

EVALUATION PROCEDURES FOR CONCEPT INTERCHANGEABILITY
IN TRANSPORTATION SYSTEMS DESIGN

by
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ABSTRACT

A design methodology is proposed for dealing with complex transportation system analysis and evaluation. The objective is the reduction of the data processing duties of the human evaluator and the increasing of the degree of consistency and completeness in design studies.

The scheme is based on a general term for subsystems and ideas (concepts) and the appropriateness of the functional interactions (compatibility) between related concepts. The design procedure would be one of setting up general lists of concepts, attributes, and situations, prior to analysis of the design requirements for necessary function, causality and range of possible concepts. The nature of interactions between concepts are discussed in order to clarify the nature of discrepancy and incompatibility.

The primary emphasis of the evaluation procedure is on the avoidance of repeating past systems design errors and of incompleteness in neglecting important alternatives in favor of more quantitative or less risky preferences.

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CHAPTER I

An Introduction to Problems of Systems Design and Evaluation

1.1. The current situation of Complexity and Uncertainty

The term "system" is used to cover a wide range of phenomena. We speak, for example, of number systems, communications systems, control systems, educational systems and weapons systems. For general purposes, a system can be defined as any entity, conceptual or physical, which consists of interdependent parts. Moreover, our concerns are limited to those systems which can display activity, i.e. behavioral systems (Ackoff, 1961 pp. 27-28)

The increasing complexity of modern systems design and implementation has resulted in heavy demands on industry and government to coordinate their respective contributions towards resolving problems of mutual interest, such as Defense, space, and now transportation. The expansive scope and multiple incommensurables of modern transportation system planning will confront many engineers with severe problems of information handling, comparison and evaluations, and will strain the limits of human faculties.

In the past, most systems developments, such as those in rocket and aircraft technology, were evolutionary in

nature, because the processes of phase-in and phase-out were slow and gradual. Progress took the form of relatively small changes and refinements in the state of the art. However, successful implementation of major new developments in transportation systems may require the imposition of a completely new system on a community or metropolitan area and will depend on the coordination of a multitude of planning, design, and construction engineers with political authorities, economists, and market surveyors.

Since large production decisions may be involved before a system can be satisfactorily use-tested, it will be necessary to have quite sophisticated analysis and design evaluation schemes, which will lead to the selection of appropriate demonstration systems or prototypes. Unfortunately, the designers' techniques of decision making and evaluation of systems interactions have not improved at a rate commensurate with the increasing complexity of systems design problems and the difficult problems of prediction, risk and uncertainty.

Almost any systems problem seems to demonstrate an inherent degree of vagueness and uncertainty. For some types of uncertainty, the designer is effectively powerless to control. Improvements in methodology can

yield very significant results in reducing complexity and increasing design productivity, even though a concrete understanding of the detailed psychological processes may be lacking. The explanations offered in later sections of this thesis for favoring certain methodologies need not be considered air-tight or binding. Analogies will demonstrate these propositions better than intricate logical exposition, and can appropriately be drawn with the patent field, with library and data classification schemes, and with prior design attempts and achievements.

The various types of uncertainty can be selected by analogy to the defense analysis field :

1. Uncertainty about planning and cost factors
2. Uncertainty about economic and social context
3. Technological uncertainty
4. Uncertainty about the public and its reactions
5. Statistical uncertainty. (Hitch & McKean, 1960. pp188-92)

However, much of defense systems analysis is based on the stereotype of a rational "enemy"; and assumptions of a rational stereotype of the commuting public tend to be considerably more unjustified.

From a design viewpoint, uncertainty is a perceptual notion and a subjective measure, unless governed by

large-scale consensus ratings. Negative uncertainty effectively takes the form of either explicit or implicit confidence, and various product conceptualizations can be pegged by the designer at a number of incremental confidence levels to indicate uncertainty.

At the very least, the overall design process should be sufficiently organized to leave the designer with a sense of the scope of uncertainty, rather than vague doubts and suspicions as to the extent of uncertainty and its degree of acceptance or understanding by others.

In addition, incommensurables (terms lacking a common denominator) will complicate the evaluation process, but some semi-quantitative analysis is still possible. It will frequently be possible to calculate the necessary value of the incommensurables either in dollars or in terms of system objectives or effectiveness, if one system configuration is to be preferred over another. Final value judgment must still be exercised, but the decision making process will be aided by the knowledge that \$ N million is at stake rather than \$ 0.1N million or \$ 10N million. (Hitch and McKean, 1960. p. 186)

Certain methodologies have been developed to deal with uncertainty and incommensurables. For some applications

PERT systems and cost-effectiveness techniques can be quite useful; both handle the communications among a large number of personnel in a visible, systematized manner. However, PERT can make only very indirect contributions to the evaluation process, and cost-effectiveness or cost-utility analysis has spawned a confusing fragmentation of terminology and technique, such that general procedural guidelines for transport systems cannot be selected by analogy.

Attempting to define cost-utility analysis poses somewhat of a semantics problem. Numerous terms in current use convey the same general meaning but have important different meanings to different people : "cost-benefit analysis," "cost-effectiveness analysis," "systems analysis," "operations research," "operations analysis," etc. Because of such terminological confusion, in this chapter all such terms are rejected and "cost-utility analysis" is employed instead."(Fisher, 1965. p. 66)

Cost-effectiveness results are usually expressed as an S-curve of cost vs. a measure of efficiency in attaining some balanced or combined factor of effectiveness, a measure which can often be straightforwardly calculated in weapons analysis. In the absence of effectiveness measures with a common denominator, cost-effectiveness techniques are of somewhat diminished value.

1.2. The Need for Systems Design Involving a
Concepts/Compatibility Formulation

In planning for large system projects, we must establish a legitimate context within which appropriate suboptimization and design refinement can occur. We must set some basic rules for analyzing systems and system ideas into subsystems, parts, or categories which can be compared to one another. The challenge of transport system design lies in maintaining the relevance and importance of the more vague theoretical conceptualizations against the temptation to deal extensively with the more familiar and manageable hardware and existing operational systems.

This vagueness associated with certain innovative ideas (due primarily to uncertainties and unmeasured qualities) requires that special emphasis be placed on maintaining "contacts" with ideas which have been considered and judged infeasible, largely on the basis of present day standards. Programmed efforts at classification, description and comparison are necessary to establish and maintain the more unusual ideas, in order that they may be available for later retrieval and implementation. Preferably, such a retrieval process should be via computer information retrieval (IR), so as

to reduce the memory load on the systems designer.

To ensure a modern, future-oriented design outlook, the lists of present system components and future hypothesized components should be combined into a single list of concepts, an inclusive term which shelters both off-the-shelf hardware and the more uncertain elements and ideas. Because the concepts must fulfill certain mission requirements and mission functions, the basis for concept definition should be primarily functional. The closest resemblance to defining a concept is the statement of claims in a patent application, based on distinctions of function or functional structure.

Uncertainty is not limited to the more exotic concepts but also to the qualifiers and descriptors, the concept attributes, and to function and interaction. Concepts have a syntax analogy in the parsing of sentences : they correspond to nouns (the names of objects or ideas). The noun modifier or adjective forms constitute the attributes of the concepts. The verb or action forms of the concept system become the functions. The verbal connective or conjunction finds its analogy in compatibility relations between related concepts. Compatibility relations indicate coordination, subordination, correlation, and causality.

Other criticisms can be directed at existing design processes, besides the fault of conservative concepts selection. Excessive partiality is often shown towards data of a quantitative nature, at the expense of the more uncertain or imprecise qualitative data, thus distorting the relative importance of the attributes themselves. Moreover, in a situation dominated by incommensurables and limited trade-off possibilities, even the best analysts may indicate a tendency to revert to traditional but woefully oversimplified techniques of one-factor analysis, i.e. relative efficiency measures of one major variable, as the basis for their final evaluations. Clearly, there is little value in performing detailed systems analysis, if one in the end is to fall back on the very simple procedures one's methodological approach was designed to avoid.

In sum, the crucial task of the design process is to balance the presentation of qualitative and quantitative information (of various degrees of certainty) before the designer. The displays must have a built-in feature to counteract the human propensity to place high priority on a certain factor primarily because it is easily measureable. The qualitative information will probably have to be digested and consolidated in order to compete for attention and priority in the same ball park with the

succinctness of the respective quantitative information. The evaluation procedure should include IR capability of assuring that all relevant information is available at the time of decision, that each decision point is highlighted and separated from mechanical data manipulation, and that the decision maker can control the level of complexity and flexibility of information listing, as well as the rate of presentation.

1.3. Thesis Objectives

The general problem is one of developing techniques for organizing the design process and can be stated as follows : "What general manual and computer techniques can be adapted as organizational and IR aids for the systems designer, and how can procedural processes be so controlled that he can concentrate on evaluative decisionmaking (with all relevant variables taken into account), rather than on constant checking for proper mechanistic procedure?"

This thesis is not an inquiry into the specific objectives of any transportation program. It is concerned with the preliminary design and evaluation procedures for such a program, given a set of objectives and requirements. Nor does it attempt to delineate, summarize, or appear authoritative on the present state-of-the-art in

system design planning. Rather, in observance of recognized, unsolved general problems of procedure, it probes into new areas of possible solution.

This effort is more exploratory than definitive. Its objectives are not those of exhaustive experimental application of existing evaluative techniques to the transport design field. The primary concern is a systematized format which will improve the quality of preliminary evaluative decisions and allow the designer to be presented with information which is relevant, functionally related, and consistently subject to conditions of attribute priority.

1.4. Basic Design Processes

Because of the varied types of systems problems, it becomes a risky venture to speculate on general design procedures. Some simple linear, i.e. consecutive listing, models for design sequence have been suggested (Table I) and these techniques can be compared with those obtained for a sizeable sample of inventors and innovative engineers (Table II). This comparison will aid in determining which inventive techniques are also adaptable to major systems design projects.

Of course, any practical design program should have provisions for both flexibility and feedback, and we must

TABLE I : DESIGN PROCESS SEQUENCES

1. Define the problem
2. Visualize the bigger framework
3. Define the subsystems
4. Analyze the subsystems
5. Study the interrelationships
6. Decide the implementation sequence
7. Design the subsystems
8. Re-examine the system requirements
9. Feedback the design results
10. Continue the design cycle (Salzer, 1961. pp. 203-4)

1. Planning the design
2. Procurement of data for design
3. Block diagrams
4. Design of the subsystem
5. Design check for standardization
6. Reliability
7. Breadboards
8. Packaging design
9. Drafting
10. Testing
11. Value analysis

(Hajek, 1965. p. 24)

TABLE II : STEPS IN INVENTING PROCESS
(based on survey of 710 inventors)

1. Observation of a need or difficulty
2. Analysis of the need
3. A survey of all available information
4. A formulation of all objective solutions
5. A critical analysis of these solutions for their advantages and disadvantages
6. The birth of the new idea - the invention
7. Experimentation to test out the most promising solution, and the selection and perfection of the final embodiment by some or all of the previous steps.

(Rossman, 1964. p. 57)

develop a procedural block diagram for design. This diagramming effort is largely an iterative process of selecting general blocks, demonstrating the interrelationships, and then adding more detailed blocks or revisions to the overall diagram.

In creating either the procedural block diagram or later the transport systems block diagrams, our main concerns should be those of balanced combinations of relevance and completeness, rather than accuracy of interrelationship accuracy. It rewards us little if some aspects of analysis are highly developed, while others may be neglected. A useful analogy is that of economic

evaluation of defense problems.

The essence of economic choice in military planning is not quantitative analysis ; calculation may or may not be necessary or useful, depending upon the problem and what is known about it. The essential thing is the comparison of all the relevant alternatives from the point of view of the objectives each can accomplish and the costs which it involves; and the selection of the best (or a "good") alternative through the use of appropriate economic criteria. . . .

1. An objective or objectives
2. Alternatives
3. Costs or resources used
4. A model or models
5. A criterion

(Hitch & McKean, 1960, pp. 118-120)

Generally the criterion problem is the most difficult obstacle to straightforward design, since there may be many types of criteria applicable :

1. criteria for the selection of alternatives
2. cost/resource criteria
3. criteria for modeling accuracy
4. evaluation criteria (based on objectives)

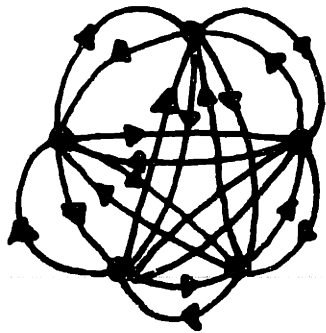
Unfortunately for the innovator, criteria are established mainly to provide a measurement or judgment standard for evaluation and almost invariably serve as a hindrance to the inventive process. Thus, even though criteria may be developed early for various stages of the design process, few requirements beyond the basic system objectives should be communicated to the inventive

design team ("brainstormers") until much of its innovating has already been accomplished. Criteria information can then be gradually transmitted for the purposes of checking/verification or design adjustment. Such a process should be designer-controlled, so that he could call at will for criteria details as he found need of them.

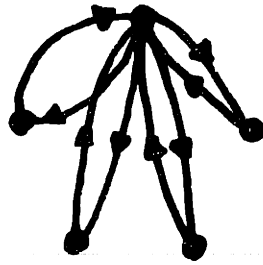
Our methodology is basically dual-purpose : first, to improve design efficiency and evaluation, and second to generate new ideas and alternatives. The balance between the two will shift increasingly in favor of the former as contract times expire.

At early stages of design, when a range of design and procedural alternatives present themselves, it would be wise to employ different employee arrangements and communications whenever appropriate. Some two-way communication models have been suggested (Fig. 1a), but there should also be provisions for the primarily non-critical "brainstormers," whose communications would be largely one-way and bereft of major criticism at the early stages of design (Fig. 1b). A subordinate staff would assist the innovative team in some of the more mechanical tasks such as calculating, testing, checking, etc.

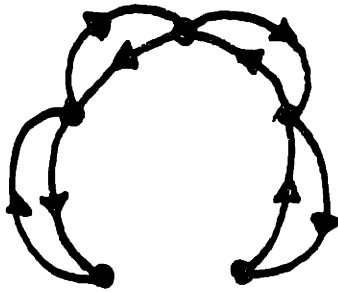
Because systems are composed of subsystems, which themselves are composed of more detailed subsystems, a heirarchal or tiered structure of complexity and detail results. Clearly, the design team at any one level could



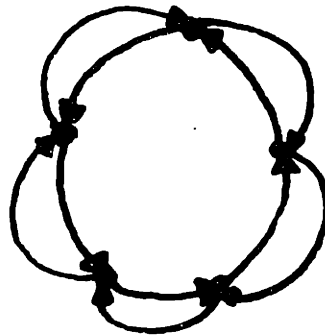
totally
connected



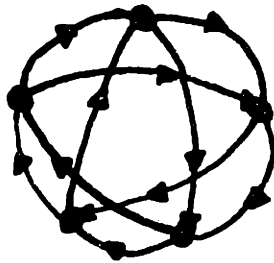
star



chain

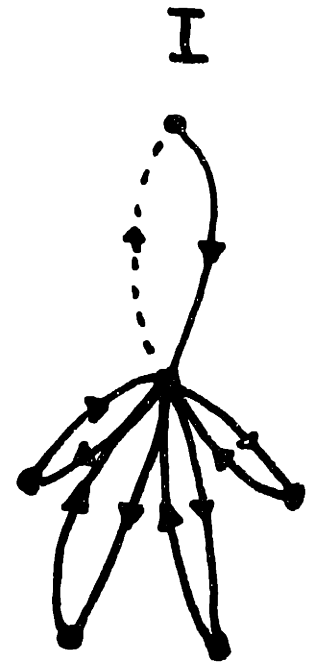


circle



pinwheel

(a)



star

(b)

Fig. 1. Group Communications (Fogel, 1963, p.372)

not maintain open communications with all other tiers.
Communication lines might be able to span only two or
three tiers at a time.

Any system can be broken up into tiers or levels of design detail. . . . The project engineer would be primarily concerned with the first and second tiers of technical effort as far as his functions are concerned. If any particular problem developed, he might actively participate in the third . . . tier of effort but only to become knowledgeable enough with the details associated with these areas in order to make some basic decision or to make a complete report to higher management.
(Hajek, 1965. pp. 11-12)

The chief engineer would be the fundamental link between the management/requirements planners and the engineering staff. He would have to steer the overall project between two extreme forms of procedure : (a) to study each situation, set of concepts and functions, and set of requirements to minute detail, before moving on to another design option, or (b) to scan superficially through each question and situation in a general way, and then continuously to repeat the process in an iterative manner to obtain greater design detail. The former method is essentially complete suboptimization, while the latter might be termed a "pure" systems approach.

In practice, the systems designer cannot proceed without some suboptimization being done and/or experience being used as a guide. He may decide on the areas of needed suboptimization and assign them to subordinates, but the systems design-suboptimization process must become a back and forth affair involving alternating applications of the two techniques. Systems design also

suffers from difficulties of coordinating technical data and interrelationships with the appropriate instructions (or, figuratively, with one's procedural position or location in the design sequence). For each instruction there is a set of rules, and it frequently is possible to present technical data and have it temporarily assimilated by the designer before he has ingested and understood the appropriate rules by which to process the technical data. Uncertainty over instructional rules is certainly not insignificant compared to technological uncertainties, but much of it can be reduced through proper information handling, displays, and human memory demands. These observations suggest that the design engineer should have recourse to a computer display or index file which would clarify instructions in times of uncertainty or misunderstanding.

If time and contract funds were unlimited, a wide range of alternatives could be selected for study, the suboptimizations performed at many levels within each alternative, definitive criteria developed, and an extensive range of data assembled for final evaluation. Under conditions of limits on contractual funding and time, the evaluations, assumptions and effects of criteria are shunted towards the early phases of design. As a general rule, the more stringent the contract limitations, the more critical are the early evaluations. Uncertainty

and suboptimization require the use of proximate criteria at numerous times in the design process and of frequent restatement or refinement of project requirements.

Depending upon the stage of the design process, there may be many different types of evaluation, possibly without even a set pattern. Because of the uncertainty factors involved, there is little reason to suspect that only one evaluation technique at any one stage will be sufficient. Experimentation could be performed with different types of evaluation procedures and the overall results evaluated qualitatively.

1.5. Basic Evaluation Processes

A natural tendency among engineers involved in evaluation procedures is to seek to substitute more quantitative techniques in place of qualitative judgments, even to the extreme of avoiding the latter. However, the very root of the term "evaluation" implies value, and our objectives should be the clarification and explanation of the evaluations performed and the deletion of unnecessary evaluations.

Evaluating, or summation of the judgment processes basic to complex response, consists of several processes forming a mental activity complex. First, perception defines the object, message or circumstances of immediate concern. Experience facilitates perception in that it enriches perceptual scope and possibly short-cuts the perceptual process. Habitual patterns of thought also affect the process, as well as categorization within the limits of individual experience. Similarities are sought between the item of

momentary interest and those previously encountered within the individual's experience, either through direct exposure or via the recorded experiences of others. (Ellis, 1962. p. 68)

Like methodology, evaluation serves a number of purposes, ranging from verification to improvement and innovation.

Evaluation studies have as their primary purposes: (1) the prediction of a system's ability to accomplish its mission, (2) the comparison of a system with alternative systems, (3) the improvement of a system, or (4) some combination of these. Beyond these more immediate purposes, there are frequently others, particularly economic and political ones, in which there is a need to demonstrate the worth of a system. (Davis & Behan, 1962. p. 479)

Evaluation may be formal, designed to secure measurement data, or informal, involving merely an examination of the product without an attempt to gather data.

The primary challenge of system design evaluation encompasses the difficult matter of compatibility, the comparison of how well all elements of the system will fit together.

The problem of interrelationship is often referred to as the interface problem. Since boundaries of systems and subsystems are seldom sharply defined, the separations are not easily made and should be the subject of continuous re-examination. The boundaries between subsystems can be defined as the basis of various considerations such as functions, equipment, and organization, but the boundaries satisfying one aspect of the system in an optimum fashion may not do so for the others. (Salzer, 1961. p. 198)

In other words, we seek to determine how compatible are certain functionally related concepts, relative to each other and to alternative combinations of concepts performing the same basic function, through a process involving :

1. Preliminary selection of sets of concepts serving as a rough model of possible systems; the more obviously incompatible combination sets are sifted out at the beginning.
2. Ongoing concept analysis and development, during which one would
 - a. Replace/substitute concepts as required to improve compatibility
 - b. Add necessary concepts
 - c. Subtract unnecessary concepts or consolidate/simplify concept groups.

Ideally, this latter evaluation and development process should be a procedure of incremental "tightening up" of evaluative details as information becomes less uncertain and more complete.

In a strict systems sense, it is incorrect to suggest then that for any interaction, the objective should be the maximization of compatibility, or even the minimization of incompatibility. Systems are so interrelated that minimization of incompatibility at one interface will cause an increase at another interface. More correctly, analysis

of compatibility entails a reduction in the most important incompatibility (or incompatibilities) in the system, based both on the importance of the interface and the relative magnitude of the incompatibility.

Incompatibility can take two forms : overdesign and underdesign. The latter is more important to engineering feasibility studies, but cost considerations increase the priority of overdesign factors. Overdesign can have two implications, depending upon whether or not safety factors have been taken into account, but consistency of definition is quite important. Since efficiency studies usually follow those for feasibility, early design emphasis would be on underdesign incompatibilities, while in later stages attentions would switch to overdesign phenomena.

Compatibility analysis would not be dissimilar to reliability studies, in the sense that both are intended to minimize the maximum disagreeable circumstances, or the limits posed by the critical sequence or conglomeration of elements within the systems. Both types of analyses are thus forms of minimax optimizations. (See Hitch & McKean, 1960, pp. 194-196). In both types, there may be little value in improving one subsystem or concept set which is far more compatible or reliable than a parallel subsystem. Such an approach to incompatibility importance merely serves as a guide to indicate which incompatibilities should be considered first in the design and evaluation

process.

1.6. INFORMATION RETRIEVAL FACTORS IN SYSTEMS DESIGN

There is a pressing need to develop computer techniques which will provide relief from the more unimaginative design requirements, such as unwieldy information processing burdens, memory demands, and explanation of complex instructions. A summary of these requirements should include :

1. Equalization of the priority of existing hardware with that of conceptualized ideas and constructs;
2. Special storage provisions for temporarily discarded ideas, so that future designers can avoid work duplication or can return to these ideas for reconsideration;
3. Selective availability of all relevant information - on tap but not in torrents;
4. Proper indexing of information which is within the computer system or available in convenient library-type reference;
5. Computer performance of the details of data listing, manipulation and recall;
6. A request command for further instructions from computer memory (a decision of the designer); a mandatory command for an instruction to correct seriously deviant designer procedure;

7. A record of the time, stage, and circumstance of each value decision;
8. Backtracking capability (reversibility without confusion) to allow the designer to make corrections and modifications to preceding decisions, while being reminded of the pertinent instructions and circumstances at that point;
9. An optional command to serve as a reminder to the designer at which position or stage in the design process he has progressed to, especially after periferal investigatory operations have resulted in side-tracking;
10. The organization of current literature in the field of transportation, with appropriate IR access and displays to reduce errors from the misinterpretation of graphs and equations or from the loss or misplacement of data.

Almost every one of the above factors concentrates on reducing the design time spent in strictly cognitive functions, of absorbing data and instructions and information on one's procedural position. In any event, the process of the designer's becoming aware of his location in the design procedure can be only partially

helped by computer aids. However, where before he would be compelled to determine where he is, he need now only observe and recognize his functional position.

Another matter which must temporarily remain unresolved is whether flexible controls should be implemented so that the designer does not unwittingly ask for too much information, or request to make too many decisions at one time or in a short period of time, thus overloading his mental capabilities. Some research information exists for the estimation of these capabilities, and this data should be used to determine what types of the afore-mentioned controls might be necessary. (Stevens, 1951).

1.7. Procedural Flexibility

While the systems procedure might include a set of instructions for the sequence of design operations, there is a need for flexibility to take account of uncertainty and differences between individuals. Another set of rules must specify approximate limits on the allowable freedoms of procedure. For prototype systems, the rules would be very non-specific, becoming more definite only after extensive test studies had been made of a range of designer preferences under conditions of favorable and well-organized projects.

Variables of flexibility should affect :

1. the types or sequence of complex information presented;
2. the rate of information presentation;
3. the specific alternatives to be chosen from a set of possibilities;
4. the rate and sequence of decision presentation;
5. the choice of further development and suboptimization of a concept, rather than development of other related concepts;
6. leapfrogging of certain stages in order to sample later critical phases of design.

