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TRANSPORTATION RESEARCH FORUM

A Methodology for Studying High Speed Ground Transportation Systems

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ABSTRACT

Planning to relieve transportation problems—resulting from existing or projected conditions within given geographic sociological aggregates—requires the critical evaluation of techno-economically complex competitive transportation systems. In order to develop meaningful and feasible solutions to these problems, the systems being considered must be evaluated comprehensively and objectively. The policies whereby the solutions become reality are the result of complex economic and political processes. The engineering efforts which preceed or support these processes must recognize the multiplicity of alternatives which face the decision-making body. In general, a range of technical and techno-economic data must be provided in order to effectively support the policy-making process. This paper describes a methodology for developing the data which supports the planning and engineering now underway within the context of the North East Corridor program. The Methodology, has sufficient generality to apply to other regions or metropolitan areas.

1. INTRODUCTION

We are in the midst of a large scale reorientation of major engineering interests and efforts. Significant private and public engineering programs are being directed to the solution of problems rooted in and nourished by developments in the economic and political structure of our society. By what appears to be a fortunate coincidence of events engineering related disciplines have reached a stage of development that will allow them to contribute effectively to the solution of many socio-economic problems that are now, or will very soon be critical. It is well known and publicized that urban development, the large scale practice of the medical functions and transportation are among the most critical problems which require urgent solutions if social and economic growth is not to be thwarted. Of these, transportation has probably the widest impact in terms of the number and distribution of people affected at a given time. It is also one of the problems whose solution lends itself most directly to the effective application of engineering techniques.

Of course, in talking about applying engineering techniques, it is not necessary to refer to the **structure** of the transportation systems, i.e., the vehicles and the networks over which they are conveyed; these have always embodied the results of many engineering labors. The problem which confronts us today transcends, but does not ignore, what is traditionally known as transportation engineering; it centers around the identification of solutions and implementation policies to satisfy the transportation needs of large segments of society.

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The solutions which are evolved must be viable; this suggests that they have depth as well as scope. The flashy, or spectacular performance aspects of the system do not provide a broad enough base on which to formulate sound policy decisions. Short of being arbitrary in the formulation of transportation solutions, there exist some minimum requirements that the evaluation process must deal with

- The performance of the system, functioning under the requirements of potential alternatives,
- The costs associated with each alternative, including the initial investment, operating expenditures and eventual removal penalties,
- The timeliness of the solution alternatives in terms of feasible hardware deployment schedules, completion of required technology R&D, network acquisition, etc.
- The impact the solution alternatives might have on the social, economic and political elements of the society segment within which they would function.

There is, of course, an interesting conceptual problem related to the methodology which would make use of these elements in the process of evolving the small number of eventual hard core decision alternatives; some insight in this area might be gained from the companion papers presented at this meeting. The topic of this discussion however, is more directly related to the approach that can be taken in attempting to define the specifically engineering oriented elements of this list.

Briefly, then, the problem can be stated as follows:

> The evaluation of transportation systems, more specifically high speed ground transportation systems (HSGT), requires the identification of selected physical and operational system aspects. The HSGT may fulfill a regional or, possibly, a more geographically restricted need. Generally, a number of competitive HSGT systems will be available for consideration. Some of these will consist of known and tried subsystems, and will only require the application of proven technologies. Others, however, may require the use of new, or untried hardware and technologies. Since unique or optimum operating policies are difficult to postulate "a priori" the identification process will need to evaluate the systems subject to ranges of potential operational policies. Given these requirements, the problem is to devise an approach to the technological analysis which is as comprehensive as it is objective.

It will be suggested in further discussions that this approach requires the identification of optimum (or near optimum) "system states" for each of the system or operational policy alternatives under consideration. These "system states" consist, in general, of descriptions or specifications of the systems' physical characteristics, its performance parameters, the implied costs and required hardware (or technology) developmental problems.

The "system states" so defined, each at or near an optimum for given hardware and operating policy alternatives, provide the basic data on which the next level of analysis is based. More specifically, these state definitions provide the material from which the previously cited evaluation requirements for large scale costing, timeliness, scheduling and socio-economic impact are evolved.

This, then, is the object of this discussion: to present an approach for developing a methodology for the study of various HSGT systems and for evolving the associated "system states."

In order to add substance to the concepts to be reviewed reference will be made occasionally to the North East Corridor program within whose context these techniques are being applied; however, this should in no way detract from their generality.

2. STRUCTURE OF STUDY METHODOLOGY

The study of transportation systems, in this case HSGT systems, involves the interaction of three major elements: the hardware concepts, the environment within which they will ultimately operate and the guiding policy statements. It should be clear from the preceding discussion that the term "study" as used here implies mainly the set of technological and techno economic investigations required to support the broader aspects of the transportation evaluation process.

It is convenient to subdivide the study into three phases which, in a logical sequence, will lead from preliminary screening of single concepts (or a group of competitive candidate systems) to the desired identification of the optimum or near optimum "system states."

The major elements and phased structure of the study can be represented schematically as shown in Figure 1. The balance of this discussion is designed to define the meaning of and interrelations between the basic building blocks of this diagram. Each element represents subsidiary studies which, depending on the scope and ultimate objective of the basic study, can acquire major proportions. Wherever possible, illustrations of actual study details drawn for the NEC program will be given in order to add realism to the review.

2.1 Guiding Policies

The main thread running throughout the study approach presented here is provided by sets of policy statements which help orient the various study activities toward realistically attainable end goals. These policy statements serve different purposes in each study phase and within each of the two major study areas indicated in Figure 1: the hardware systems and the environment.

Although it might appear superfluous to point out what seems intentively obvious, the strong interaction between hardware transportation systems and the environment through which they move needs to be emphasized. At high speeds this interaction becomes particularly significant in shaping and even limiting the systems' performance. The environment carries, for HSGT systems, a wide connotation: it includes the terrain features, the geology, the overall climatic features as well as the more obvious urban and rural aspects commonly dealt with in slower systems. The methodology structure illustrated in Figure 1 recognizes these significant environmental influences. It also recognizes that the environment can not be dealt with in an amorphous, unstructured way. Guiding policy statements are necessary to define within each study phase the appropriate environmental parameters.

For instance, in the earliest study phase—the "Identification" portion of the diagram in Figure 1—the policy statement may simply identify the network alternatives against which the systems would be sized. The complexity of the policy specification increases in later study phases. In the "System Definition" portion of the diagram in Figure 1 policy statements are required to define specific and possibly elaborate networks, terminals, etc.

