, or it may include additional (non observable) criteria: public opposition, esthetics, etc.

The fact that the DSS is addressing primarily semi-structured problems, or problems which evolve dynamically within the DSS framework, implies that the DSS (requires a series of *innovative implementaton strategies typically called adaptive designs*, for instance, "*approche evolutive*" (J. Courbon, et al., 1979) or *middle-out design* (D. Ness, 1975). The underlying idea is to identify a relevant problem and to tackle it right away in order to give the decision maker something to work with. From this "embryonic" start (A. Barbarie, 1981) the task and its methodology can be further defined and the whole system can evolve. This implies learning both from the part of the user and the designer/analyst. The EDSS assure this flexibility and adaptive approach as the user starts first with a simple model of the decision and the (physical) processes related to it (stored in the process data base), which in the course of the study will be consequently refined and become more comprehensive. To this end, the DSS has to assure the inclusion of numerous interlinked smaller models designed to be used separately, but also interactively by analysts, policy makers and decision makers at various levels (J. Kindler and D. Loucks, 1982). Hence, both the analysts' and the users' communities can explore and understand better the key issues of a problem, identify what options for conflict resolutions are available and assess impacts of alternative policies. This in return feeds back into the DSS, generating more comprehensive models, (i.e. new paradigms of a process) additional data, etc., thus enriching the DSS for further applications. This adaptive approach is an important consideration for the EDSS support organization, as it calls for quite a different culture towards systems implementation than that typical of EDP, etc. This must be kept in mind when training the EDSS support staff.

A2-2 : DECISION SUPPORT SYSTEMS (DSS), MANAGEMENT INFORMATION SYSTEMS (MIS) AND OPERATIONAL RESEARCH / MANAGEMENT SCIENCE (OR/MIS)

Many of the concepts of DSS are also characteristic of MIS and the fields of OR/MS in general. However, we claim that DSS represent a distinct field from at least two viewpoints. Firstly, in terms of its approach, in particular, that the effective design of management oriented information systems must be based on a detailed understanding of management decision processes utilizing diagnostic and descriptive methodologies (see P. Keen and M. Morton, 1978), rather than the prescriptive and/or normative methods typical of the OR/MS areas. Secondly, DSS are distinct in terms of their impact on and relevance for managers. DSS imply the use of computer related technologies and sciences to:

1. support managers in relation to decision making in the context of semi-structured tasks;

2. aid managerial judgement rather than replace it;

3. improve decision making ***effectiveness*** as distinct from its efficiency. Here, DSS is concerned with issues such as ***managerial cognitive processes, learning methods, bounded rationality,*** etc.;

It should be evident from these "systems objectives", that whilst the possibility of implementing DSS is based on technologies typical of IS (data processing information systems), this "technological connection" is practically the only linkage between DSS and IS. In fact:

1. DSS requires radically different design and implementation strategies to those used in the IS area, as

2. DSS systems aim to be relevant to, and in the context of the "daily praxis" of the strategic decision making process.

These comments should not surprise us as IS systems have never aimed to achieve such "system objectives". At best, they have only aimed to do so in a most indirect and remote sense.

Looking at the relationships between DSS, MIS, OR and MS, the following summary is useful.

1. MIS systems

   1.1 Are ***addressed to structured tasks*** for which operating procedures, decision rules, information flows, etc. can be well defined. The major impact of such systems has been in this area.

1.2 The major gain of MIS systems has been achieved by *improving efficiency*, i.e. reducing costs through reducing clerical staff, increasing turnaround times, etc.

1.3 The impact on the decision making process has usually been *indirect* - reports, summaries, information access, etc.

2. OR/MS

2.1 These have, again, mainly been addressed to structured situations (but to problems rather than tasks) in which objectives, information, constraints, etc. can be accurately predefined.

2.2 The *gains* achieved have been in terms of *devising better solutions* to certain classes of problems, i.e. plant location, operational control, economic forecasting, etc.

2.3 The *impact* on the decision making process has not been on its "daily praxis", but in the *provision of detailed recommendations* for dealing with complex problems.

3. DSS aims

3.1 To address decision making situations where there is sufficient structure for the employment of analytic methodologies, but *where managerial judgement is essential*. In other words, DSS aim to be relevant to semi-structured decision tasks.

3.2 The gains sought are in *extending the "bounded rationality"* of the manager, thus to improve his *effectiveness*, in other words, to improve his overall performance. If the user is represented by multiparty decision makers, DSS also aims at improving the communication between different organizations and the "effectiveness" of the problem solution capabilities.

3.3 DSS aim to be relevant to managers by providing a supportive tool which *does not pretend* to automate the decision making processes, to provide prescriptive solutions (as distinct from alternatives) or to require predefined objectives.

The DSS system building approach emphasizes the use of analytical methods that are diagnostic and descriptive in nature. The use of such methodologies is common to all classes of DSS systems. Another common feature is that of basing system design on the structure, context and dynamics of the decision making process (as discussed already in the text). However, precisely because such systems aim to be relevant to "the daily praxis" of specific decision making situations, they have to be tailored to such situations and we cannot think of "typical designs". The DSS discussed in this paper is an *ad hoc system* designed for dealing with environmental problems. It is only a generalized system in the following senses:-

1. it recommends the use of design and implementation strategies based on the diagnosis of, and description of the decision mak-

ing process and of the socio-economic and natural processes the decision deals with.

2. Many classes of DSS systems require the development of specific tools, languages and data base management systems. The system discussed here uses a different approach. It aims at integrating tools, languages, data base management systems, etc., *with which the user's community is already familiar*, even though some of these may be mutually incompatible in the sense that they exist in different operating environments. Thus, its implementation would require hardware/software translation solutions. The authors would like to reiterate that they focus not on any particular software tool proposed in this paper. They are presented to illustrate that the tools supporting the concepts of the proposed EDSS *do exist* and can be integrated.

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APPENDIX 3: EDSS DOCUMENTATION LANGUAGES

A3-1: SADT AS A DECISION MAKING CYCLE DOCUMENTATION LANGUAGE

Let us briefly summarize the objectives of the EDSS documentation language SADT, which we have already outlined in Chapter 3 of this paper.

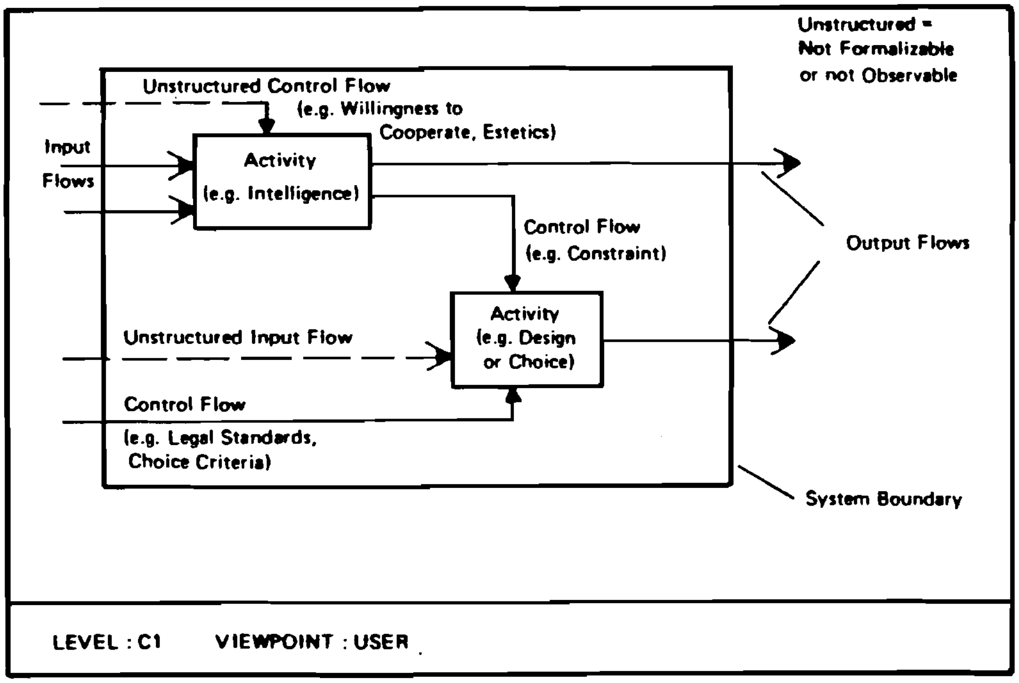
The language provides an ongoing documentation tool which both integrates and formally separates the design and implementation functions. The language allows equally to represent and to document the various viewpoints (paradigms) of the same decision making process (i.e. what we have termed the user, EDSS builder and the programmer viewpoints. Further, due to the representation of data flows connecting the activities (transformations) of a SADT "activigram" *the data management problem is exposed right at the outset.*

These features are, within the dimension of the enterprise described here, from the managerial and user viewpoint, fundamental. In particular, this feature of the structured language *enables the* "horizontal" and "vertical" *division of labour*. Specific tasks such as documentation and design can be spread across disciplines and organizations, whilst projects can be conducted at different developmental phases, i.e. identification, design and implementation phases may be concurrent.

For a more detailed discussion on SADT the reader is referred to the publications listed in the reference list (in particular to Ross and Schoman, 1977 and Softech Inc. 1976). Here we will just summarize briefly the graphical representation conventions underlying the EDSS documentation language, especially as in some points modifications and alterations for the EDSS discussed were necessary. A particular decision making cycle is always represented by at least two viewpoints: that of the user and that of the EDSS builder (coordinator). A third viewpoint may be included (the software engineer) in the implementation phase of the decision making cycle, when specific pieces of software are to be implemented. However this viewpoint "activigram" is not so much an inherent tool of the EDSS itself. Rather it is a mechanism for linking to the EDP documentation tools (recall here the discussion of chapter 4.9 of this paper).

Thus the activigrams include first the description of *the problem context* (i.e. what decision making cycle is addressed) as well as the *problem viewpoint* (user, EDSS builder, programmer).

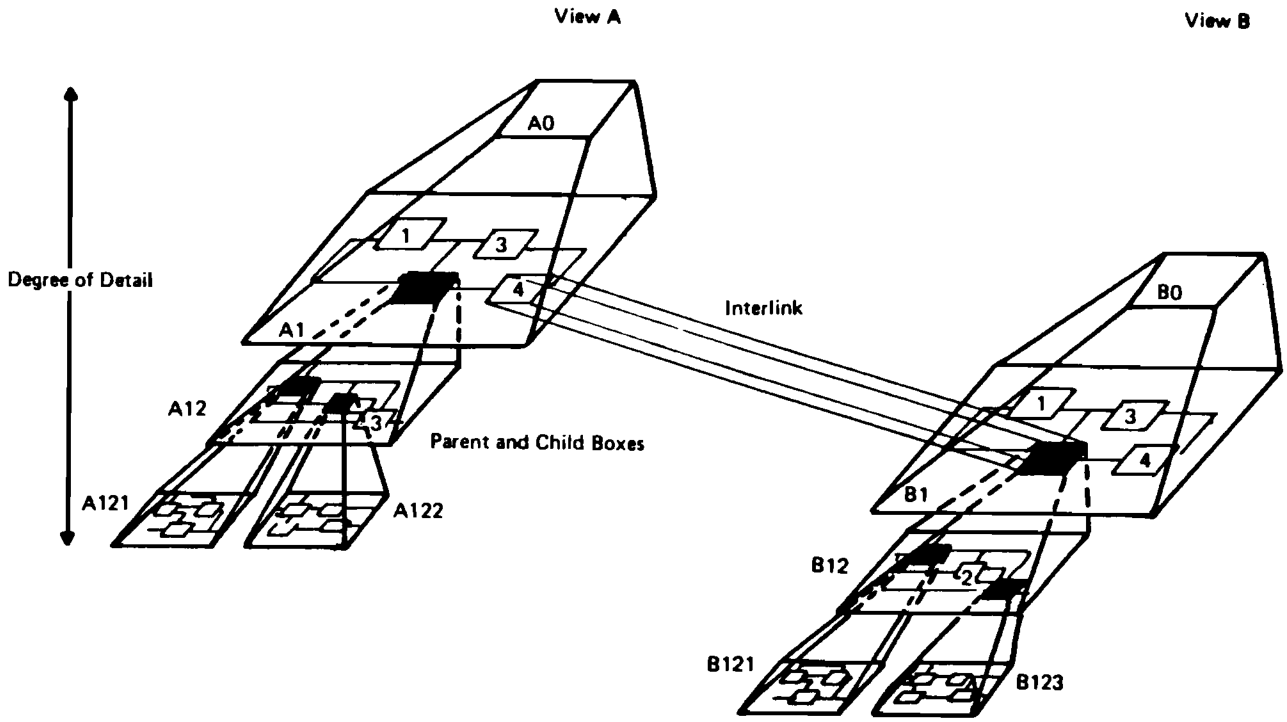
The "activigrams" differentiate between activities/transformations and information and data flows. Flows may be *structured/observable*, formalizable) and *unstructured* (not observable). Flows may designate or originate a transformation/activity or provide *control* on its operation. Within the context of structured flows, controls constitute typically things like data standards, constraints, objective functions within an optimization framework, formalizable choice criteria (e.g. $a \geq x$, etc.) or the like. Graphically this is represented using the following conventions:



Conceptually the "activigrams" are based on a top-down development approach. This is represented by the structured hierarchical decomposition of the diagrams. Thus any activity in a diagram may be further disaggregated into a number of sub-activities at a lower (more detailed) representation level. This is equally documented on the various activigrams, through a system of enumeration, corresponding to the nodes (i.e. the activities) of a tree-like hierarchical structure[34].

Of course, the way and the detail of disaggregation of the activities pursued in a particular task in the "activigrams" (based on the different viewpoints) may be different. The activities of viewpoint A may equally correspond with activities of viewpoint B at a different level of aggregation.

[34] Recall here the conceptual equivalence to the TREE hierarchical data access software, discussed in Chapter 4 and Appendix 4 of this paper.



This is the last feature included in the "activigrams", namely the precision of the correspondence of the activity described with the activities of the diagrams referring to the *same* task but from different viewpoints, e.g. in the form of $A_1 \approx B_2 \approx C_{311}$.

Finally, in relation to the activities described in a diagram, the SADT methodology foresees equally, that in supplement to the proper diagram, the individual activities and the flows involved are described in more detail. This is the starting point for data analysis and functional software specifications (this however applies only to the EDSS builder viewpoint and the programmer viewpoint diagrams).

A3-2: AN ILLUSTRATION

In order to illustrate the potential role of a documentation language like SADT, EDSS builder viewpoint "activigrams" for an IIASA case study dealing with the impacts of centralized versus decentralized renewable energy resource development at the regional level were developed. This study, which serves as an illustrative example here is extensively documented by Katsonis and Gourmelon (1983). Examples for the associated process descriptions in the proposed EDSS format can be found in Appendix 4.

The main problematique addressed by this study was to evaluate the impacts associated with the development of renewable resources (in particular solar energy) for the supply of energy (electricity) at the regional level, to evaluate alternative energy systems in terms of their systems configuration, their level of centralization/decentralization, their economics and their resource impacts.

In terms of the actual data input (energy demand, solar radiation, etc.), the study was applied to a region in southern France, however, the region described and the problem addressed can be considered as typical for a large number of regions representing similar geographic and socio-economic characteristics.

The region is "poor" in terms of indigenous energy resources being thus obliged to import the energy requirements (for instance, electricity) from other areas of the country or from abroad. From the perspective of a global harmonized development of the region, it does not appear desirable to plan the construction of large size classical power plants, relying on imported primary energy carriers (oil, natural gas or coal), increasing thus the (political) dependence of the existing energy supply system and generating an additional source of air pollution.

On the contrary the objective is to develop local energy resources, increasing thus the region's self-sufficiency and inducing further stimulus to the development of other regional resources (industrialization, employment, etc.). The harvesting of solar energy is particularly attractive for the regional development as a complement to large scale centralized plants installed at the national level, both in that it enables the implementation of such a system with resources available at the regional level (provided a certain local industrial know-how) and contributing to its socio-economic development, as well as in improving the environmental quality of the region. This through (a) matching better the energy services requirements of the consumers in terms of energy carriers required, load curves, etc. (i.e. through a (partly) decentralization of the energy system) and (b) by substituting conventional fossil power generation capacities, which are major contributors to environmental degradation.

The following figures A-3-1 to A-3-10 try to illustrate how the EDSS could intervene within a case study addressing the problematique outlined above. The activities pursued include the definition of the (sub) region in terms of the renewable resources available (e.g. solar radiation), assessment of the regional energy demand, development of alternative energy supply scenarios and assessment of their impacts (see EDSS builder viewpoint activigram level A0 (Figure A-3-2)).

Of particular interest is how the proper EDSS tools, proposed in this paper intervene in such a case study, in particular the process data base with its associated process models and their linkage to other mathematical models (in the case study illustration the MINOS linear programming package): see in particular, level A6 (Figure A-3-8) and A7 (Figure A-3-9) diagrams. Note that the representation of the technical realization of such a linkage is subject to the programmers' viewpoint of the SADT diagram.

With reference to earlier statements in this paper we would like to emphasize again the adaptive design strategy used in the EDSS development and the resulting "evolutionary" character of the "activigrams" documenting it. Consequently the following figures are "snap-shot" pictures of a particular EDSS implementation at a given time instant, which in the course of a particular task will get further modified/transformed (as indicated by the feedbacks to activities within the task described through the following SADT diagrams).