As a rule, procedural flexibility should always exceed requirements flexibility.

1.8. Design Degrees of Freedom

Given certain basic requirements for transportation systems, we must seek a further understanding of the relation to each other of functions, attributes, concepts, and compatibility. Then one would be able to identify the minimal number of "degrees of freedom" in order to describe and specify the system, and to develop descriptive elements for every possible item, position, time, condition, process or attribute.

The degrees of freedom can be related to the types

of questions which may be asked about the system or concept. A fundamental requirement of the design engineer is that he be able to solve problems, or to ask and answer detailed questions of himself and his work.

"Fixing" the system situation involves the complete specification of the responses to all possible questions which can be asked about the system. The lowest number of non-redundant and non-overlapping questions for most man-machine systems appears to be six : WHO, WHERE, WHAT, WHY, WHEN and HOW. There are many variations within any one category, but the six general questions seem to be both necessary and sufficient. Consequently, we may infer that the minimal number of general degrees of freedom for the system is also six.

This matter is quite important, since most machine-machine systems have no more than five general degrees of freedom, lacking the human interactions of the WHO term. Having one less degree of freedom means that these systems tend to be much more manageable for design engineers. Even advanced aerospace systems with a limited sixth degree of freedom (the WHO of the astronaut) are still comparatively manageable in concise engineering terms, compared to the transportation example,

for which different types of users, non-users, and operators all interact in a very complex manner.

For the transportation case, formulation of the six main questions might take the form of a combined problem statement, a sample of which might be :

"How well (or how effectively) does System Type A
.....HOW.....WHAT.....
transport passenger types X and Y in metropolitan
..WHY.....WHO.....
area B at future time period T and for how much?
.WHERE.....WHEN.....HOW.....

As applied to a particular problem situation, there evolve two major subcategories between the six major question types -- between the identifiable elements of functional interactions and the processes or objectives themselves.

<u>ELEMENTS</u>	<u>PROCESSES</u>
WHO : Users, non-users	HOW : Functional explanation
WHERE: Location	
WHAT : Concepts	WHY : Justification
WHEN : Time (special conditions)	

Fixing all the six questions or degrees of freedom for a particular problem defines the system and its situations which characterize alternate orientations or functions of the system. Generally, the situations are

primarily a function of WHERE and WHEN - location, time, and environmental conditions such as weather, accidents, etc.

Usually, no matter how complex a mechanism or system may be, there is some consolation to the engineer to know the number of degrees of freedom possible, the number he might wish to consider as variable, the alternatives within any one degree of freedom, and which degree of freedom he would like to vary while the others remain approximately constant.

It might also be noted in this regard that, for a complex analytic procedure, a "degree of freedom" approach to instructional organization and explanation should also aid the engineer's comprehension of his tasks.

1.9. DESIGN PHASES AND CONCEPTS/COMPATIBILITY OUTLINE

When properly structured, a design procedure can serve a checklist function as well as being a systematization format for the acquisition of useful quantitative data. Essentially what is needed is a set of "road maps" for guidance through the labyrinth of design decisions and instructions. These road maps would vary for the different stages of the design and procurement cycle, and the concerns of this thesis will be directed towards the

earlier research periods, the conceptual and definition phases of systems design.

A program of system management must recognize the natural order of actions during the life cycle of a system. The system must be first conceived; this is designated the "conceptual phase," during which the idea and the requirement for a system are born. It must then be defined; this is designated the "definition phase," during which it is determined that all the elements of the system will fit together technically and economically. The system must then be physically acquired; this is the "acquisition phase," during which detail design, development, production and testing of the actual elements of the system must take place. It must then be delivered and put to use; this is the "operational phase," during which the system is ready to be operated and the mission of the system can be fulfilled.

(AFSCM 375-4, 1966. p. 1)

For transportation systems design, it may prove useful to add a demonstration phase between definition and acquisition, but even this phase is beyond the scope of this thesis.

The conceptual phase must avoid excessively conservative approaches if the final system is not to be obsolete or woefully inflexible the day it becomes operational.

The conceptual phase provides integrated broad systems requirements, a system concept to satisfy the system requirements, the necessary technology, a certain level of confidence in the technical and economic feasibility of the system concept, . . . and . . . documents . . . required for the definition and acquisition of the system.

(AFSCM 375-4 p. 6)

The definition phase will be a continuation of the conceptual phase, with greater emphasis on compatibility relations. Its requirements would be :

1. Effective use of present and future facilities and resources;
2. Preparation of detailed program management plans;
3. Determination of realistic cost and schedule estimates;
4. Identification of high-risk areas;
5. Definition of intersystem and intrasystem interfaces and corresponding responsibilities;
6. Evaluation of time-cost-performance trade-offs.

(AFSCM 375-4. p. 39)

In this context, the outline for a concepts/compatibility procedural approach as employed becomes :

1. Statement of overall objectives by contracting agency;
2. Restatement of requirements by contractor; choice of general alternatives;
3. Construction of general systems lists : concepts, functions, attributes, conditions;
4. Application of causality requirements to yield selected concepts, functions, etc.
5. Set up structure for compatibility studies, evaluation measures;
6. Evaluation trade-offs, checks for errors.

CHAPTER II

The Description of General Systems

2.1. The General Procedural Diagram

The starting point for any systems problem is a set of general requirements for program management and design. The new Department of Transportation, (DOT), might be expected to follow similar analytic procedures, as employed currently by the Air Force in setting the format for requirements:

1. Balance the factors of performance, time, cost and other resources to obtain the required system;
2. Minimize technical, economical, and schedule risks during the development and production effort;
3. Control changes to systems requirements during development and production;
4. Document decisions concerning the program;
5. Identify the significant actions to be accomplished by all organizations participating in systems management;
6. Establish requirements for flow of information between responsible organizations.

These general requirements and cost/time limits on the contract must then be translated and restated as design-oriented requirements and systems questions to be answered, as the first step in the design process. Under these conditions, an organized procedure of design analysis, synthesis and evaluation can be constructed for the purpose of assimilating information on the set of possible systems to be considered. The diagrammatic model is represented in Fig. 2, which incorporates many of the causal features of PERT charts and also has the advantage of differentiating between various individual and group responsibilities. The main divisions in operational responsibility were again derived by convenient analogy to recent Air Force charts of similar format (AFSCM 375-4, 1966. p. 38ff)

1. Requirements and objectives
2. System planning
 - a. General & specific predesign set-up
 - b. General & specific computer operations
3. Technology
 - a. Innovative groups (Brainstormers)
 - b. Subordinate, supporting R&D personnel

Parallel to the restatement of overall objectives, general location and user lists could be constructed from the general requirements.

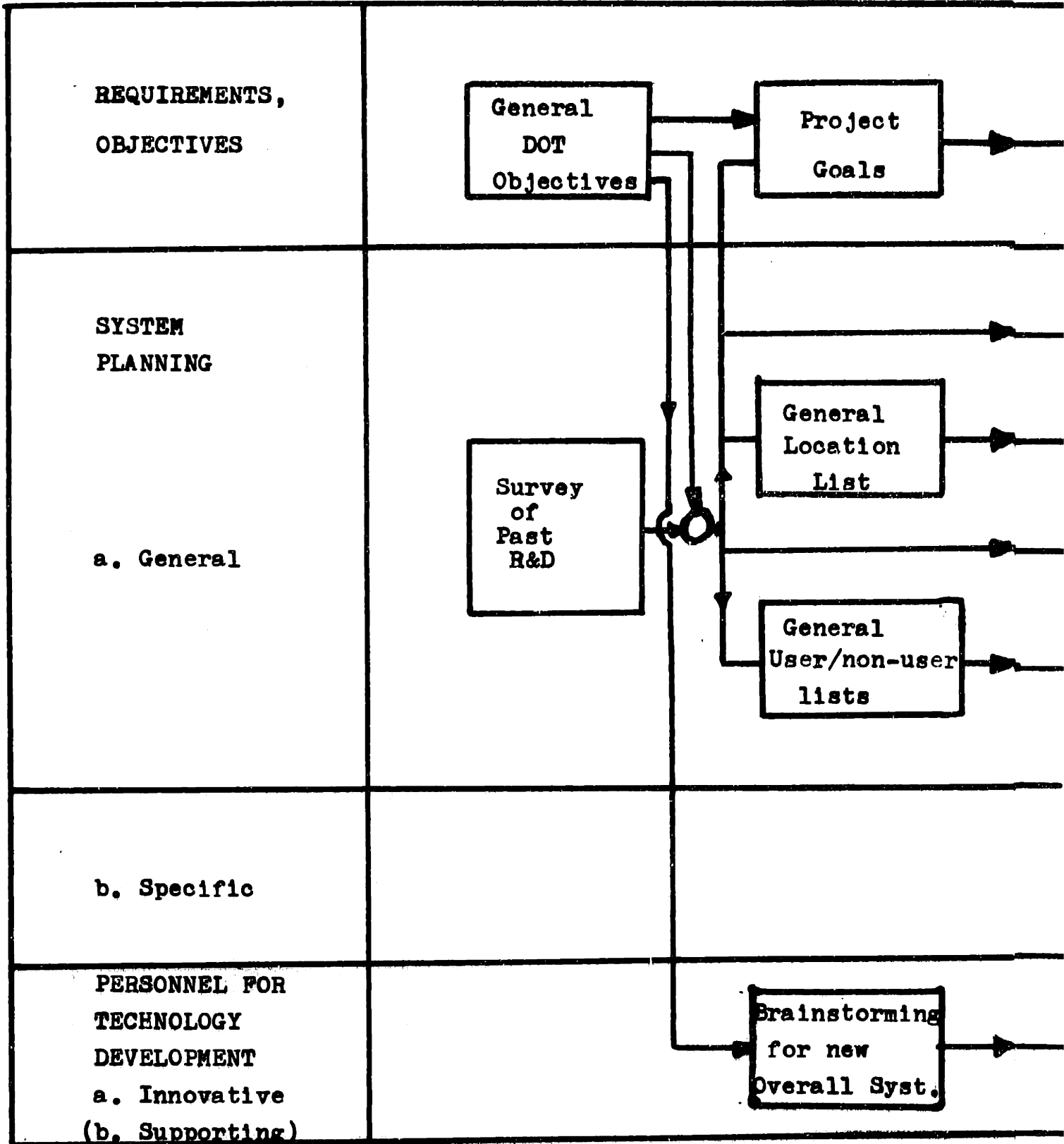
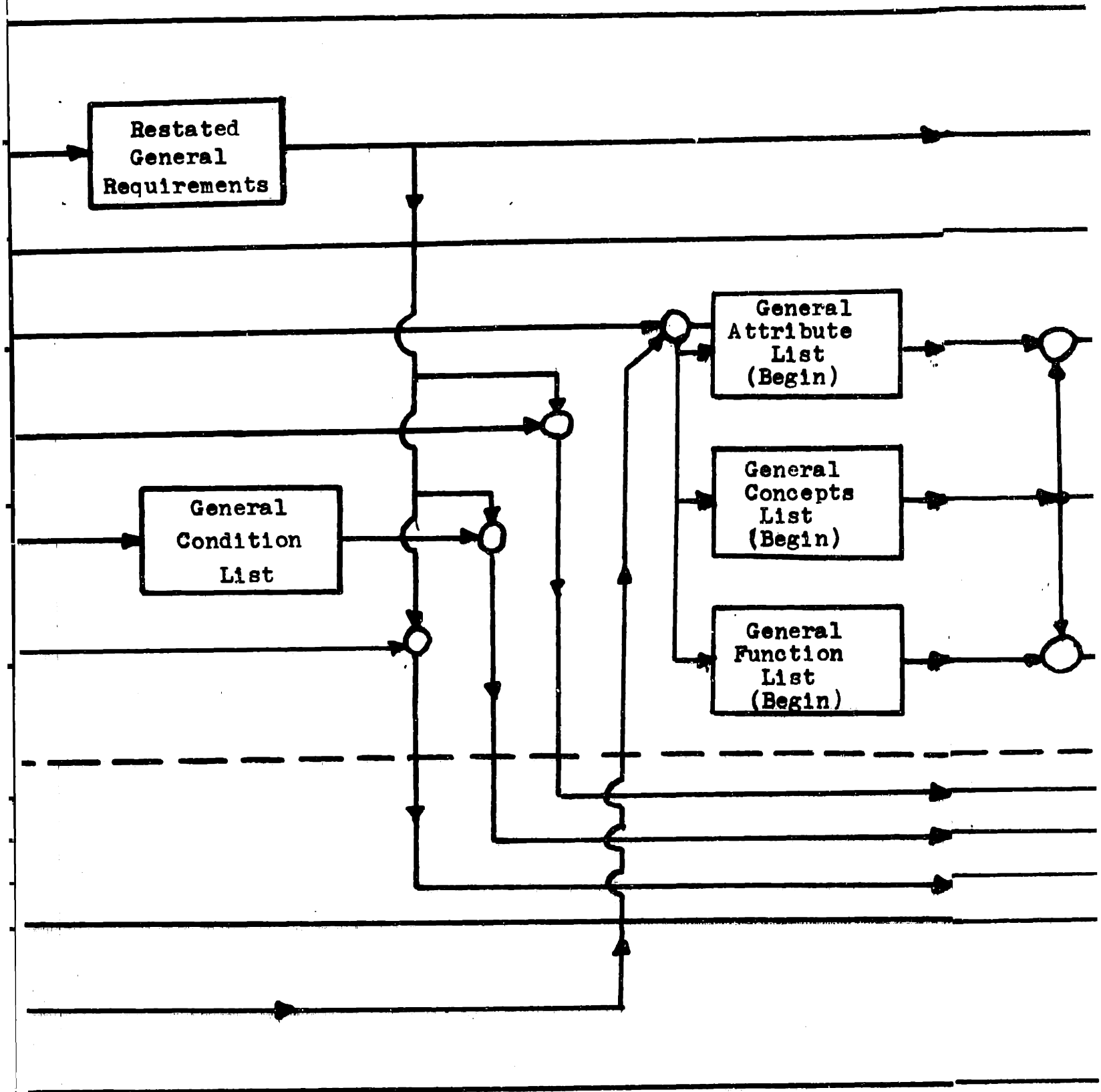
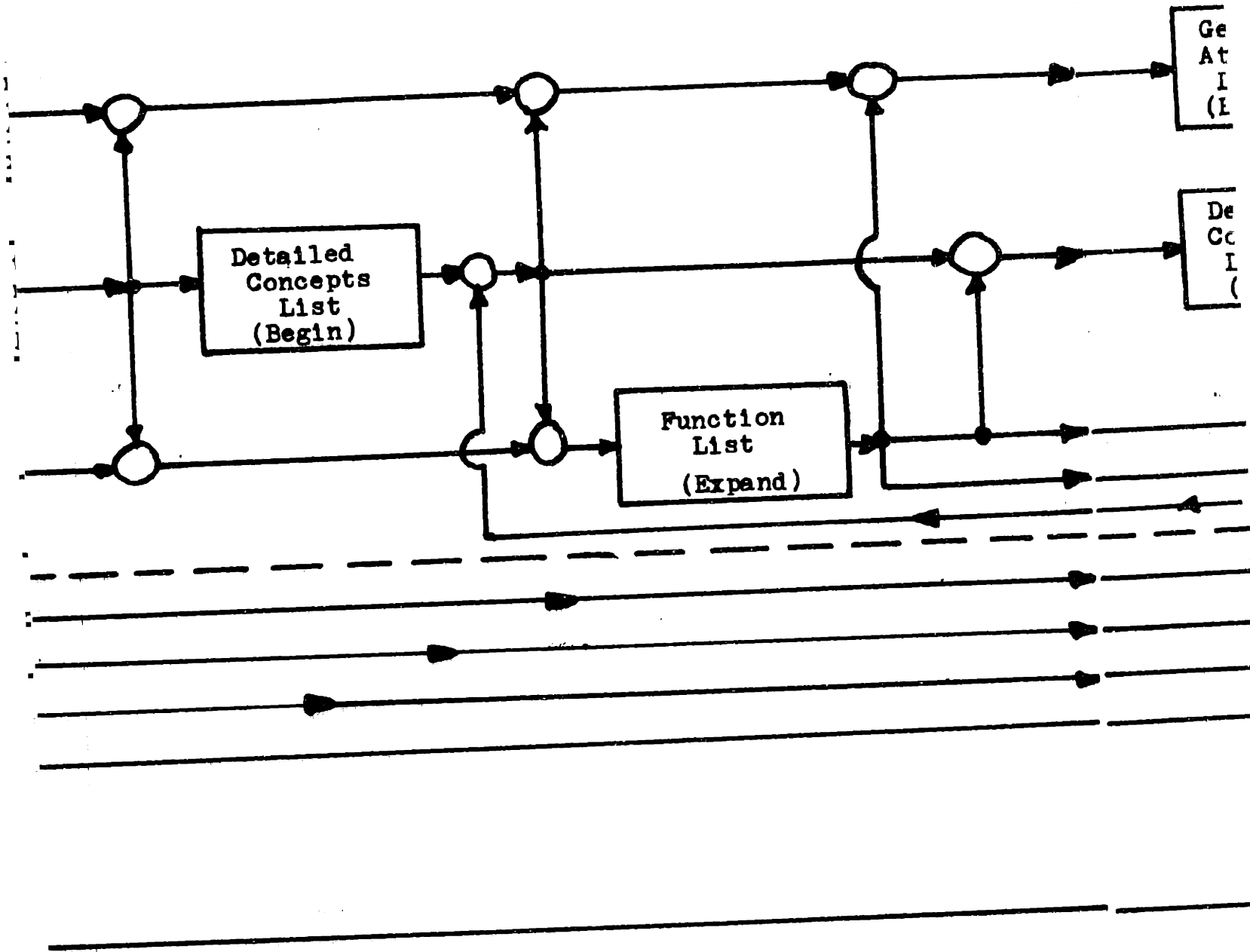
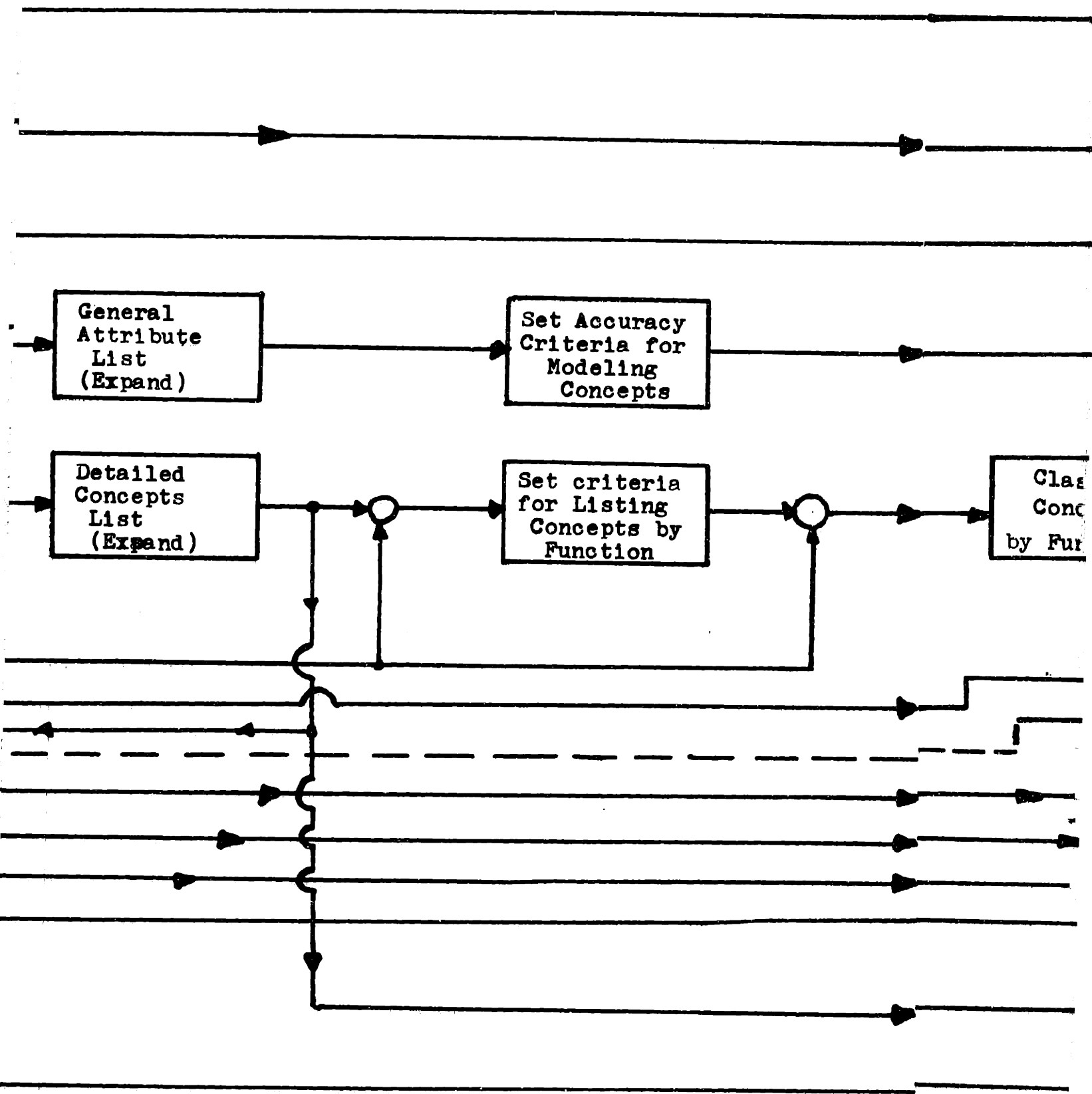
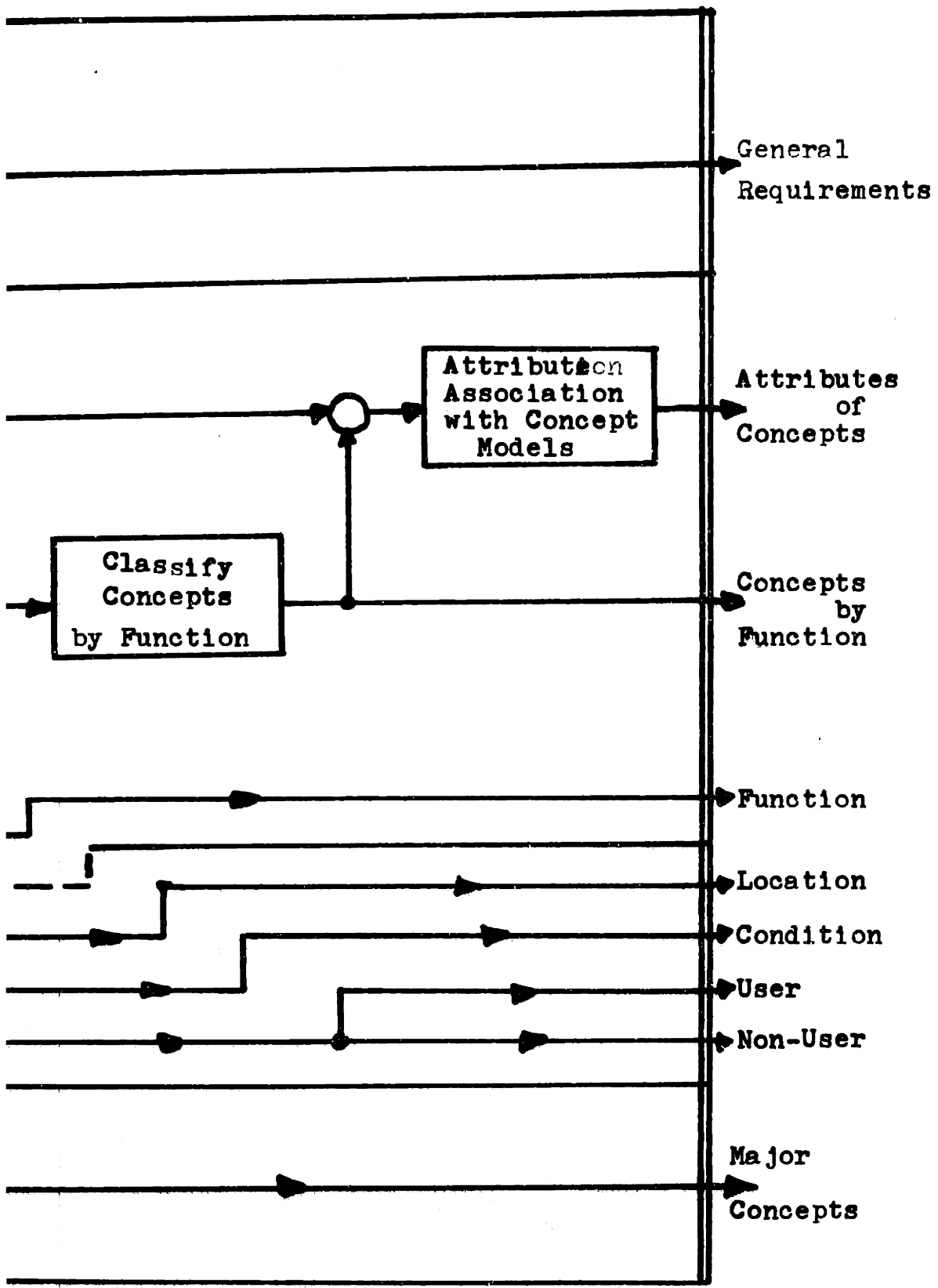


Fig. 2. Process Responsibility Chart (General)









2.2. General Descriptive Elements: Situations

The setting of the situation is the main step towards establishing the individual degrees of freedom. Situation factors will convey various degrees of information, depending upon the extent of specification completeness, involving any of the following elements :

1. Location
2. Time
3. Users and non-users
4. Conditions
5. Different functional status (e.g. standby vs operational)

For ground transport systems, general tables of location, condition, users and non-users are given in Tables III to VI. To specify condition, we would need to recognize and define the internal and external environments of the system, so that several special "unpredictable" environmental effects such as weather, accidents, and fire could be included.