Policy guidelines play an equally significant role in shaping the specific hardware analysis. In this context they are the basis of various system and subsystem specifications (as shown in the "Indentification" phase); in the later stages they are the basis of various system operating policy alternatives.

2.2 The Environment

High performance ground transportation systems must be atuned to the environmental constraints to a historically unprecedented degree. No longer is it possible to design the systems in the traditional engineering way e.g. matching energy, guidance and control requirements to desired vehicle capacities and network operational policies. The higher speeds and the sometimes overriding economic considerations require the systems to be, in addition, totally responsive to the environmental constraints. From the structural/dynamic design of the suspension system, which match the guideway terrain induced response, to the new vehicular areodynamic shapes the systems reflect the specific characteristics of the environment. The environmental constraints are unequivocal. Terrain topography, geology, hydrology, climate, atmospheric characteristics, etc. are precisely defined as soon as networks and routes are identified. For this reason it seems appropriate to designate the environmental effects as "objective constraints." This designation helps to differentiate them from the subjective or policy dictated constraints such as the permissible noise and atmospheric pollution levels, the acceleration limitations, etc.

Figure 2 is an illustration of major terrain features in the general region of the NEC. It is not difficult to perceive that fundamental system modifications are entailed as a result of operation in each of the major land forms which define the region.

2.3 Hardware Systems

In the broadest sense a transportation hardware systems comprises the totality of subsystems and elements of subsystems which are necessary to fully describe its performance.

Each of the subsystems consists of aggregates of secondary subsystems. This can be illustrated with the following examples:

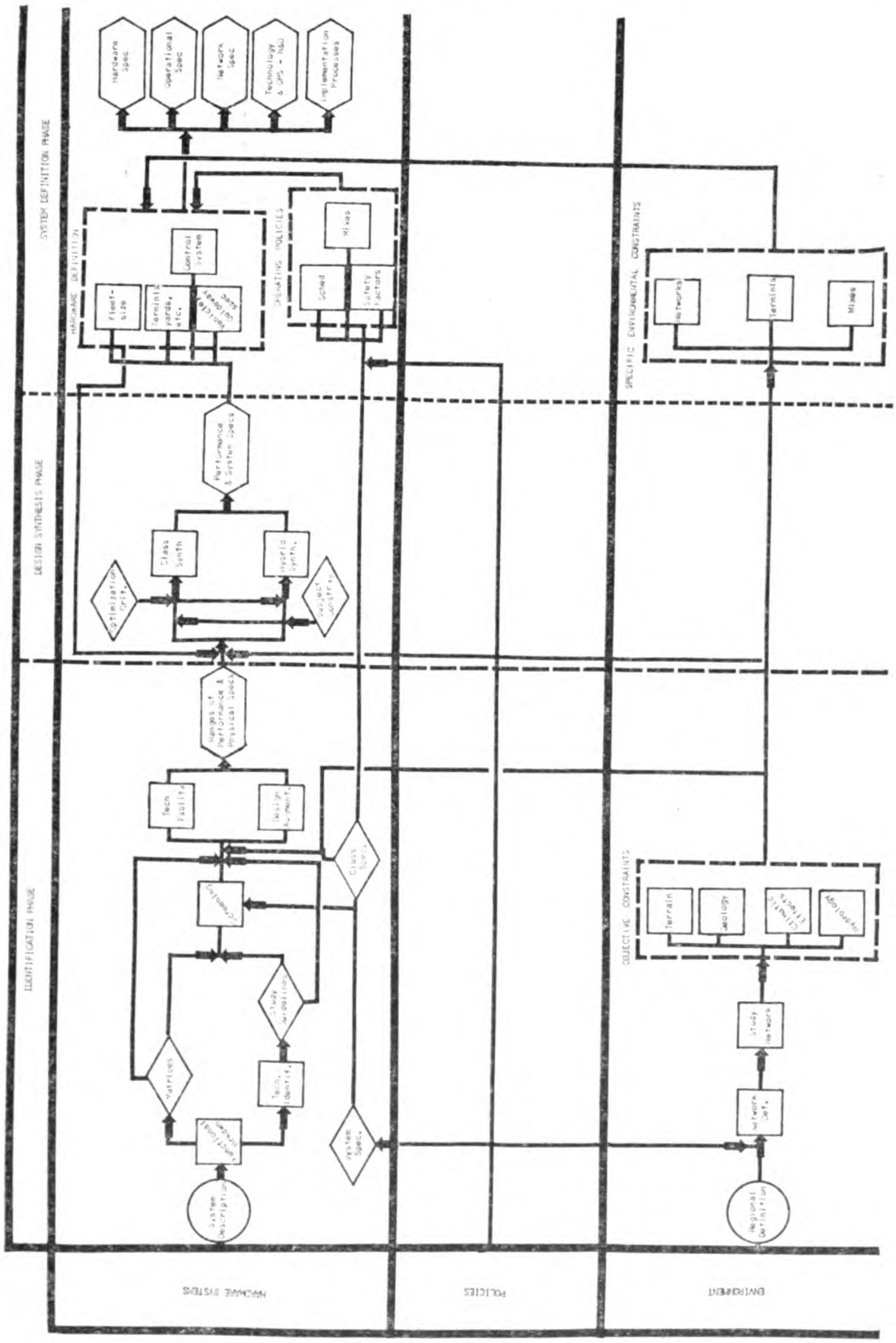

FIGURE 1
Schematic of HSGT Study Methodology

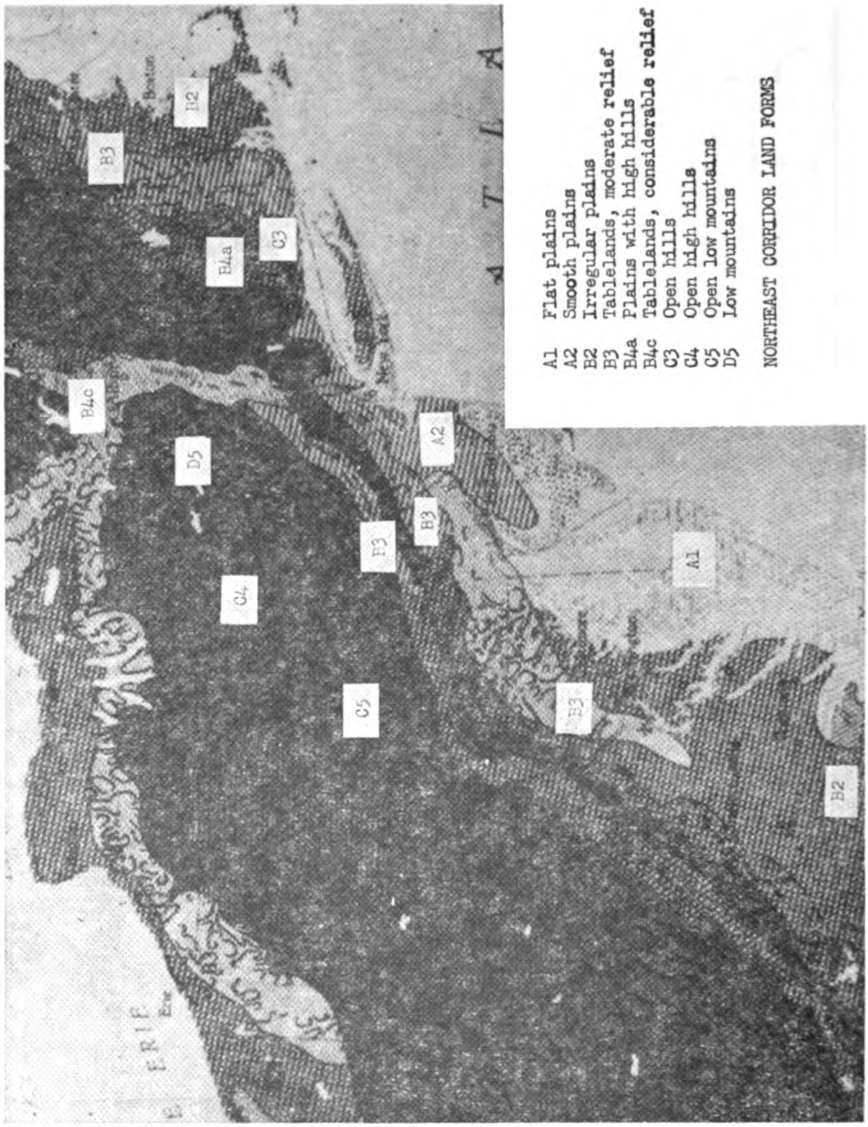
A1 Flat plains
A2 Smooth plains
B2 Irregular plains
B3 Tablelands, moderate relief
B4a Plains with high hills
B4c Tablelands, considerable relief
C3 Open hills
C4 Open high hills
C5 Open low mountains
D5 Low mountains
NORTHEAST CORRIDOR LAND FORMS
ERIE

FIGURE 2

VEHICLE SUBSYSTEM		
– STRUCTURAL	SECONDARY	SUBSYSTEM
– SUSPENSION	"	"
– BRAKING	"	"
– POWER PLANT	"	"
– ENVIRONMENTAL CONTROL	"	"
– CONTROL	"	"
– COMMUNICATION	"	"

GUIDEWAY SUBSYSTEM		
– STRUCTURAL	SECONDARY	SUBSYSTEM
– ENERGY TRANSFER	"	"
– COMMUNICATIONS	"	"
– CONTROL	"	"
– SWITCHING	"	"

Finer breakdowns are possible and necessary for purposes of meaningful analyses. This can be illustrated as follows:

POWER PLANT SECONDARY SUBSYSTEM	
– PRIME MOVER	SEGMENT
– CONVERTER	"
– TRANSMISSION	"
– FUEL STORAGE & UTILIZATION	"
– CONTROLS	"

The purpose of the breakdowns of ever increasing complexity is to identify to a necessary degree of detail the technological elements, their functions, interrelations and interfaces with the environment. Meaningful descriptions of system performance and breakdowns must be founded on the identification of all component parts and their functional interactions.

The discussion of hardware systems is further aided by a classification of like systems into representative classes. While it is not possible to define a unique classification scheme which serves all possible analytical needs, the transportation system categories shown below represent a reasonable and workable approach.

PROPOSED

CLASSIFICATION

OF

HSGT SYSTEMS

RATIONALE:—*				CLASS. NAME	CLASS. DESCRIPTOR
CONTINUOUS CAPACITY		° Any System which employs an essentially continuous and unbroken succession of capacity;—classical example is that of a moving belt.		Continuous Capacity System	CCS
BATCH CAPACITY	DOOR TO DOOR	° Automation of convention highways and vehicles.		Automated Highway Systems	AHS
		° Multi-modal vehicles using separate and new automated guideways for intercity portion of trip.		Multi-modal Systems	MMS
		° Passenger carrying vehicle is ferried on intercity portion of trip.		Auto-Ferry Systems	AFS
	STATION TO STATION	° Guideway Enclosure	° Guidance & Support		
		Dependent	Contract and/or Generated	Tube-Inherent Systems	TIS
		Independent	Rolling/Sliding Contract	Rolling Sliding Systems	RSS
		Independent	Generated	Tracked Levitated Systems	TLS

* Any specific system is to be classified in the applicable class nearest the top of the table.

In the study of transportation systems, the identification of system and subsystem commonalities provides a valuable analytical tool: the drafting and interpretation of system and subsystem performance specifications is facilitated and proper emphasis can be given to the analysis of each system's original or unique features. The similarity of system functions and/or constraints in each category also helps to quickly identify otherwise nonobvious potential subsystem commonalities which render viable, maximize, or improve the performance of incompletely defined concepts of transportation.

2.4 Study Phases

A logical study structure is presented in Figure 1. It consists of three major phases. The functions of the first phase, designated here as "Identification" are twofold: to reduce the analysis only to the meaningfully appropriate systems for the desired purpose (in this case, high speed ground transportation in the NEC), and, for this restricted group of systems to generate the engineering performance data necessary to fully evaluate their capabilities.

The purpose of the second phase, designated here as "Design Synthesis," is to identify preliminary, and to some extent generalized, preferred states for the system(s) under review. Since, in general, several diverse and competitive concepts will be under investigation, the technological analytical efforts carry the responsibility of determining the systems' capabilities (and limitations) with objectivity and under a common set of ground rules. The identification of preferred systems states, i.e. optimum or near optimum, provides the means for achieving the desired objectivity and ground rule commonality.

The optimization must, of course, be carried out with respect to objective criteria such as the various aspects of system cost. Other objective criteria can be found in various aspects of passenger physical response to the systems' performance or in the systems' effects on the surrounding environment. In most cases the chosen optimizing criteria is interchangeable with any of the other possible choices which appear in the analysis as constraints when not used in the first role. For instance, it is possible to seek the minimum cost system configuration subject to constraints (among others) of maximum level of pollutants discharged into the atmosphere. Conversely, the minimum pollution configuration may be desired subject (among others) to cost constraints. In either case parametric optimization analysis provides an objective description of the system performance under ideal optimum or near optimum conditions.