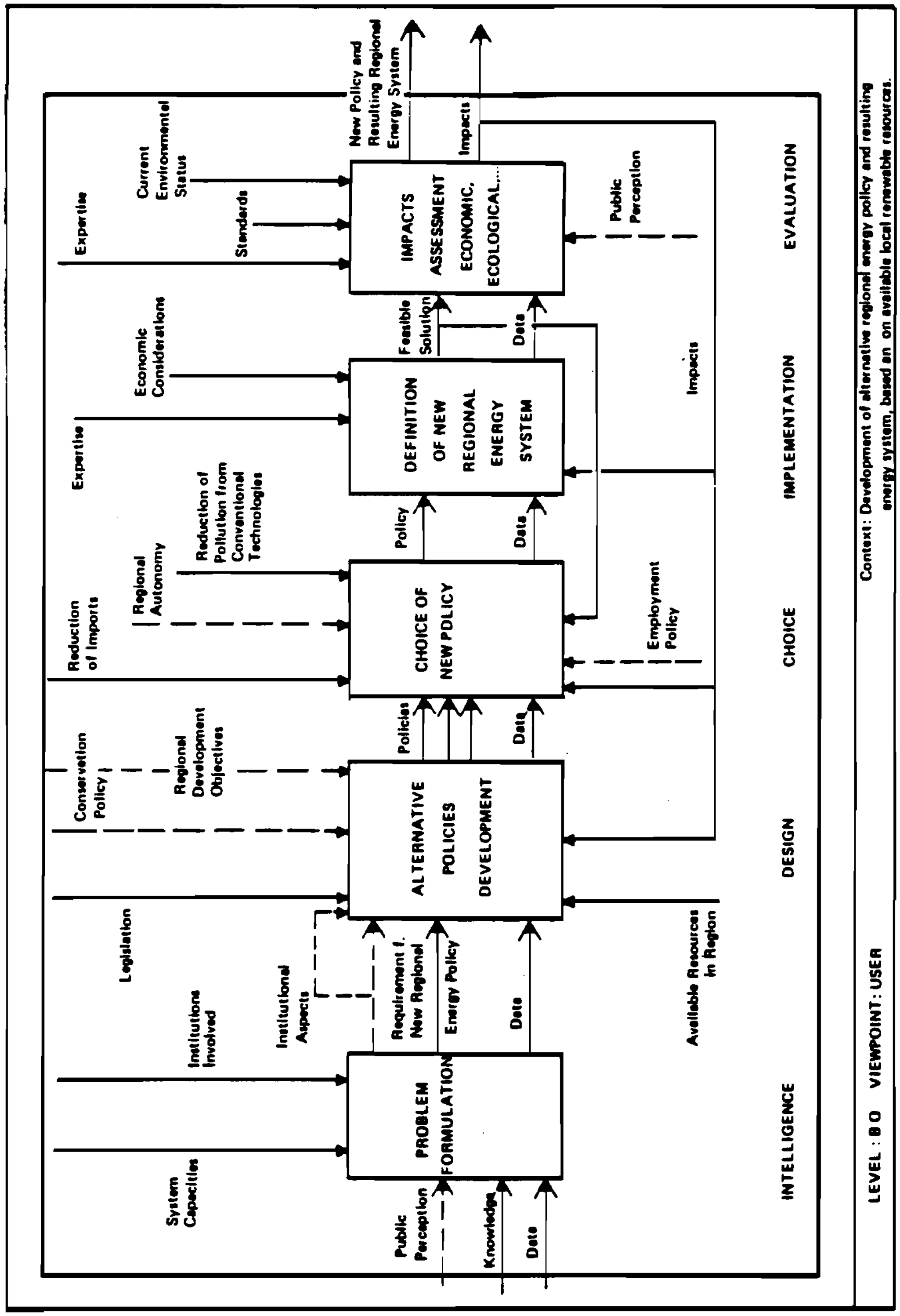


Figure A-3-1. SADT illustration : user viewpoint activigram (level B0)

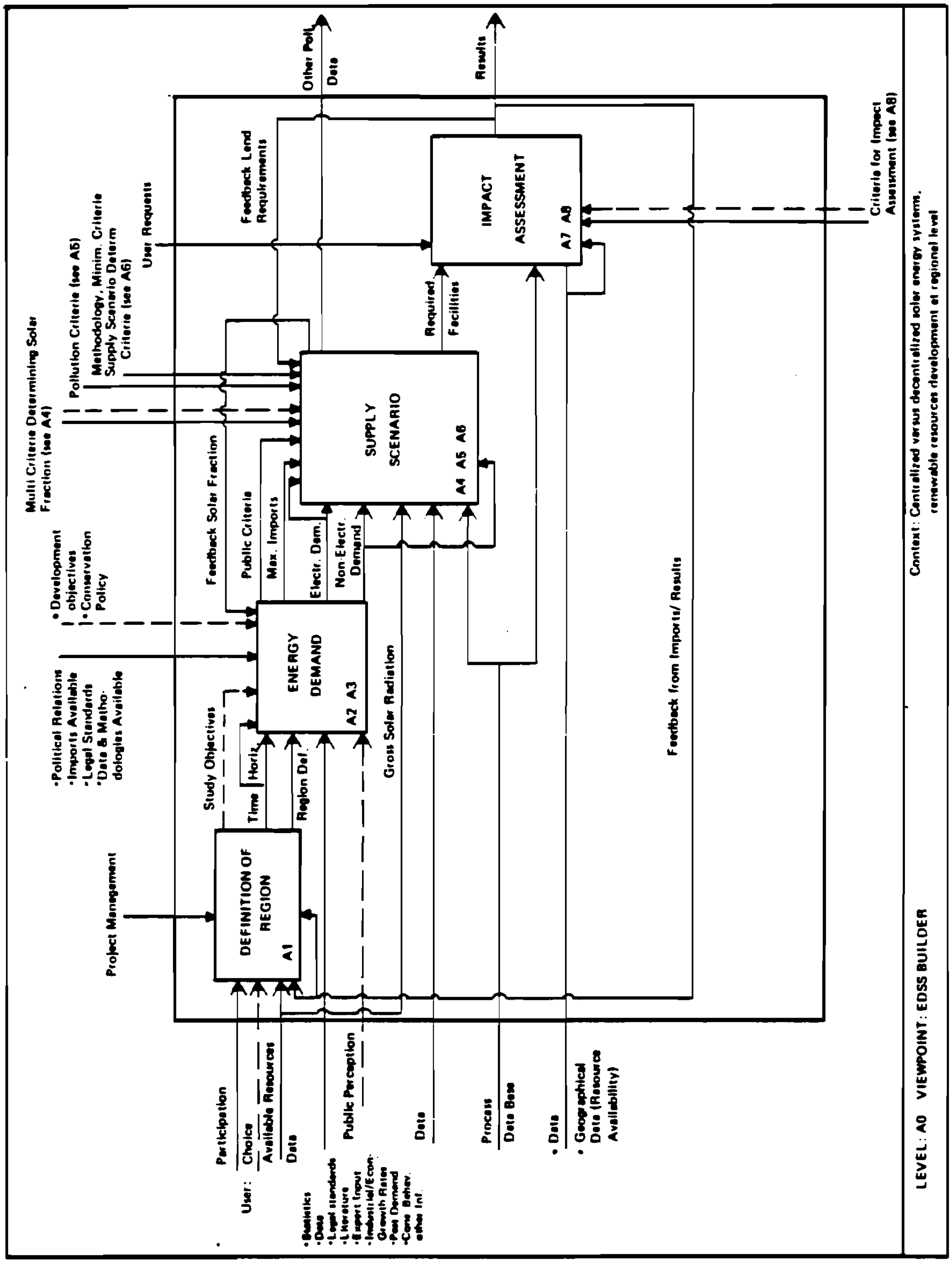


Figure A-3-2. SADT illustration : EDSS builder viewpoint activigram (level A0)

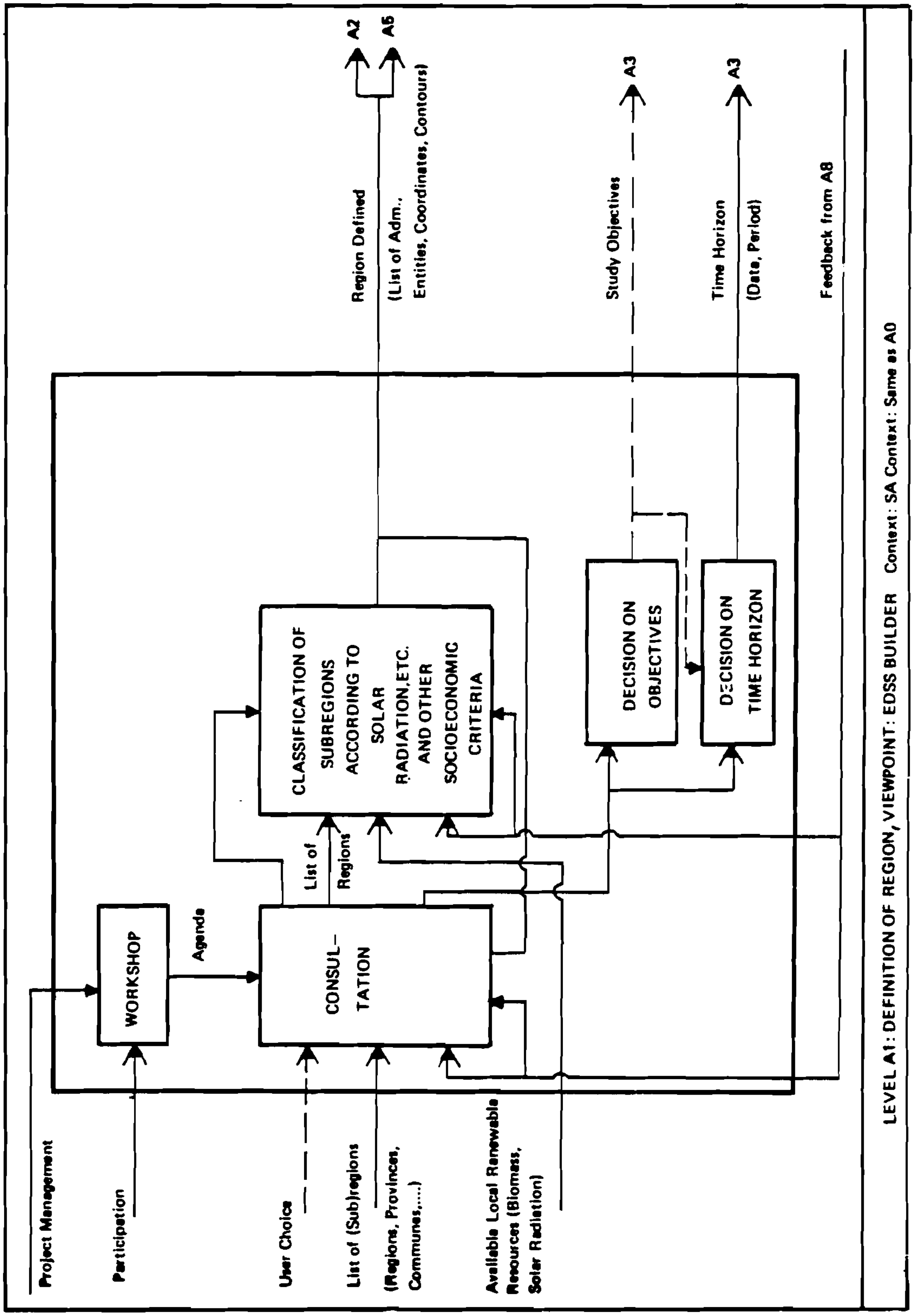


Figure A-3-3. SADT illustration : EDSS builder viewpoint activigram (level A1)

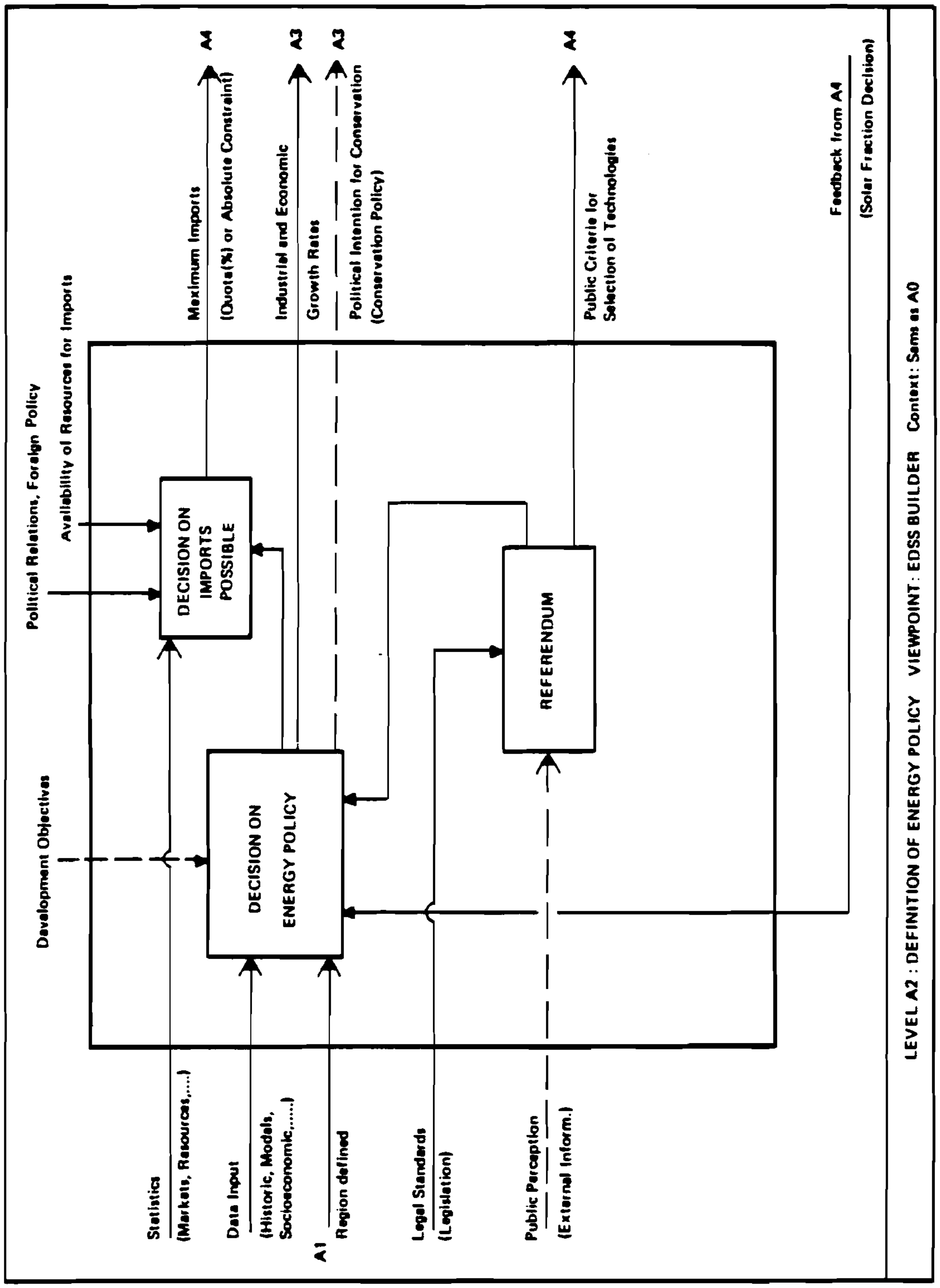


Figure A-3-4. SADT illustration : EDSS builder viewpoint activigram (level A2)

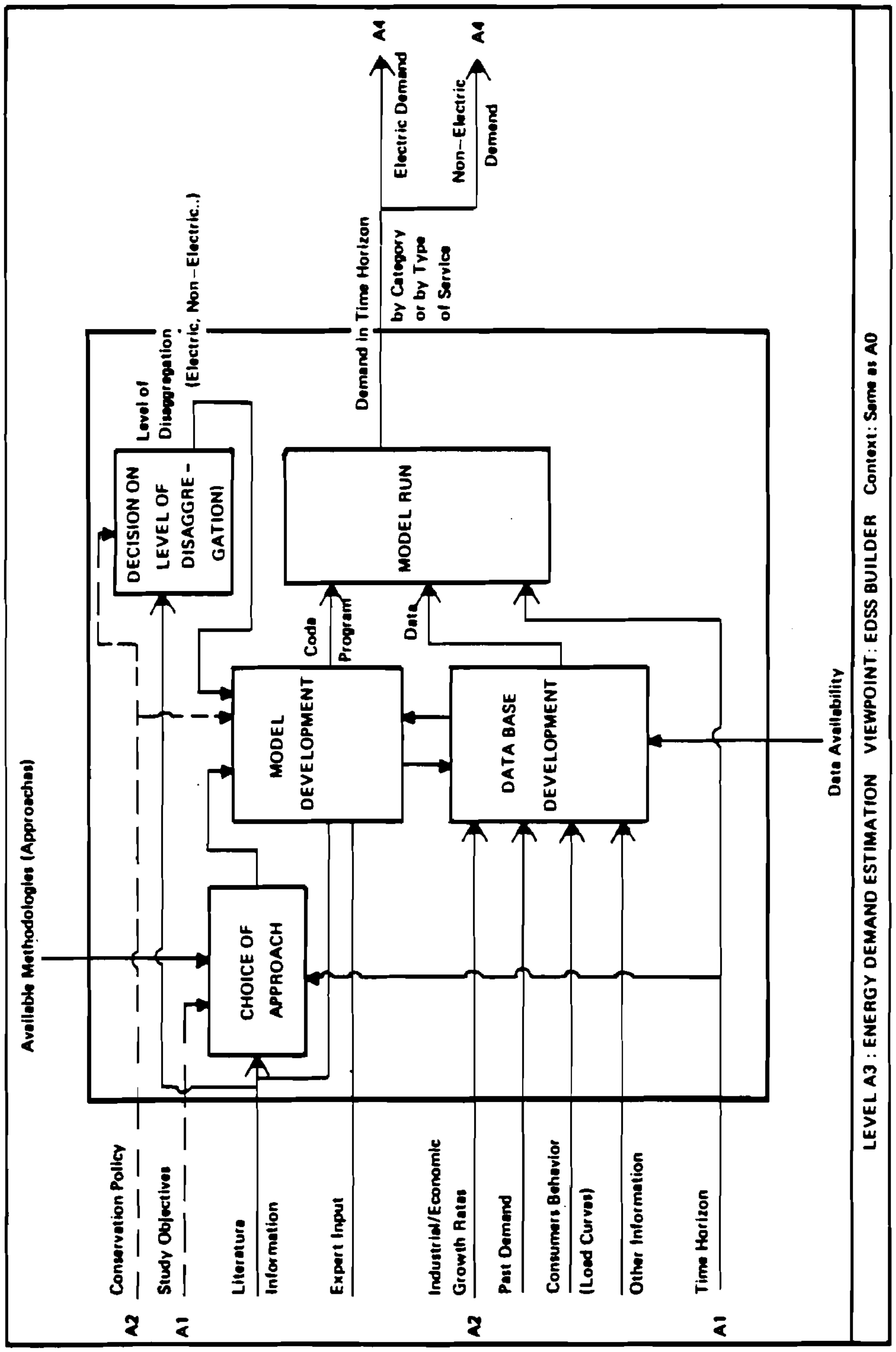


Figure A-3-5. SADT illustration : EDSS builder viewpoint activigram (level A3)

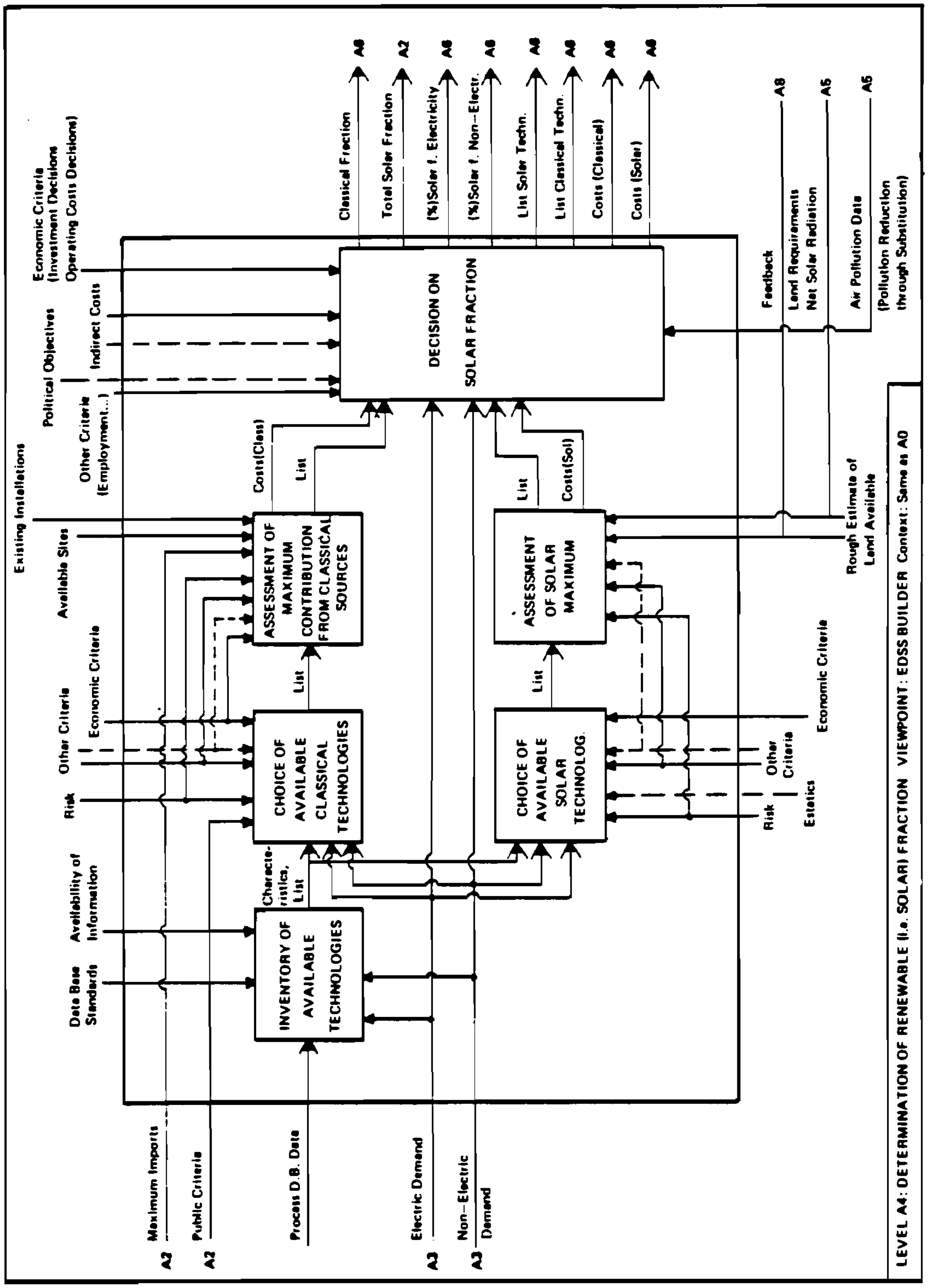


Figure A-3-6. SADT illustration : EDSS builder viewpoint activigram (level A4)