TABLE III Location List

- | | | |
|--------------|------------------|--------------|
| a. Northeast | c. North Central | e. Northwest |
| b. Southeast | d. South Central | f. Southwest |

Each area would be identified by state(s), city(s), and:

- | | | |
|-----------------------|-------------------------|-------------------------------|
| 1. Urban network only | 3. Urban to urban | 5. Urban,
suburban & rural |
| 2. Urban & suburban | 4. Suburb to suburb | |
| | 6. Urban and rural only | |

Table IV Specific Conditions

1. Optimal
 2. Weather dependent : snow, rain, wind, etc.
 3. Visibility dependent : night travel, power failure
 4. Period of heavy use, system overload
 5. Period of an accident or breakdown
 6. Average
-

TABLE V System Users

1. Daily commuter
 2. Businessman (on special mission)
 3. Distance shopper
 4. Short distance shopper
 - a. Inner city
 - b. Outer city
 5. Recreational traveler
 - a. Inner city
 - b. Outer city
 6. Shippers
 - a. Produce
 - b. Manufacture
-

TABLE VI System non-users

1. Operators
 2. Maintenance men
 3. Station personnel
 4. Pedestrians
 5. Nearby residents
 6. Animals
 7. Nature lovers/conservationists
 8. Nearby businesses
 9. Institutions (hospitals, colleges)
 10. City services
 11. Regular taxpayers
 12. Regional politicians
 13. Users of another transportation mode
 14. Designers and planners
-

2.3. General Descriptive Elements : Functions and Concepts

A general function list can be constructed from a combination of two viewpoints : the idealized requirements approach and the empirical study of selected situations of past, present and partly developed future systems. For completeness, each past and present function would need to be extrapolated into the future to yield new variations or combinations of functions (with their respective confidence

levels. As will be discussed later in more detail, causality takes the form of a network of related functions, so that investigating all apparent causality relations for a number of representative systems should produce fairly complete function lists. The proper starting points for such "function generation" would be human functions and activities.

The concepts list should spring fairly easily from the function lists if the criteria for concept classification were functional and/or structural, and if structure were defined to follow function rather closely. Special attention would have to be paid to those cases of function not following form. Individual concepts could also be gleaned from a literature search or could be supplied by DOT as preliminary data (along with functions and attributes) from accumulated results of previous contractor efforts.

Within the causal framework, certain functions could be studied to yield others as "spin-off," and concepts and attributes might suggest more functions. The union of all these function sets would provide a relatively complete, non-redundant function list, without any necessary order or strict classification.

A classification framework is essential to organize

both function and concepts lists. When complex final functional interactions or concept relationships need to be simplified or subordinated to one another, certain diagramming techniques may be of considerable use, such as Venn, Karnough (Flores, 1960. pp. 136-42), and McCulloch diagrams (Fogel, 1963. pp. 281-85). McCulloch's approach is based on an adaptation of Venn diagrams, where Figs. 3a and 3b are equivalent. Abbreviation of

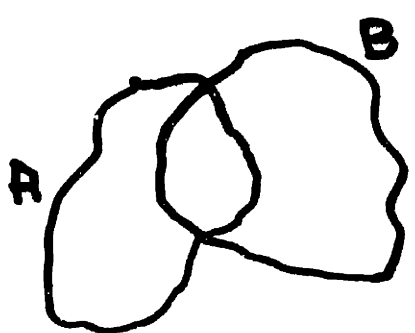


Fig. 3a

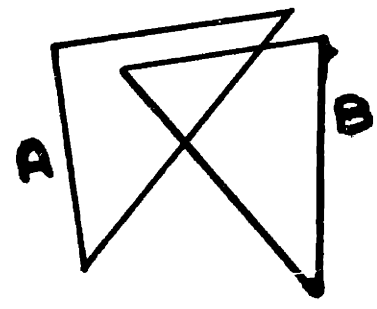


Fig. 3b

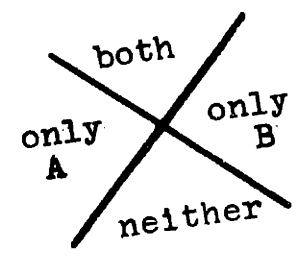


Fig. 4

Fig. 3b by its abbreviation X (Fig. 4) combined with the functional relations

- ~ not
- and
- ∨ or
- ⊃ implies
- ⊆ if and only if

can produce the logical representation of Table VII. Extension of more complex Venn diagrams (Fig. 5a) produces

the McCulloch diagram of Fig. 5b. Some simplifications in relations and notation are

$$\begin{aligned} \cdot \times \cdot \quad \cdot \times \cdot \quad \times \cdot &= \times \cdot \\ \cdot \times \cdot \quad \times \cdot \quad \cdot \times \cdot &= \times \cdot \\ \cdot \times \cdot \quad \cdot \times \cdot \quad \cdot \times \cdot &= \times \cdot \end{aligned}$$

TABLE VII

McCulloch Diagram Logical Relations

$$\begin{aligned} A \times B &= A \cdot \sim B & A \times \cdot B &= (A \cdot \sim B) \vee (\sim A \cdot B) \\ A \times B &= A \cdot B & A \times B &= A \equiv B \\ A \times \cdot B &= B \cdot \sim A & A \times B &= B > A \\ A \times B &= \sim A \cdot \sim B & A \times \cdot B &= A \vee B \\ A \times B &= A \cdot (B \vee \sim B) = A & A \times \cdot B &= A > B \\ A \times \cdot B &= (A \vee \sim A) \cdot B = B & A \times B &= \sim(A \cdot B) \\ A \times B &= \sim A \cdot (B \vee \sim B) = \sim A & A \times \cdot B &= \sim(A \cdot B) \\ A \times B &= (A \vee \sim A) \cdot \sim B = \sim B & & \end{aligned}$$

From the study of functional interrelationships would be developed a tiered classification, relating function to subfunction, where a set of subfunctions constitutes the potential elements of a major function. Just as functional systems are composed of subfunctions, so are concepts composed of subconcepts and, at the most detailed compositional level, of "microconcepts," a term which will be used to distinguish the smaller

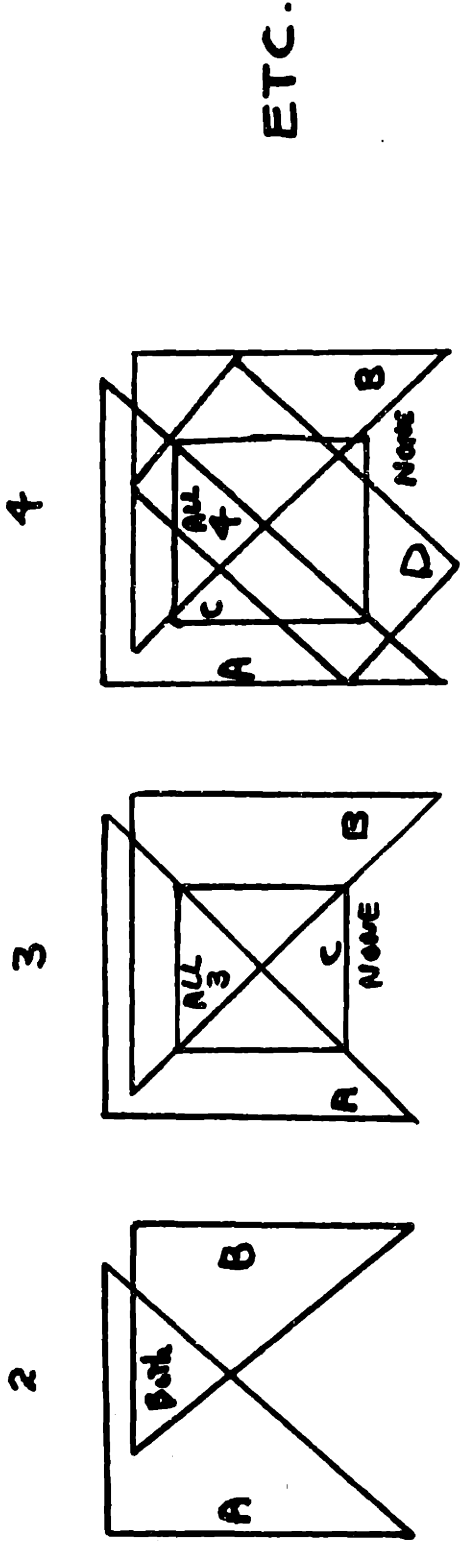


Fig. 5b Extension of McCulloch Diagrams to Multiple Sets

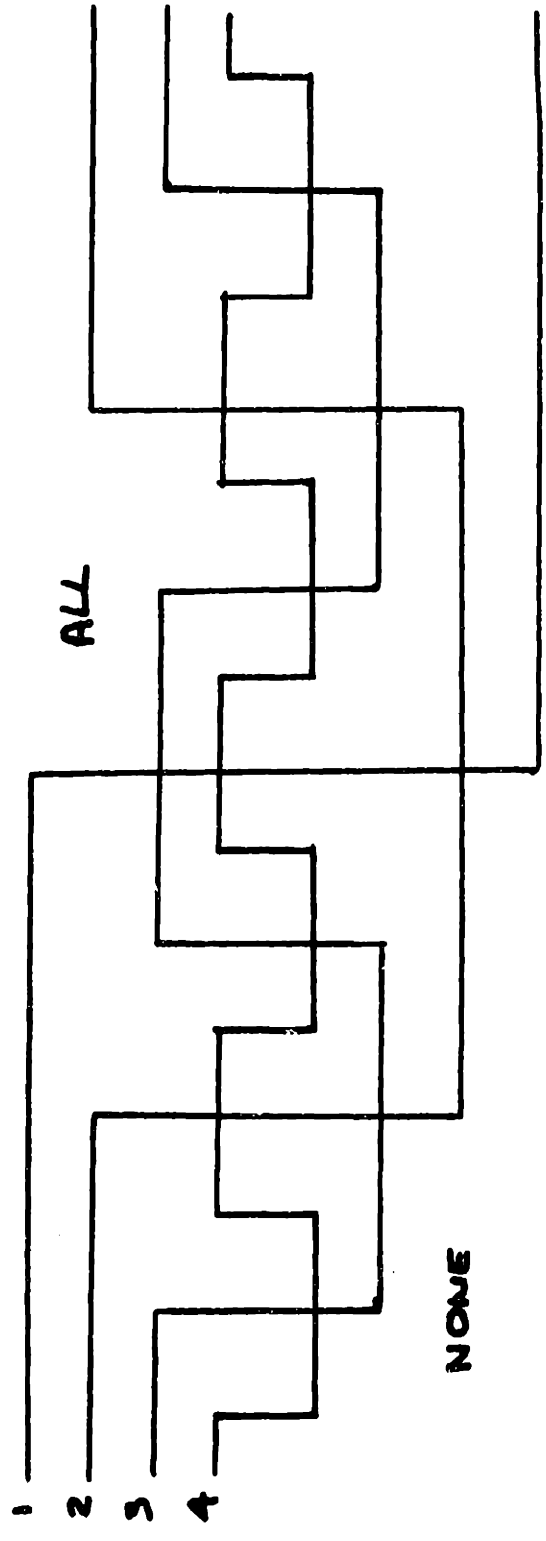


Fig. 5a Extension of Venn Diagrams to Multiple Sets

building blocks from the larger, more complex subsystem concepts. Convenient criteria must be employed during the classification process, both to ensure ease of concept manipulation and establish designer consensus on concept definition.

What makes a concept significant is that the classification it institutes is one into which things fall, as it were, of themselves . . . a significant concept so groups or divides its subject matter that it can enter into many and important true propositions about the subject matter other than those which state the classification itself. Traditionally, such a concept was said to identify a "natural" class rather than an "artificial" one. Its naturalness consists of this, that the attributes it chooses as the basis of classification are significantly related to the attributes conceptualized elsewhere in our thinking. . . . A natural grouping is one which allows the discovery of many more, and more important, resemblances than those originally recognized.

(Kaplan, 1964. p. 50)

The organization of the function/concepts lists must be subject to rules for the maintenance of parallelism and consistency of classification and definition. For simplicity and understanding, each classification category should not be required to contain elements which are mutually exclusive, since such stipulations result in very lengthy and redundant lists. Instead, we merely subject the listing to consistent rules of exclusivity, non-exclusivity and inclusivity :

1. **Exclusivity** : all items within the category are exclusive and only one of them can be applied for any selected system.
2. **Non-Exclusivity** : all items are not exclusive and any number of them can be applied together.
3. **Inclusivity** : all items apply and must be considered together, e.g. for an automobile :
engine; transmission; driveline;
suspension; etc. etc.

In classification, there will undoubtedly be problems of overlap, combination and duplication of functions or concepts. One can test for subsystem and microconcept overlap by the use of Venn diagrams for periodic analytic and synthetic checks, and those concepts which serve multiple functions will be listed in multiple fashion in the concepts list. A general definition subroutine might be applied to the process as an on-going procedure for much of the contractual period.

1. **Examine** as many definitions of the concept, past and present, as possible. Keep in mind the chronology of the definitions examined.

2. Try to identify the core of meaning toward which the definitions seem to be evolving.
3. Formulate a tentative definition based on this core.
4. Examine usage of the concept in the context of the problem or question to which the research is directed and determine if the meaning you have formulated will serve the decision maker's or research objectives. If not, make necessary revisions.
5. Submit the definition to as wide a critical appraisal as possible and make any justifiable revisions suggested by the criticism.

(Ackoff, 1962. p. 150)

Sample listings of the upper three tiers for functions and concepts are provided in Tables VIII and IX. An important classification distinction must be made at the second tier :

- a. Systems functions/concepts (i.e. those which are yet dependent upon specific location)
- b. Component functions/concepts (i.e. those which are not dependent upon specific location).

There are other forms of possible classifications, such as those based on human functions (Table X), and on the six basic types of hardware equipment (Table XI), but these techniques would seem most useful when providing information and alternatives within the regular context of function/concept listing.

TABLE VIII Sample List of General Functions

I. NETWORK FUNCTIONS

B. Component Functions

1. Station/vehicle interactions
 - a. Express travel
 - b. Local travel
 - c. Enter station
 - d. Hold for passenger transfer
 - e. Vehicle distribution, segmentation
 - f. Vehicle processing and protection
 - g. Vehicle insulation
2. Station/passenger interactions
 - a. Enter station
 - b. Provide directions to passenger
 - c. Ticket and schedule processing
 - d. Distributions of passengers within station
 - e. Protection of passengers from accident
 - f. Weather insulation
 - g. Rescheduling capability; redistribution
 - h. Entertainment, activity, conveniences
 - i. Aesthetic function of station
 - j. Baggage handling
3. Storage facilities (and access)
 - a. Parking of private vehicles
 - b. Parking of rented vehicles
 - c. Storage for maintenance vehicles
 - d. Storage for stand-by vehicles (cont.)

(Table VIII - continued)

4. On-line facilities

- a. Rest stop and recreation functions
- b. Vehicle emergency maintenance
- c. Power supply for vehicles & equipment
- d. Limitation on air pollution & noise
- e. Aesthetic function
- f. Clearance of channels during accidents and inclement weather
- g. Traffic observation, planning and schedule calculation

5. Switching and interchange functions

- a. Provide lateral constraints
- b. Provide vertical constraints
- c. Minimize radial accelerations
- d. Provide acceptable safety and reliability performance
- e. Minimize requirements for braking, velocity loss in transit

6. Control functions

- a. Overall system scheduling, distribution, safety checks
 - b. Readjustment capability for weather, accidents
 - c. Provide acceptable safety, reliability, response performance
-

TABLE IX Sample list of General Concepts (3 tiers)

I. NETWORK CONCEPTS

A. System concepts

1. Planning concepts
2. Switching provisions
3. Ownership and payment
4. Route layout
5. Control concepts
6. Scheduling concepts
7. Use regulations

B. Component concepts

1. Station/vehicle concepts
2. Station/passenger concepts
3. Storage facilities
4. On-line facilities
5. Control equipment

II. GUIDEWAY CONCEPTS

A. Systems concepts

1. Elevation concepts
2. Environment concepts
3. Channel orientation

B. Component Concepts

1. Permanance, design flexibility
2. Cross section
3. Guideway surface
4. Structure
5. Supports
6. Switch design
7. Ramps, merging
8. Juncture design
9. Emergency exit

(Table IX - continued)

III. VEHICLE CONCEPTS

A. Systems concepts

1. Modular concepts
2. Passenger, baggage configurations
3. Travel modes
4. Destinations

B. Component concepts

1. Body construction and design
2. Propulsion
3. Suspension

TABLE X Human functions

1. Sensing : involving instructions, short- and long-term memory, and a sensing mechanism;
 2. Identifying : involving instructions, memory, models, and capability for sensing and identification;
 3. Interpreting : involving instructions, memory, models, capability for sensing, identification, and interpretation, and interpreting rules;
 4. Communicating : involving interpreting and, sensing and/or identifying in a man-machine or man-man context;
 5. Activity : involving any combination of the above plus an output involving force, motion or physical productivity.
-

TABLE XI Types of Hardware Equipment

1. Input equipments, which accept the information or material on which the system is to operate;
2. Communication equipments, which furnish the information links joining the various parts of the system;
3. Logical-control equipments, which govern the flow of information, process information to derive new information, and, when appropriate, control the flow of material in the system;
4. Reflexive control equipments, which control repetitive, short-time responses;
5. Handling equipments, which move material around the system;
6. Output equipments, including both effectors which carry out final action with respect to material, and displays which provide information to human controllers.

(Goode & Machol, 1957. p. 408)

2.5. General Descriptive Elements : Attributes

Formulation of the general attribute list should follow soon after the function and concept lists have begun. Brute force methods of obtaining attributes from functions and concepts could be employed, but the process would inevitably be quite inefficient. Nor would it be wise to begin systematically from the upper function and

concept classification tiers and proceed downward, since a confused multitude of attributes would result for each subsystem considered. It appears that the wisest technique is that of starting at the bottom of the lists (at the microconcept and microfunction levels) and proceeding upward in a synthetic manner. One would be taking advantage of past experiences of suboptimization of smaller subsystems and could also employ a useful strategy or postulate to focus on special system functions. This postulate states that the attributes of a complex concept or function consist of the non-redundant sum of the attributes of all the elemental microconcepts and smaller subsystems plus the attributes which are associated solely with the combination of any set of such microconcepts and subsystems and which are not characteristic of the component subsystems themselves. Such a statement is logically straightforward, but should be, nevertheless, quite useful as an organizational aid. It has the advantage of concentrating attention on the more unobvious combinatorial attributes and allowing for computer checks on redundancies.

Attributes should be listed regardless of inherent vagueness or non-quantifiability. Attribute measurements are not always uniquely or accurately determined, but whether they are or not, the systems designer and evaluator

would like to be assured that particular attributes have been considered in the design process. A general but categorically complete checklist is to be preferred over the detailed but only partially complete statement of attribute-concept interrelationships.

As with functions and concepts, there will probably develop problems of attribute overlap, and similar redefinition cycles should be performed.

CHAPTER III

Describing the Selected Systems

3.1. Further Application of DOT Requirements

It will now be necessary to make some specific selections, to state more detailed preferences among the numerous system alternatives possible. From the restated design objectives, types and priorities of systems users, operators, affected communities, location, range, completion time and various operating conditions must be indicated, as part of the predesign process. During preliminary design efforts, simplifying assumptions could be made for combining similar situations and for concentrating design attentions on fewer, more manageable situations. The selection procedure is outlined in Fig. 6.

The system objectives and relative priority can be analyzed, explicitly and implicitly, for required function and sequence of function (causation) for each major situation. Usually, for a general statement of all possible systems, the function listing is very basic and devoid of detail. Even under these circumstances, the number of different transport subsystems and components which might be able to perform the given set of functions may be very large indeed. Hence the design engineer should and must be given the opportunity to select