The complete technological evaluation of the systems requires, in final analysis, a rather detailed understanding of the system-environment interrelations, (in this context the environment carries the more complex connotations associated with specific networks, terminals, demand factors and operational policies). Since a complete optimization study, taking these factors into account, would impose great analytical difficulties analysis in the "Design Synthesis" phase uses generalized descriptions of the environment which are, at best, only statistically representative of actual conditions likely to be encountered along the routes and within the networks. It is left to the third study phase, the "System Definition" to interpret these results in terms of the more precise network requirements. Obviously some iteration between the last two study phases is to be anticipated. This, however, is no different from usual solutions to complex engineering and mathematical problems.

3. THE "IDENTIFICATION" PHASE

The study, in this phase, is characterized by screening and technological analysis functions. The basic inputs are descriptions of single or groups of systems. These descriptions will, in general, vary in complexity and the degree of engineering data detail. The basic analysis relies on two major derivatives of the policy guidelines: the definition of objective constraints, and the system and subsystem specifications.

3.1 Objective Constraints

The objective constraints consist of a set of data which define the significant environmental constraints associated with a chosen network. It is not important, at this point in the study, to accurately define the networks in their fullest detail. Preliminary estimates however, made with some insight into the eventual network configurations are helpful. Added advantages are gained if the preliminary routes can be chosen to be, in addition, statistically representative of the final environmental configurations.

The significance of the statistical representation of terrain features lies in the associated distribution of major land forms over the chosen route. (See Figure 2) The systems' performance and costs (both initial investments as well as operational) will depend in great measure on the curves, grades, tunnels and other major engineering structures encountered along the route. For a given system, passenger comfort requirements, safety or costs will limit the maximum tolerable speed associated with the dynamic and aerodynamic forces imparted to the vehicle by the guideway structure and configuration. Obviously, there exist advantageous combinations of guideway configurations, as dictated by prevailing terrain features, and hardware assemblies designed to meet the terrain constraints. It is for this reason that the systems analysis which adequately weigh the merits of one hardware configuration versus another need to be carried out within realistic environmental constraints.

3.2 Systems Specifications

The second important policy guidelines derivative are the specifications for the overall systems and their associated subsystems. These documents translate into commonly accepted engineering guidelines the gross objectives of the desired transportation solution. In the case of the HSGT study for the NEC the predominant objectives include, among others, requirements for low door to door time, predictability of arrival time, system and service flexibility, etc. The systems specification stipulates design and performance objectives for the system considered and, in turn, provides guidelines for the formulation of more detailed specifications.

In order to provide a common baseline for initial system screening a specification document may define gross guidelines for evaluating the door-to-door capabilities of various competitive concepts. This is illustrated in Figure 3 by a set of curves defining acceptable, marginal and unacceptable travel times expressed in terms of trip distance. These curves were constructed statistically using known or projected travel time data for competitive systems and arbitrary assumptions of interurban travel time. It should be emphasized that the curves do not represent actual conditions; they are, simply, arbitrarily

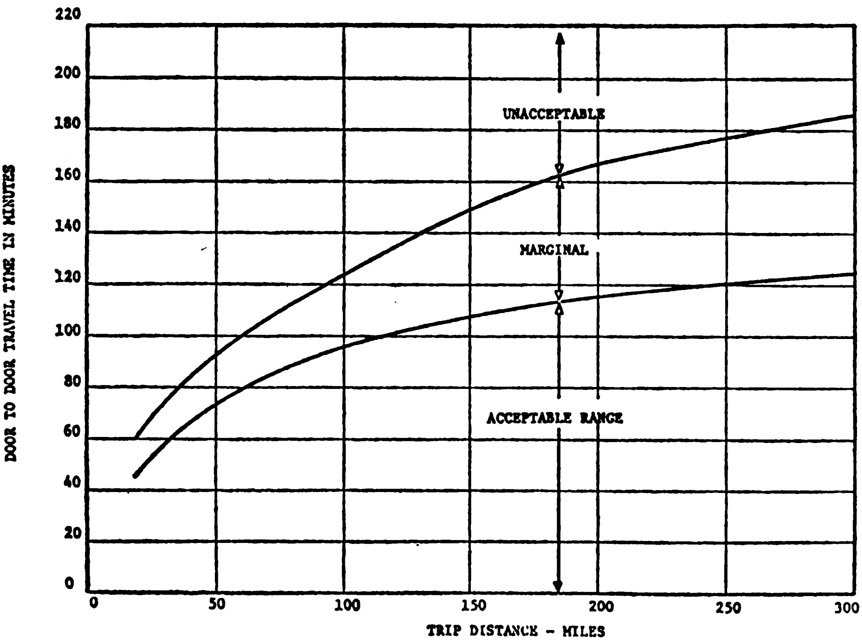

FIGURE 3
HSGT Door to Door Travel Time Requirements

derived guidelines to permit simultaneous and objective evaluation of systems of diverse station-to-station and door-to-door capabilities.

In addition, the specification document can, and should, define basic system safety goals, goals for various facets of the passenger comfort problem, (e.g. acceleration and vibration levels), system schedule predictability, terminal interfaces, etc.

The systems specification document plays a major role in orienting the initial screening process. This has as its objective the early identification of only those systems which show a distinct potential for their intended purpose, e.g. HSGT in this discussion. For obvious reasons, the screening process requires, that the basic system engineering data be systematically organized. This organization is enhanced by the use of gross system descriptive matrices and study guidelines.

3.3 System Matrices

System matrices may be constructed to any desired degree of detail with the complexities of subsystem breakdown described in Paragraph 2.3. An example of a preliminary descriptive matrix showing typical subsystems for representative systems in each of the major classes is shown in Figure 4. It is quite obvious that when these matrices are properly constructed they present at a glance the unique and common features of the competing systems. Moreover, they are equally effective in suggesting the gaps in engineering data which need to be filled before meaningful system evaluations can be made.