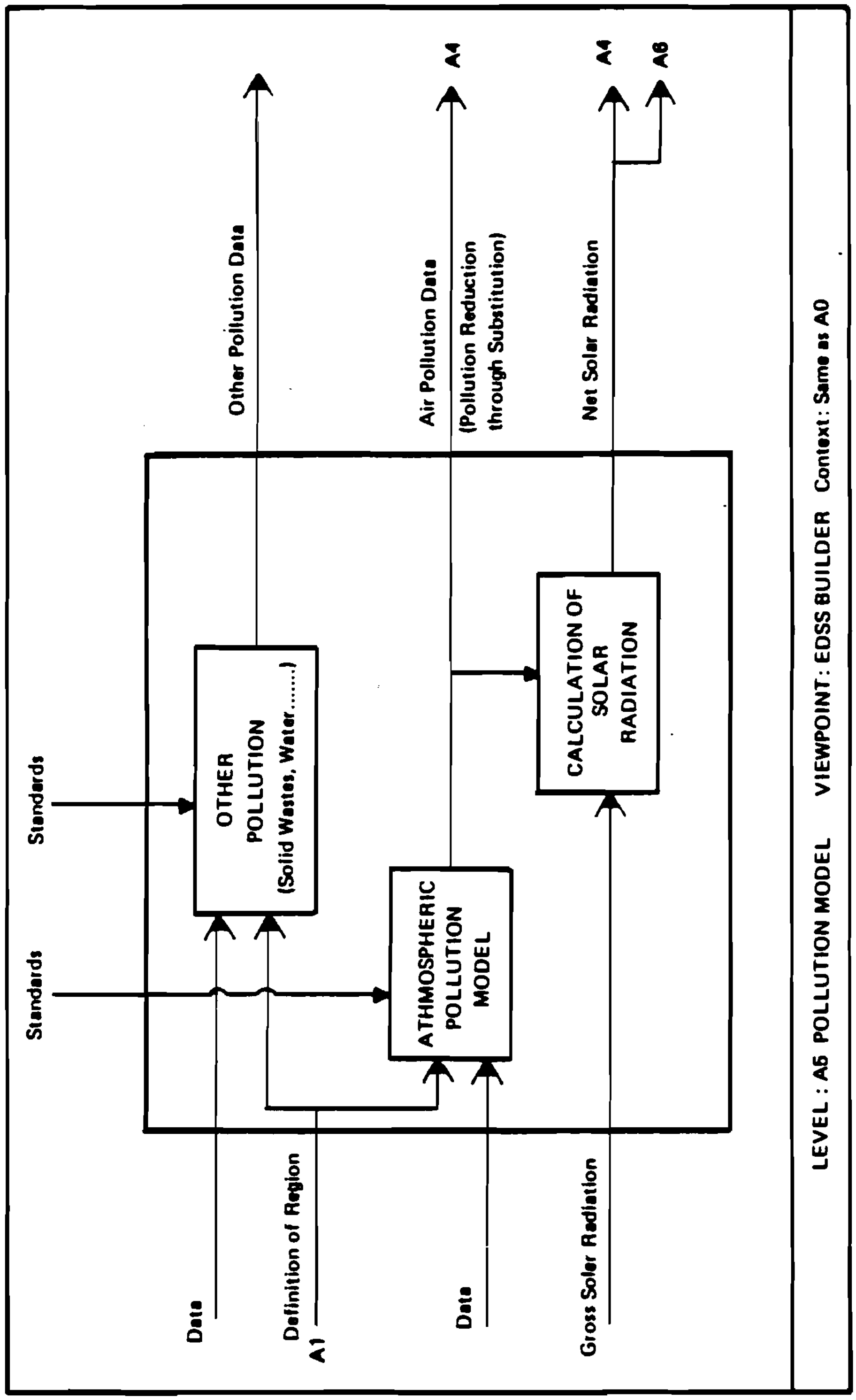


Figure A-3-7. SADT illustration : EDSS builder viewpoint activigram (level A5)

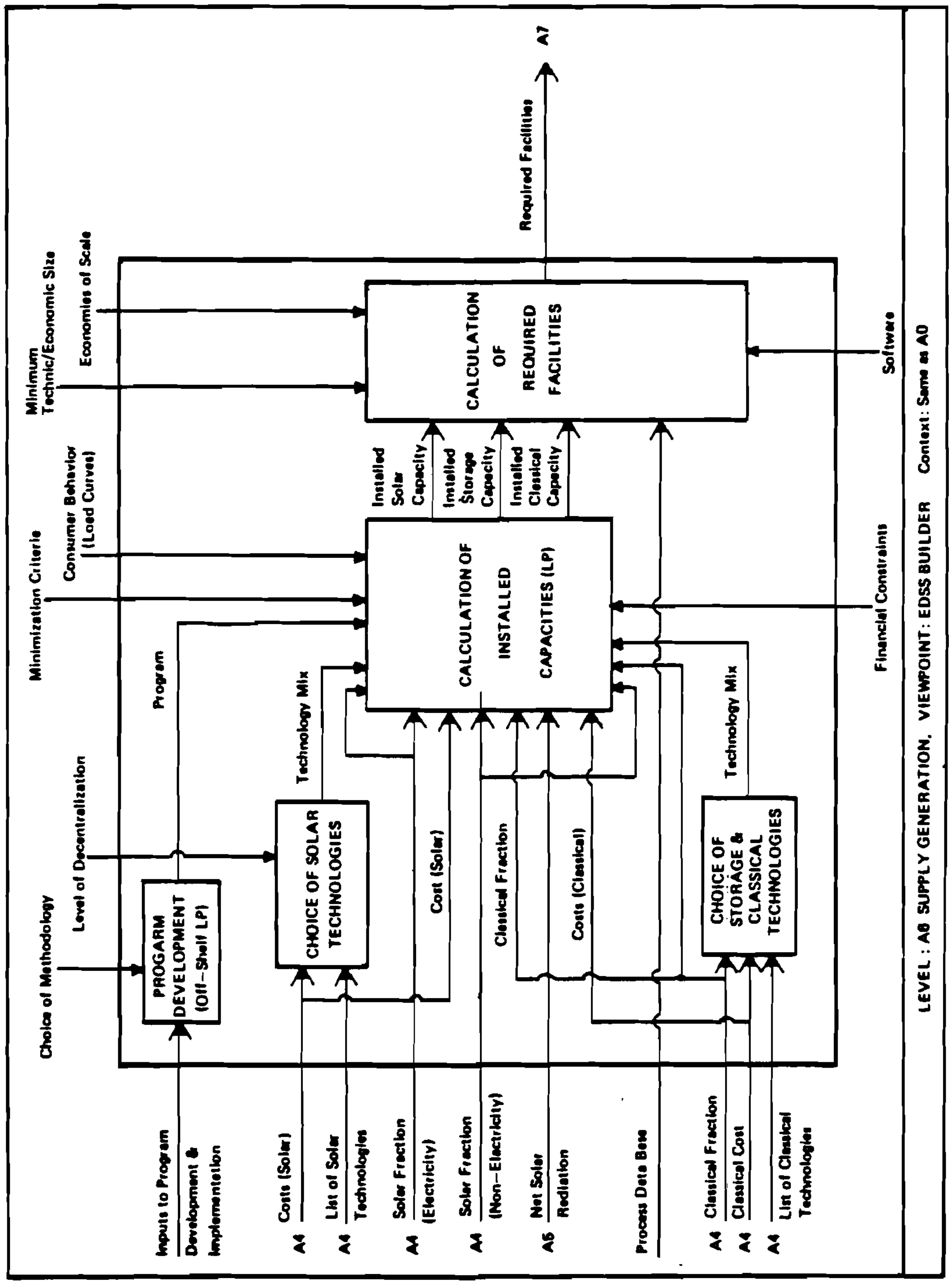


Figure A-3-8. SADT illustration : EDSS builder viewpoint activigram (level A6)

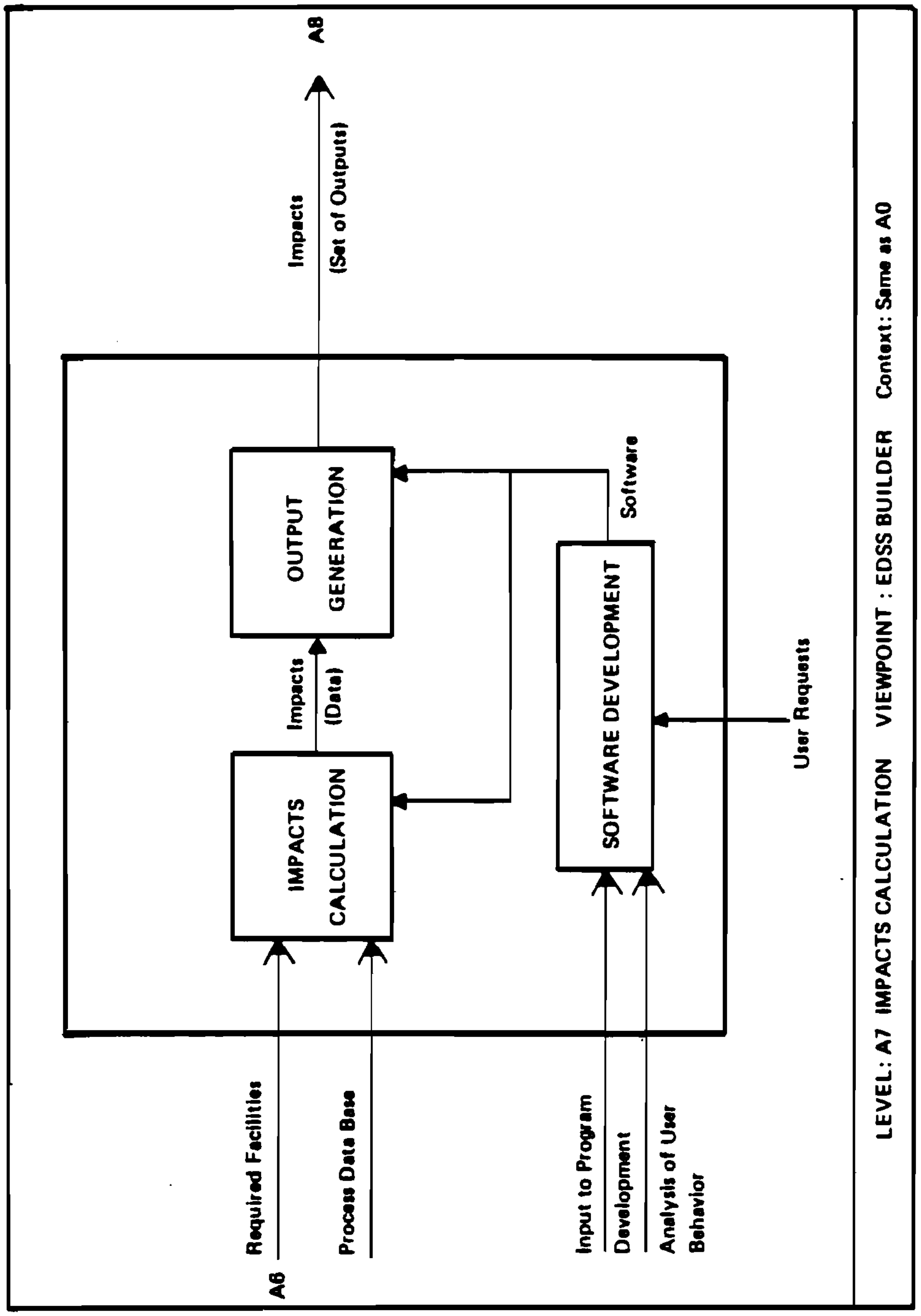


Figure A-3-9. SADT illustration : EDSS builder viewpoint activigram (level A7)

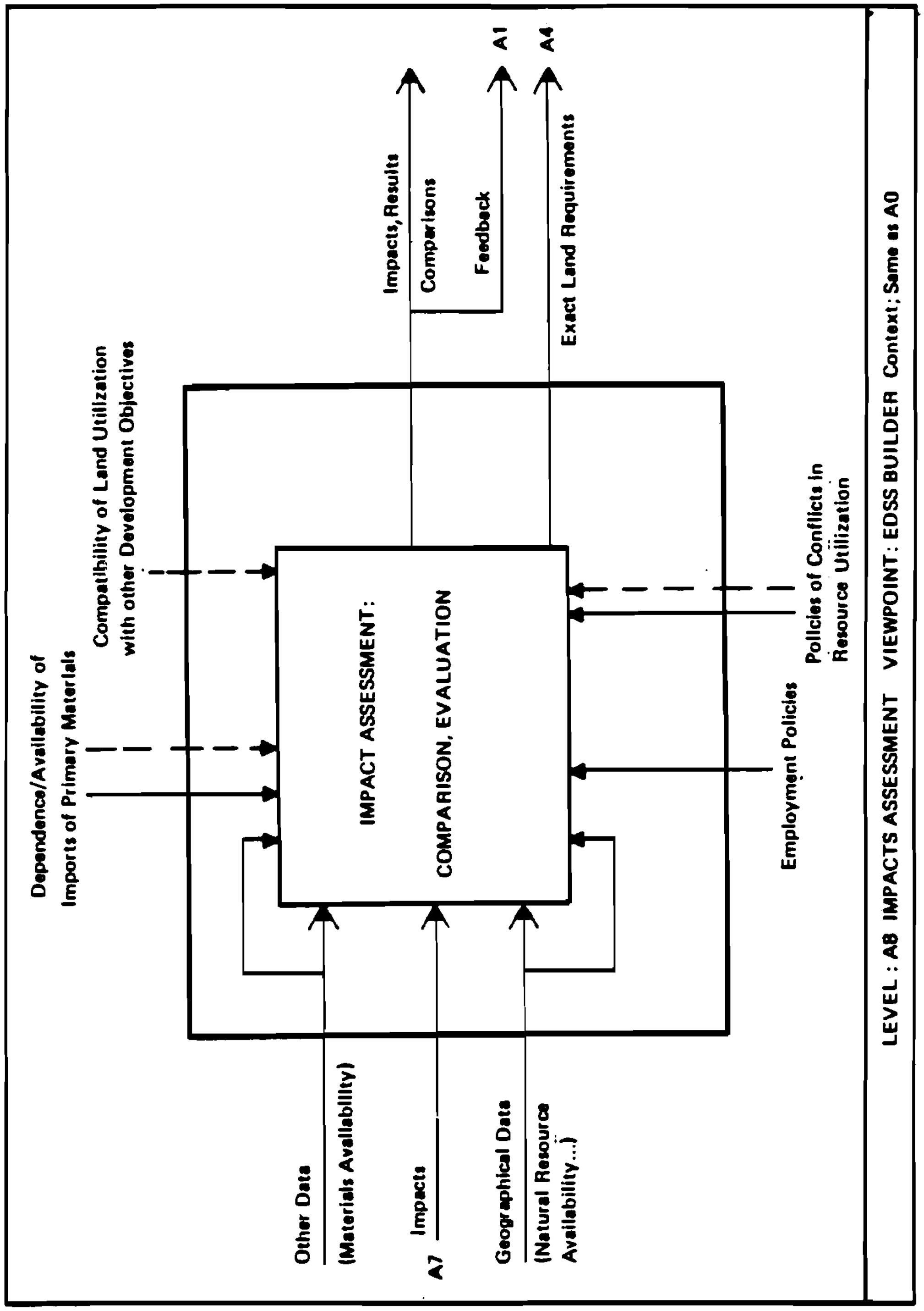


Figure A-3-10. SADT illustration : EDSS builder viewpoint activigram
(level A8)

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APPENDIX 4: PROCESS INFORMATION SYSTEMS, PROCESS DATA BASE TOOLS AND ASSOCIATED EDSS SOFTWARE

A4-1: A BRIEF DISCUSSION OF PROCESS INFORMATION SYSTEMS WITH REFERENCE TO THE IIASA FACILITY DATA BASE AND THE PROCESS ENCYLOPEDIA DATA BASE OF STATISTICS CANADA

PROCESS INFORMATION

The concept of a process is fundamental in the representation of socio-economic resource systems. It has its theoretical roots in activity analysis (Koopmans, 1951) and has been further elaborated by Georgescu-Roegen (1970).

In recent years, problems of resource scarcity and environmental degradation have led to the extension of economic systems to include natural resources, externalities and socio-demographic factors. Energy analysis, environmental impact analysis, and technology assessment have become significant new fields for applied research. The feature common to these areas of interest is the focus on the processes that transform resources and energy into the goods or services that meet human needs.

Over the last 25 years, there have been two relatively independent lines of development of applied process models in economics: input-output models at the macro-economic level (Leontieff, 1951; Matuszewski, 1972; and Gigantes, 1970), and, sector specific process models as for instance described in Hudson and Jorgenson (1978), Russell and Spofford (1972), Russell (1973), Kydes and Rabinowitz (1981), Pilati and Sparrow (1980) and Carasso et al. (1975). The importance of process models has also been recognized in the field of ecology (Clark and Holling, 1979).

Process models tend to be information-rich. Limitation in the availability of process information imposed by the cost of obtaining such information has restricted the development of process models (Hudson and Jorgenson, 1979).

Input-output process information is readily available in most countries as it is compiled and published by national statistical offices, however, for most applications, the input-output representation of a process is not adequate for the following reasons: the process boundaries are not well defined; flows are measured in currency units; there are no stocks; the information is retrospective in the sense that the descriptions are derived from measurements of past – usually 3 to 5 years – flows; processes are represented at a relatively high aggregate level, as a result of the use of currency units; the degree of aggregation and the use of currency units make the process descriptions time and nation specific in that each description represents the specific mix of processes at that time and place; finally the relationships between input flows and the output flow for each process are linear and proportional.

Process information compiled for sector specific models is normally compiled by the model developers. In fact, the compilation of process data usually requires the preponderance of research funds in the development of process models. *Information from this source is usually richer* than input-output data in that it is *measured in physical quantity units;* it is much less aggregated and process boundaries better defined. However, process data collected for sector specific process models are not readily accessible because they are dispersed over a large number of research institutions, none of which has a specific mandate for information dissemination. Furthermore, process descriptions compiled for sector specific models are often incomplete -- for example process descriptions compiled for energy modeling may not include non-energy flows. Also the information is in the specific form required by the mathematical structure of the model and its computer system. For example, the process descriptions take the form of constraints in an optimization framework.