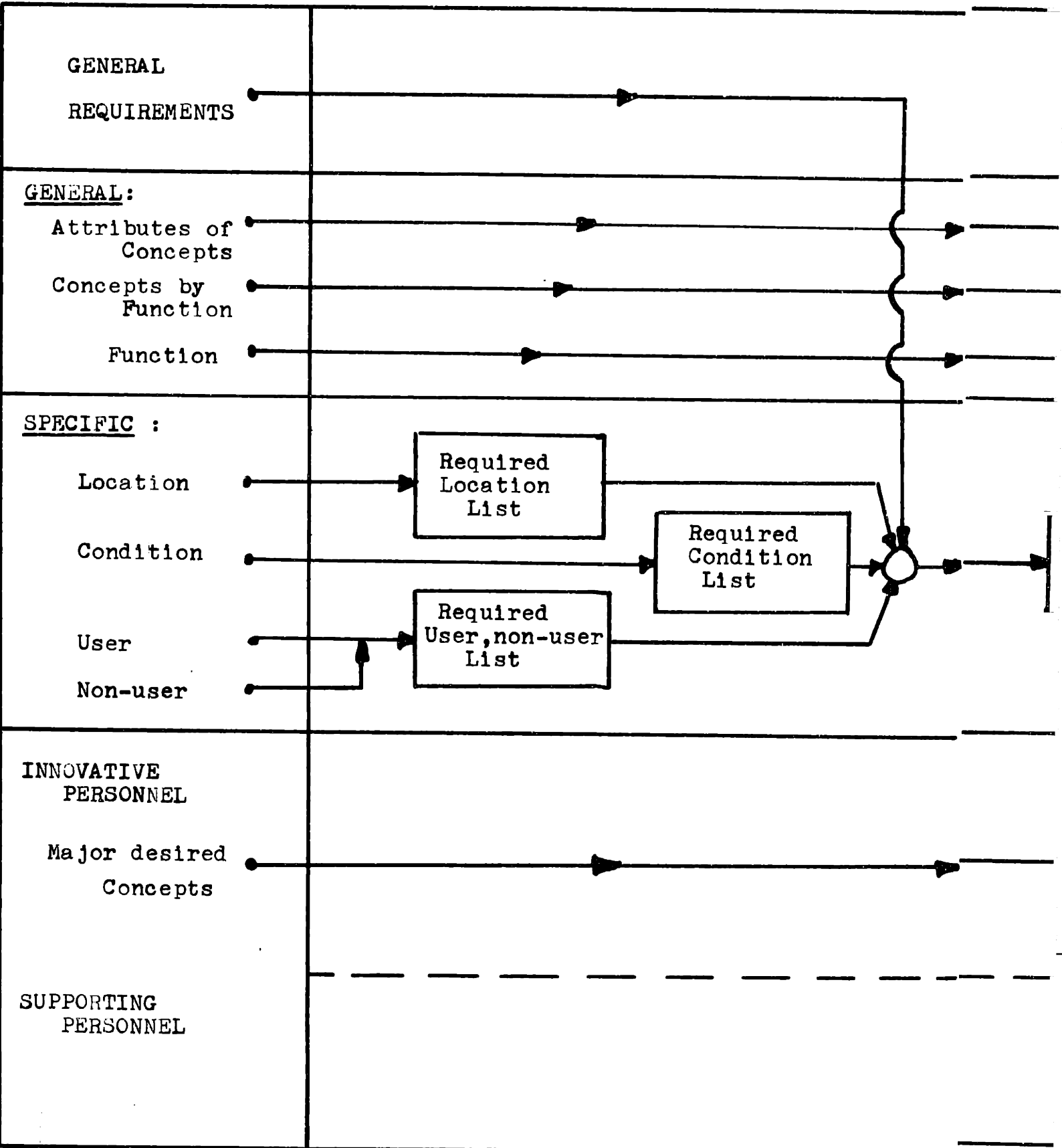
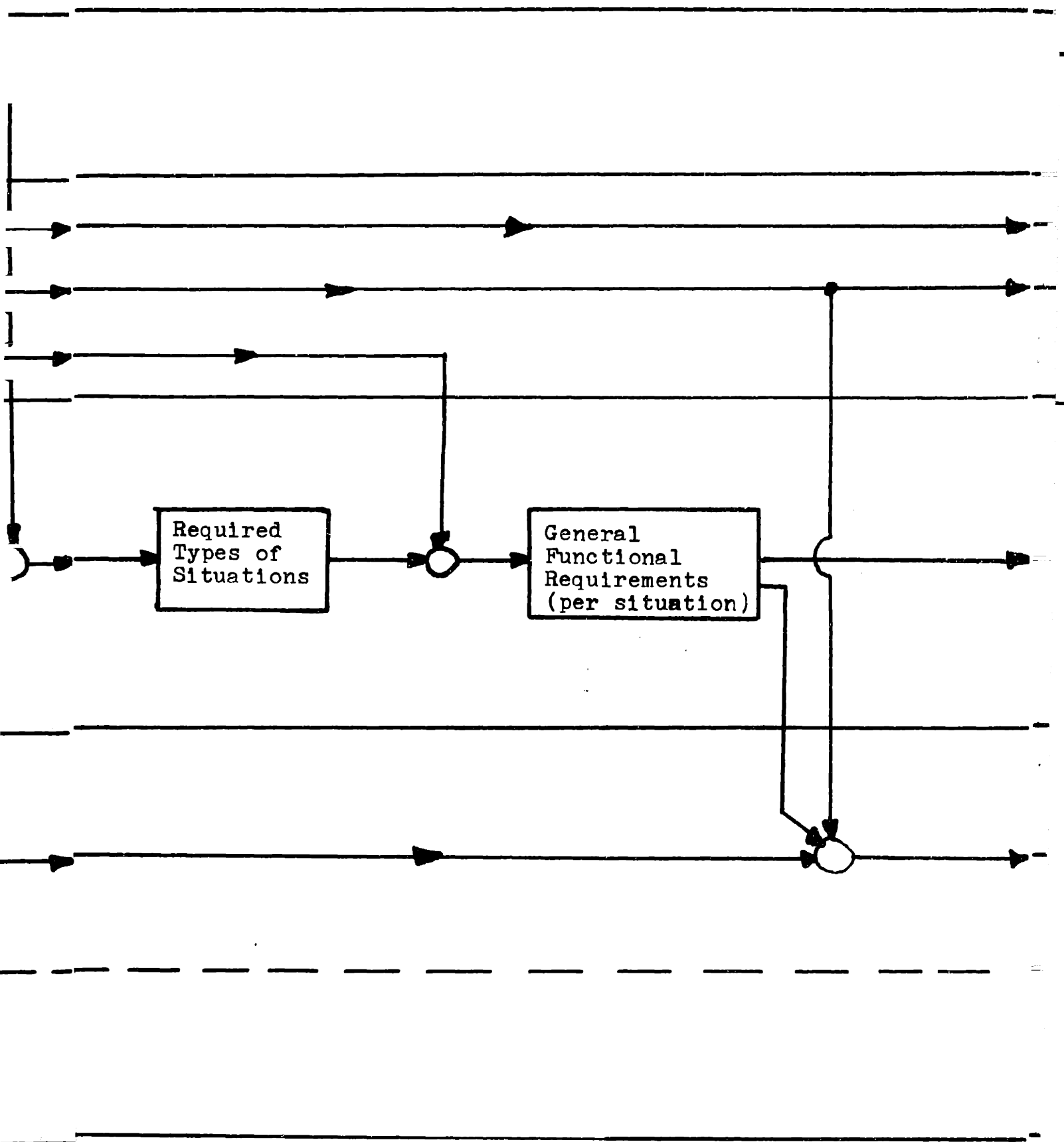
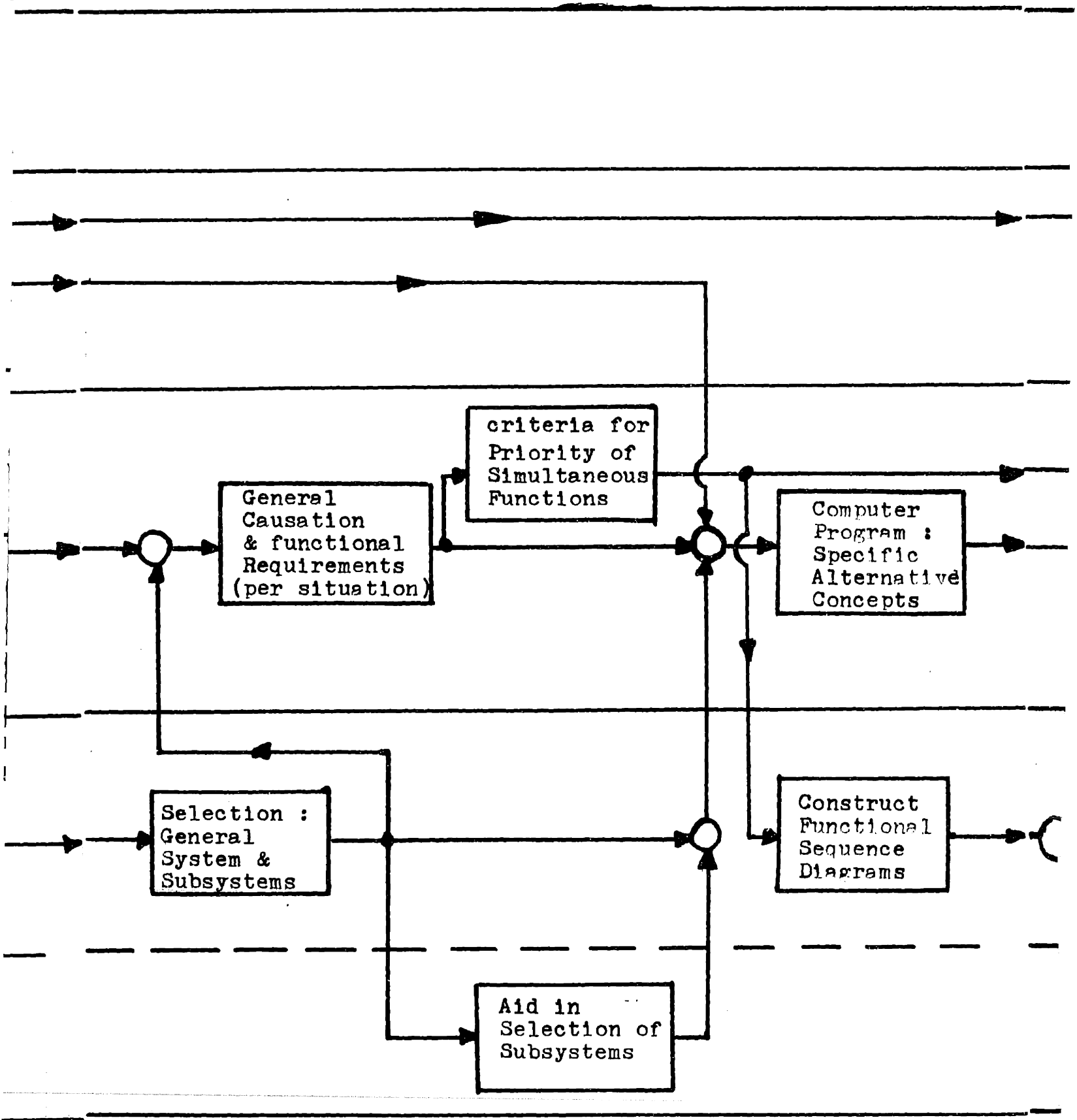
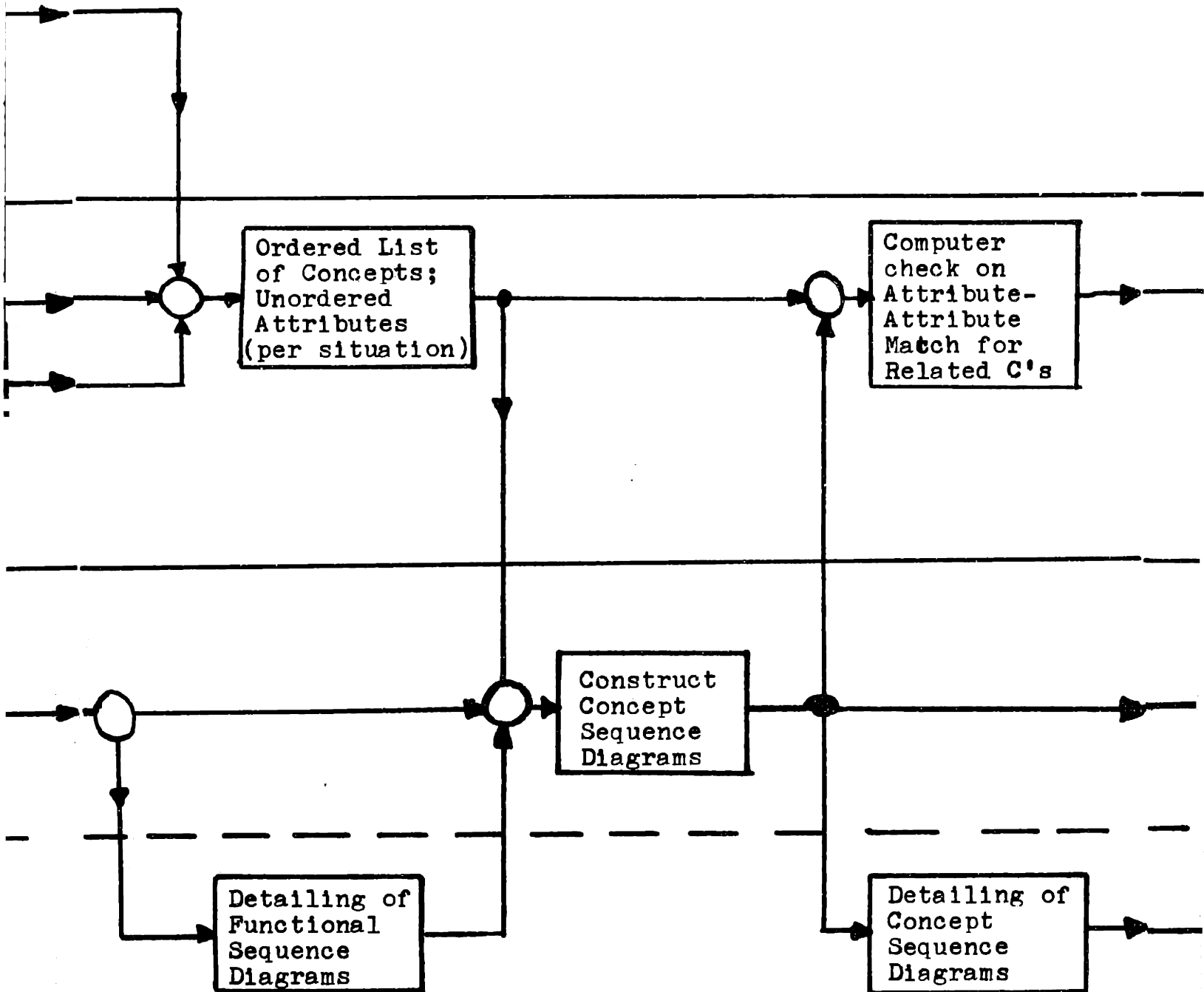
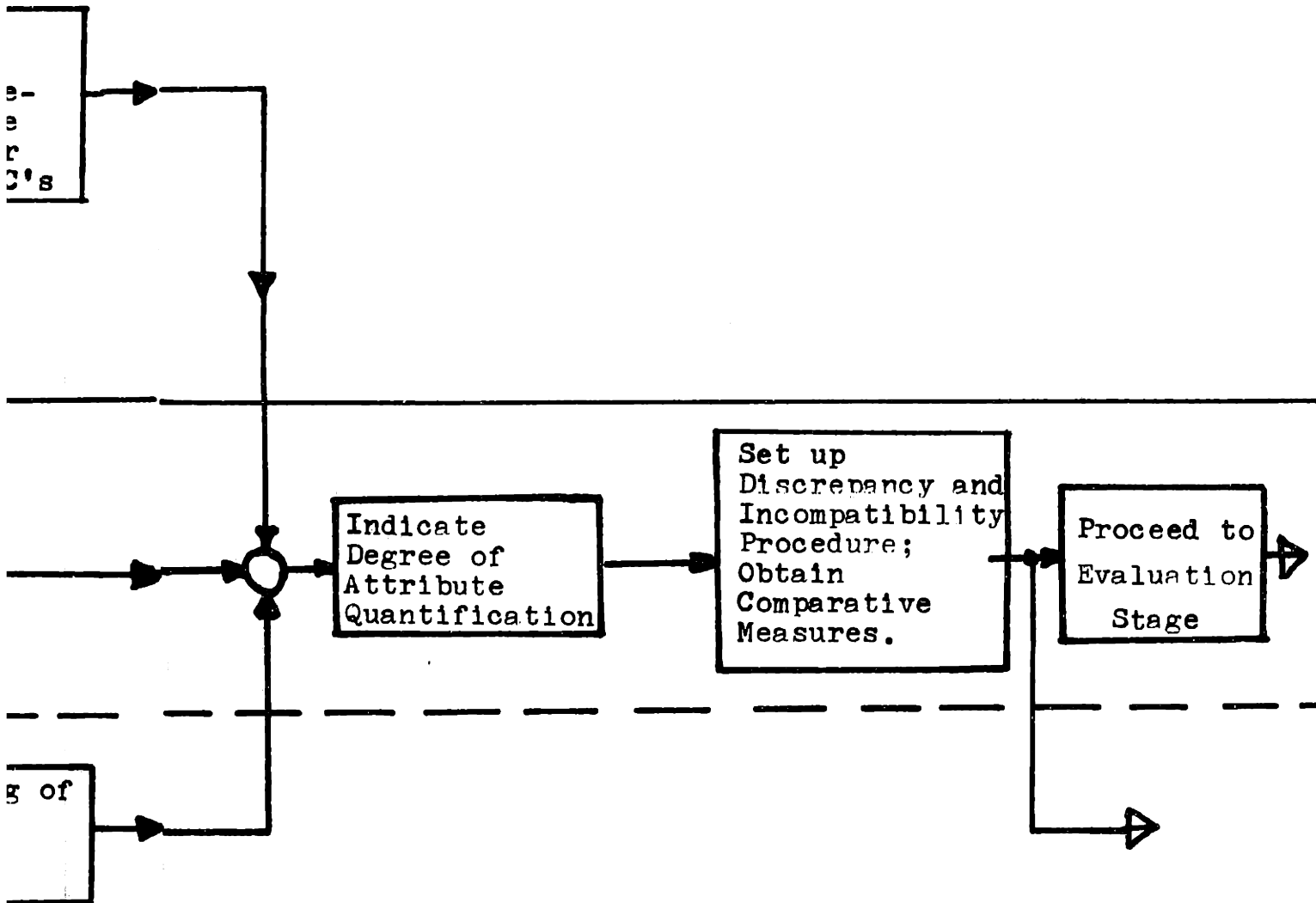


Fig. 6. Concepts/Compatibility Selection Procedure









certain preferred types of components in order to provide (a) a definite direction to the design effort, (b) designer control over the type of project to be considered (at least at the initial stages), and (c) early simplifying suboptimization. For example, a systems requirement for a HSGT system generally might be redefined and suboptimized in terms of a tunnel and air-suspended train complex.* The extent

*The military analogy of the restated requirements is the Technological War Plan, TWP.

The TWP covers requirements in terms of environment, threat, and systems concepts; existing and required technology; and available and required resources to support advances in technology and systems The TWP relates the technological efforts to future alternative systems and interrelates information from higher echelons, AFSC divisions, and the applicable using standards or organizations.

(AFSCM 375-4. p. 18)

The required function links are stated in terms of missions : mission requirements, mission functions, and system/subsystem/support requirements and functions (equipment, procedural & personnel). To function performance criteria must be added requirements for environmental control, safety, maintainability and support.

of prior selection of major components will be determined by the contract time and resources available.

The investigation of selected function and selected concepts sequence will be continued in more detail in the following sections, 3.2 to 3.5.

Wherever possible, additional information should be sought out beyond the supplied information on user requirements. Various methods of interviewing agency personnel for clarification might include :

1. Asking them specific questions about what they think their requirements are.
2. Analyzing recent information requests and probing the circumstances which motivated the request.
3. Monitoring current programs or similar research programs.
4. Obtaining a measure of "satisfactory" performance improvement.
5. Determining the type and amount of information available to the DOT task setters.
6. Obtaining the problem statement used for the formation of the system requirements.

(Becker, 1963. p. 245)

This process may periodically add elements to the general lists (Fig. 2), as well as aiding in the selection process

of Fig. 6. A sample listing of system requirements in terms of specified users, locations, ranges and completion time (including some preliminary specification of system type) is supplied in Table XII. These three sets of different requirements shall be used in following sections as continuous examples of the concepts/compatibility selection and development process.

3.2. Specific Situations

For the specified requirements of the three examples chosen, the modeled situations can be expressed, based on information on selected system users, location and specific conditions applicable. (Tables XIII to XV). For each example, just two situations are represented for simplicity.

TABLE XI A : System Requirements for Example A
An automated car and guideway system

Primary users : daily commuters.
Secondary users : periodic commuters, shoppers
Vehicle channel capacity : N_A / hr.
Acceleration capability : A_a
Vehicle carrying capacity : at least 4 passengers
Vehicle serves as a second car ; also a single car
for small families.
Vehicle operated manually on conventional roadway;
controlled automatically on special guideway
Entrance station processing takes less than a minute
System operational by 197X.
Compact parking & storage provisions
All weather operation
Traffic disruption due to accidents due to accidents or
breakdowns equal to or less than present systems.
Safety and reliability requirements.
Air pollution rate less than present systems.
Land use requirements
Cost range for above requirements not to exceed $\$C_a$
..... etc.

TABLE XI B : System requirements for Example B
A HS. inter-city underground train system

Primary users : businessmen, public officials,
long-distance travelers.
Channel capacity : N_B / hr.
Max. Acceleration required : A_b
Range of passenger capacity per train : P_1 to P_2
Travel time between L_1 and L_2 is less than T_b
(continued)

(Table XIIB - continued)

Station processing time less than t_b minutes
Trains reversible, with interchanges
System operational by 198X.
Traffic disruption due to accidents or breakdowns
less than comparable flight systems.
Safety, rescue, reliability requirements for tunnel.
Pollution and noise rate less than comparable systems.
Land use requirements for stations, storage.
Cost range for above requirements not to exceed $\$C_o$

TABLE XIIC : Systems Requirements for Example C
An urban-suburban capsule-transfer train system

Primary users : daily commuters
Secondary users : Periodic commuters, shoppers
Channel capacity : N_c / hr.
Acceleration capability : A_c
Range of passenger capacity per train : p_1 to p_2
Capsule transfer time less than t_c seconds.
Station processing time less than T_c minutes.
Trains reversible (subsurface or above ground operation)
System operational by 197X.
Compact parking, storage & land use requirements
All weather operation
Traffic disruption due to accidents/delays less than
comparable present systems.
Safety and reliability requirements.
Pollution and noise rate less than comparable systems.
Cost range for above requirements not to exceed $\$C_c$

TABLE XIII : Selected System Users (Priority listing)

Example A

1. Daily commuter
2. Short distance shopper
3. (Recreational)
4. (Long distance shopper)

Example B

1. Special mission businessman
2. Public official
3. Distance shopper
4. Distance traveler

Example C

1. Daily commuter
2. Specific mission businessman
3. Shopper, short & long distance
4. (Intra-city recreation)

TABLE XIV : Specific location

Example A

Urban-suburban network,
Boston, New York,
Los Angeles

Example B

Urban-to-urban network
or chain; Northeast
or Southwest.

Example C

Urban-suburban network,
Boston, New York, LA.

TABLE XV : Specific Conditions (each applicable)

Examples A & C

1. Optimal
2. Weather dependencies
3. Visibility effects
4. System overload
5. Accident period
6. Average

Example B

1. Optimal
 2. System overload
 3. Accident period
 4. Average
-

TABLE XVI : Simplified Specific Situations
(Northeast, urbanized location)

<u>Examples A & C</u>	<u>Example B</u>
1. Daily commuter; optimal conditions	1. Businessman, traveler; optimal conditions
2. Daily commuter delay due to overload or accident	2. Businessman, traveler; delay

3.3. Major Systems, Causality and Functional Sequence
Diagrams

Functional analysis is a necessary consequence of
and check on the system requirements.

Before any system requirement can be established
as valid, its implications in terms of functional
requirements are investigated to the extent
necessary to ensure its feasibility. . . . To
document the system performance requirements and
constraints . . . it is necessary to translate
the functions identified into gross design
requirements and constraints. . . .

[Functional sequence diagrams] assure that
(1) total system requirements are considered and
firmly established prior to equipment selection,
(2) maximum flexibility of decision during
initial design requirement tradeoffs is permitted,
(3) a firm basis is provided to evaluate potential
design approaches against system requirements,
and (4) an early and evolving frame of reference
is established to evaluate program changes and
decisions.

(AFSCM, 1966. pp. 29, 45)

The analogous Air Force process can be summarized as
follows :

In the process of preparing functional programs and related systems engineering documentation, alternative methods and functions will be identified. . . . Design tradeoffs must be made in terms of time, cost and performance. Decreasing both development leadtimes and costs will be considered equal in importance to the achievement of performance. It is essential to identify the various modes of operation to assure that these modes can be further defined in technical detail.

(AFSCM 375-4, 1966. p. 45)

For the designer, the required functions become desired functions, such as acceleration, power, etc. Other functions may be considered secondary, acquired, or concomitant functions, such as aspects of cost, weight, and noise. Examples of derived functional sequences are illustrated in Table XVII. Such listings result from a combination of more detailed causitive information due to the selection of a particular system type and of the general functions of a ground transportation system (Fig. 7), for which scheduling, access, processing, distribution, passenger support and protection, conveyance, and redistribution functions are related in a causal manner.

Multiple overlapping functions present a problem until criteria of priority have been established and the criteria applied to each such situation. For our simple examples, lower priority functions have been

TABLE XVII Sequence of Desired Functions

Example A : Automated car/guideway system. (Daily commuter)

Situation # 1: Optimal

1. Enter vehicle at residence
2. Manual operation on conventional roadway
3. Enter station
4. Station toll check
5. Switch to automated operation
6. Exit from station
7. Accelerate
8. Attain cruise speed and travel
9. Decelerate into station
10. Proceed to exit gate
11. Switch to manual operation
(or interchange switch, revert to #6)
12. Travel to parking location
13. Parking
14. Exit from vehicle

Situation #2 : Delay

1. Enter vehicle (residence)
2. Manual operation on road
3. Enter station
4. Station toll check
5. Switch to automated opn.
6. Wait, reroute, or eject (rescue)capability
7. Exit, accelerate, travel
8. Decelerate into station
9. Proceed to exit gate
10. Switch to manual operation
11. Travel to park location
etc.