CLASS	SPECIFIC CONCEPT	GUIDEWAY			VEHICLE				ENERGY		
		STRUCTURE	TRACK	OTHER	STRUCTURE	SUSPENSION	PROPULSION	OTHER	SOURCE	DISTRIBUTION	OTHER
CCS CONTINUOUS CAPACITY SYSTEMS	⋮ TEX-TRAIN ⋮			WAYSIDE MOTORS	NO SIDES OR CEILING		FRICTION DRIVE				
MMS MULTI-MODAL SYSTEMS	⋮ STARRCAR ⋮	HALF TUNNEL	SLOT						BATTERY AND THIRD RAIL		
AFS AUTO FERRY SYSTEMS	⋮ RROLLWAY ⋮		WIDE GAGE	HI SPEED SWITCH		FLANGELESS WHEELS		GUIDANCE BY VERT. AXIS WHL'S. ONE SIDE ONLY			
TIS TUBE INHERENT SYSTEMS	⋮ GVT ⋮	DOUBLE TUBE CROSS VALVES		GUIDEWAY SPRING SUSPENDED			PNEUMATIC PLUS GRAVITY				
RSS ROLLING/ SLIDING SYSTEMS	⋮ UNITED AIRCRAFT ⋮				AIRCRAFT TYPE	GUIDED AXLE CG TRANSLATION	GAS TURBINE MECHANICAL DRIVE				
TLS TRACKED LEVITATED SYSTEMS	⋮ AEROTRAIN ⋮		INVERTED "T"			FLEX. SKIRT OPEN PLENUM		PROPELLOR			

FIGURE 4
Matrix of Unique Features of HSGT Concepts

3.4 Study Guidelines

The preformance of HSGT systems involves the simultaneous operation of diverse components fulfilling various functional roles which interact with one another and the external environmental constraints. The analysis, likewise, must address itself to an evaluation of a number of interacting technologies and must employ the data and techniques peculiar to many related disciplines. The analytical task, associated with each separate study, can be sharply delineated against the backdrop of specific study guidelines drafted to cover the needs of the various transportation classes. An example of a study guideline derived for the "Tube Inherent Systems" is shown in Figure 5. Systems falling in this class depend exclusively, for their performance, on operation within a tube. Generally, these systems are gas dynamic and/or gravity actuated. The study guideline in Figure 5 covers the vehicle and guideway subsystems only and it suggests a logical program to derive performance data for the significant secondary vehicle and guideway subsystems and their associated subsystem segments.

The technological analysis functions characteristic of this study phase involve studies of technical feasibility (or performance and physical definition) and studies of design augmentation. Both are oriented by the previously discussed study guidelines but the former apply to the subsystem originally and sufficiently identified in the initial concept description. The latter however, refer to the subsystems which were omitted in the original description, (see Figure 4), or were incompletely defined.

Both, the feasibility and the design augmentation studies rely heavily on the availability of detailed performance specifications. These can be defined separately for each major subsystem or, as is done in the HSGT study, as part of a larger class specification.

3.5 Class Specifications

The class specifications describe requirements to be met by a given category of transportation systems and stipulate the physical and performance characteristics of the various subsystems which must be developed in order to support the subsequent study evaluations. These specifications are, in general, consistent with the system specifications, Paragraph 3.2, and, as a consequence, reflect the same major transportation solution objectives. Quantification of parameters with emphasis on the class description, or class peculiar group is, however, far more extensive in this document. An example of the level of detail required to specify the physical and performance characteristics of the system is shown in Figure 6. This is only the list of parameters, each of which is elaborated in greater detail in the body of the specification. The particular list shown here represents the scope of the specifications developed for the class of multi-modal systems.

4. THE "DESIGN SYNTHESIS" PHASE

The studies carried out in the "Identification" phase define ranges of performance and physical characteristics associated with the various subsystems of the given transportation concept(s). Considering, for the moment a hy-