Both the WELMM project of IIASA and the Process Encyclopedia project of Statistics Canada represent attempts to compile data bases of process information. Initially these data bases were intended to support particular modeling applications. *In both cases it became clear that process descriptions could be compiled in such a way that they could support a variety of different modeling applications.* Indeed processes can be defined such that they are neither site-, nor plant- nor nation- specific -- at least for a large number of processes. Equally it is possible to link or "map" two systems together, which was attempted between the two systems described hereafter (see Figure A-4-1 and Grübler et al, 1982).

A4-1-1:THE FACILITY DATA BASE OF THE WELMM APPROACH

In order to assess the natural resource requirements of resource development strategies (in particular energy strategies) an analytical approach called WELMM was developed at IIASA (Grenon and Lapillonne, 1976). The WELMM approach involves an assessment of the requirements and the availability of *W*ater, *E*nergy, *L*and, *M*aterials and *M*anpower resources. For quantitative analysis, the WELMM approach is based on computerized data bases of primary resource availability at the global,

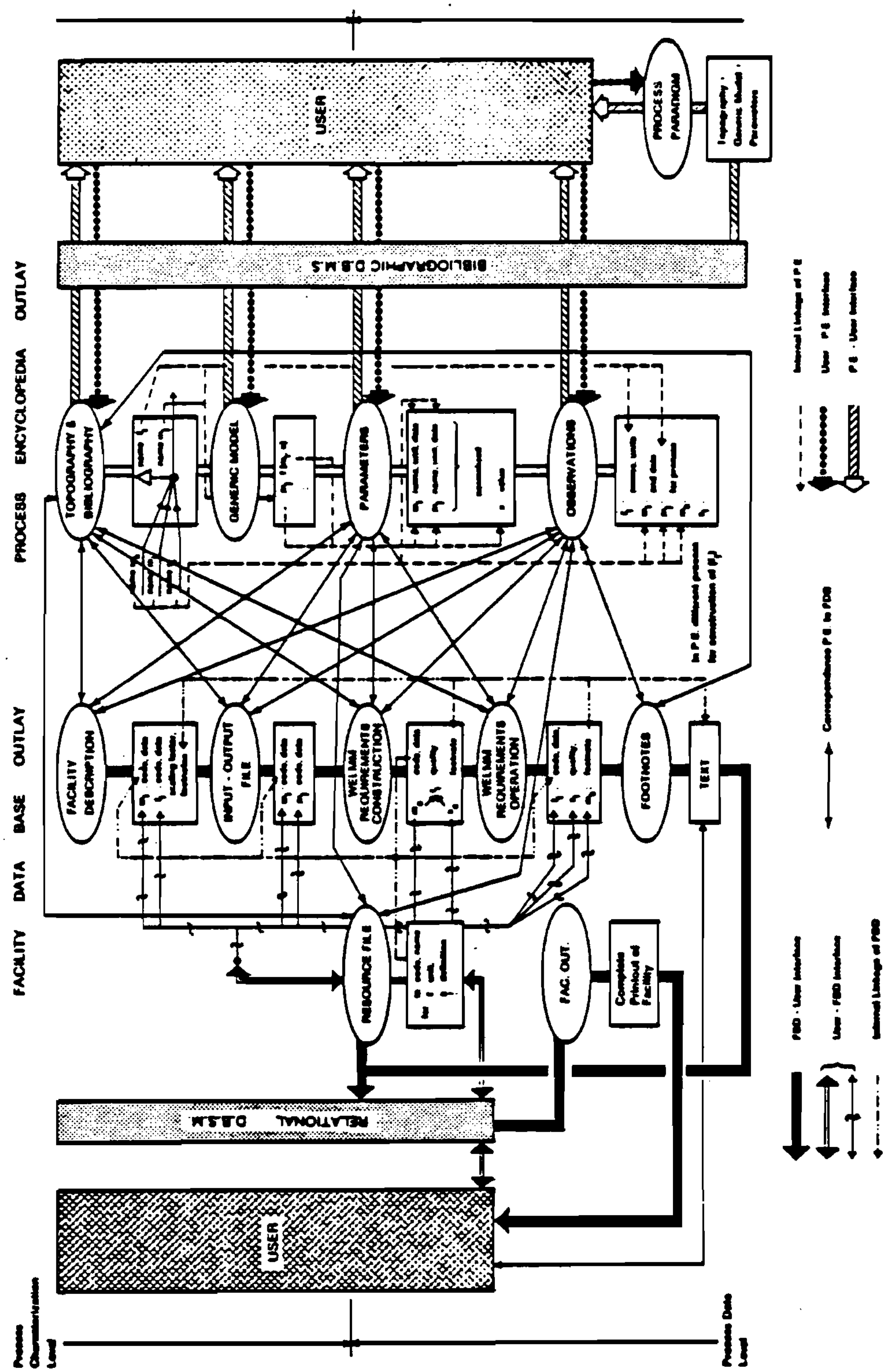


Figure A-4-1. High level representation of PE → FDB mapping.

national or regional level (Medow, 1983; Grenon and Medow, 1983; Merzeau, 1980), and on data bases of resource requirements for industrial processes deployed in processing primary (energy) resources to the commodities required by the final consumer (see Figure A-4-2). At each of the transformation steps of such a resource processing system, corresponding industrial processes can be defined. Within the Facility Data Base (FDB) (Grübler and Cellerier, 1983), the boundaries of the process analyzed are drawn in such a way that a process corresponds to an industrial unit or facility. The technological characteristics of any particular facility are independent from their location; in addition there is an increasing trend towards standard size classes, particularly for energy facilities (e.g., pressurized water reactors of 1000 or 1300 MWe, crude oil tankers of 250000 or 300000 DWT, etc.). Both factors mentioned above make WELMM-type analyses (i.e., at a "typical" industrial facility level) easier for a variety of applications including comparisons of alternative technologies for the production of specific products or services (Grübler, 1980; Merzeau, Grenon and Grübler, 1981; and Katsonis and Gourmelon, 1983), or for the comparison of whole resource processing systems (Resources Group, IIASA, 1979 and Grübler, 1984). However, the process boundary defined for the FDB is flexible – at a conceptual level and from the point of view of the actual data base structure. Aggregation and disaggregation of processes stored in the FDB have been tested and have proved feasible (Kopytowski et al., 1981).

Also it should be noted that the concept of a "typical" facility with respect to technology and size cannot be applied to primary resource extraction processes because the individual deposit characteristics determine the choice of the appropriate technology as well as the proper resource flows for the construction and operation of a mine. The FDB has therefore been complemented by a substructure on coal mines, taking the individual deposit characteristics into account. The data of the Coal Mines Data Base (CMDB) is further analyzed by statistical analysis techniques to obtain relational data on the influence of deposit parameters on technology choice and WELMM resource requirements (Astakhov et al., 1983).

Another characteristic of the FDB is that it covers *both the actual transformation process, as well as the construction process* of the plant *(the fund)*, in which the transformation takes place. Within the FDB the resource-flows are accounted for either as a total of the construction period or per year of full stream operation. The resource flows accounted for are direct resource requirements, i.e. the resource flows consumed on-site for the construction and operation of a facility (concrete, structural steel, water, chemicals, etc.) and those resources (e.g., metals) embodied in the capital goods of a facility which are physically on site.

After the collection of raw data (through literature, existing data bases or questionnaires) the data is analyzed *before* computerization. The information on a particular process in the FDB is paradigmatic in the sense that the data stored are "hard" data. The data analysis and judgement is documented within the FDB which contains qualitative and bibliographical information in addition to numerical information.

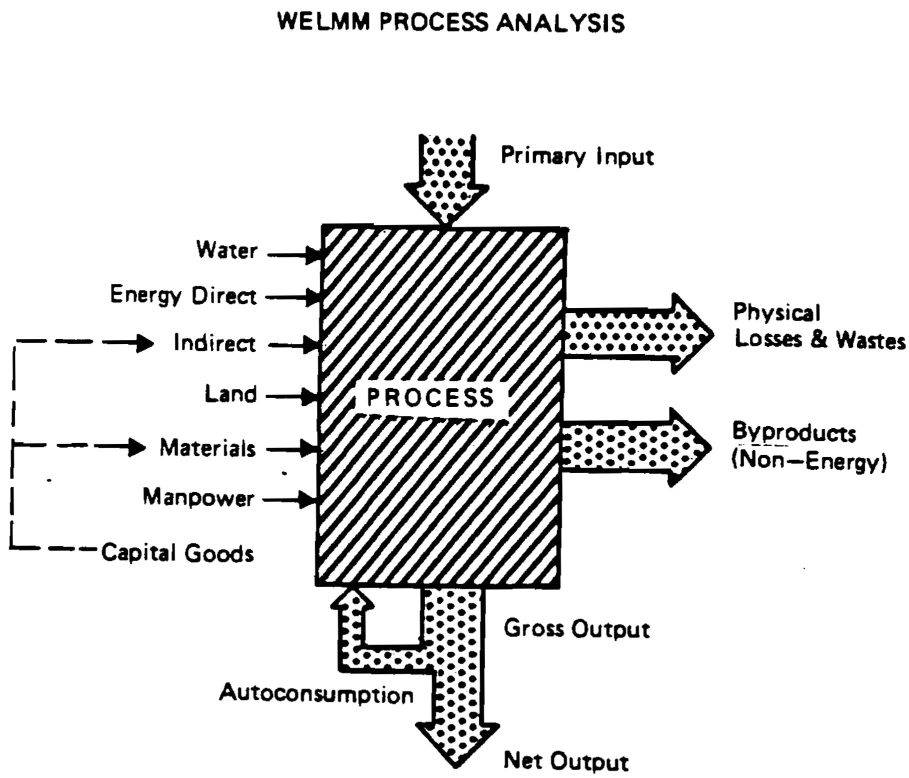


Figure A-4-2. WELMM process analysis.

The data in the FDB is divided into four blocks: process identification (name, location, capacity, etc., including two text files with information on the particular facility as well as on the process(es) it deploys), process characterization (list of primary and secondary inputs and net outputs), WELMM requirements for construction and, finally, WELMM requirements for operation. In the last two, data is accompanied by a quality indicator (ranging from one to five and indicating possible ranges of uncertainty) and a footnote (giving details about the origin of the data, conversion factors employed and/or alternative data estimates). For the CMDB the data organization is similar, however the particular mine and its deposit is described in more detail in 14 blocks followed by the WELMM requirements for construction and operation (stored as specific values to facilitate further analysis and generation of relational information) and a text footnote.

All data are stored in a relational data base management system called INGRES (developed at the University of Berkeley) (Held et al., and Woodfill et al., 1979), which operates on top of the UNIX system on a PDP 11/70. Additional interactive programs developed within the WELMM Project for data entry and retrieval, statistical analysis and linking to other data bases on primary resource availability, have been implemented.

A4-1-2:THE PROCESS ENCYCLOPEDIA PROJECT OF STATISTICS CANADA

The Structural Analysis Division of Statistics Canada is a research group concerned with the development and operation of 'structural' economic models of the Canadian economy. The first models were comparative static input-output models which were extended in a variety of ways to include energy flows in physical units, employment, interactions along provinces, and prices (Structural Analysis Division, 1980a). In the last five or six years, the focus of the development work shifted to time structured socio-economic-resource modeling.

From this experience it became clear that input-output representations of 'production' processes were inadequate for the reasons outlined above. As a result it was decided to establish a project to determine the feasibility of compiling a data base of industrial process descriptions; this data base became known as the Process Encyclopedia.

In the methodology of the Process Encyclopedia, a process is described by means of three basic sets of information:

Definitional Information, which consists of a process name, the names of the flows that cross the process boundaries, and the names of the transformation nodes and funds within the boundaries. This definitional information is in fact a directed graph which in the language of the Process Encyclopedia is called topography.

Relational Information, which describes the form of the relationships among the flows of a process. This relational information defines the parameters of the functional forms of the process model, or as it is called in the Process Encyclopedia: the generic model.

Quantitative Information, which is simply the values of the parameters defined by the generic model associated with the topography of the process.

There can be more than one generic model associated with each topography and in turn there can be more than one set of parameter values associated with each generic model.

The explicit recognition of relational information or generic models permits the representation of non-linear relationships between input flows and output flows, the definition of control variables, and the introduction of time lags between input flows and output flows.

The use of definitional information permits the representation of structure within a process. Funds or stocks can be distinguished from transformation nodes -- thus allowing for dynamic modeling applications.

In addition to the three basic sets of information, the Process Encyclopedia contains indexing information in order to access the data base and also 'observations' of processes. 'Observations' are measured values of the input and output flows. A set of observations is associated with a topography which defines the flows. Parametric information may be obtained through the analysis of observations. Provision is also made for including bibliographic information on data sources and quality.

The Process Encyclopedia is a tool for refining process descriptions as well as a data base of 'good' process descriptions. Raw data in the state in which it has been found can be entered into the Process Encyclopedia without transformation. Such data may be incomplete and inaccurate in the sense that it has not been subject to mass and energy balances or other filter edits. This raw data can be analyzed and refined within the Process Encyclopedia and the resulting 'good' or paradigm process can be saved in the data base. The Process Encyclopedia has been extensively documented (Structural Analysis Division, 1980b).

A4-1-3: CONCLUSIONS ON PROCESS INFORMATION SYSTEMS

Process descriptions, which encompass definitional, relational, and quantitative information are an appropriate set of building blocks from which to build process models *(which can be overlaid by behavioral models).* Process units can be defined and quantified in such a way that they are neither site- nor nation-specific.

Process descriptions that are complete in the sense that they encompass all input and output flows including those associated with stocks can serve a wide variety of modeling applications. *The mathematical form of the description of each process should be 'natural' and independent of the mathematical form of the model(s)* which may use the process description. The process descriptions can be transformed by the model builder as required.

Process information is a more detailed level of information to support modeling activities than any other type of information (e.g., input-output tables). *If the process information system is adequately designed it is model- (or application-) independent.* This in turn implies that the user of process information has to generate his own "paradigmatic" process data out of the process information system. The process information system therefore has to support this "clean" data generation with appropriate tools and/or should store flagged "hard" data, which has been analyzed already for a certain field of application (e.g., the WELMM Facility Data Base data).

Process information is not necessarily country or site specific if collected at the appropriate level (e.g., the engineering level). Engineering information of this type as well as the use of *physical indicators* result in data validity over long periods (unlike) economic data or input-output (I-O) tables. Also within the concept of process analysis, the dynamics of a given system (e.g., introduction of new technologies, changing economic or resources intensiveness of a particular process in the long-term can be dealt with relatively easily (again unlike I-O coefficients).

Process data is information-rich, i.e., the building of process information systems is a data-intensive, long-term activity that requires continuity. Because process information has long-term validity it is possible to build up process information systems (provided they are carefully and flexibly designed) over long periods, starting first with specific application-oriented process information and enlarging the system later on until sufficient information becomes available for the process information system to be model -- or application -- non-specific. This goal can only be achieved if the information system is build up through an interdisciplinary and international effort. Because process information is not country- or site-specific, problems should not occur in the exchange of process information on the engineering level. However, because of the long-term nature of the exercise of process information collection, the information system should be hosted within an environment assuring continuity, and adequate (computer and manpower) resources to support a certain level of permanent effort. This environment would best be provided by a governmental statistical office or the like (i.e. the CSI).

Once such a process information data base is developed and built up, it can easily be enriched and enlarged whenever it is accessed for specific applications which in return will generate additional information to be included into the system. Again in order to promote this access or straight link to other process information systems it is necessary to ensure a certain minimum, permanent effort in process information systems construction.

A4-2: PROCESS DATA BASE TOOLS: EXAMPLES FOR PROCESS TOPOGRAPHIES, PROCESS MODEL DOCUMENTATION LANGUAGE, PROCESS PARADIGMS AND OTHER PROPOSED EDSS TOOLS

The process topography graphical representation language, we have already discussed in Chapter 4 of this paper. Figures A-4-3 and A-4-4 illustrate the application of this representation language in representing a facility of the WELMM Facility Data Base in general and an example of a chemical transformation process stored in the Process Encyclopedia data base. Further examples of process topographies can be found in the process paradigm examples presented in Figures A-4-6 and A-4-7 based on the case study (Katsonis and Gourmelon, 1983) which we used already to illustrate the decision cycle documentation language SADT in Chapter 3 and Appendix 3. Note here that to-date the topography representation language software is *only* capable of displaying *definitional* information on a particular process (i.e., in the form of its topography). In a further step the same software should be adopted to also present numerical data on the flows of the process, equally in a graphical summary form like the process topography diagram.

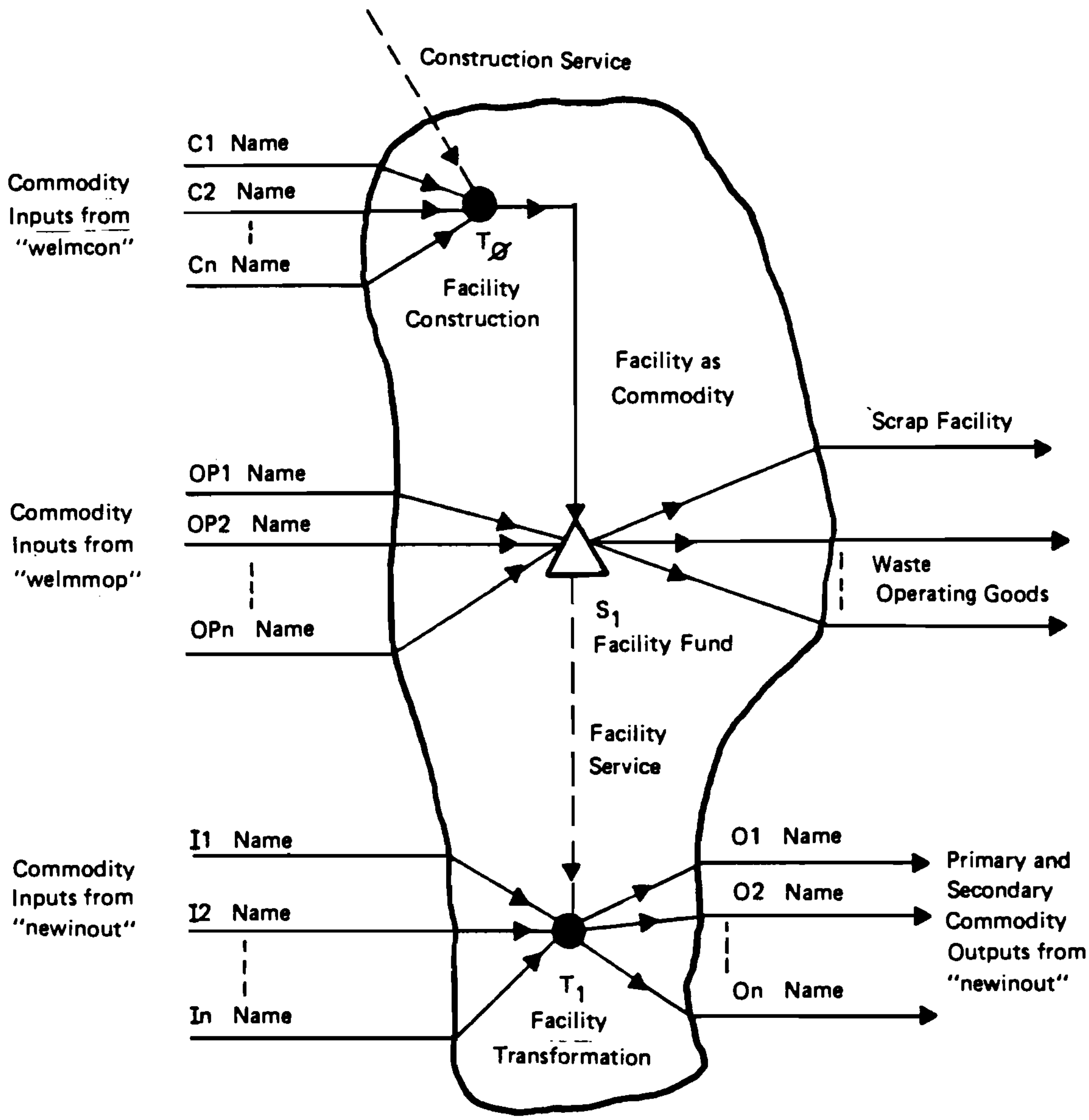


Figure A-4-3. Topography "WELMM facility".