Example B : High speed train and tunnel system. (Traveler)

Situation #1 : Optimal

1. Park; alight from other transport mode
2. Enter station
3. Station toll check
4. Proceed to platform
5. Enter train
6. Accelerate and travel
7. Deceleration at destination
8. Exit from train
9. Go to station exit
(or for switch at interchange, revert to #4 above)

Situation #2 : Delay

1. Park; alight from other transport mode
2. Enter station
3. Station toll check
4. Reroute, wait, eject and rescue capability
5. Proceed to platform
6. Enter train
7. Accelerate and travel
8. Deceleration and exit
9. Go to station exit or interchange

(Table XVII : continued)

Example C : Surface train and capsule transfer (Commuter)

Situation #1 : Optimal

1. Park; alight from other transport mode
2. Enter station
3. Station toll check
4. Proceed to platform
5. Enter capsule
6. Shift to staging area
7. Accelerate
8. Travel
9. Transfer, if necessary
10. Decelerate
11. Exit from train
12. Proceed to destination via other transport mode

Situation #2 : Delay

1. Park; alight from other transport mode
 2. Enter station
 3. Station toll check
 4. Proceed to platform
 5. Reroute, wait, eject and rescue capability
 6. Enter capsule
 7. Accelerate
 8. Travel
 9. Transfer if necessary
 10. Decelerate
 11. Exit from train
 12. Proceed to destination via other transport mode
-

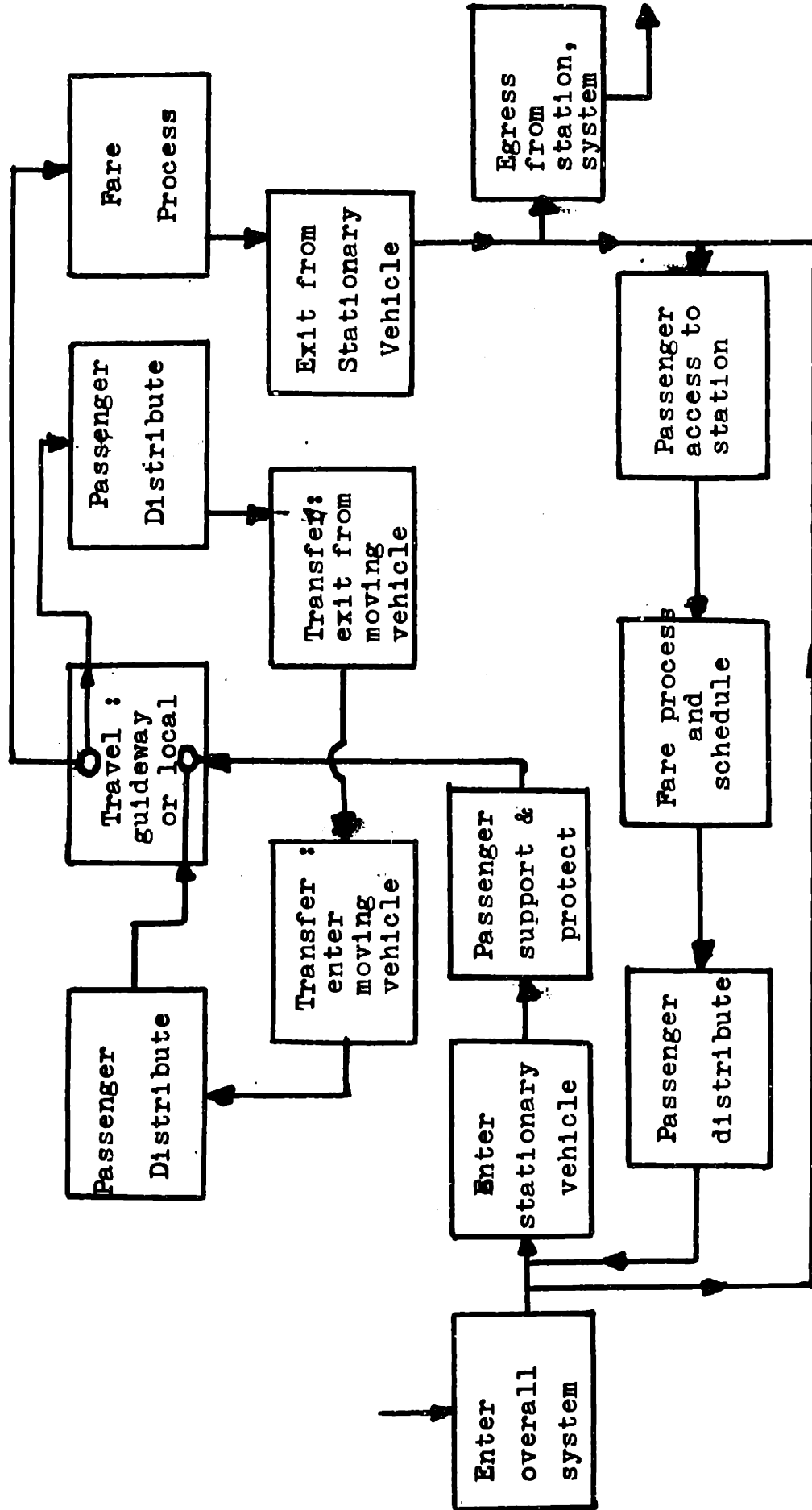


Fig. 7. Simplified General Functional Sequence Diagram (for functions directly involving passengers)

temporarily neglected in order to demonstrate the basic "critical" function sequence, a shortest-path description of the sequence of primary functions. A verbalized description for a commuter traveling by rail might be :

Begin at home...walk to car or bus... ride to destination ... park or alight ... walk to station ... enter station ... walk to ticket window ... obtain ticket ... walk to ticket check area ... ticket check ... walk or ride to platform ... enter vehicle ... etc.

There would be related functions to this shortest-path formulation, such as provisions for information and instruction, conveniences (rest rooms and restaurants) and baggage storage/handling. The initial stages of function sequence specification would proceed from studies of human activities and capabilities, with the degree of possible adjustment, of course, a matter to be decided between the engineer, sociologist/anthropologist, and public relations agency.

The general function/causation format of Fig. 7 can be combined with that of Table XVII to yield the specific functional relations for each of the three examples (Figs. 8, 9, & 10).

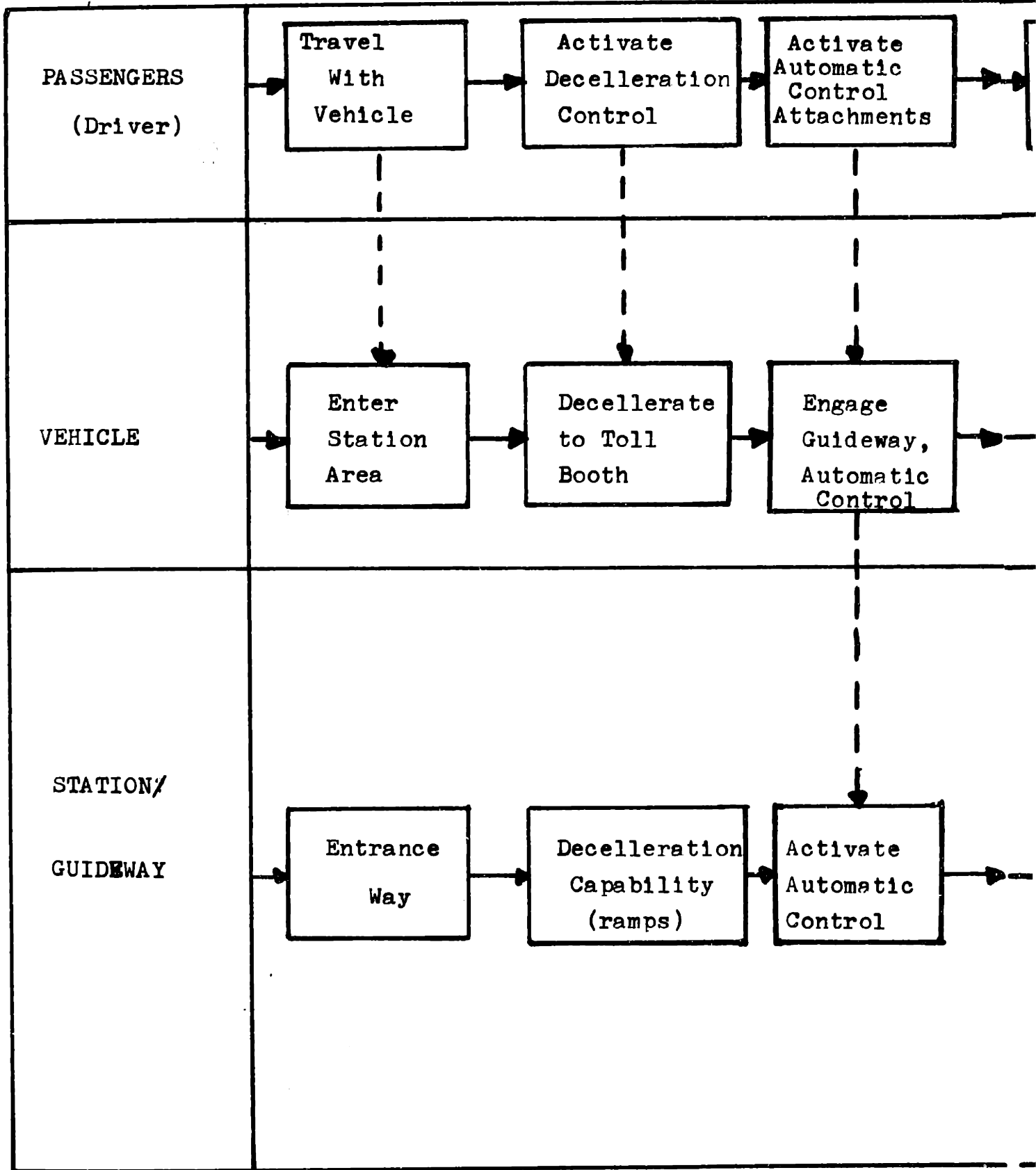
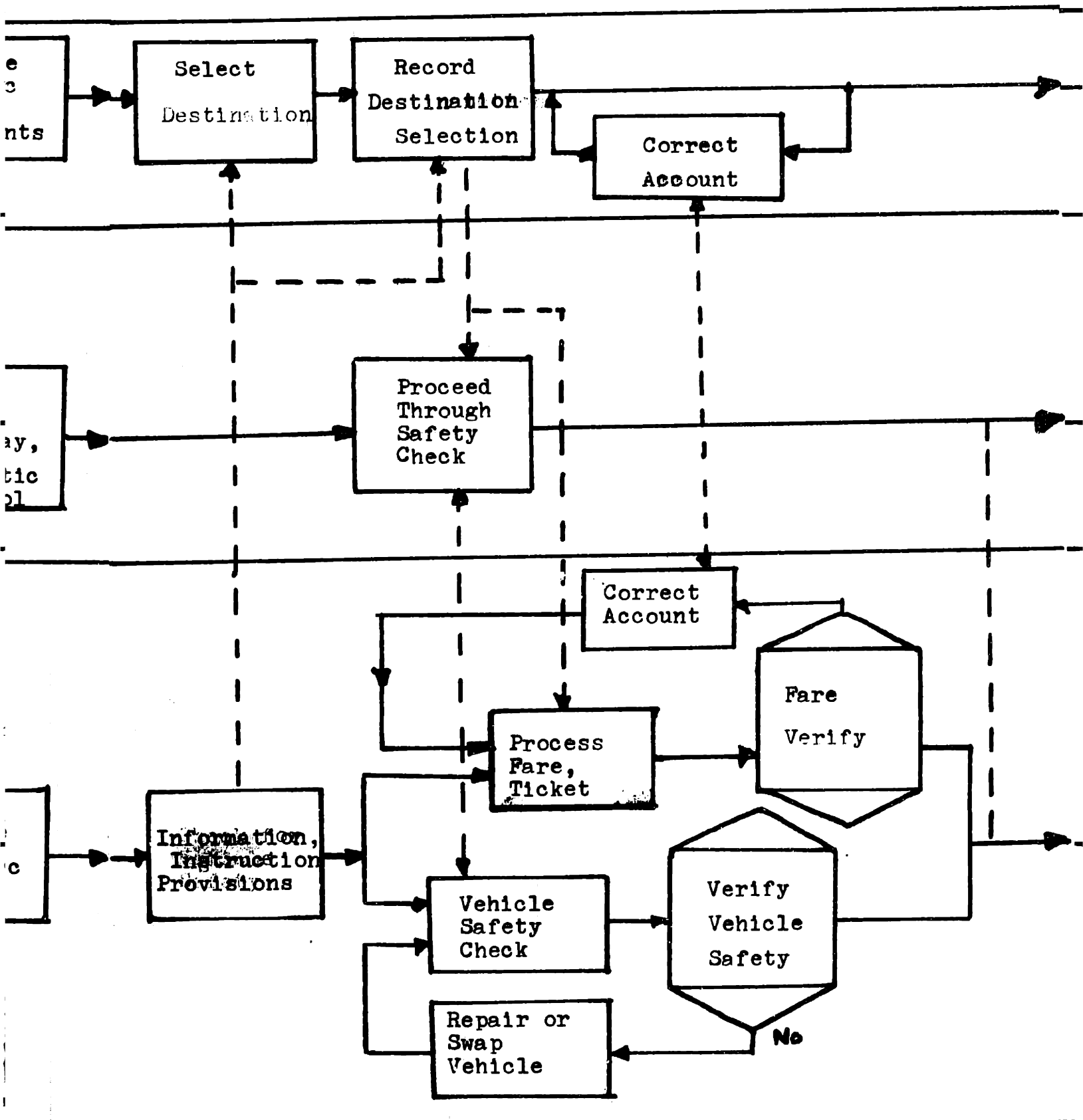
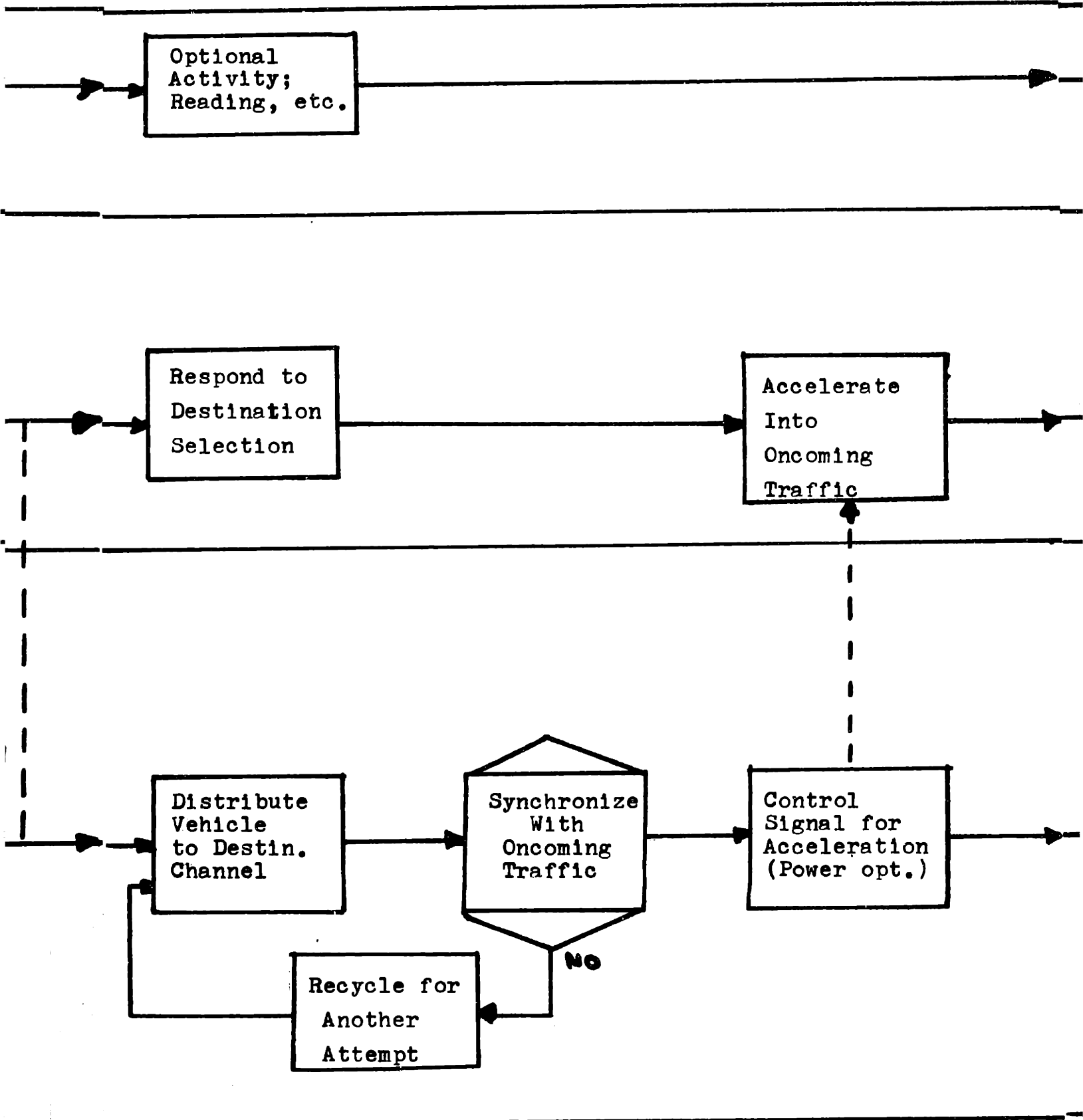
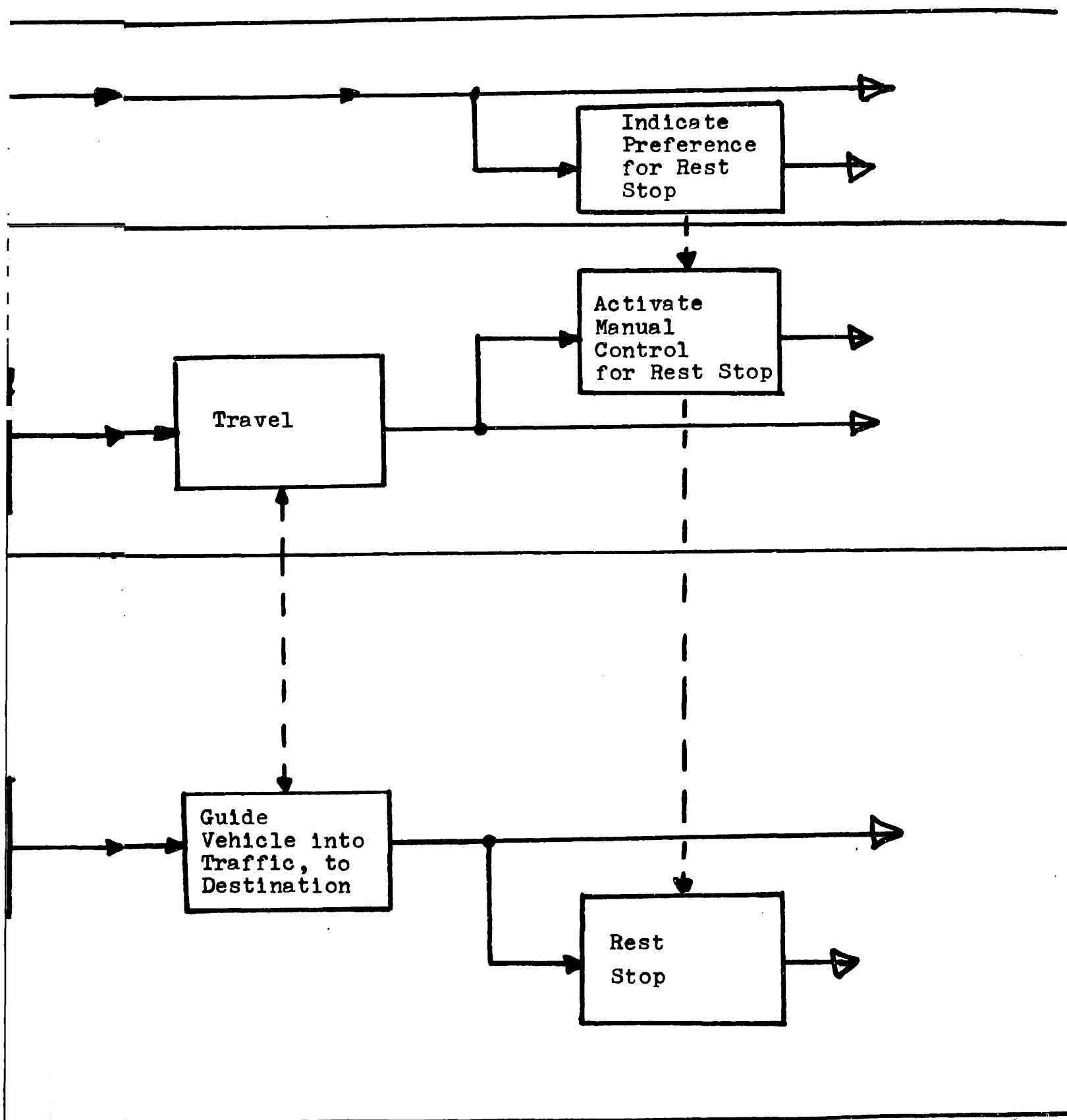


Fig. 8. Functional Sequence Diagram : Example A
(Automated car, guideway system, optimal situation)