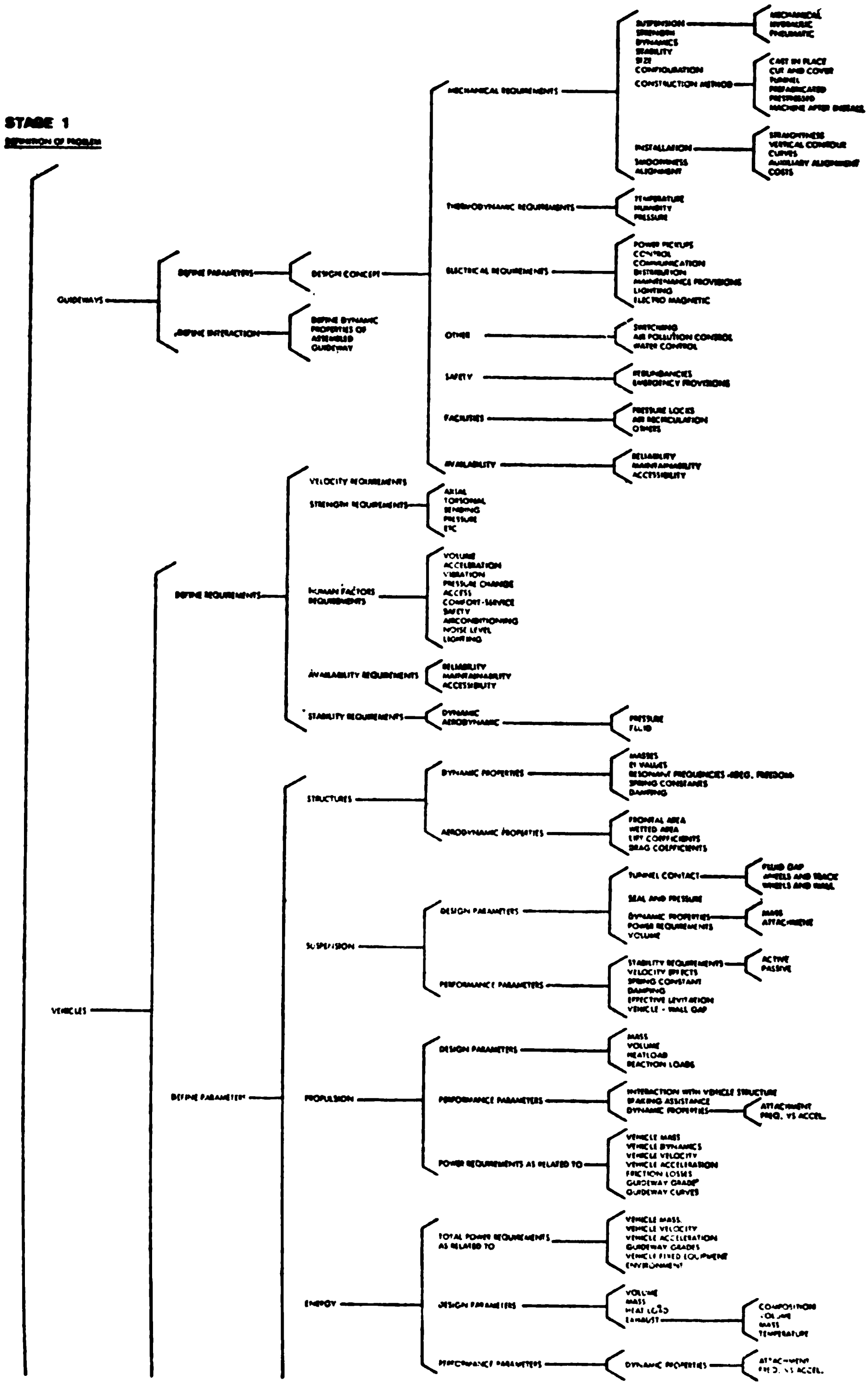

FIGURE 5
Typical Study Guide - Inherent Systems

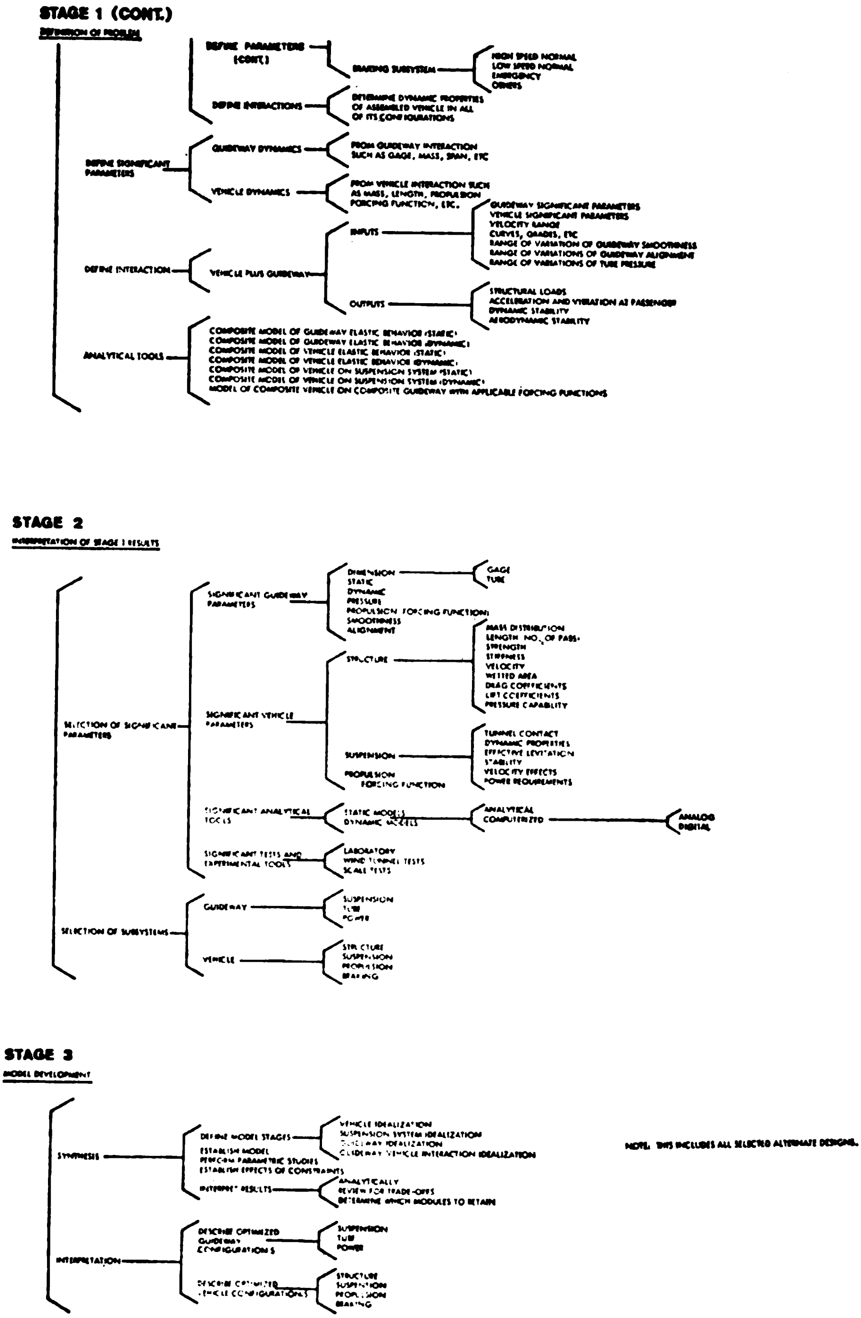
STAGE 1 (CONT.)
DEFINITION OF PROBLEM
DEFINE PARAMETERS (CONT.)
BRAKING SUBSYSTEM
HIGH SPEED NORMAL
LOW SPEED NORMAL
EMERGENCY
OTHERS
DEFINE INTERACTIONS
DETERMINE DYNAMIC PROPERTIES OF ASSEMBLED VEHICLE IN ALL OF ITS CONFIGURATIONS
DEFINE SIGNIFICANT PARAMETERS
GUIDEWAY DYNAMICS
FROM GUIDEWAY INTERACTION SUCH AS GAGE, MASS, SPAN, ETC
VEHICLE DYNAMICS
FROM VEHICLE INTERACTION SUCH AS MASS, LENGTH, PROPULSION FORCING FUNCTION, ETC.
DEFINE INTERACTION
VEHICLE PLUS GUIDEWAY
INPUTS
GUIDEWAY SIGNIFICANT PARAMETERS
VEHICLE SIGNIFICANT PARAMETERS
VELOCITY RANGE
CURVES, GRADES, ETC
RANGE OF VARIATION OF GUIDEWAY SMOOTHNESS
RANGE OF VARIATIONS OF GUIDEWAY ALIGNMENT
RANGE OF VARIATIONS OF TUBE PRESSURE
OUTPUTS
STRUCTURAL LOADS
ACCELERATION AND VIBRATION AT PASSENGER
DYNAMIC STABILITY
AERODYNAMIC STABILITY
ANALYTICAL TOOLS
COMPOSITE MODEL OF GUIDEWAY ELASTIC BEHAVIOR (STATIC)
COMPOSITE MODEL OF GUIDEWAY ELASTIC BEHAVIOR (DYNAMIC)
COMPOSITE MODEL OF VEHICLE ELASTIC BEHAVIOR (STATIC)
COMPOSITE MODEL OF VEHICLE ELASTIC BEHAVIOR (DYNAMIC)
COMPOSITE MODEL OF VEHICLE ON SUSPENSION SYSTEM (STATIC)
COMPOSITE MODEL OF VEHICLE ON SUSPENSION SYSTEM (DYNAMIC)
MODEL OF COMPOSITE VEHICLE ON COMPOSITE GUIDEWAY WITH APPLICABLE FORCING FUNCTIONS
STAGE 2
INTERPRETATION OF STAGE 1 RESULTS
SELECTION OF SIGNIFICANT PARAMETERS
SIGNIFICANT GUIDEWAY PARAMETERS
DIMENSION
GAGE
TUBE
STATIC
DYNAMIC
PRESSURE
PROPULSION (FORCING FUNCTION)
SMOOTHNESS
ALIGNMENT
SIGNIFICANT VEHICLE PARAMETERS
STRUCTURE
MASS DISTRIBUTION
LENGTH (NO. OF PASS.)
STRENGTH
STIFFNESS
VELOCITY
WETTED AREA
DRAG COEFFICIENTS
LIFT COEFFICIENTS
PRESSURE CAPABILITY
SUSPENSION
TUNNEL CONTACT
DYNAMIC PROPERTIES
EFFECTIVE LEVITATION
STABILITY
VELOCITY EFFECTS
POWER REQUIREMENTS
PROPULSION FORCING FUNCTION
SIGNIFICANT ANALYTICAL TOOLS
STATIC MODELS
DYNAMIC MODELS
ANALYTICAL
COMPUTERIZED
ANALOG
DIGITAL
SIGNIFICANT TESTS AND EXPERIMENTAL TOOLS
LABORATORY
WIND TUNNEL TESTS
SCALE TESTS
SELECTION OF SUBSYSTEMS
GUIDEWAY
SUSPENSION
TUBE
POWER
VEHICLE
STRUCTURE
SUSPENSION
PROPULSION
BRAKING
STAGE 3
MODEL DEVELOPMENT
SYNTHESIS
DEFINE MODEL STAGES
VEHICLE IDEALIZATION
SUSPENSION SYSTEM IDEALIZATION
GUIDEWAY IDEALIZATION
GUIDEWAY VEHICLE INTERACTION IDEALIZATION
ESTABLISH MODEL
PERFORM PARAMETRIC STUDIES
ESTABLISH EFFECTS OF CONSTRAINTS
INTERPRET RESULTS
ANALYTICALLY
REVIEW FOR TRADE-OFFS
DETERMINE WHICH MODULES TO RETAIN
INTERPRETATION
DESCRIBE OPTIMIZED GUIDEWAY CONFIGURATIONS
SUSPENSION
TUBE
POWER
DESCRIBE OPTIMIZED VEHICLE CONFIGURATIONS
STRUCTURE
SUSPENSION
PROPULSION
BRAKING
NOTE: THIS INCLUDES ALL SELECTED ALTERNATE DESIGNS.