Related to the process model, Figure A-4-5 displays a Process Model diagram based on the structured model documentation language developed at Statistics Canada. Other examples can be found in the process paradigm presented in Figures A-4-6 and A-4-7. The concepts and graphical conventions underlying the process model documentation language is further elaborated in the following section A4-3 (taken from McInnis and Page, 1979).

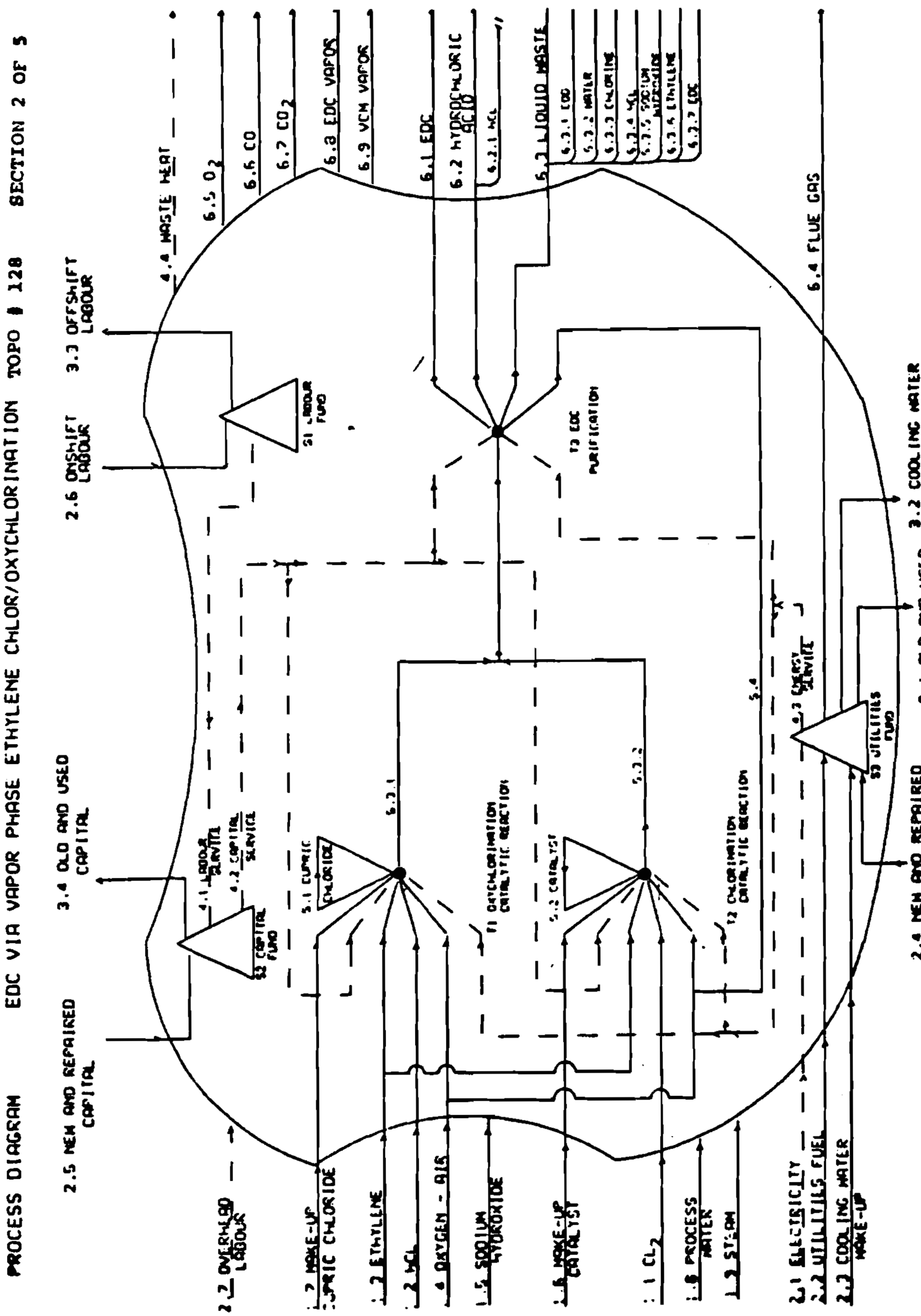


Figure A-4-4. Topography for a chemical process (from the Process Encyclopedia)

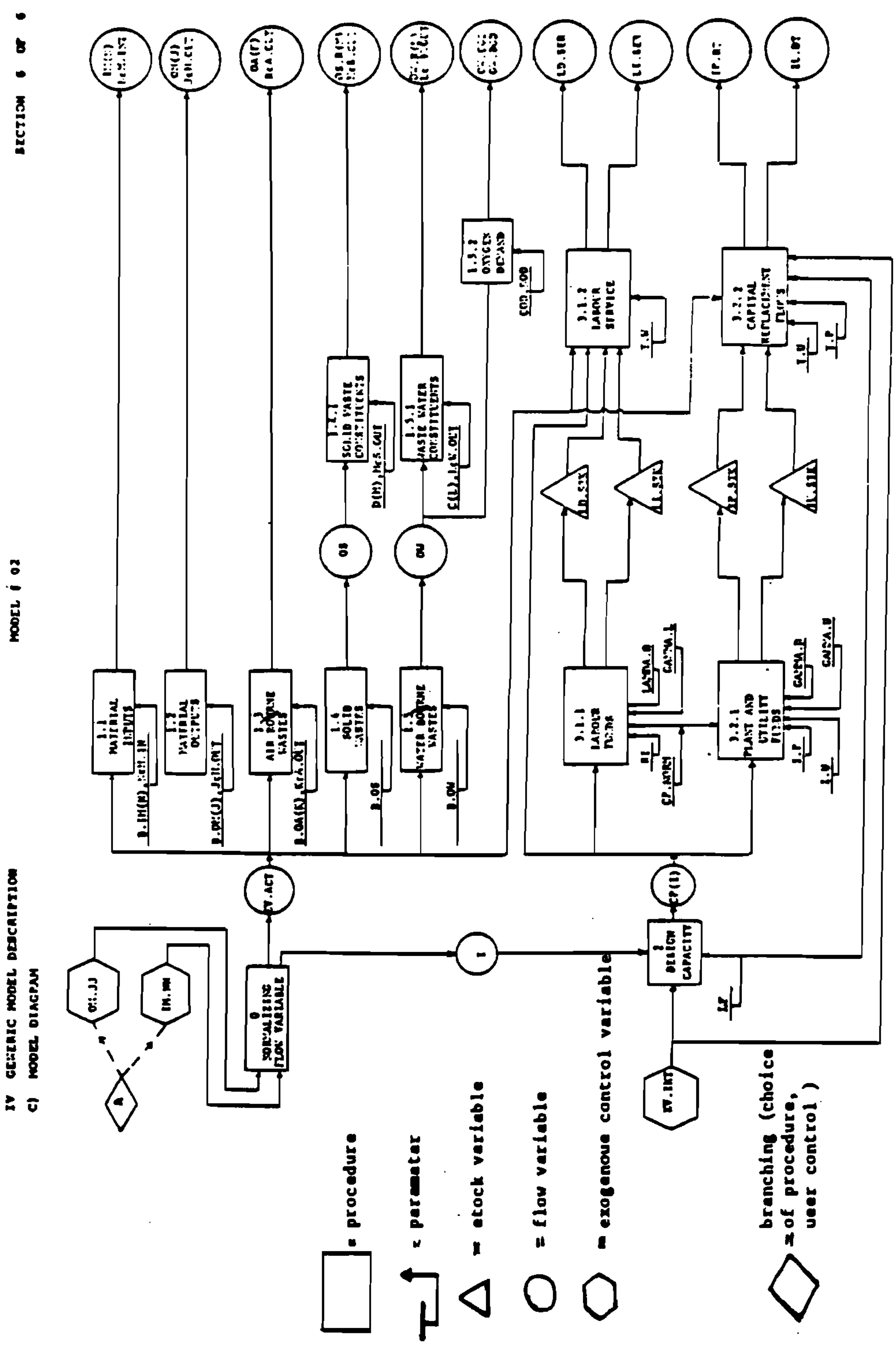


Figure A-4-5. A process model diagram from the Process Encyclopedia

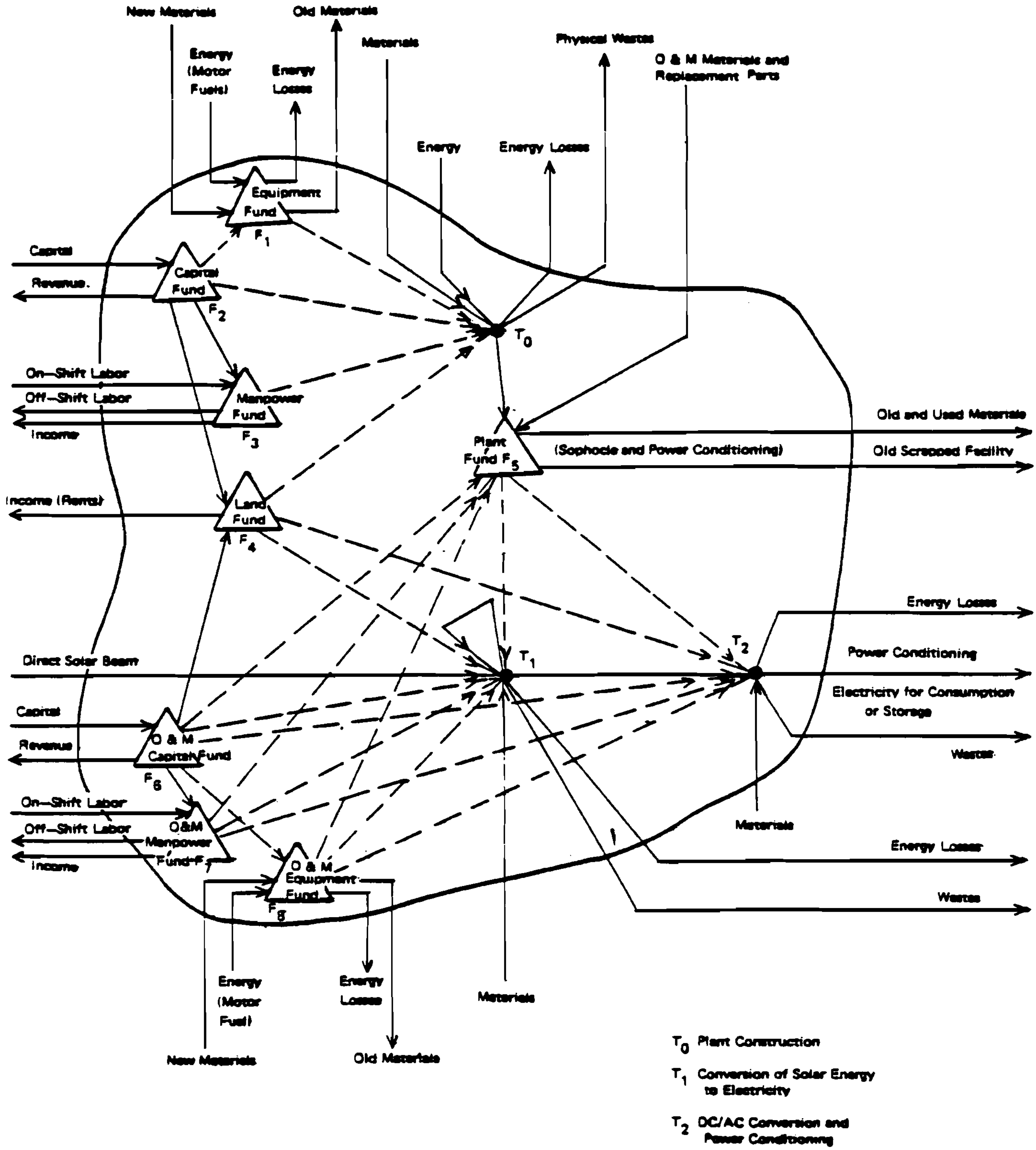


Figure A-4-6. Example for proposed process description in EDSS: process topography for solar energy-electricity conversion with photocells

Process Topography: Photocell

List of flows

Input flows

Code	Name	Destination	Used in model	Type	Unit
C_1	Capital	F_2	2	mass	
MP_1	On-shift Manpower	F_3	2	mass	manhours
E_1	Direct Solar Beam	T_1	1,2	energy	
C_2	Capital	F_6	2	mass	
MP_4	On-shift Manpower	F_7	2	mass	manhours
	New Materials	F_8		mass	
	Energy (motor fuels)	F_8		energy	
	Materials (comp. unknown)	T_1		mass	
	Materials (comp. unkown)	T_2		mass	
	New materials (")	F_1		mass	
	Energy (motor fuels)	F_1		energy	
M_7	Materials	T_o	2	mass	kg
	ready mixed concrete	T_o	2	mass	kg
	aluminium	T_o	2	mass	kg
	cement	T_o	2	mass	kg
	copper	T_o	2	mass	kg
	metacylate	T_o	2	mass	kg
	plastics	T_o	2	mass	kg
	putty	T_o	2	mass	kg
	sand	T_o	2	mass	kg
	silicon	T_o	2	mass	kg
	steel	T_o	2	mass	kg
	water	T_o	2	mass	kg
E_7	Energy	T_o	2	energy	
PF	Prefabricated equipment	T_o	2	mass	
	O & M materials and replacement parts	F_5	-	mass	-

Figure A-4-6 (2). Example for proposed process description in EDSS: process topography lists (photocells) part 1

Output flows

Code	Name	Origin	Used in model	Type	Unit
	Revenue from capital	F_2	-	mass	-
MP_2	Off-shift manpower	F_3	2	mass	manhours
	Income	F_3	-	mass	-
	Income (rents)	F_4	-	mass	-
	Income from capital	F_6	-	mass	-
MP_5	Off-shift manpower	F_7	2	mass	manhours
	Income	F_7	-	mass	-
	Energy losses	F_8	-	energy	-
	Old materials	F_8	-	mass	-
	Wastes	T_1	-	mass	-
E_4	Energy losses	T_1	1,2	energy	
	Wastes	T_2	-	mass	-
E_3	Electricity for consumption or storage	T_2	1,2	energy	
E_5	Energy losses	T_2	1,2	energy	
	Old scrapped facility	F_5	-	mass	-
	Old and used materials	F_5	-	mass	-
E_8	Energy losses	T_o	1,2	energy	
M_8	Physical wastes	T_o	2	mass	
	Energy losses	F_1	-	energy	-
	Old materials	F_1	-	mass	-

Figure A-4-6 (3). Example for proposed process description in EDSS: process topograhy lists (photocells) part 2

Internal flows

Code	Name	Origin	Destination	Type	Unit
-	Equipment service	F_1	T_o	service	-
-	Capital service	F_2	T_o	service	-
MP_3	Manpower service	F_3	T_o	service	manhours
L_1	Land service	F_4	T_o	service	m^2
L_2	Land service	F_4	T_1	service	m^2
L_3	Land service	F_4	T_2	service	m^2
-	Capital	F_2	F_3	mass	-
-	Capital	F_2	F_4	mass	-
-	Capital	F_6	F_4	mass	-
-	Capital	F_6	F_7	mass	-
-	Capital service	F_6	F_5	service	-
-	Capital service	F_6	T_1	service	-
-	Capital service	F_6	T_2	service	-
-	Capital service	F_6	F_8	service	-
MP_6	Manpower service	F_7	F_5	service	manhours
MP_7	Manpower service	F_7	T_1	service	manhours
MP_8	Manpower service	F_7	T_2	service	manhours
-	Equipment service	F_8	F_5	service	-
-	Equipment service	F_8	T_1	service	-
-	Equipment service	F_8	T_2	service	-
-	Plant service	F_5	T_1	service	-
-	Plant service	F_5	T_2	service	-
-	Ready plant	T_o	F_5	mass	-
E_6	Energy	T_1	T_1	energy	
E_2	Energy	T_1	T_2	energy	

Figure A-4-6 (4). Example for proposed process description in EDSS: process topography lists (photocells) part 3

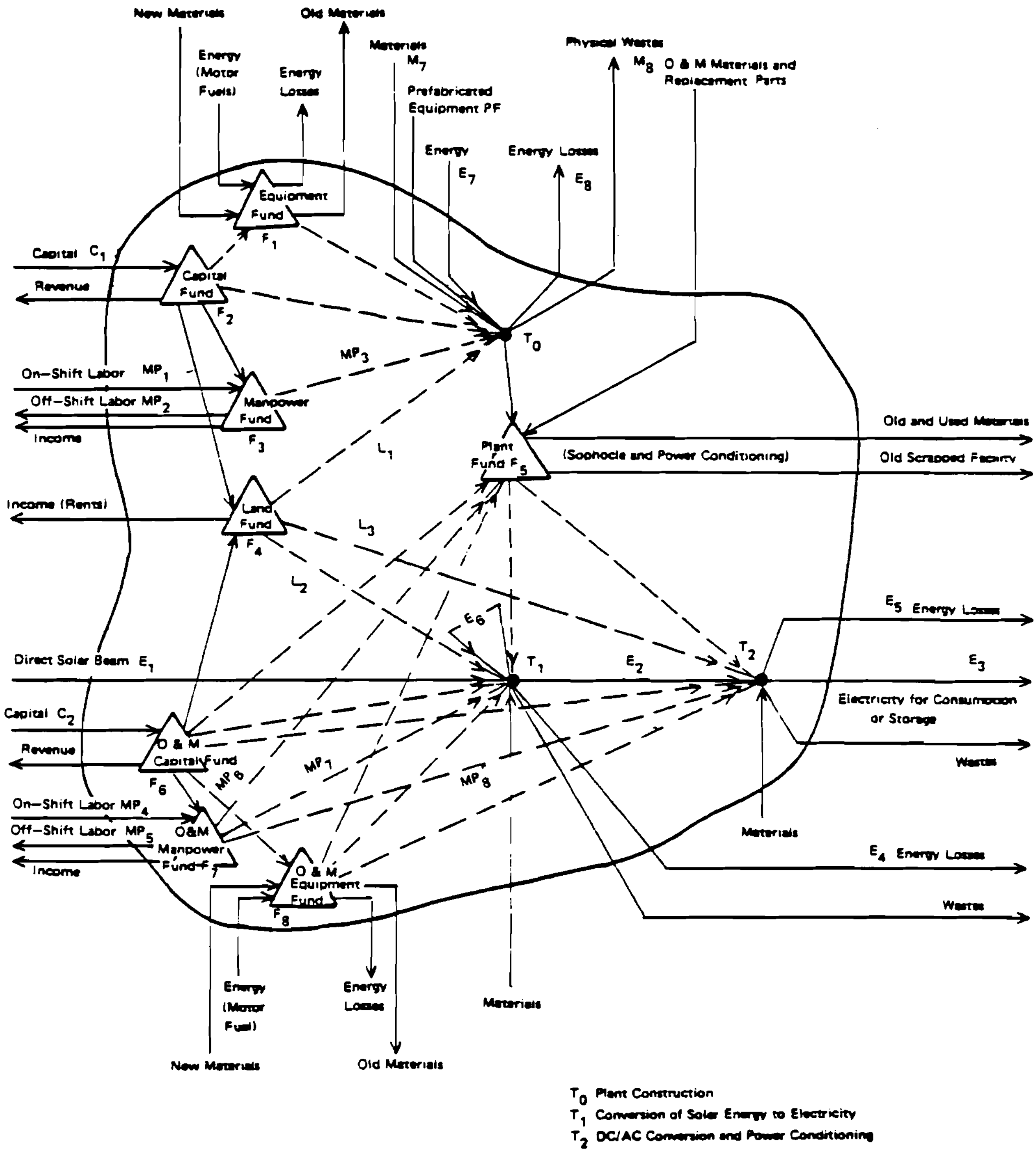


Figure A-4-6 (5). Example for proposed process description in EDSS: process topography described by process model (solar energy-electricity with photocells)