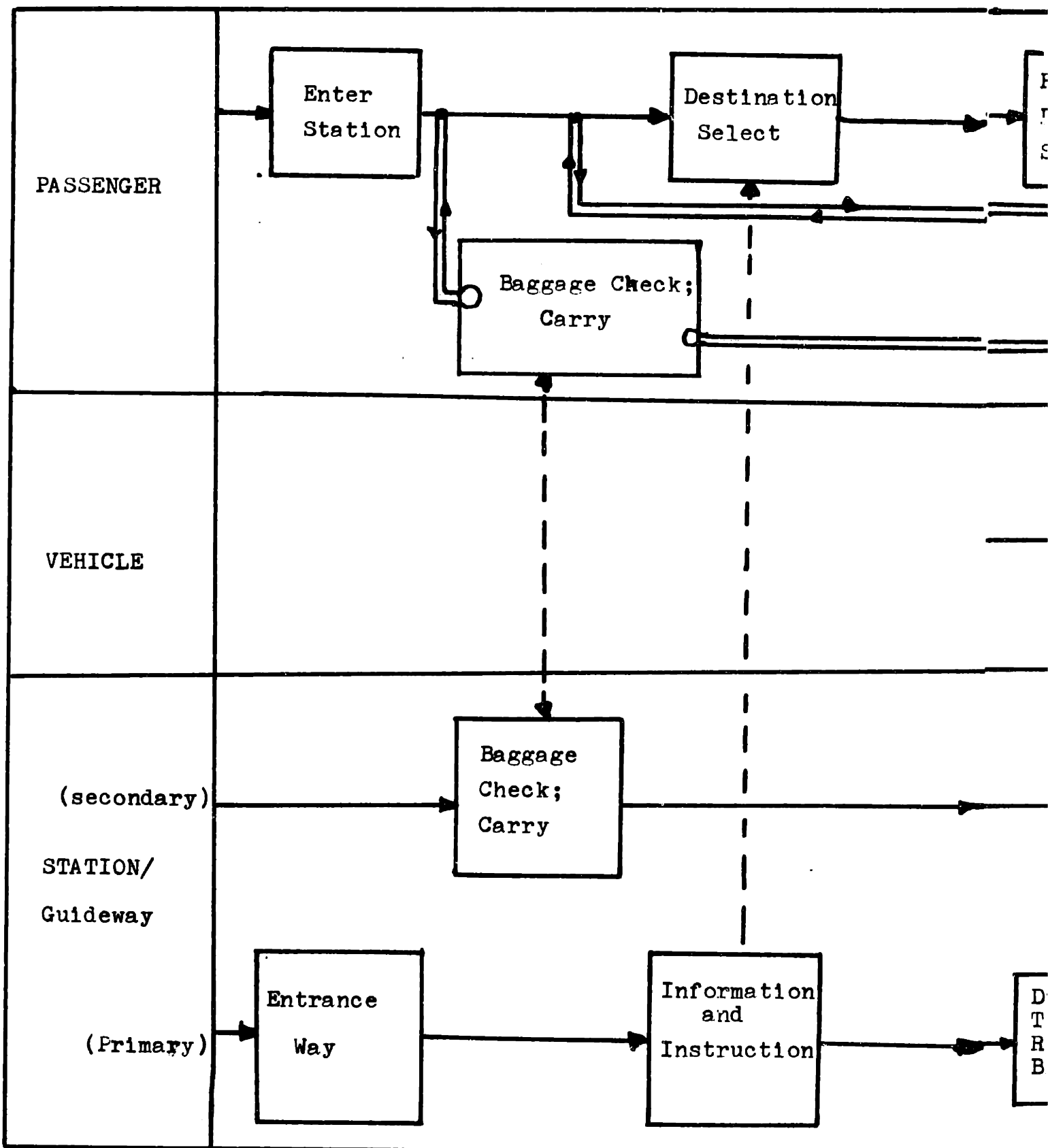
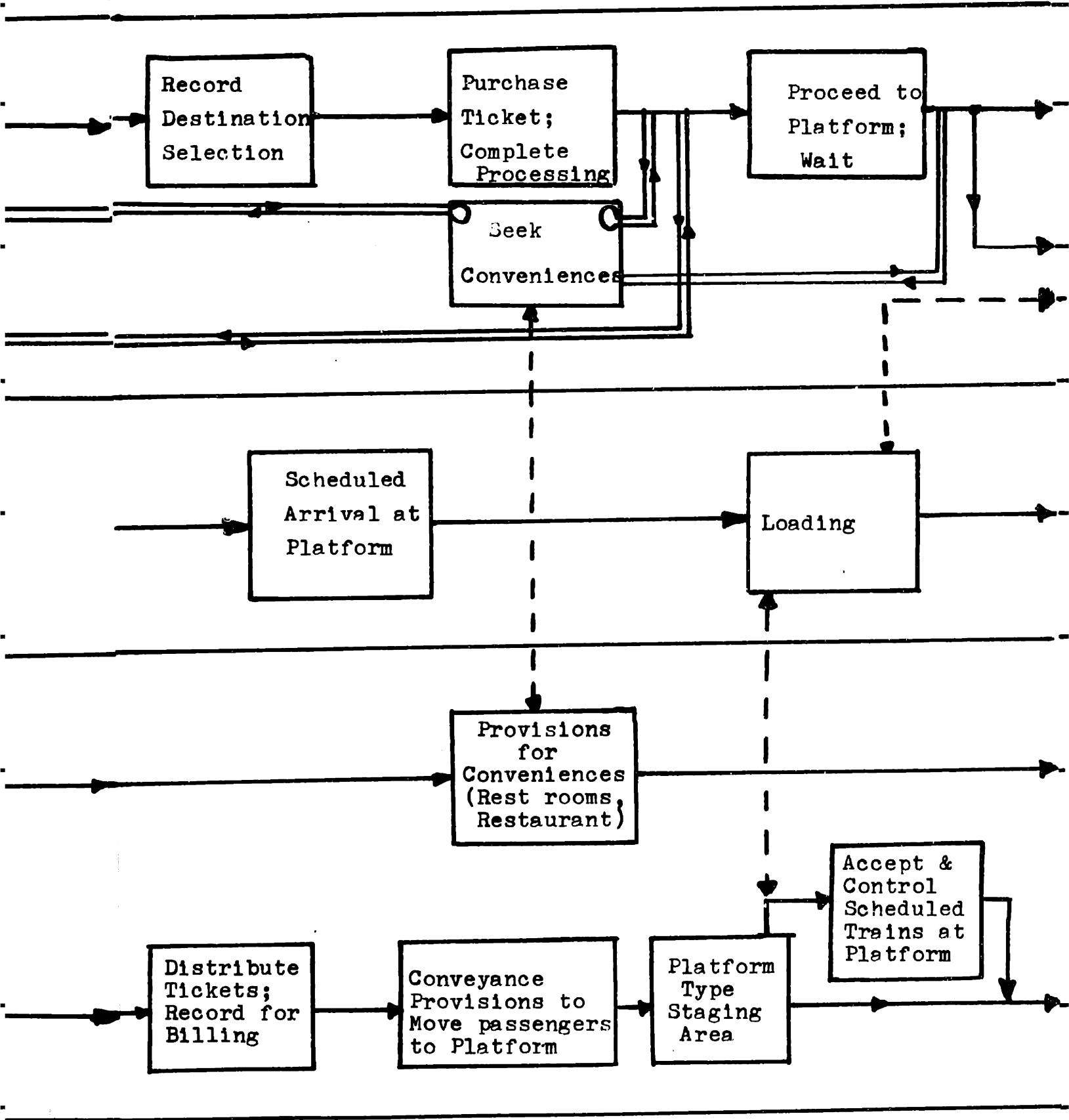
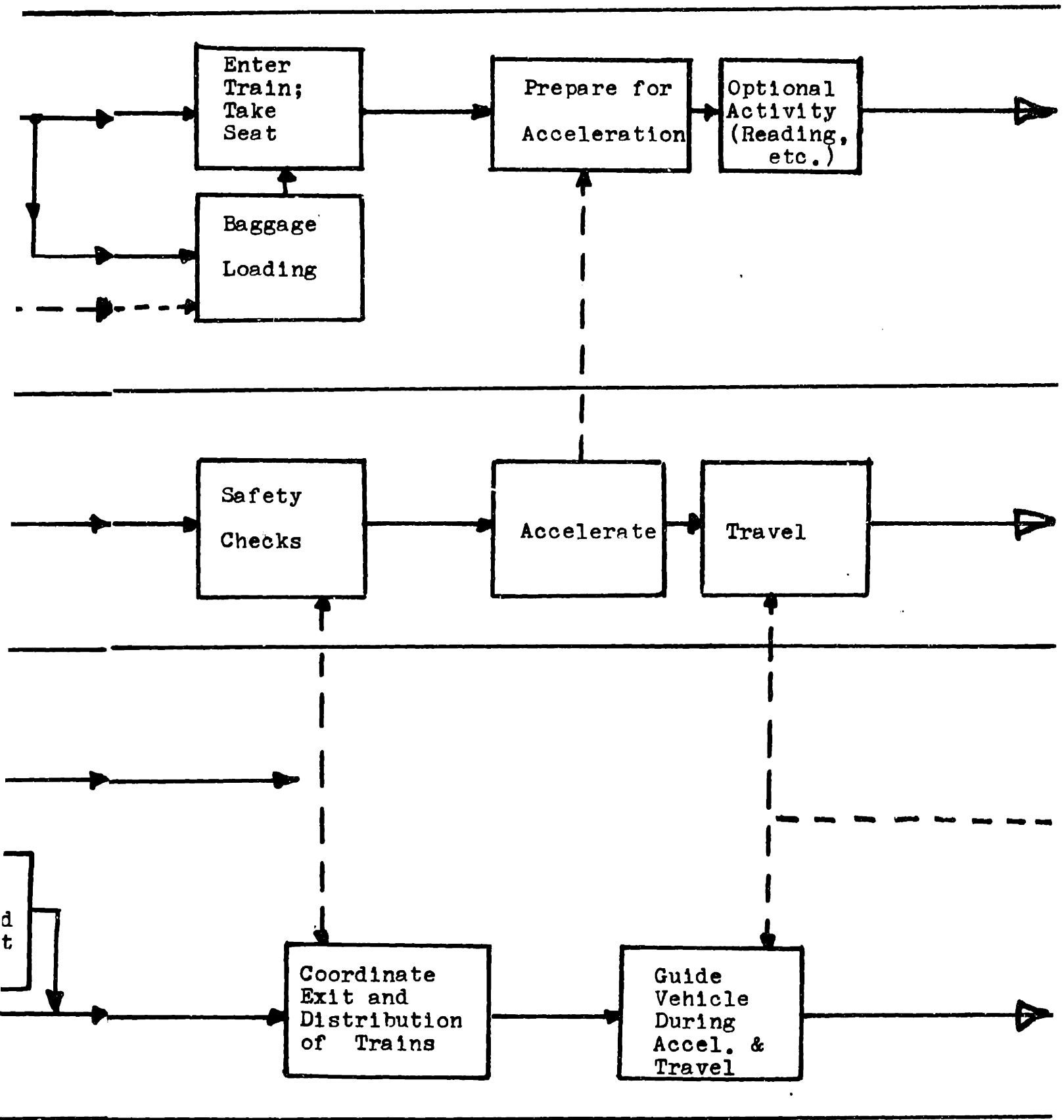


Fig. 9. Function Sequence Diagram : Example B
 (High speed train & tunnel, optimal situation)





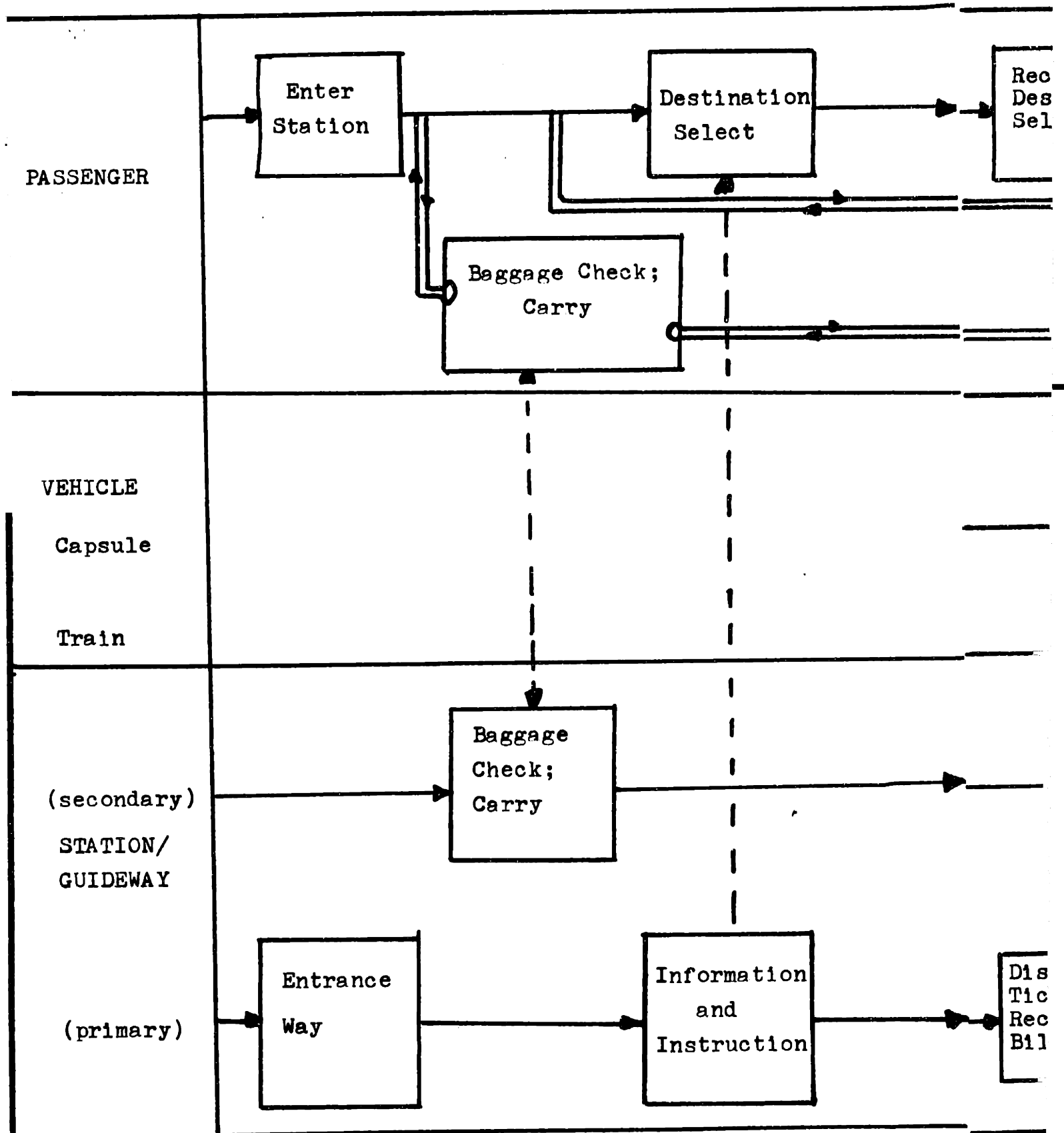
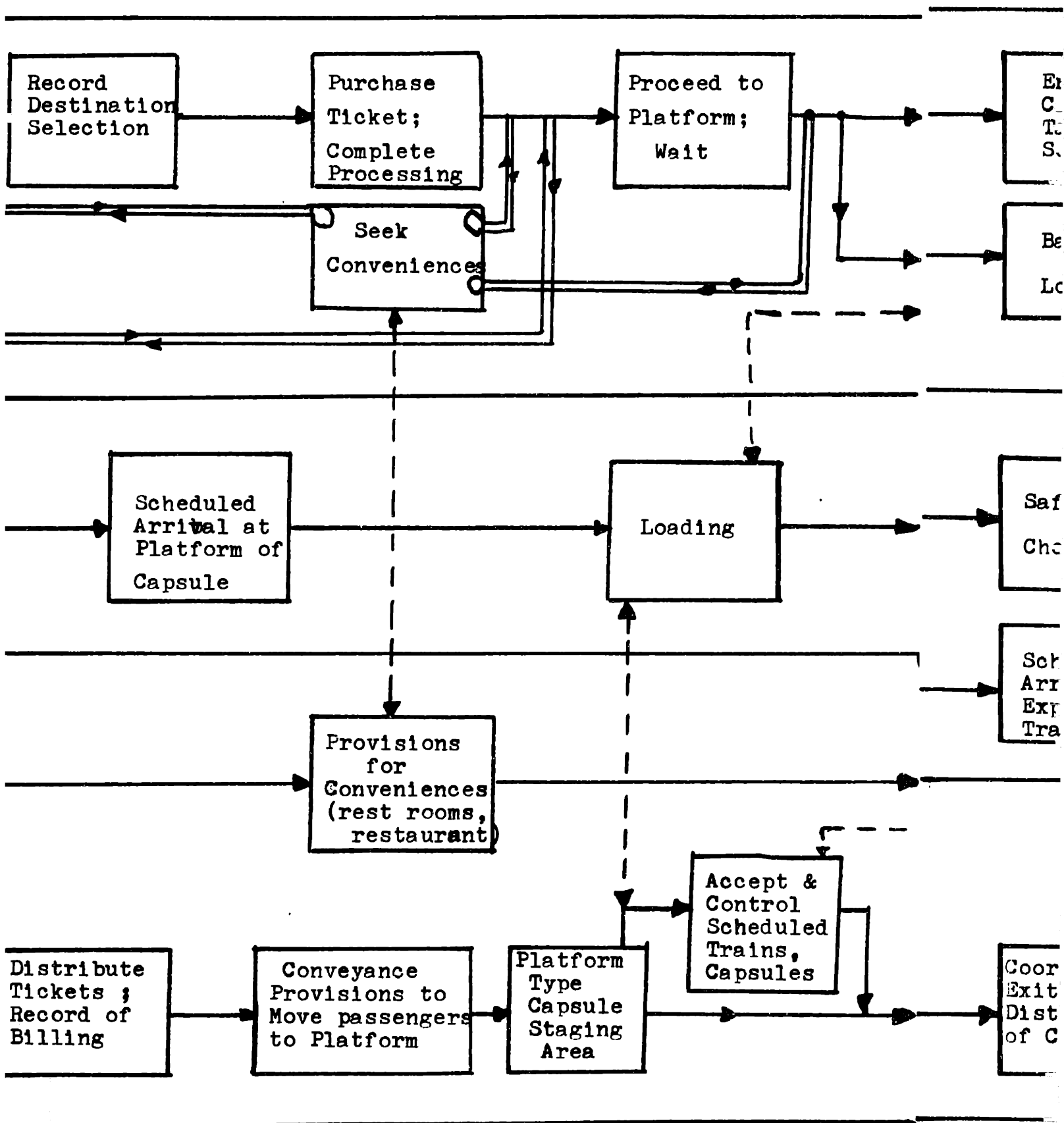
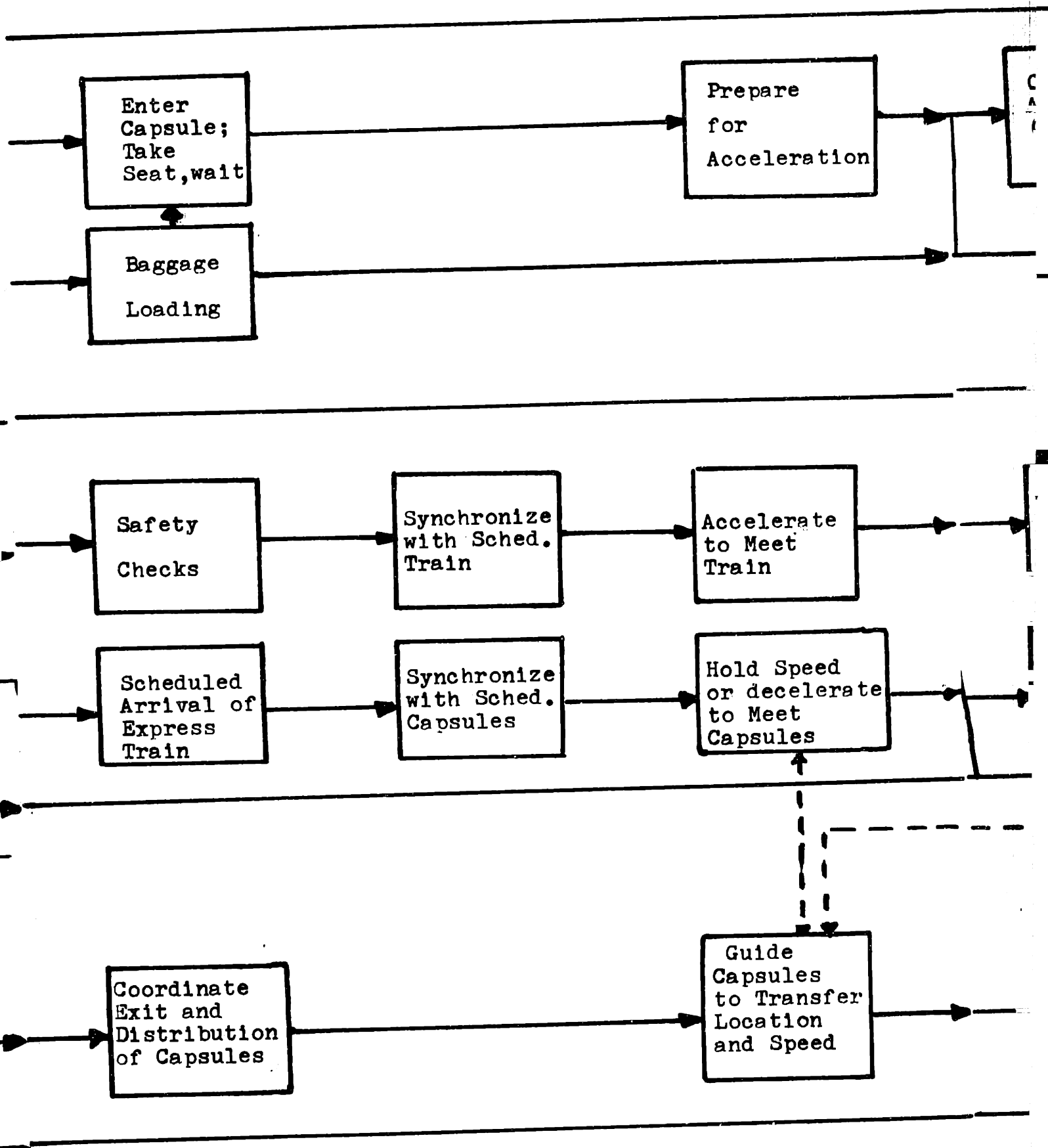
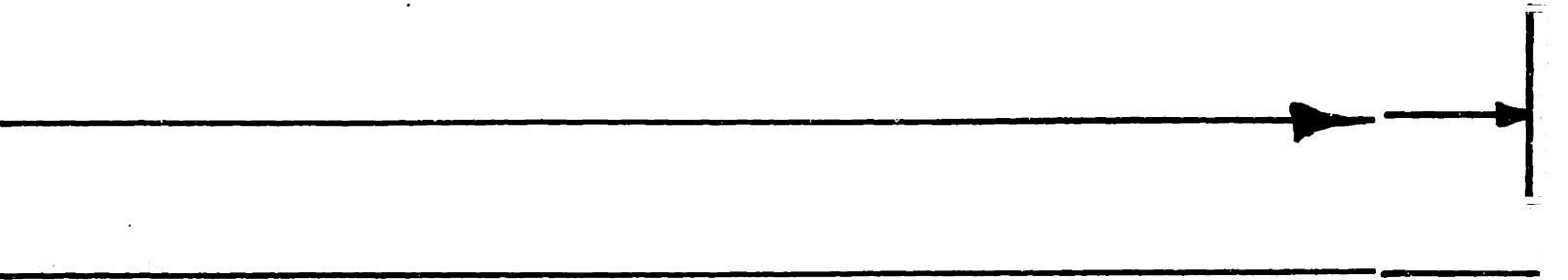
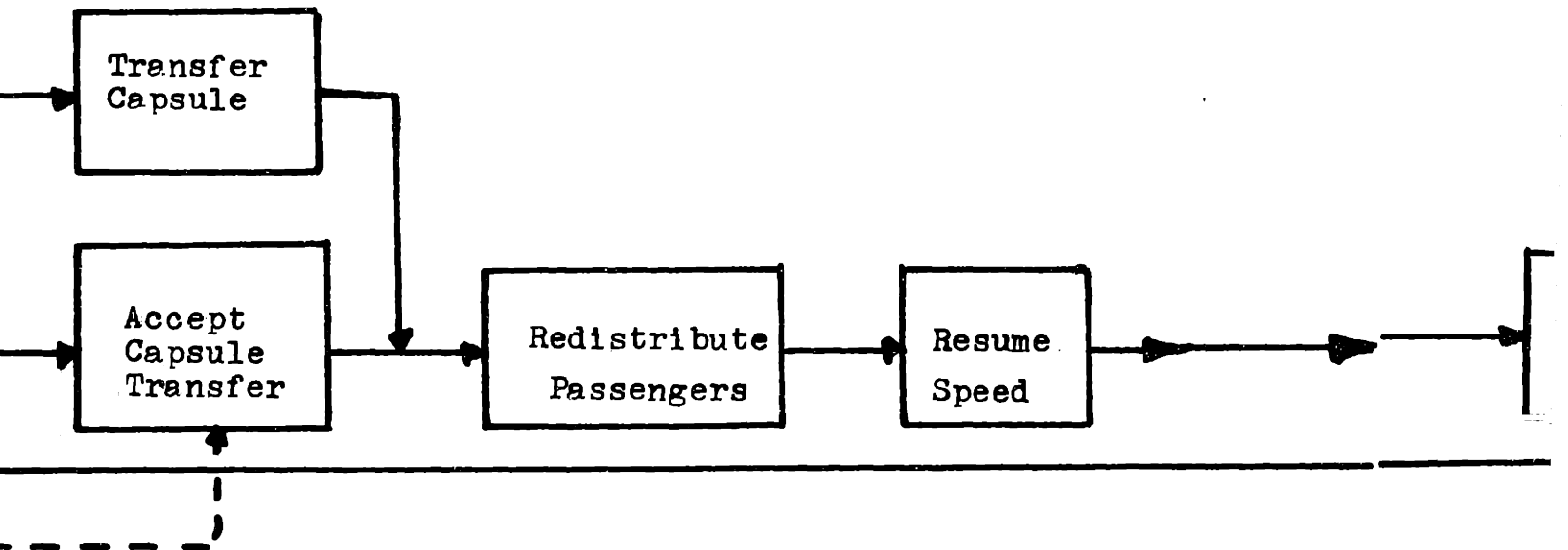
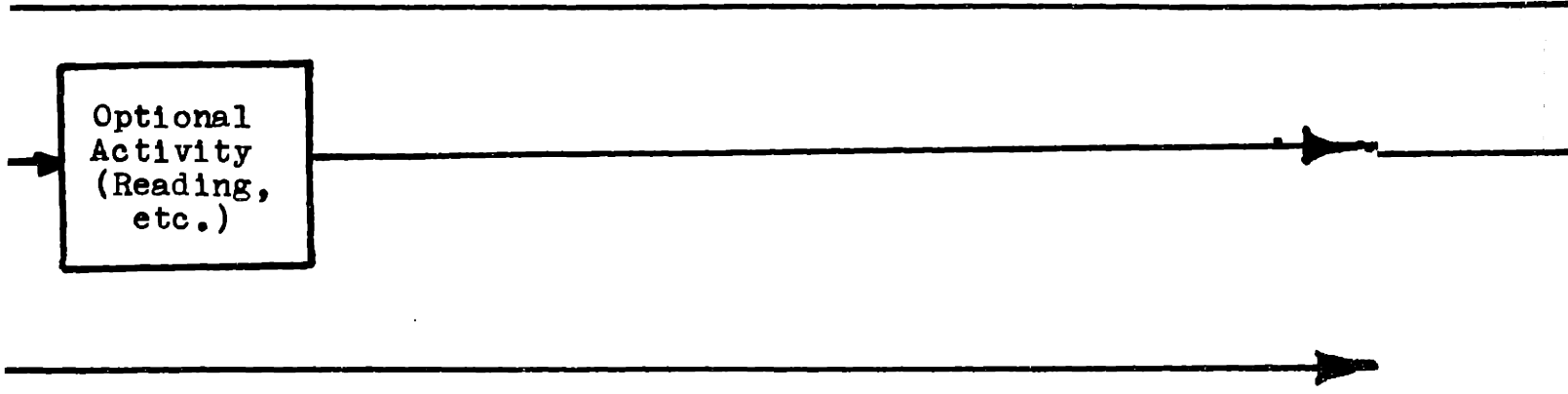
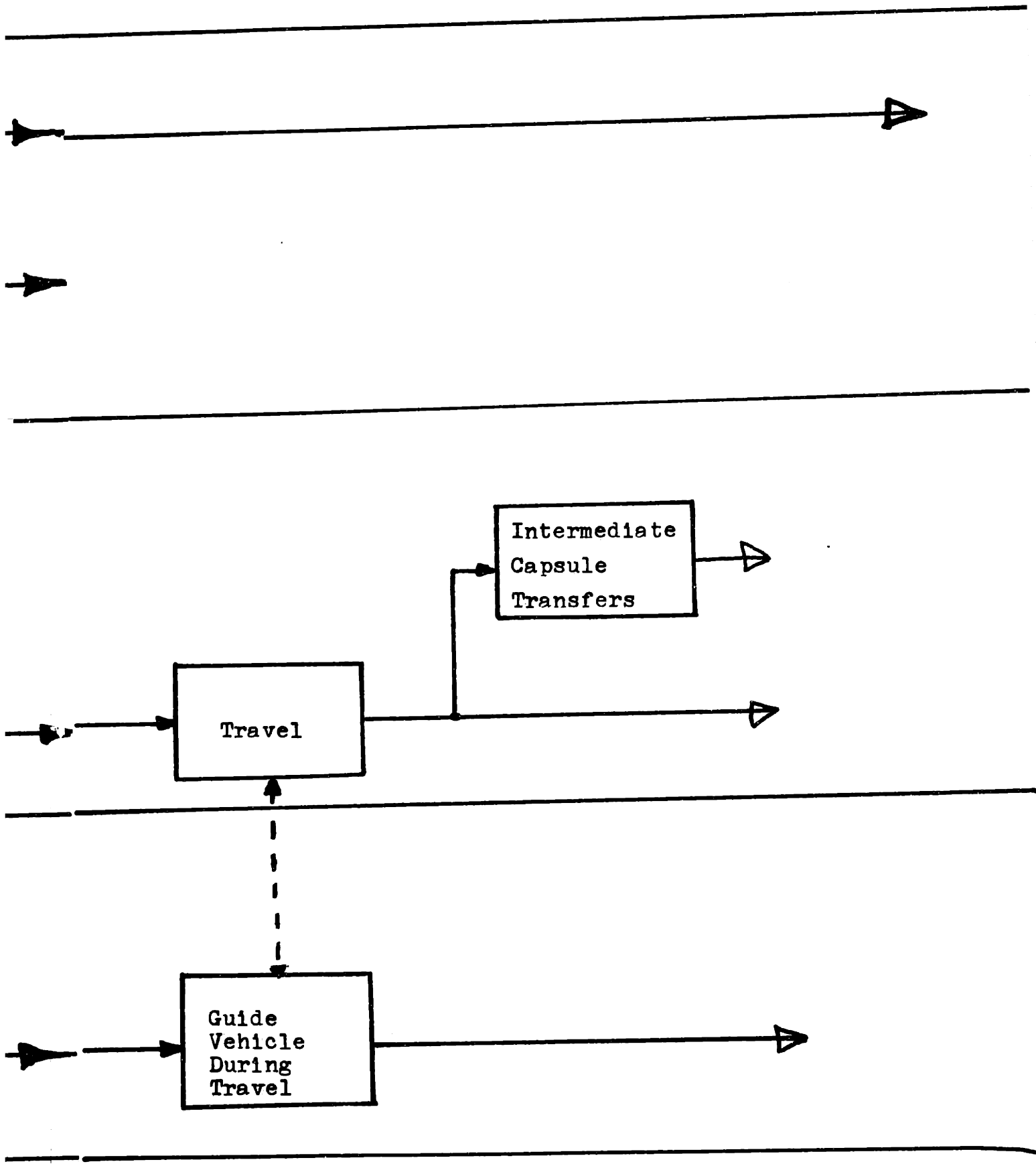