FIGURE 5

PRELIMINARY MULTI-MODAL CLASS DESIGN OBJECTIVES AND REQUIREMENTS SPECIFICATION

Second Tier System Requirements

1. VEHICLE
1.1 Configuration
1.2 Aerodynamics
1.3 Dynamics
1.4 Structure
1.5 Propulsion
1.6 Suspension
1.7 Auxiliary Power
1.8 Vehicle Communications
1.9 Vehicle Command and Control
1.10 Braking
1.11 Switching and Transfer
1.12 Environmental Control

2. GUIDEWAY
2.1 Configuration
2.2 Aerodynamics
2.3 Dynamics
2.4 Structure
2.5 Energy Distribution
2.6 Communications Distribution
2.7 Command and Control (Provisions for those functions which guideway must accommodate)
2.9 Environmental Control

3. ENERGY SYSTEM
3.1 Vehicle Supply
3.2 Guideway
3.3 Terminals
3.4 Communications and Control
3.5 Support Facilities
3.6 Emergency Requirements

4. TERMINALS
4.1 Configuration
4.2 Functions and Services
4.3 Location
4.4 Switching and Transfer

5. SYSTEM COMMUNICATIONS AND CONTROL
5.1 Control Policies
5.2 Vehicle Monitor
5.3 Guideway Monitor
5.4 Communications
5.5 Computational System
5.6 Command Implementation
5.7 System Operation

6. SUPPORT SYSTEM
6.1 Maintenance
6.2 Administration
6.3 Operations
6.4 Logistics
6.5 Personnel

7. SYSTEM INTEGRATION
7.1 Vehicles
7.2 Guideway
7.3 Terminals
7.4 Communication & Control
7.5 Energy
7.6 Support
7.7 Network

FIGURE 6

draulic motor as a typical subsystem these outputs might take the form of equations, or diagrams depicting.

horsepower delivered	vs	rpm
fluid pressure	vs	torque
motor weight	vs	horsepower
Motor efficiency	vs	motor construction details

tankage and piping requirements, etc.

It is the primary mission of the "Design Synthesis" study phase to use blocks of similar data derived for the aggregate of subsystems to define optimum component matches.

This process requires, first, the identification of suitable objective optimization criteria, i.e. criteria which would not favor one system over another. Obviously, it would be of little consequence to optimize both an aircushion and a high speed rail on the basis of a criterion which minimizes the system costs associated with providing levitation. On the other hand, a criterion which minimizes the cost incurred in isolating the passenger compartment from excessive vibration would provide meaningful system comparisons particularly if speeds and route imposed constraints on the guideway were similar in both cases.

4.2 Optimization Constraints

The optimization study requires, in addition, the specification of meaningful and realistic constraints. The objective (or route dependent) constraints would define the real world limitations within which the systems operate. These constraints are supplemented by specifications of system operational limitations which are based, generally, on physiological, psychological or political considerations. The second group of limitations can be designated as subjective constraints. Although they do not always include human factors considerations e.g. vibration or noise tolerable levels, they do reflect, as a whole, subjective or policy requirements. Minimum headway between vehicles or maximum station waiting times, two typical subjective constraints, in final analysis, reflect individual opinions on the tolerable levels of safety or personal annoyances.

4.3 Optimization Procedure

This optimization process is basically, little more than the systematic, mathematically oriented, traditional engineering tradeoff study. Recognizing this should provide a sufficient warning to the too strongly oriented computer applications analyst. The mechanized and computerized optimization study cannot, at this stage of mathematical and engineering sophistication, fully replace the sound engineering judgement founded in the broad and diversified experience of the industry. It can provide however, significant, and from the standpoint of complex system analysis, invaluable insight into the system's behavior. It does this by its ability to handle simultaneously large numbers of quantitative relationships and by providing a more reasonable indication of a system's correct optimum state than is possible to obtain with ordinary tradeoff analysis.