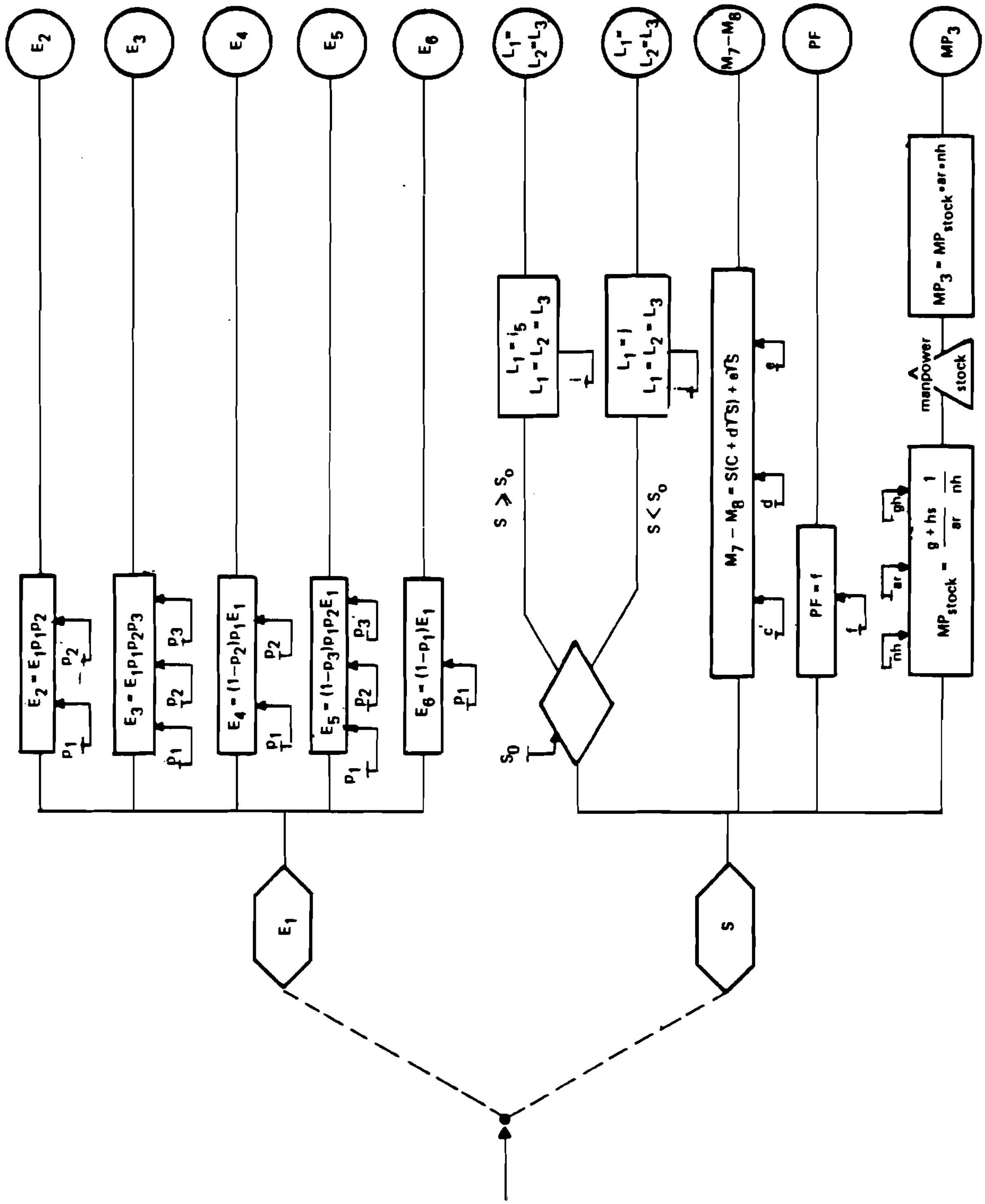


Figure A-4-6 (6). Example for proposed process description in EDSS: process model diagram for photocells process model

Process Model 1

$$E_7 - E_8 = a\ S + b \qquad \text{(kcal)}$$

$$E_3 + E_5 = E_2$$

$$E_4 + E_6 + E_2 = E_1$$

$$E_3 = E_1\ p_1\ p_2\ p_3$$

$$E_2 = E_1\ p_1\ p_2$$

$$E_3 = S\ E_1\ (x,\ y,\ t)\ p_1\ p_2\ p_3$$

$$E_2 = E_1\ p_1\ p_2$$

$$E_3 = E_1\ p_1\ p_2\ p_3$$

$$E_4 = (1 - p_2)\ p_1\ E_1$$

$$E_5 = (1 - p_3)\ p_1\ p_2\ E_1$$

$$E_6 = (1 - p_1)\ E_1$$

with

$$E_1 = S\ E_1\ (x,\ y,\ t)$$

Figure A-4-6 (7). Example for proposed process description in EDSS: process model data base for photocells (part 1)

Process Model 2

Equations of Model 1

and:

$M_7 - M_8 = S\ (c + d\sqrt{S}) + e\ \sqrt{S}$ (kg)

$PF = f$ (kg)

$MP3 = g + hS$ manhours

$L1 = iS$ if $S > 13.65\ m^2 = S_o$

$= j$ if $S < 13.65\ m^2 = S_o$

$MP_3 = MP_1 - MP_2$

$MP_4 - MP_5 = MP_6 + MP_7 + MP_8$

$L_1 = L_2 = L_3$

Figure A-4-6 (8). Example for proposed process description in EDSS: process model data base for photocells (part 2)

Process Model Description

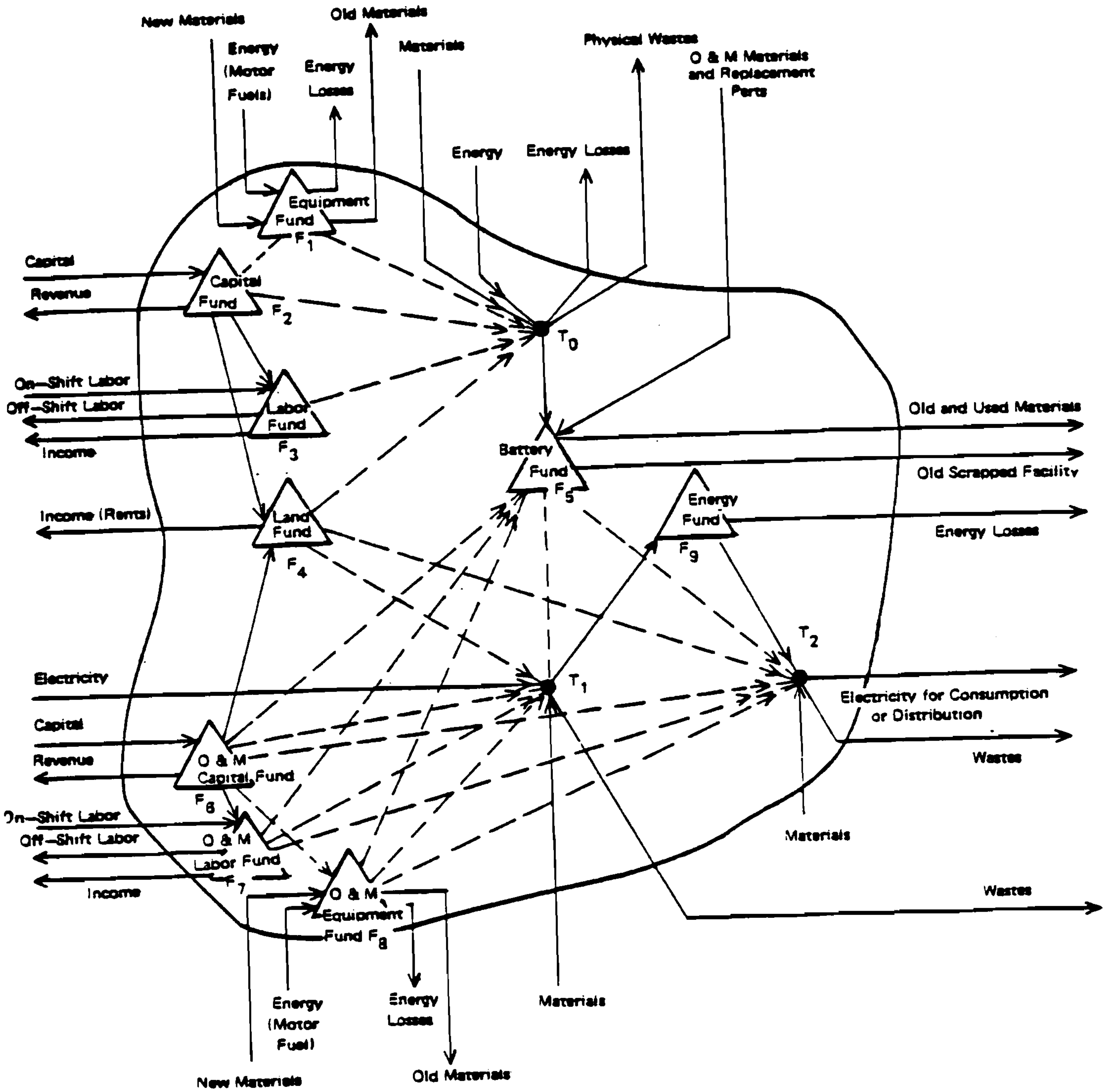
Exogenous variables

Code	Unit	Description
S	m^2	heliostat area
E_1	kwh/m^2	net solar radiation
x,y	deg.,min., sec.	geographical coordinates
t	day of year	time

Parameters

Code	Name	Value	Unit
p_1	efficiency rate of conversion of solar energy to electricity	0.11	unitless
p_2	system's efficiency	0.98	unitless
$(1-p_2)$	(autoconsumption rate)	(0.02)	
p_3	efficiency of the power conditioning and dc-ac convertor	0.95	unitless
c	material scaling coefficient	-0.218	kg/m^2
d	material scaling coefficient	3.4787	kg/m^3
e	material scaling coefficient	13	kg/m
f	prefabricated equipment weight	5	kg
g	maintenance requirement	90	manhours
h	operation scaling coefficient	1.648	$manhours/m^2$
i	land scaling coefficient	6.646	unitless
j	minimum requirement for heliostat installation	13.65	m^2

Figure A-4-6 (9). Example for proposed process description in EDSS: process model data base for photocells (part 3)



T_0 Plant Construction

T_1 Storage Charge

T_2 Storage Discharge

Figure A-4-7. Example for proposed process description in EDSS : process topography for energy storage with batteries

Process Topography Batteries

List of flows

Input flows

Code	Name	Destination	Used in model	Type	Unit
C_1	Capital	F_2	2	mass	
MP_1	On-shift manpower	F_3	2	mass	
E_1	Electricity	T_1	1,2	energy	
C_2	Capital	F_6	2	mass	
MP_4	On-shift manpower	F_2	2	mass	
-	New materials	F_8	-	mass	-
-	Energy (motor fuels)	F_8	-	energy	-
-	Materials (comp. unknown)	T_1	-	mass	-
-	Materials (comp. unknown)	T_2	-	mass	-
-	New materials (comp. unknown)	F_1	-	mass	-
-	Energy (motor fuels)	F_1	-	energy	-
M_7	Materials	T_o	2	mass	kg
E_7	Energy	T_o	2	energy	
PF	Prefabricated Equipment	T_o	2	mass	kg
-	O & M materials and replacement parts	F_5	-	mass	-

Figure A-4-7 (2). Example for proposed process description in EDSS : process topography lists (batteries) part 1

Output flows

Code	Name	Origin	Used in model	Type	Unit
-	Revenue from capital	F_2	-	mass	-
MP_2	Off-shift manpower	F_3	2	mass	manhours
-	Income	F_3	-	mass	-
-	Income (rents)	F_4	-	mass	-
-	Income from capital	F_6	-	mass	-
MP_5	Off-shift manpower	F_7	2	mass	manhours
-	Income	F_7	-	mass	-
-	Energy losses	F_8	-	energy	-
-	Old materials	F_8	-	mass	-
-	Wastes	T_1	-	mass	-
-	Wastes	T_2	-	mass	-
E_4	Electricity for consumption or distribution	T_2	1,2	energy	
-	Old scrapped facility	F_5	-	mass	-
-	Old and used materials	F_5	-	mass	-
E_8	Energy losses	T_o	1,2	energy	
M_8	Physical wastes	T_o	2	mass	kg
-	Energy losses	F_1	-	energy	-
-	Old materials	F_1	-	mass	-
E_5	Energy losses	F_9	1,2	mass	-

Figure A-4-7 (3). Example for proposed process description in EDSS : process topography lists (batteries) part 2

Internal flows

Code	Name	Origin	Destination	Type	Unit
-	Equipment service	F_1	T_o	service	-
-	Capital service	F_2	T_o	service	-
MP_3	Manpower service	F_3	T_o	service	manhours
L_1	Land service	F_4	T_o	service	m^2
L_2	Land service	F_4	T_1	service	m^2
L_3	Land service	F_4	T_2	service	m^2
-	Capital	F_2	F_3	mass	-
-	Capital	F_2	F_4	mass	-
-	Capital	F_6	F_4	mass	-
-	Capital	F_6	F_7	mass	-
-	Capital service	F_6	F_5	service	-
-	Capital service	F_6	T_1	service	-
-	Capital service	F_6	T_2	service	-
-	capital service	F_6	F_8	service	-
MP_6	Manpower service	F_7	F_5	service	manhours
MP_7	Manpower service	F_7	T_1	service	manhours
MP_8	Manpower service	F_7	T_2	service	manhours
-	Equipment service	F_8	F_5	service	-
-	Equipment service	F_8	T_1	service	-
-	Equipment service	F_8	T_2	service	-
-	Plant service	F_5	T_1	service	-
-	Plant service	F_5	T_2	service	-
-	Ready plant	T_o	F_5	mass	-
E_2	Energy	T_1	F_9	energy	
E_3	Energy	F_9	T_2	energy	

Figure A-4-7 (4). Example for proposed process description in EDSS : process topography lists (batteries) part 3

A4-3: THE PROCESS MODEL DOCUMENTATION LANGUAGE [35]

THE STRUCTURAL DIAGRAM

The Structural Analysis Division of Statistics Canada has in its development of various models evolved a "Structural Diagramming" technique that allows model development to be clearly partitioned into the design and implementation phases. The design phase culminates in a structural diagram of a model that can be independently implemented. The structural diagram also serves to uniquely define all parameters and relations that constitutes a complete specification of the model. This aspect of the structural diagram makes it eminently useful in delineating generic models[36] for process descriptions. Moreover, the structural diagram enables a systematic documentation of the definition and meaning of all variables associated with it. All generic models in the Process Enyclopedia are thus documented according to this structural diagramming technique and a description of that technique is given herein.

Models use two fundamental concepts, variables and procedures. Variables represent information about objects defined by the model and procedures represent the relationships between the objects taking the values of variables as input and producing new values of variables as output.

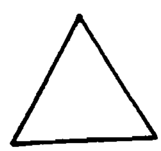
[35] TAKEN FROM MCINNES AND PAGE, 1979.
[36] For the purpose of this subsection we use the terms generic model and process model interchangably.

Variables

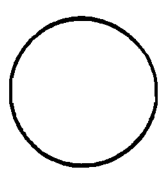
Variables may be divided into two groups, those that are calculated by the model and those that are not. This is the familiar distinction between endogenous and exogenous variables.

We distinguish two kinds of endogenous or model determined variables, those representing levels or stocks such as population or capital stock and those representing flows such as GNP or other information such as per capita consumption.

A triangle is used to represent an endogenous stock variable and a circle is used to represent an endogenous flow variable.



stock or level endogenous variable



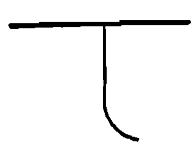
flow or other endogenous variable

We also distinguish two kinds of exogenous or predetermined information: parameters and exogenous variables. The distinction between exogenous variables and parameters is not clearcut; nevertheless we feel that it is a useful distinction. Exogenous variables often represent flows (occasionally parameters) and thus may be expected to change over time or are subject to large variations. Parameters represent structural constraints and may be expected to be stable or subject to moderate trends over time. To illustrate this point consider the equation which relates the area of a circle to its radius.

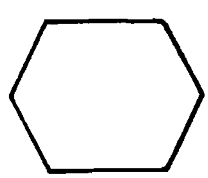
$$A = \pi r^2$$

Given the exogenous variable r and the value of the constant parameter the 'model' may be used to calculate the value of the endogenous variable A.

A horizontal line is used to represent a parameter and a hexagon is used for an exogenous variable.



parameter

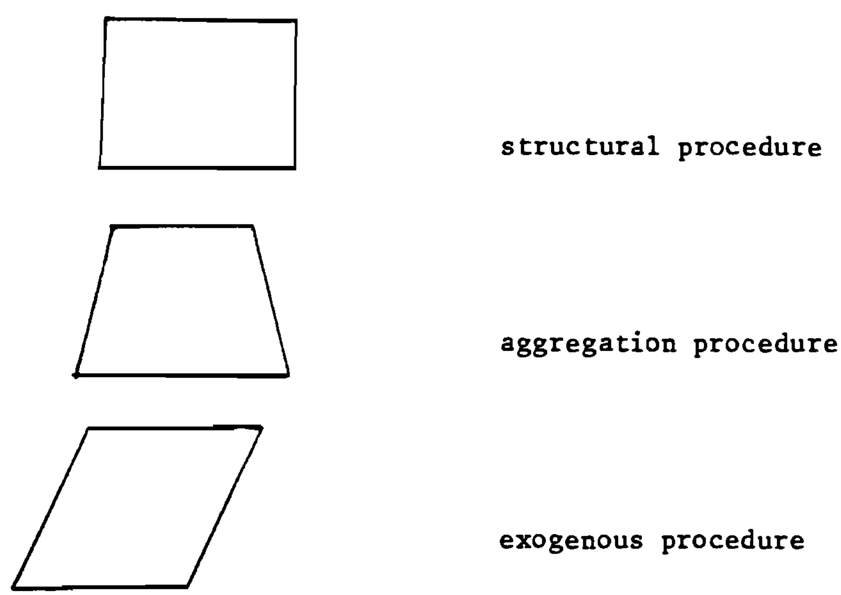


exogenous variable

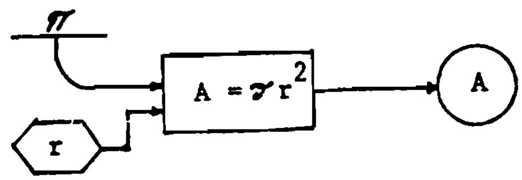
Procedures

Procedures are represented as four sided figures. In addition to the general form which is a rectangle, two special procedures are identified. A rhombus is used to represent the procedure aggregation: a parallelogram is used to represent a procedure which is not part of the structure of the model but is nevertheless part of the code of the model system.

Procedures for projecting exogenous variables fall into the category.