Fig. 10. Function Sequence Diagram : Example C
(High speed train and capsule transfer; optimal)









After preliminary sequence diagrams have been constructed, other design groups would be delegated responsibility for lower tier responsibility, and the design process would proceed iteratively, tier-by-tier to achieve greater design detail. At later stages of the design and evaluation process, certain aspects of directed graph theory might prove useful in demonstrating various definite causal effects and existence/non-existence relations (see Harary, 1965).

In forming the causality nets, we should be careful not to rely on an excessively causal explanation of system functions.

There exist some unsatisfactory qualities about causal explanation. If our knowledge of causal properties and the particular situation at hand were sufficient, the situation would be acceptable. However, there are numerous phenomena which our weak knowledge of specific causality cannot explain and for which other types of explanatory techniques might be appropriate. Thus any causal framework, (analytic or synthetic) would involve rechecking by appropriate non-causal explanatory techniques.

(Kaplan, 1965. p. 148)

An example of the non-causal approach is statistical explanation.

A more complete approach to explanation might involve not the selection of appropriate causes but the rejection of obviously inappropriate or inapplicable

factors. There would be some "deadwood" causes carried through much of the analysis, but it would be better to discard them later when certainties would be greater and the overall problem better understood.

3.4. Concepts Sequence Diagrams

The concept sequence diagrams would be obtained from the substitution of a concept or concepts for each indicated function or set of functions (Fig. 11), in actual design circumstances via IR reference to the general function and concept lists. The arrows shown in the diagram for the automated car/guideway example connect and interrelate one concept with another, for either one-way or two-way function interactions.

The designer could choose from a list of options where alternative sets of concepts would be associated with functions. Within the limitations of both specified subsystems and situations, much of the design choice would be concentrated on the selection and patching in of alternate concepts intervening between the users and the specified subsystems (in the functional sense). It will be necessary to note and record which of the three requirement types of concept or function is being considered : necessary (specified), selected, and optional. Interaction requirements fall into three similar categories :

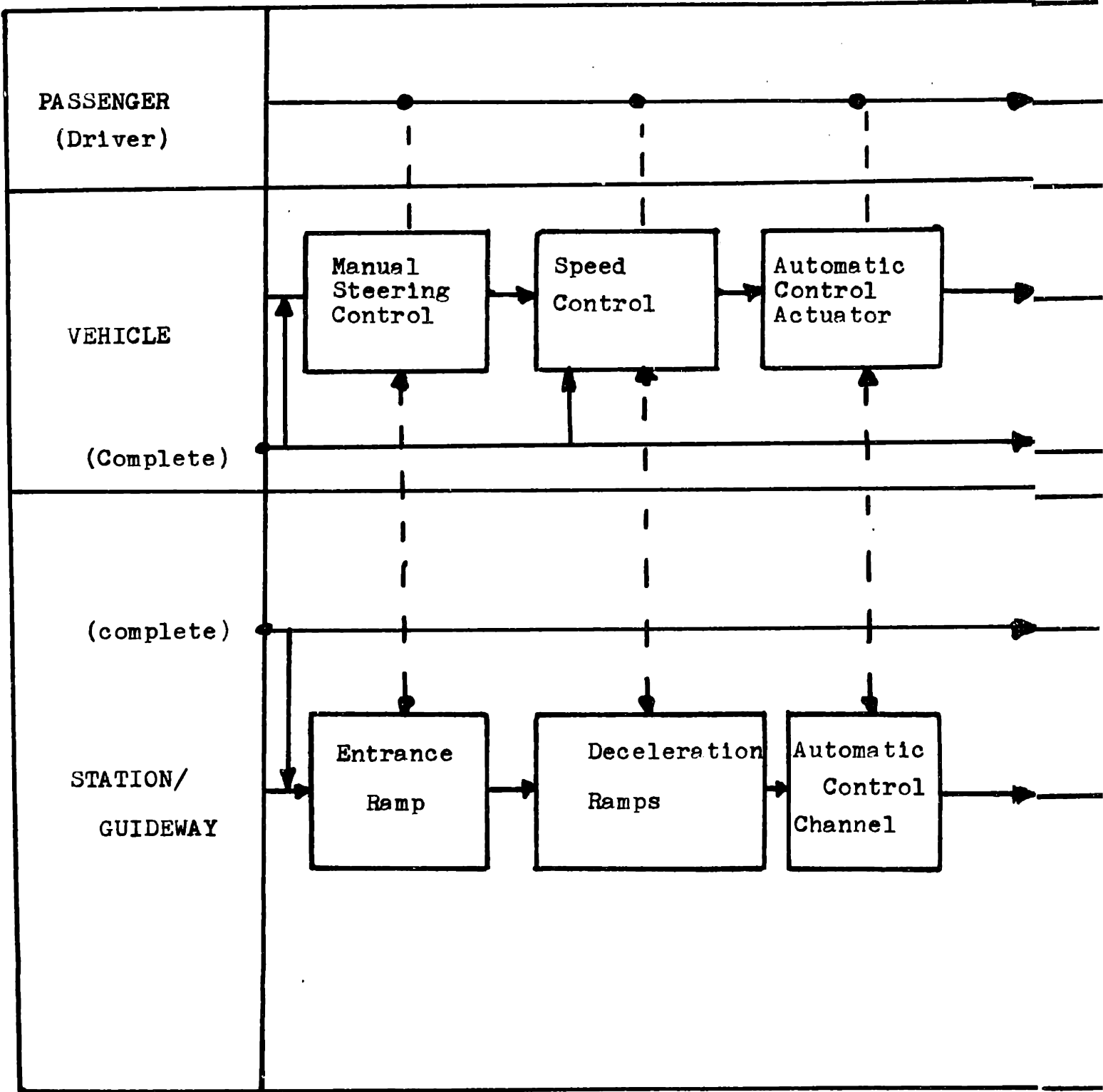
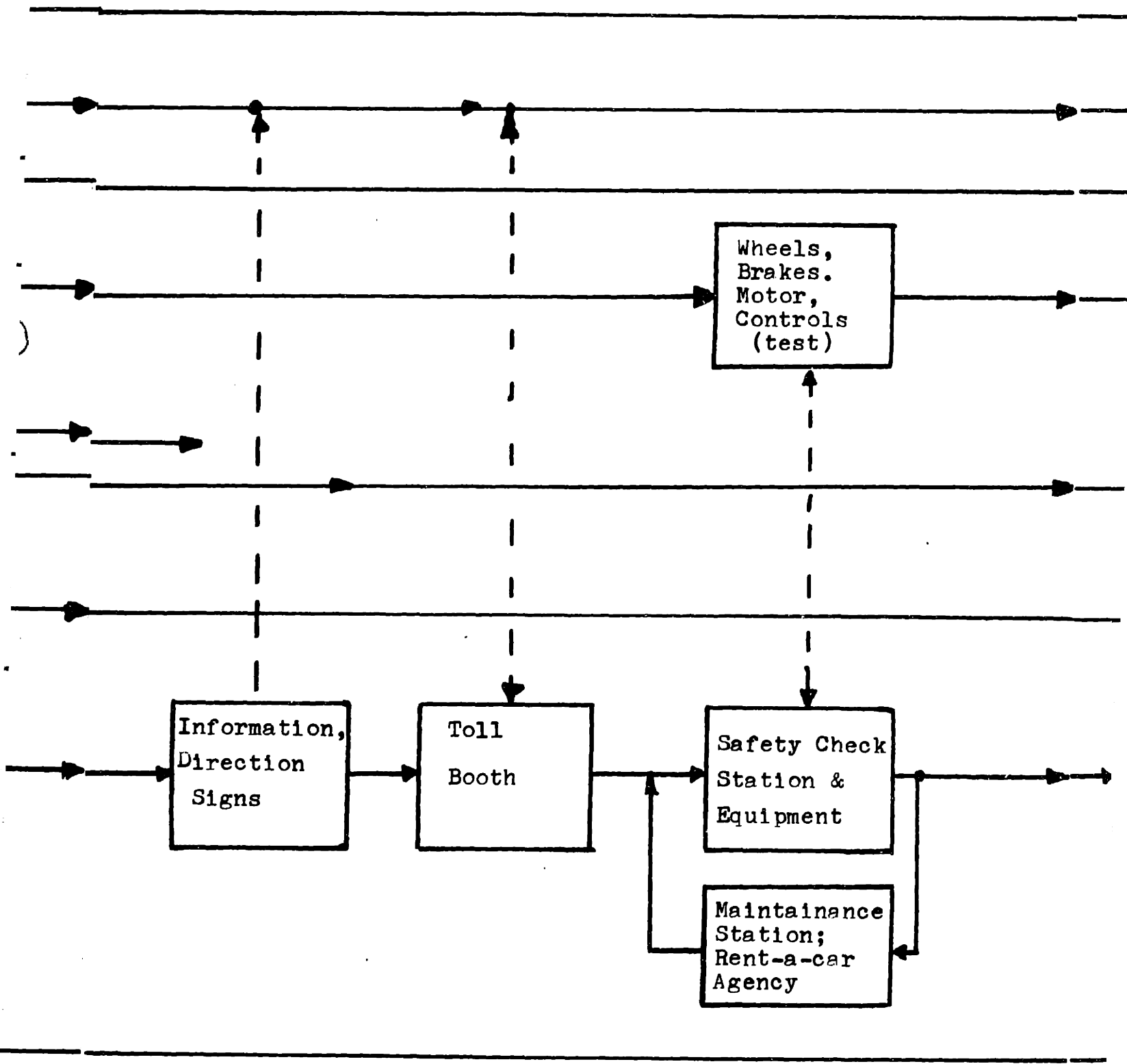
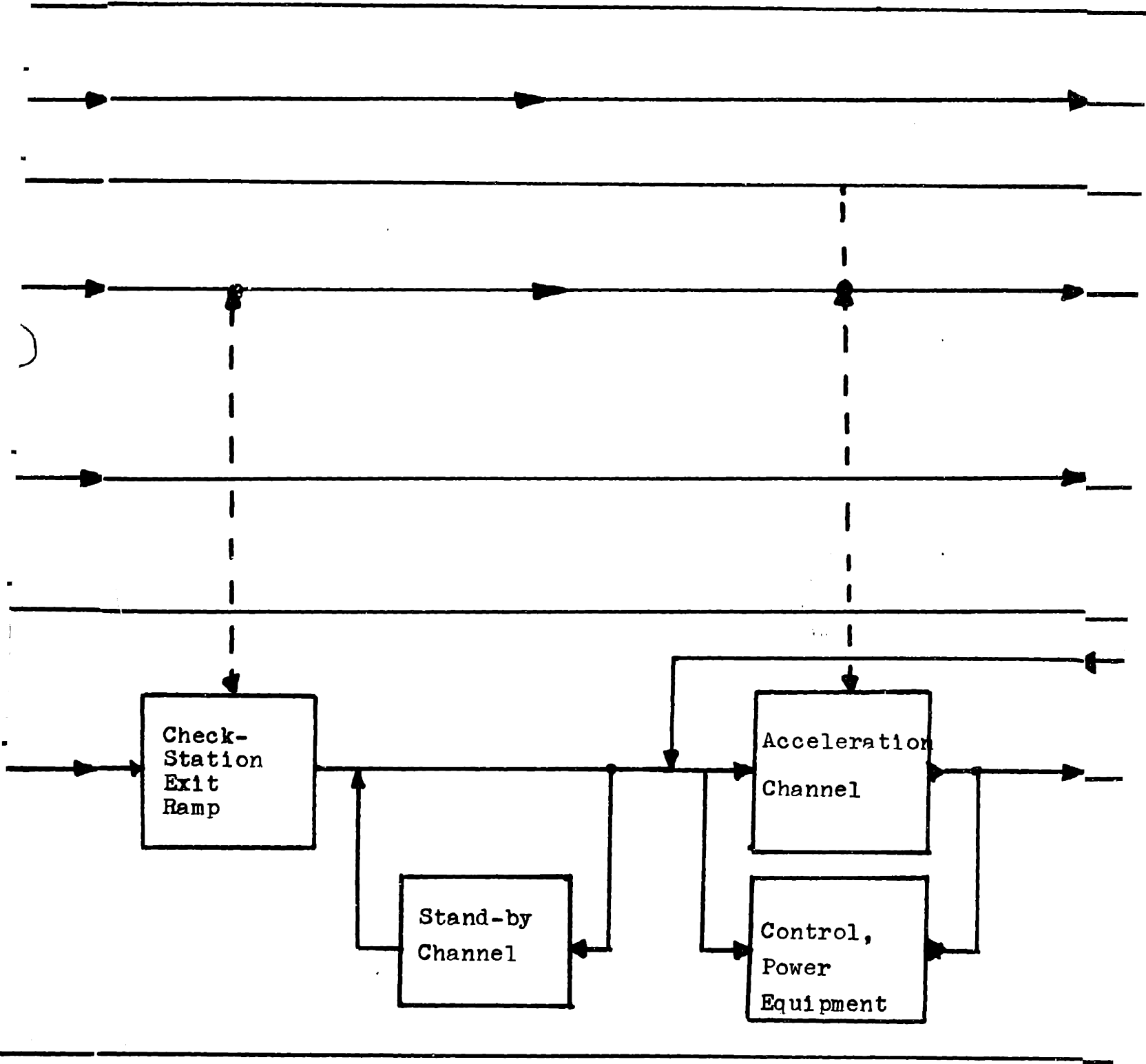
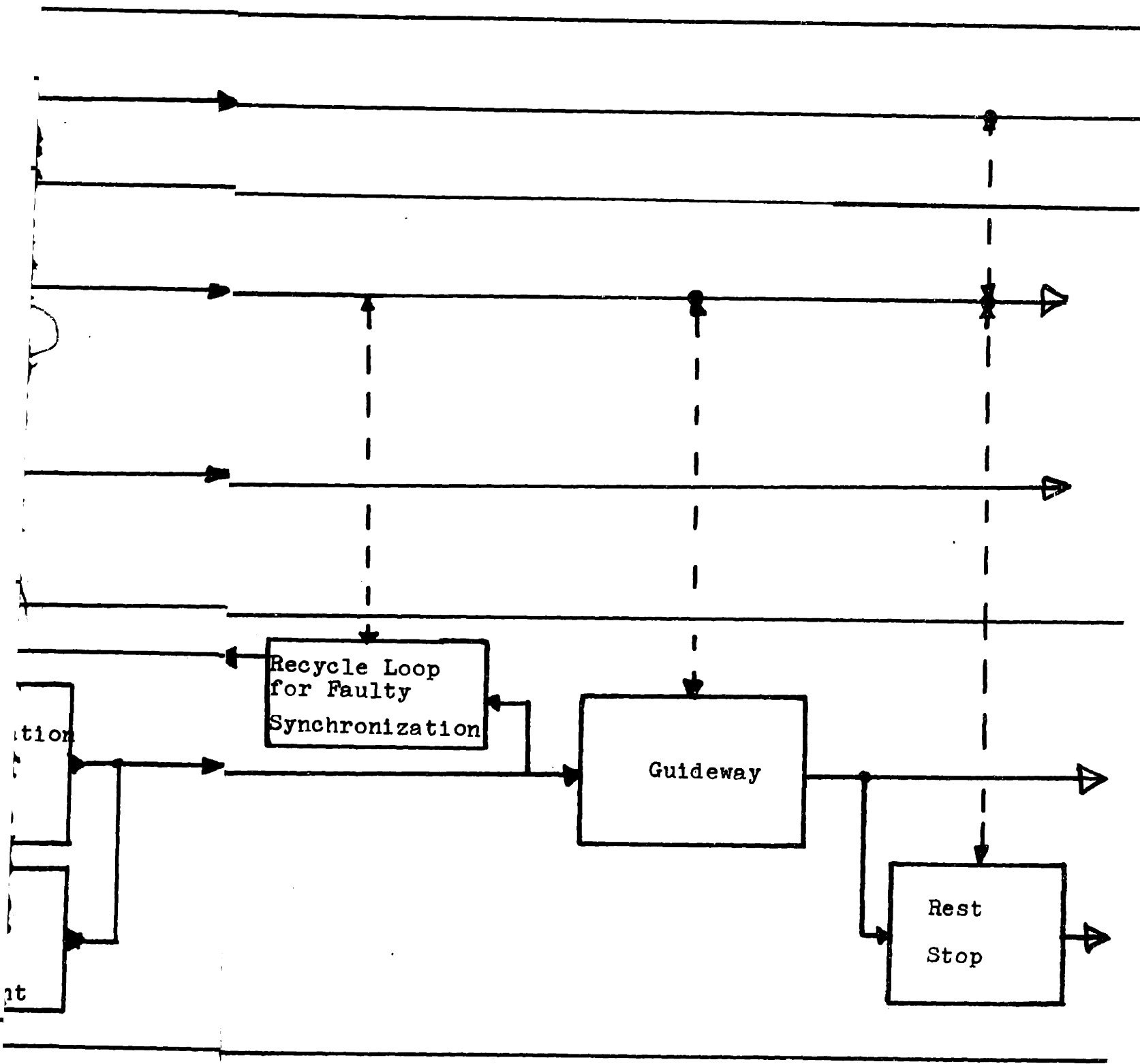


Fig. 11. Concept Sequence Diagram : Example A
(automated car, guideway system, optimal situation)







specified (e.g. continuity), selected (criteria for performance, cost) and optional.

Concepts sequence diagrams would serve as fundamental aids in revealing the existence of continuity relations, functional interactions, compatibility and intervening concepts. Each interaction would be identified by letter or number, which could be keyed to a more detailed set of diagrams illustrating the attributes involved and the nature of the particular compatibility problem.

The designer would have the option of using dummy functional concepts either for cases of obvious or cookbook engineering or for deferred decisions due to uncertainty. One could either return later to specify the nature of these dummy concepts or delegate the tasks to subordinates.

3.5. Matching of Attributes and Concepts

A critical decision point is reached when the criteria for matching attributes with respective concepts must be proposed. It would, of course, be quite inappropriate and almost meaningless to list all the attributes associated with a given concept under all conditions, despite the availability of computers for information handling. Each concept will have to be modeled rather succinctly and each relevant and distinct

situation simplified and idealized so that some minimal set of attributes can be found which will describe the overall performance characteristics of the concept or set of concepts in question. For early design trials, these simplified models for matching attributes with concepts will be fairly crude and inexact, but by diligent listing of all modeling assumptions and by using technical personnel for organized checking and refining of the analysis, the work quality of the innovative team may be improved considerably.

Once the attributes of certain common concept situations have been determined and a record made of this progress, the information could be checked and programmed into an automatic retrieval scheme, whereby all future attribute listing of pertinent attributes for preliminary design would be done automatically. These provisions would allow the systems designer to shift larger pre-analyzed chunks of data about during his analysis and present him with a cumulative core of suboptimized information during the predesign stages. For later, more accurate design, these previous suboptimizations would have to be rechecked.

The designer would feel confident that a fairly complete source of concept attributes would be available to him on demand. With such a method of systematized attribute selection, he is better able to manipulate very tentative, vague and complex concepts and is less

inclined to be casual, perfunctory or confused in his approach.

Probably more important than the choice of the criteria themselves is consistency in their application. A checklist of attribute requirements and allowable ranges should be on hand (or automatically displayed) when criteria are being applied. The criteria themselves might be in the form of a limit on the maximum number of attributes applicable to a concept-concept match, on the maximum allowable modeling error, on the maximum allowable error increment caused by dropping the least significant attribute, or other similar restriction on the number of attributes. For many of the very qualitative attributes, the relative significance of the attributes could be estimated from past and present surveys of passenger responses to issues. (Table XVII)

While these procedures may not appear altogether rigorous, they nevertheless would contribute immensely to avoiding the "one-factor" type of analyses and would serve as a constant checklist reminder to the designer that he had designated certain incommensurables as important design parameters.

One could begin the matching process in the same manner that the general attribute list was originally constructed, beginning with consideration of microconcepts

TABLE XVIII Attribute-concept Selection & Matching Criteria
(Representative but not necessarily optimal techniques)

General technique : The number of matched attributes is expected to increase with number of functions performed; the total number is the sum of certain "common attributes" (e.g. cost, safety) and the selected attributes.

TRIAL 1 : The number of selected attributes is proportional to the number of functions. An approximate proportionality factor $K \pm \Delta K$ is chosen.

TRIAL 2 : The number of selected attributes is based on a consensus of designer "confidence" in providing P% accurate modeling of actual conditions with C% confidence.

TRIAL 3 : The basis of choice is a rating scheme, whereby the attributes are rated in importance from 1 - 10, and all of them below rating R would be dropped.

TRIAL 4 : Compilation and comparison of trials 1 to 3.

.

Criteria selection would appear at times to be the most difficult aspect of systems design and is fraught with many shaky decisions. It is beyond the scope of this thesis to investigate the many means of criteria selection, many of which are semi-empirical.

and concentration on the more unobvious combinatorial attributes. Most microconcepts are relatively simple building blocks, usually existing today in hardware form or familiar conceptualizations, for which a consensus of attributes can be catalogued fairly easily. Because many innovative ideas are often simply recombinations of existing microconcepts, the specification of the attributes will be less difficult than the straight-forward brute force procedure, if a catalog of microconcept attributes already exists.