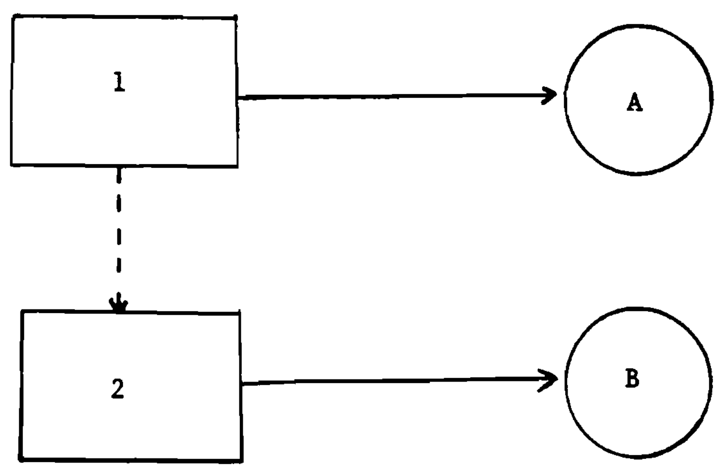


Procedures are connected to variables (and variables to procedures) by solid directional lines. These connecting lines are called relational flows and represent the use of a particular variable in a procedure or the definition of a variable by a procedure. For example, the 'model' to calculate the area of a circle may be represented as follows :



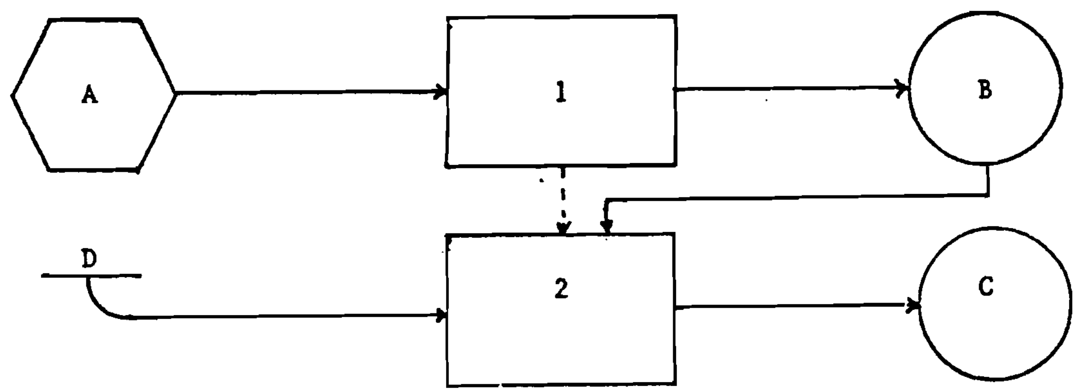
Procedural Flows

In addition to relational flows we define procedural flows which indicate flow of control. Procedural flows are represented by dashed lines which join procedure to procedure.



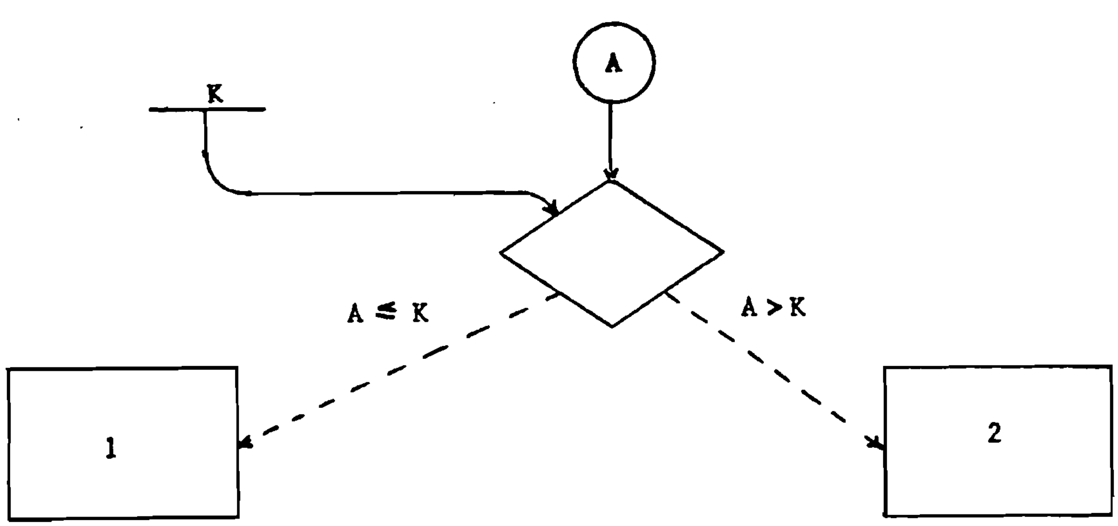
Thus, this segment reads "do procedure 1 which defines variable A, then do procedure 2 which defines variable B".

Where procedural flows and relational flows are the same, we have adopted the convention that the procedural flows be omitted. For example in the segment



the dashed line would be omitted. A special symbol, namely a diamond is used to represent branching.

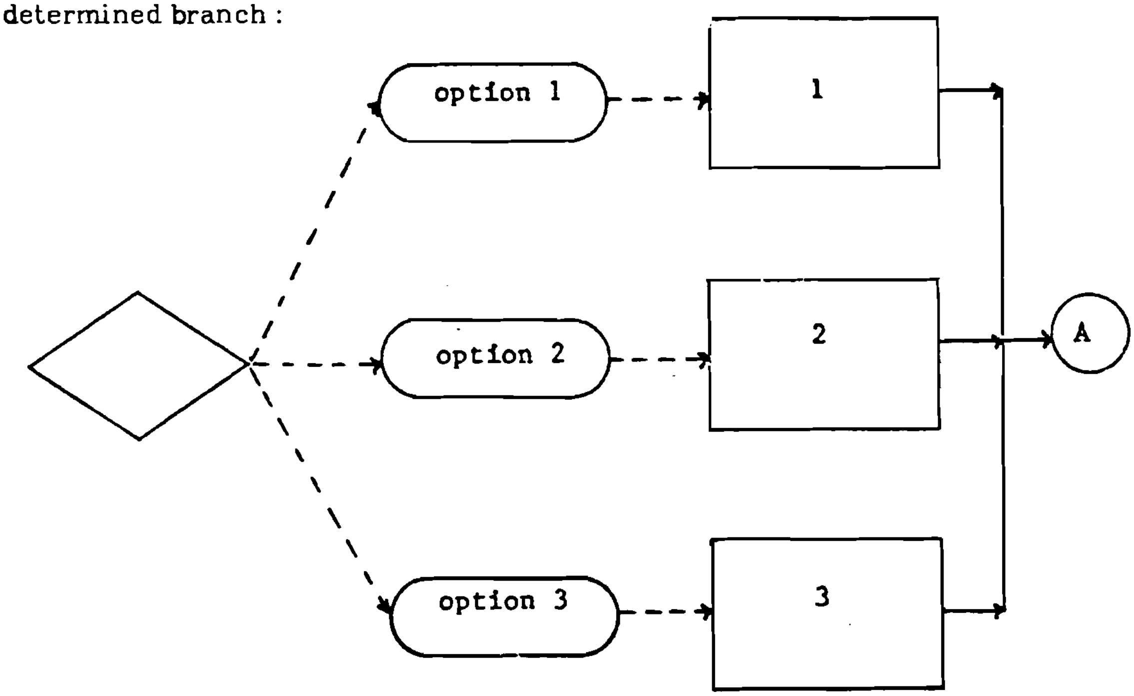
Branching occurs when control is passed to one procedure *or* to another depending upon criteria that are endogenous to the model or are user supplied. To illustrate the two permissible syntaxes for branching consider the following examples:



This segment is an example of a model-determined or endogenous branch such as 'if A is equal to or greater than K, do procedure 1, if A is less than 1, do procedure 2.

Note that the branching symbol is *not* a procedure which defines a variable, rather it is a procedure that determines the flow of control. Thus, relational flows may enter the diamond, but only procedural flows may emerge.

The following sequence demonstrates an exogenous or user-determined branch :

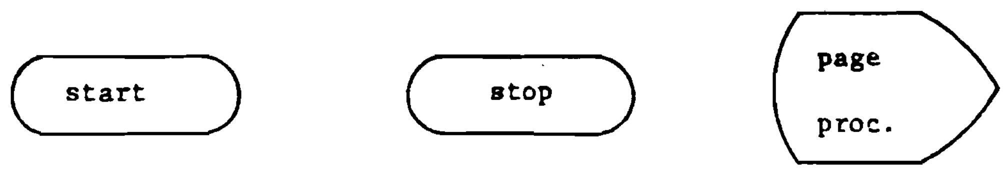


This segment indicates that the user must choose either option 1 or option 2 for determining A. The choice of option 1 implies that procedure 1 will be used to determine A and the choice of option 2 that procedure 2 will be used.

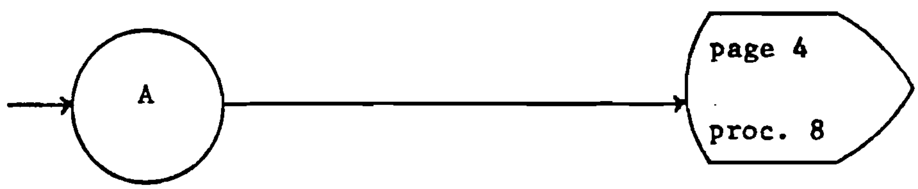
The use of the ellipsis and the absence of relational flows into the diamond distinguish exogenous from endogenous branches.

Special Symbols

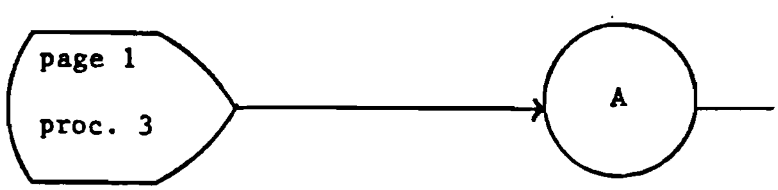
Several additional symbols are needed to complete the set. These are symbols to represent 'start', 'stop' and 'off-page connector'.



The off-page connectors are used as follows:



This indicates that variable A will be used in procedure 8 on page 4, and



indicates that A has been defined by procedure 3 on page 1.

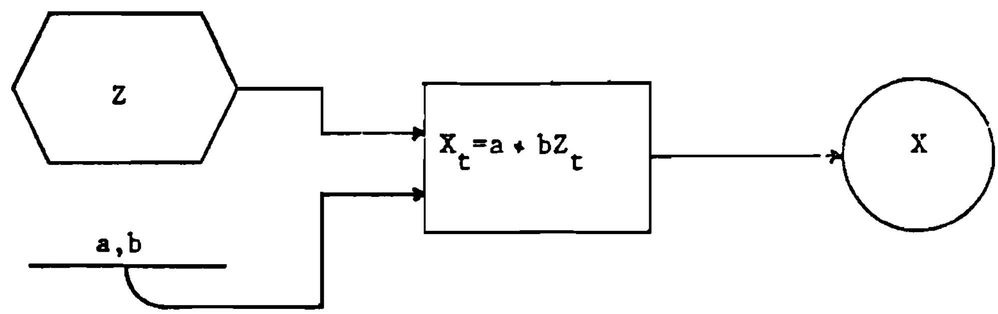
By convention when connecting relational flows cross-page boundaries the variable involved is repeated on both pages. The off-page connector can also be used to connect procedural flows.

Time Structure

For the purpose of documenting time-structured models we have adopted the convention of dropping time subscripts except where lead and lag relationships are involved. For example the equation

$$X_t = a + bZ_t$$

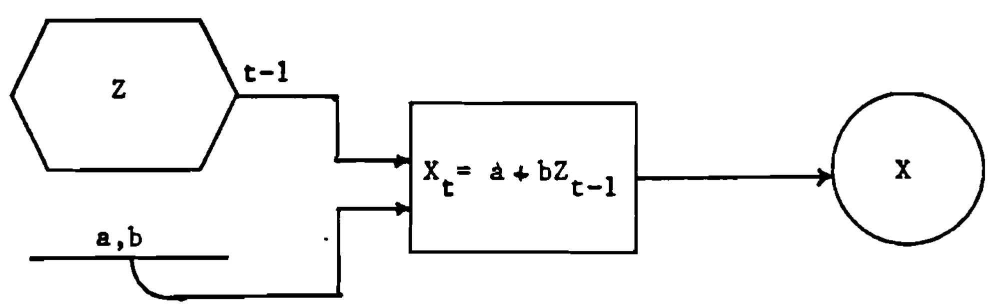
is represented as:



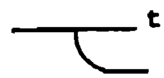
but :

$$X_t = a + bZ_{t-1}$$

is :



Time-varying parameters are distinguishable from parameters that are invariant with respect to time by placing a t to the right of the horizontal line as follows :



VARIABLE AND PROCEDURE DOCUMENTATION

The structural diagrams are, of course, in themselves not complete model documentation: they must be complemented by information about procedures and about the variables that are calculated by and used by the procedures.

The links between the structural diagrams and this information are variable and procedure names. Each variable and procedure is assigned a name which appears in the diagram.

The variable and procedure names are intended primarily to provide unique and abbreviated identifiers for each variable and procedure. A secondary objective is to convey sufficient information about the variable or procedure so that the unique names can be assigned to new variables or procedures without searching the entire list to determine whether the name is already in use.

The procedure names are used to reference the structural diagrams to the text which presents and explains the formula represented by the procedure. The variable names are the familiar 'mneumonics' which serve to label variables so that exogenous variables and parameters can be assigned values and calculated variables can be analyzed and reported. The names assigned to decisions (diamonds) are used in the documentation of the available options.

A master list of procedures is appended which contains the following information about procedures:

(i) procedure names;

(ii) names of variables entering or used in the procedure;

(iii) names of variables calculated or defined by the procedure;

(iv) procedure type - aggregation procedure or other;

(v) English description, e.g., the function of the procedure (optional).

Analogously information about variables is appended in a master list which consists of the following items:

(i) mneumonic name;

(ii) dimension - scalar, vector, matrix;

(iii) if vector or matrix, the space in which the dimensions are defined and the title list for this space;

(iv) variable type - exogenous endogenous, parameter, constant parameter;

(v) name of the procedure which calculates or defines the variable (if endogenous);

(vi) English language description of variable.

As an illustration of process model documentation using above outlined structural diagramming technique see the example presented in Figure A-4-6 above.

A4-4: A REFERENCE TO SOME OTHER SOFTWARE TOOLS OF RELEVANCE TO THE EDSS

Thus, we have discussed the main EDSS tools, namely the documentation *language for the decision making cycle representation* (SADT for the "activigrams") in Chapter 3 and Appendix 3, *the process information system*, and the documentation *languages for process definitions* ("topography" language) *and for process model documentation* ((generic) process model structured documentation language). Also, we have tried to illustrate the latter's application for process descriptions by way of the study area already used to illustrate the SADT "activigrams" documentation language.

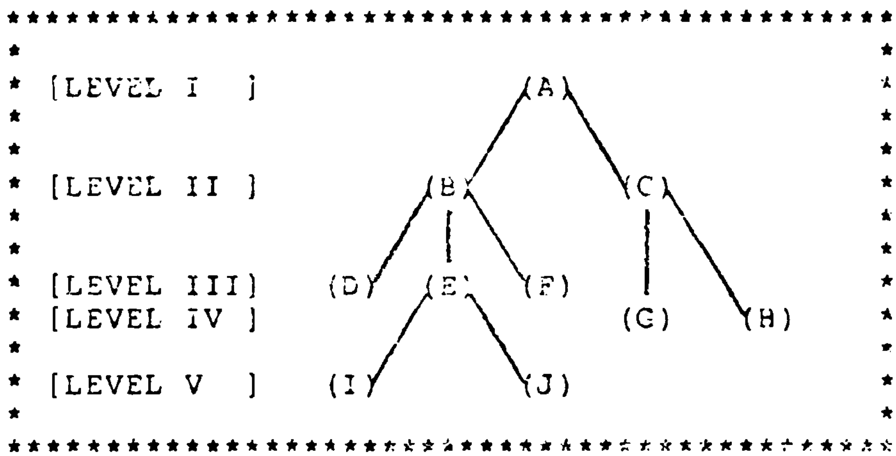
However, the EDSS will dispose of other specific software tools to – (a) ease the system access to the user and to (b) provide linkage to other formal EDP – documentation tools for analysis and documentation of a particular task within the framework of a formal MIS system.

Relating to point (a) above we have stated in the text of this paper the need for a powerful, user-friendly natural language data base management system. However, we envisage the requirement for an additional tool to *assist decision makers in the unstructured search* for data in the intelligence phase of the decision making cycle. This tool shall allow the user to scan quickly the contents of the EDSS and enable him interactively to filter out information, data, etc. The system provides thus a simplified form of a *systems thesaurus* and can be linked to a formal detailed thesaurus once this becomes developed for the EDSS and for other data files available. In relation to the interactive data filtering software we make reference to the so-called TREE, hierarchical data access and filtering software, developed at IIASA (Medow, 1983).

The TREE system was designed to simplify the process of interaction between the user and the computer. More specifically, to help the user in the filtering and linkage of data with various types of models, both stored on computer. This is achieved first, by limiting the number of actions or decisions on the user's part in predefining access, filtering and display methods available to him and secondly by using a hierarchical tree as method of structurization and classification. At each of the nodes of the tree structure the user may access and filter data and link these to the particular model chosen (see Figure A-4-8).

The TREE program is constructed as a non-binary tree relying on linked lists and a special search algorithm, providing the user with a conversational form of access to the computer and serving as a "telescope" which can be directed to the parts of a larger structure, of interest to the user.

The actual TREE software is in FORTRAN code in order that it is independent from the particular DBMS used for normal data access. In relation to the EDSS, a main feature and role of a software like TREE will not only be to provide access to data (stored in the Resource Data Base of the Process Data Base of the EDSS) and models (process model data base of the EDSS) but equally to direct the user and to give him an overview of



It is neccessary to understand how the above tree is restructed, in order that movement, as well as appending, and deleting nodes, is possible. The diagram below shows the same tree restructed.

The levels of the tree are indicated by the square brackets "[]". Note that they all have an index of 0. The nodes of the tree are indicated by the round parenthesis "()". All of the nodes belong to the level which is directly to the left of them.

Initially when you first begin, you are always located at the top most level name [0:I]. From any node or level it is possible to make one of following movements; a.) Directly up to the parent node,if it exists. b.) Down to the level name below. c.) Left or right the the neighboring node in the current level.

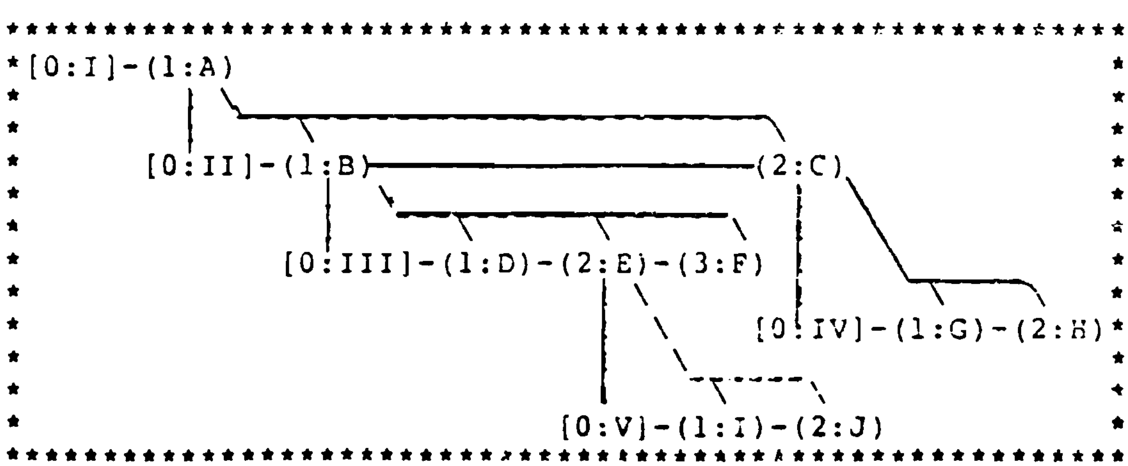


Figure A-4-8. An illustration of the TREE structure.

the contents of the EDSS, allowing him to access data separately or in a combined form (e.g., "paradigm" representations of all data relative to a particular process stored in the Process Data Base, etc.).