CHAPTER IV

Evaluation of Discrepancy and Incompatibility

4.1. The Attribute-Attribute Linkage

The study of causality and compatibility is basically an analysis of interactions between concepts. There are many different types of interactions : visual (information, aesthetic), material, force (physical and social), energy, momentum, and others. For the purposes of compatibility studies at any tier, it will prove useful to employ a control volume or black box approach : to hypothesize a modeled boundary surface across which inputs and outputs flow (e.g. energy, matter, passengers, vehicles, information, etc.). Two basic types of attributes can be differentiated:

1. static or state attributes, such as weight, size, structural strength, shape, etc.);
2. input/output attributes, such as into & from a vehicle, guideway vibrations to suspension, air intake and exhaust, etc.

The functional output attributes of one concept can be linked causally with the input attributes of appropriate other concepts, the state attributes would be linked non-causally, and then cross-over relations would be indicated (such as the relation between weight and momentum of a rocket motor). This matching

process could be performed graphically (as in the example of Fig. 12), either manually or by computer. A compatibility existence check could be applied to this process, the criterion for failure being the existence of "dangling connectors," or unmatched attributes (e.g. input oil flow to a hydraulic system, without a complementary output flow from the supply).

An interaction takes place when the attributes of one concept has an "appreciable direct" effect on the attributes of another. "Appreciable" attributes and their relative significance can be determined from the selection criteria of Table XVIII. "Direct" effects imply that no intervening concept exists in the model.

The most important type of interaction, in terms of the all-important viewpoint of the system users, is that of man-machine relations, and this is the most logical interface for which detailing and quantification of attributes can begin. However, compromises must be made between this approach and that of employing the pre-selected general systems concepts, standardized equipment, accumulated information and test data, and time.

4.2. Discrepancy and Incompatibility

There will be varying degrees of uncertainty

surrounding the attributes in any given situation, and the first step in procedurally minimizing this uncertainty is the labeling of the quantitative, semi-quantitative, or qualitative nature of the attributes, preparatory to determining means of measurement and comparison. No spurious priority ranking should be added by this process, in order that the tendency to place special evaluative emphasis on the more quantitative attributes will be minimized.

There is a wide continuum between quantitative and qualitative estimates, based on confidence and uncertainty. The file data on each attribute relation should state the highest confidence level of measurement, importance rating and significance, and relevant data in the form of Venn diagrams, survey results, calculations, test results and analogies.. One area of concern for the project engineer is to balance the updating of the more uncertain information to higher levels of confidence and to avoid overquantification.

Measures of compatibility effectiveness (qualitative or quantitative) are based on two types of submeasurements:

1. Discrepancy between the linked attributes.
2. Incompatibility between related concepts.

For the more uncertain cases, estimates of discrepancies and incompatibilities would be largely intuitive. For more quantitative examples, partial measures can be appraised. Whatever discrepancies that may exist will be some function of the attribute difference,

$$D_i = f_i (A_j - A_j')$$

IN OUT

expressed in non-dimensional linearized form so that discrepancies between a number of different concepts over one attribute can be manipulated by superposition to provide a summation measure of discrepancy. A case in point would be an electrical filter with many noise inputs.

A weighted sum of the quantitative discrepancies would yield the quantitative incompatibility I_T of the system,

$$I_T = \sum_i \sum_k s_{ik} D_{ik}$$

or, if the input (or output) discrepancies are summed, the quantitative input incompatibility I_1 (or output incompatibility I_1') of the concept

$$I_T = \sum I_i = \sum \sum s_{ik} D_{ik}; \quad I_i = \sum s_i D_i$$

where s = the weighting function for each attribute

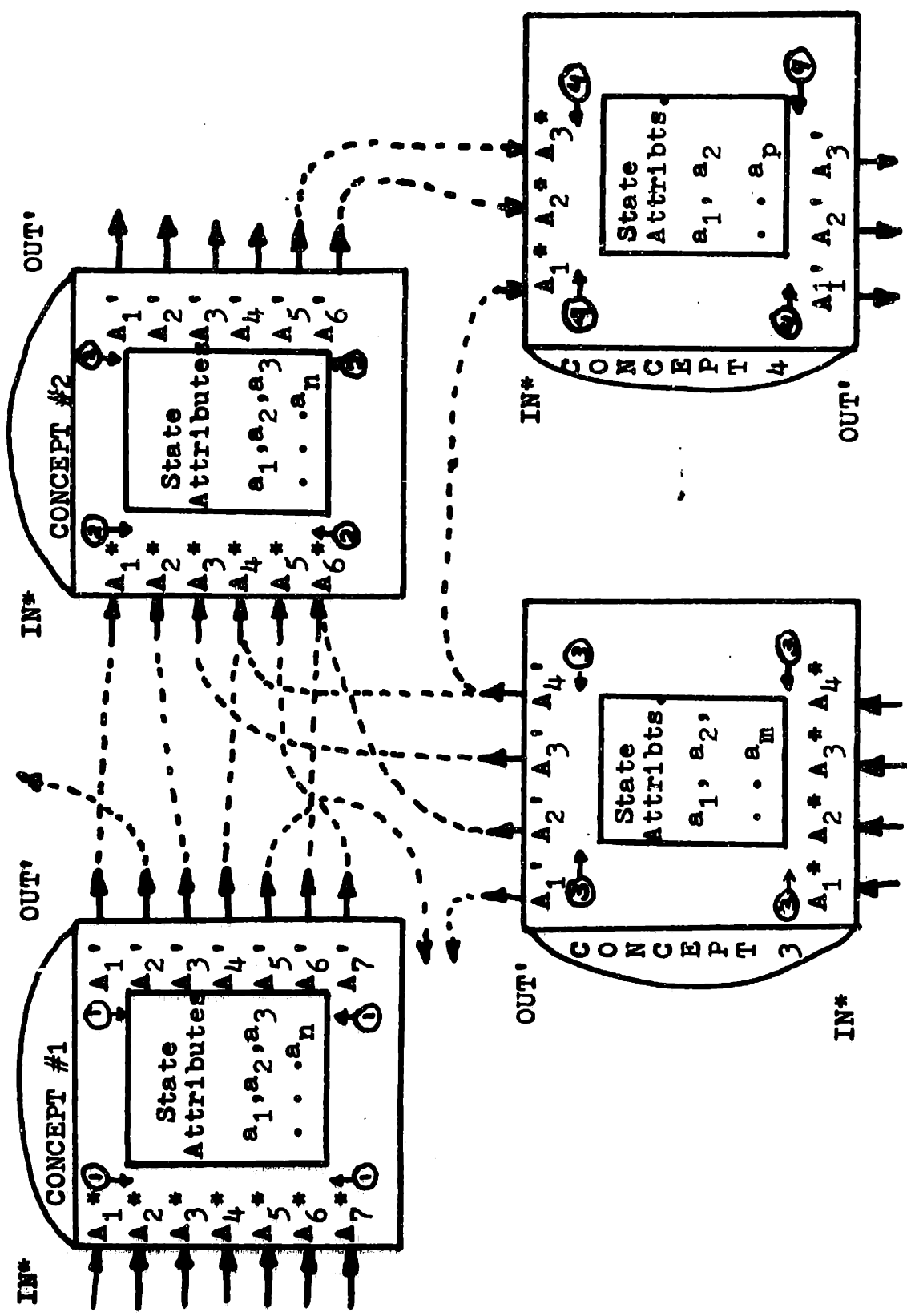


Fig. 12. Attribute-Attribute Linkage for Causally-related Concepts
(input/output attributes only)

per situation. However, this quantitative measure of incompatibility must never be confused with overall system incompatibility, which involves many incommensurables, unless an appropriate black box model can be constructed.

The compatibility problem has three basic stages : the determination of feasibility, efficiency, and optimality.

In order to reach an optimal solution to problems of choice, we must be able to value various "situations" or outputs. Then we can revise our choices and shift resources to get the maximum value that is possible in the face of whatever constraints confront us. Even if we cannot always compare the values of different outputs, however, we can find some positions that yield more of some valuable outputs without yielding less of any others. When we cannot produce more of one output without sacrificing another, we have reached an efficient position. Many other situations are feasible, of course, by using the resources inefficiently.

(Hitch and McKean, 1960. p. 109)

Some rough criteria are needed to limit inaccuracy in modeling and in actual incompatibility. The modeling can be performed for an assumed range of required accuracy, with the designer having the option to specify the particular degree of accuracy, depending upon certainty and estimated concept significance in the design process. Approximate safety factors in design could also be set. The assumptions of the model

must be clearly stated and recorded, and alternate models developed in order to increase the design choice possibilities.

If it were decided that a severe design discrepancy existed, the explanation could be due to two factors :

1. The model is inaccurate
2. The actual concepts are incompatible for design.

One would first make a quick check for model accuracy, before implementing a procedure with the following options :

1. Substitute a different type concept from the list of alternatives;
2. Modify the attribute characteristics by selecting a slightly different variant of the original concept;
3. Add an intervening or buffer concept;
4. Remove an appropriate concept;
5. Set new safety factors ;
6. Any combination of the above.

The feasibility problem is a matter of estimating whether underdesign exists (with limited consideration of overdesign), of whether the range of output attributes linked to a concept exceed that range for its input attributes, taking account of relevant

safety factors. Studies of efficiency compatibility become a process of substituting more specific, detailed and appropriate concepts models for more general, oversized or undersized ones, reducing the uncertainty of attributes and major excesses/insufficiencies of design incrementally, until considerations of trade-offs and optimality becomes meaningful. In application, all three techniques will overlap and interact, since in modifying very complex efficient systems for "optimality," there is uncertainty whether system feasibility has been maintained.

4.3. Qualitative Compatibility and Evaluation

Qualitative comparison of attributes is a more critical problem and suffers from less cumulative data. Elementary techniques of checklisting, cataloguing and description can be quite useful, whether related to some fixed standard of reference or to a purely comparative procedure dealing with variants of the system itself. Venn diagrams can display function, concept and attribute information in limited visual form, and sketched area ratios can be used to represent semi-quantitative relationships.

The alternate concepts available for any design problem could be surveyed for preference of procedural

order of design, merely to determine which concept combination will be analyzed first. It might also appear that, given a set of general objectives, a listing of attribute priority would be useful, but this may not be the case. For example, the attribute order for the muffler of a piston engine will differ from that for its gas turbine counterpart, as will an arrangement of series-coupled mufflers. Slight changes in concepts and situations can yield notable differences in attribute order. How then are we to specify changes in priorities for various situations? In the economic sense, priorities reveal little about how to delegate incremental costs among particular items and alternatives. One could go directly to a more valuable measure of trade-off by asking the specific question, "How much of value A are we willing to relinquish in order to increase value B by a degree X?"

Other model processes to show qualitative relations have been suggested by Kemeny (1961. p. 35), such as directed graphs, algebraic group theory and group transformations, and matrix notation to show relation and communication. Stimulus-response methods can yield laboratory data with limited applicability to overall systems operations.

The systems designer, in the final analysis, will have to supplement his technical education and knowledge with a clearer understanding of the role and scope of values in transportation system man-man, man-machine interactions, and thereby improve design predictability. A far more detailed analysis of the role of values in decision making is given in Churchman, 1961.

4.4. Evaluation Criteria

Useful criteria will be required for comparison of the results of trading off among the variables of cost, performance and time.

... each decision between two or more design alternatives in the final analysis will depend on trade-offs between three variables : cost involved in implementing the function . . . , schedule or time delay involved in implementing the function, and performance capability (including the predicted reliability of the function).

(Meister, 1965. pp. 67-68)

There are numerous types of evaluation criteria, depending upon how one subdivides the problem :

1. Ultimate vs. Approximate
2. Performance vs. Representational, the first describing system or subsystem performance, the second describing (representing) system characteristics which are involved in or will eventually result in system performance.

3. Terminal vs. Intermediate
4. Internal vs. External
5. Mechanistic vs. Behavioral

(Meister, 1965. pp. 82-83)

The criteria for a particular system situation can be formulated through the responses to the following questions :

1. What constitutes adequate performance of the mission in terms of mission parameters?
2. Should two or more systems appear capable of adequately performing the mission, what is a further measure of performance in mission parameters that will indicate which system will better perform the mission?
3. For each proposed system, what functions of system parameters do the mission performance criteria involve?
4. For each proposed system, what is the sensitivity of the system parametrized mission performance measures to design detail, availability of subsystems in state-of-the-arts, and quality of systems support?
5. How shall the cost or penalty factors associated with procurement of each proposed system be computed in order to obtain a basis for comparison? (Ellis, 1962. pp. 13-14)

4.5. Optimization Techniques and Trade-offs

The operational objective of system optimization is that of achieving maximum system performance potential compatible with some minimized function of time and cost. It is very important that we not seek maximization of one factor at the same time we try to minimize another separately; a system cannot have maximum performance and minimum cost, although semantics may lead the evaluator into this fundamental logical trap when he is attempting to justify his conclusions.

The trade-off relation between function, time, and cost/performance attributes is demonstrated in Fig. 13.

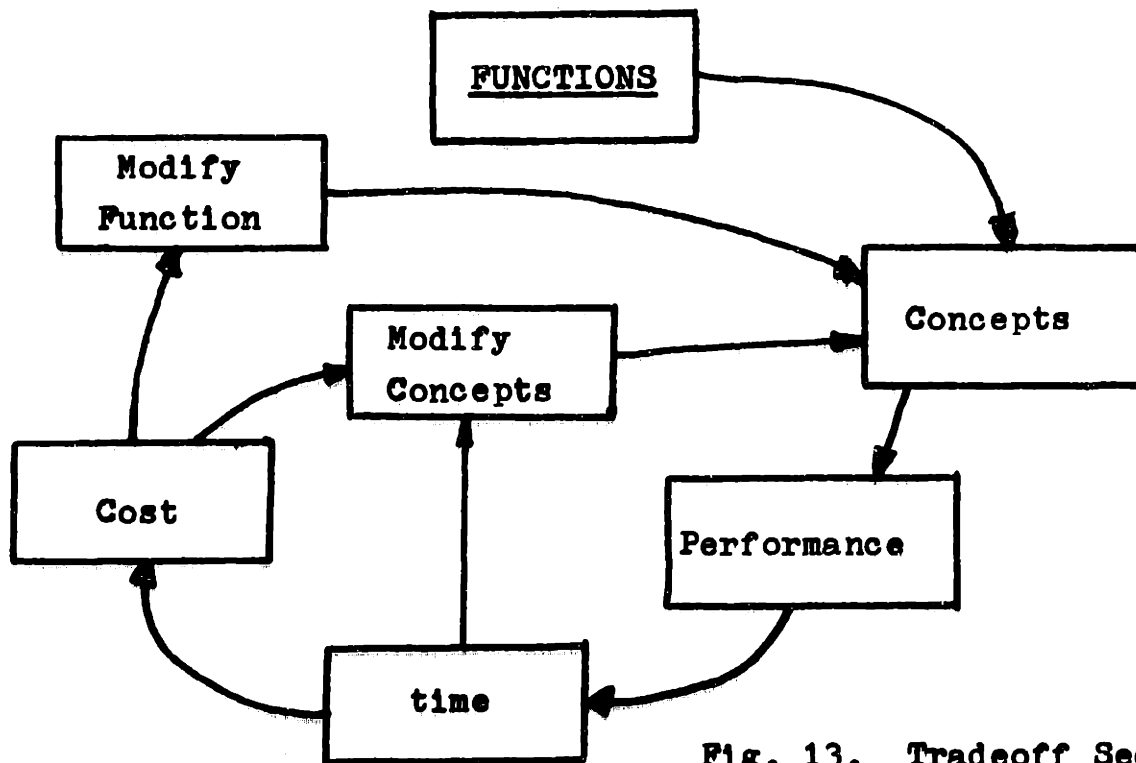


Fig. 13. Tradeoff Sequence

The specific quantitative techniques available have been studied extensively through Operations Research and cost/effectiveness analyses (Table XIX).

TABLE XIX : Quantitative Optimization Techniques Available

1. Direct method of calculation
2. Classical differential calculus method
3. LaGrange multiplier method
4. Calculus of variations
5. Experimental search method
6. Steepest descent/ascent
7. Linear and non-linear programming
8. Dynamic programming
9. The maximum principle

(Fan, 1966)

4.6. Evaluation Risks and Uncertainties

Appreciation of the importance of risk and uncertainty is a common consequence of experience with current system design and evaluation. Some of the major risks are the uncertainties in market services and market shifts, in public acceptance and adaptability, in safety and failure problems, in costs and financing, and in the spin-off effects of the system technology. Moreover, the "risk matrix" would differ depending upon the various situations

applicable, and there may be little consensus on risk preferences and gambles, there being general dissimilarities between the (conservative) decision maker and the (radical) analyst and consultant.

Criticality of risk can be reduced by clever contingency planning and use of deferred decisions, and if systematic quantitative analysis can narrow the choice to a set of efficient points the burden placed upon intuitive judgment for optimality is reduced, and the quality of judgment should be improved.

4.7. Techniques for the Avoidance of Fallacy

As has been mentioned, the main objectives of systems evaluation are those of completeness, of avoiding the omission of significant factors, and only secondarily the detailing of quantitative or rigorous methodology. Even here, there will be a tradeoff between objectives, since some applied methodology of any sort almost invariably leads to the exclusion of alternatives and hence incompleteness.

Thus we need flexible methodology, multiple evaluation techniques, and non-archaic criteria. While we seek at least a semi-optimal result, our objectives are essentially two-fold : to develop "good" techniques and avoid "bad" ones. If the selection of "good"

techniques is to be left unavoidably open and vague, more evaluative effort and specified format should be directed towards identifying and shunning the "bad" techniques. There is considerably more agreement as to what constitute "bad" procedures and "failure to learn from past mistakes in systems design."

The evaluation format presented to the design evaluator as an aid might then include :

1. A general checklist or suggestion list of various useful techniques and options;
2. A specific checklist of errors, oversimplifications and common biases that can affect an evaluator's performance.

With a systematized design procedure, errors generally take the form of mistakes in judgment, errors which are not necessarily the fault of the evaluator himself.

1. Overloading, i.e. unrealistic output demands upon human perception and information handling capacity.
2. Fatigue
3. Multiple functions performed simultaneously
4. Monitoring without informational feedback
5. Uncontrolled ambient environment i.e. the necessity for recording or transforming under

difficult environmental conditions

6. Intellectual disparities (inadequacies)
7. Precision demands
8. Motivational, emotional, psycho-physiological operator status
9. Response incompatibility (with required visual-motor functions)

(Ellis, 1962. pp.70-72)

Specific examples of evaluative errors have been noted by Hitch (1960, 120-122; 164-174) :

1. Rigidity of the requirements approach
2. Limited use and value of priorities approach
3. Criterion errors
 - a. Maximizing gain while minimizing cost
 - b. Overlooking absolute size of gain and cost
 - c. Setting wrong size of gain and cost
 - d. Neglecting spillovers
 - e. Using wrong concepts of cost or gain
(neglect of sunk costs)
 - f. Allocation of joint costs

What would be most advantageous for the design evaluator is a general and fairly complete checklist of procedural and judgmental errors. While he will always be uncertain about the correctness of his results, he could at least feel confident that certain

common and identifiable mistakes had not been made.

A sample listing of such a generalized fallacy chart has been drawn up, based on an adaptation of an existing list of 51 fallacy types related to semantic argument (Fearnside and Holther, 1959) and is presented in Table XX.

4.8. Checking Procedures

An evaluation check team should be set up towards the end of/after the basic completion of the analysis, in order to determine whether bad techniques had been employed and where. This process could be streamlined by computer IR access to the cumulative decision record of the designers and evaluators and the assumptions they used. Of course, checks for completeness would take precedence over checks for accuracy.

A second check method is to use independent teams to describe the overall functions of the various alternative systems that were evaluated and compare them with the original basic DOT requirements.

4.9. Computer Aids

The computer system should perform the indexing and literature searching functions, and supply data to the designer in the form of various content, index, and storage options (Table XXI).

TABLE XX : Systems Design Fallacies

Material Fallacies

1. Faulty generalization
 - a. Hasty generalization
 - b. Unrepresentational generalization
 - c. Faulty causal generalization
2. Post hoc reasoning (assuming the cause)
3. Faulty analogy
4. Composition and division
5. The all-or-nothing mistake
6. The false or non-existent dilemma
7. Non-exhaustive classification
8. Non-exclusive classification
9. Unnecessary vagueness
10. Overprecision
11. Word magic and jargon

} ignored positive alternatives

Psychological Fallacies

12. Emotional coloration
13. Misusing authority
14. Self righteousness
15. Wishful thinking
16. A priori assumptions
17. Cultural bias
18. Diversions : humor, ridicule, irrelevancies

Logical Fallacies

19. Suppressed quantification (overstatement)
 20. Trouble with conditionals and alternatives
 21. Ambiguous terms
-

TABLE XXI : Types of Information Indexing & Format

*Spectrum of index/document record from simple to complete :

1. Document number and index terms or names
2. Selected specific characteristics, graphs
3. Title or brief remarks
4. Abstract
5. Abridged document
6. Full-length document

*Index format

1. Manual cards
2. Punched cards
3. Printed books
4. Magnetic tape, strips or disks
5. Digital code on film, video tape

*Document file

1. Hardcopy originals
 2. Photocopied segments
 3. Continuous microfilm
 4. Unitized microfilm
 5. Magnetic tape, strips or disks
 6. Video tape
-

CHAPTER V

Conclusions and Recommendations

The main objectives of this thesis were concentrated on synthesizing a basic methodology for setting up the evaluation of transportation system design alternatives. Common rules of logic, consistency, checklisting and functional separation and sequencing of design techniques can be applied to varying degrees of detail and flexibility. Clearly, a compatible man-machine information retrieval and manipulation procedure should be implemented to allow a greater concentration of time on value-laden decisions and evaluation and less time on checking and rechecking for proper procedures and appropriate rules for each situation.

The number of required tasks for complex designs can be partially controlled by limiting the amount of repetition of design effort. In fact, a major payoff of an organized design methodology should be a cumulative structure of knowledge and experience, far better assimilated than today's mountainous volumes of fragmentary technical reports. In the limit, the designer's task may become one of manipulating pre-analyzed and pre-evaluated subsystems for clearly specified situations, in a far less complicated and more organized manner than is currently the case.

The search for design and evaluation completeness will have many primary and spin-off effects of value, especially in the accumulation of alternative proposals. New and better alternatives will be suggested as the analysis proceeds, and thus it would be unwise to specify too many stipulated requirements on objectives and procedure, since the resulting inflexibility does not open the way to development of a more complete list of alternatives. Rather, primary emphasis should be given to limiting the mechanistic forms of human data processing and to providing checklists of the errors and fallacies of past systems design procedures.

As was explained at the beginning of this report, the research effort herein described has been mainly investigative and not authoritative. Continued analysis should be extended to practical case studies, computer applications, and development of some of the examples discussed earlier. To date, a preliminary computer program has been written by Paul Wieselmann for listing various classification tiers of concepts. The basic technique, involving a string manipulation language - SNOBOL (Farber, 1964; CTSS, 1966)- appears to be applicable, but the present program is not yet sufficient to satisfy task requirements. In sum, the next step in concepts/compatibility analysis should be computer programming consistent with designer requirements.

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APPENDIX

Sample Concepts Listing, for Vehicle : Components :
Propulsion, thus beginning at the fourth tier :

A. Multiplicity of propulsion type

1. Integral type (single propulsion type)
2. Separate type : off-guideway travel
3. Separate type : one guideway travel
 - a. High speed
 - b. Low speed
 - c. Combination
4. Separate type : intermediate travel (stations)

B. External propulsion type

1. Gravity
2. Pressure differential across vehicle
3. Cable & pulley ; moving track or belt
4. Push-pull hitch
5. Flat car (piggy-back)

C. Internal propulsion type

1. Fuel/power supply
 - a. direct supply
 - i. on-board storage
 - ii. guideway pick-off
 - b. Storage methods
 - i. concentrated
 - ii. distributed

c. Supply methods

1. fuel lines

ii. slider and electric cables

iii. roller and cables

d. Fuel type

2. Motor/drive type

a. Prime mover

1. rocket

ii. jet

iii. ramjet

iv. turbojet

v. turbofan

vi. turboprop

vii. internal combustion engine

viii. electromagnetic - rotary

ix. electromagnetic - linear

x. steam

xi. nuclear

b. Powered contact points

c. Power cut-off

i. Circuit breaker

ii. clutch mechanism

d. intermediate drive components

.

The classification scheme would continue in similar fashion.