Finally, we make some comments on the conceptual/practical equivalences between the EDSS documentation languages (SADT, the process topography, etc.) and the formal EDP documentation tools in use at CSI.

One of the objectives of the proposed usage of particular documentation tools[37] , was in fact to profit from existing experience and familiarity with EDP documentation tools. Although the EDSS documentation tools are, as a function of the EDSS adaptive design strategy, less stringent in that they are oriented towards *description*[38] and not towards "efficient" software development, their conceptual equivalence to the functional part of formal EDP documentation tools like DAFNE is obvious (see Figure A-4-9 and compare with the modified SADT diagrams for the decision making cycle or even the process topographies presented earlier in this paper).

The main (and radical) difference is that the functional requirements on the EDSS with respect to a particular task, evolve throughout the decision making cycle. This is a function of the user learning about, and improving his understanding of the problem addressed by way of his

[37] Here we would like to recall that tools are presented in this paper as illustrative examples, without any ideological objective to propose a *particular* tool for the CSI EDSS system. Tools are a straightforward function of the specifics of the proposed EDSS, however, for practical reasons, the advantage of tools with which the user community is already familiar is obvious.

[38] Recall here the EDSS objective of improving the effectiveness (i.e., learning, understanding) of the user as opposed to improve his efficiency or the software efficiency of a particular EDSS configuration.

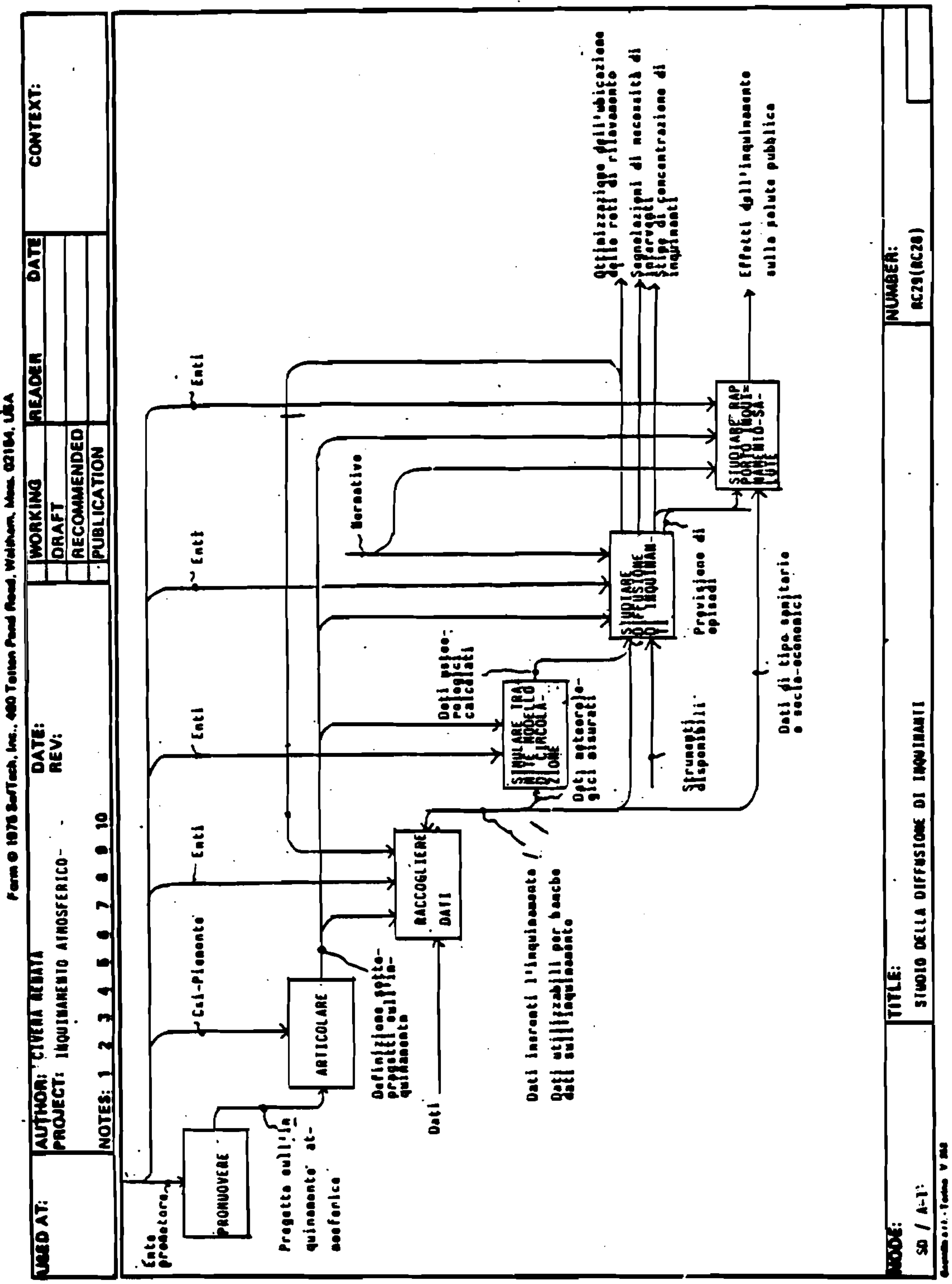


Figure A-4-9. Examples of DAFNE functional analysis documentation using SADT for air pollution project at CSI.

use of the EDSS itself. Thus, the user's perception of the problem changes and evolves (creating the need for additional EDSS facilities), as a result of his user of "actual" EDSS facilities. Therefore, there is nothing like a final "most efficient" system configuration resulting from that type of careful functional analysis characteristic of the EDP field.

The second difference relates to the second component of the DAFNE methodology, the data analysis in addition to the functional analysis and its verification feedback on the latter. The CSI performs this by using the Entity Relationship model (Chen, 1976) as illustrated in Figure A-4-10. In view, however, of the evolving nature of a particular task within the EDSS (e.g., introduction of unstructured information flows, or formalization of previously unstructured flows), not only the functional specifications on the system evolve, but equally the resulting data requirements. This in particular, is the case with data developed ad hoc within a particular task (i.e., the contents of the Resource Data Base) and it would be in contrast to the basic EDSS objectives to impose on the user a particular view of data. Therefore the adaptive design and implementation strategy we advocate (if the system is to be called a Decision Support System), has to find its equivalence equally with respect to the data, a user may, ad hoc, like to integrate into the system. The EDSS should respond to the user's view on how this data should be described and stored in the system. Data introduced into the EDSS within the framework of a long-term oriented activity, such as the EDSS process information system can, on the other hand, well be described within the Entity-Relationship model in use at CSI (recall here the discussion of flow attributes, a topography "owning" a number of process models, etc. in

Chapter 4 of this paper).

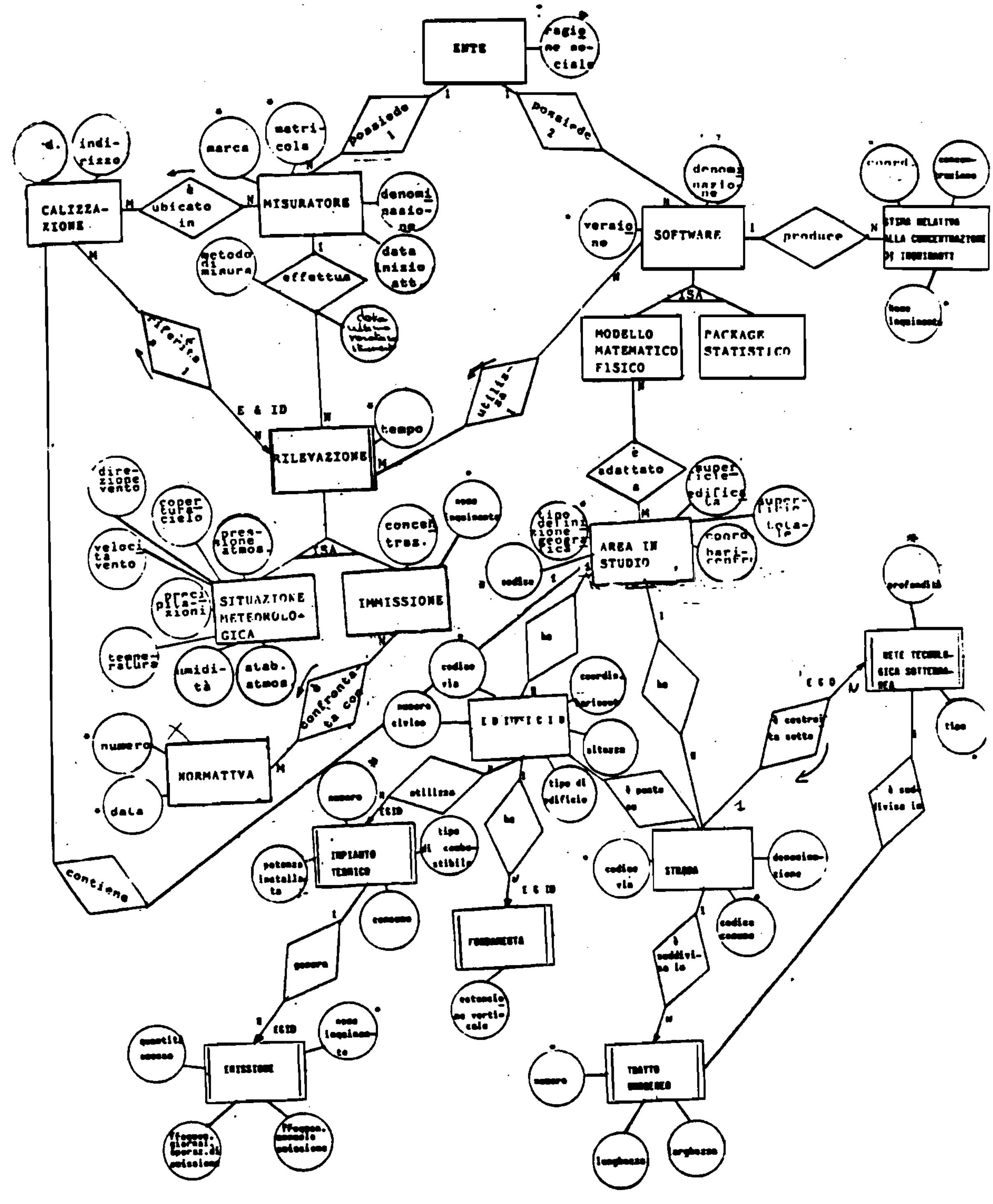


Figure A-4-10. Data analysis based on entity relationship approach for air pollution project at CSI.

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APPENDIX 5: SUMMARY OF TERMS AND (PARTIAL) SYNONYMS OF EDSS

Summary of Terms and (partial) Synonyms

EDSS:	DSS, MIS literature: (see references list)
Decision Support System (DSS)	
Environmental DSS (EDSS)	
DSS addressing structured (programmed) tasks ↔	*Management Information System (MIS)*
EDSS procedures (methodologies) documentation ("activigrams") ↔	*Decision Making Process*
	Phases of decision making process
	- *intelligence* ↔ *observation and influence*
	↔ *attention and search for alternatives*
	- *design* ↔ *evaluation (of alternatives)*
	- *choice* ↔ *decision*
	↔ *selection of alternatives*
	- *implementation* ↔ *implementation*
	- *evaluation*

Figure A-5-1. Summary of terms and partial synonyms: EDSS and DSS, MIS literature

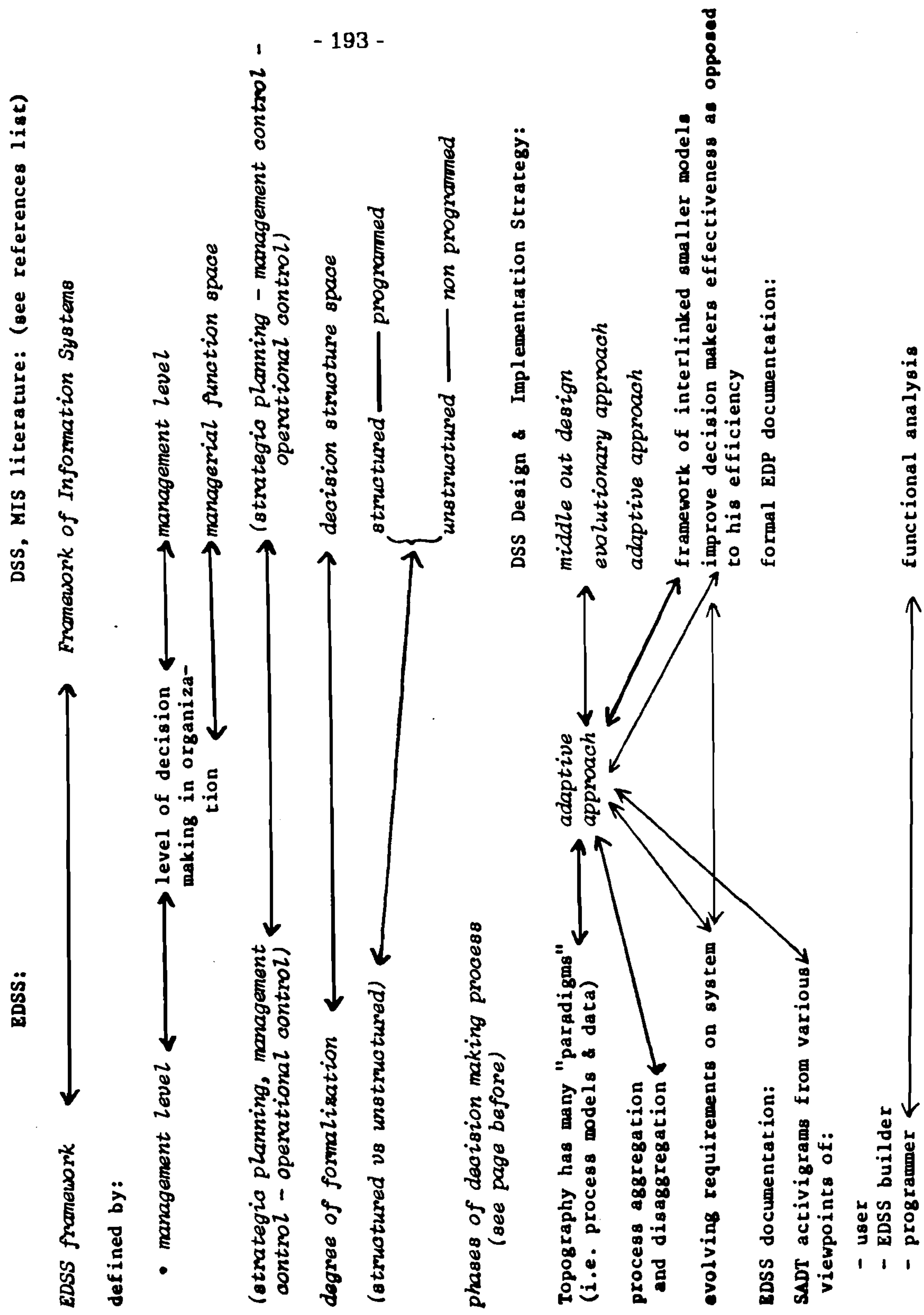

Figure A-5-1 (2). Summary of terms and partial synonyms: EDSS and DSS, MIS literature, DSS design and implementation strategy

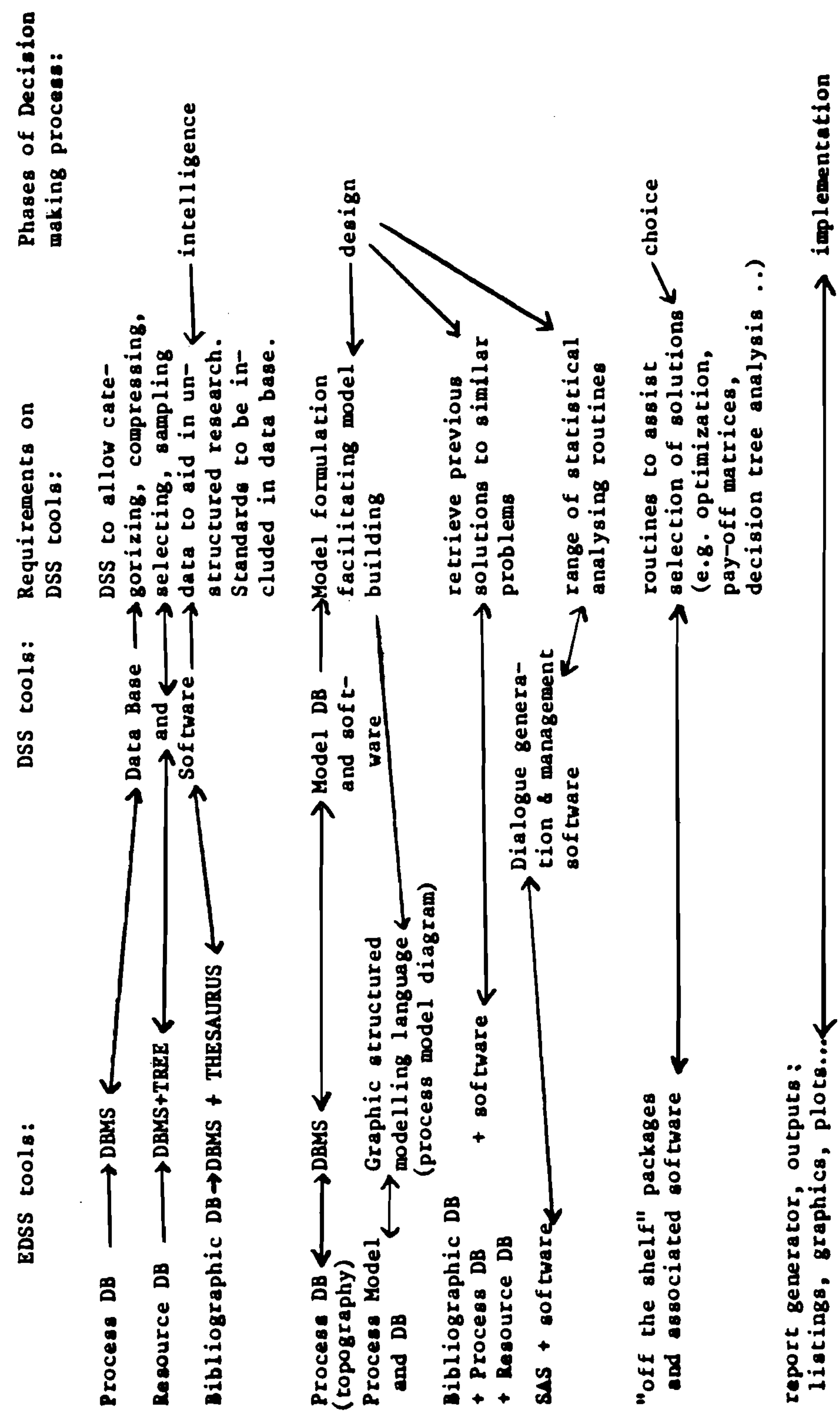

Figure A-5-1 (3). Summary of terms and partial synonyms: EDSS tools and DSS tools, requirements on DSS tools, phases of the decision making process