The optimization approach can be best described through a typical example. The problem is to define optimum states for a tracked air cushion vehicle/ guideway configuration as suggested by Figure 7. The optimizing criterion for this example is the total system cost. The constraints include trip time service frequency, passenger demand and allowable RMS vertical acceleration. A schematic of the computer program logic is shown in Figure 8. Performance, subsystem interactions, basic engineering and costing relationships are stated in equation form and then programed in the respective modules shown in Figure 8. Further details of one single item of this Figure, mainly the suspension subsystem block, are shown in Figure 9. Finally, as an indication of possible solutions obtainable with this technique Figure 10 illustrates the minimum passenger trip costs associated with system optimized according to various travel time constraints. For each optimum system state the program generates a complete specification of subsystem performance. This is illustrated in Figure 11 which presents the variations in pad area and volumetric flow rates associated with the same optimum system states shown in Figure 10.

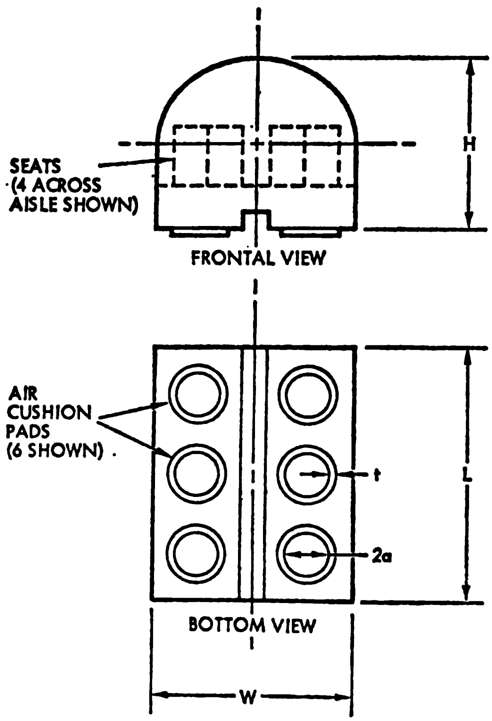

FIGURE 7
Assumed Vehicle Configuration

5. "SYSTEM DEFINITION" PHASE

In the first two study phases the system(s) were screened, technically analyzed, and synthesized in optimum, or near optimum configurations. For simplicity, these efforts were confined to generalized descriptions of the networks, systems and service requirements. In the last study phase the results of the previous analyses are interpreted in terms of realistic environmental and operating policy considerations.

5.1 Environmental Constraints

The eventual selection of a transportation system requires that numerous alternative operating modes be considered in order to establish preferred funding and service policies.

Service considerations require, among other factors which will be reviewed shortly, that various network alternatives be examined. This requires that single system and system mix networks be identified in order to define comprehensively the service qualities of the given systems. These alternatives will affect the estimated demand loads since they will examine the effects of changes in cost, travel time and passenger convenience associated with travel time between any two points serviced by the network.

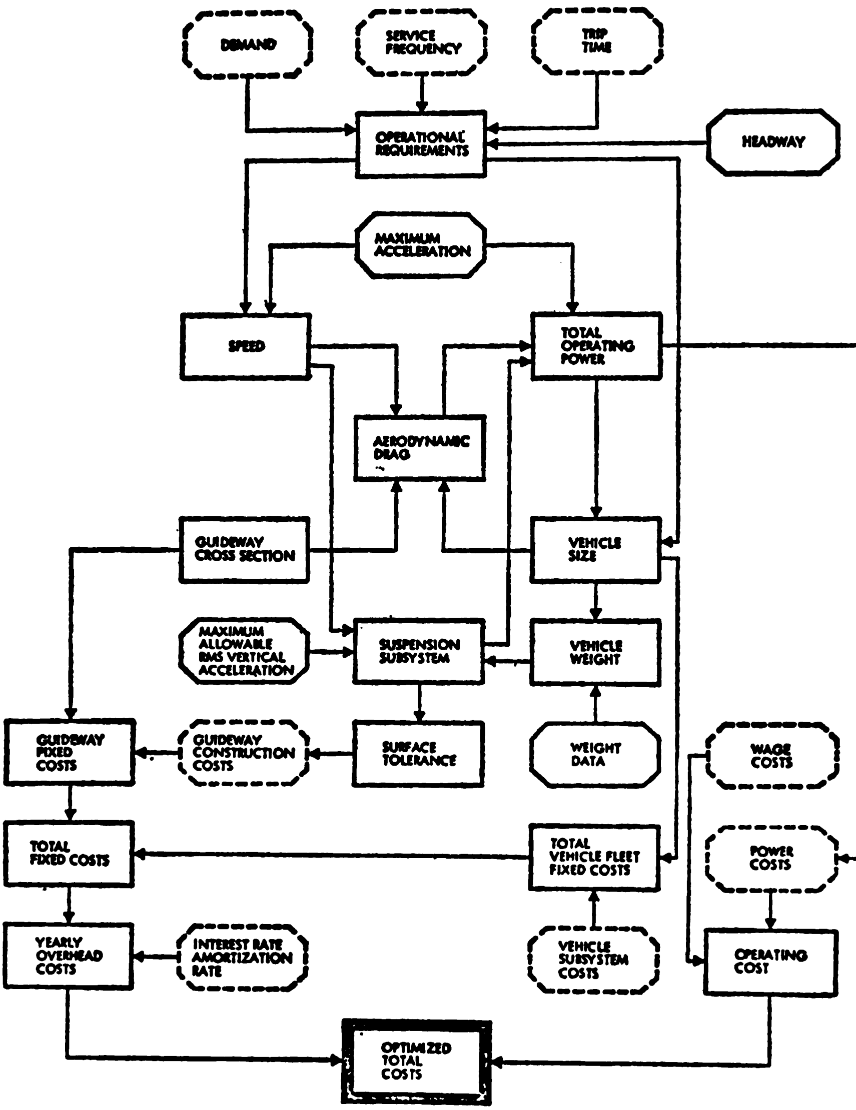

FIGURE 8
Transop Optimization Problem Block Diagram

The network alternatives could also result in system design or performance changes if the specific routing should impose unusual requirements on the hardware configurations. Incidentally, this suggests the importance of dealing with statistically representative networks in the early study phases.

The network alternatives, whether for single or mixed systems, will, obviously, have a significant impact on the control and communications subsys-

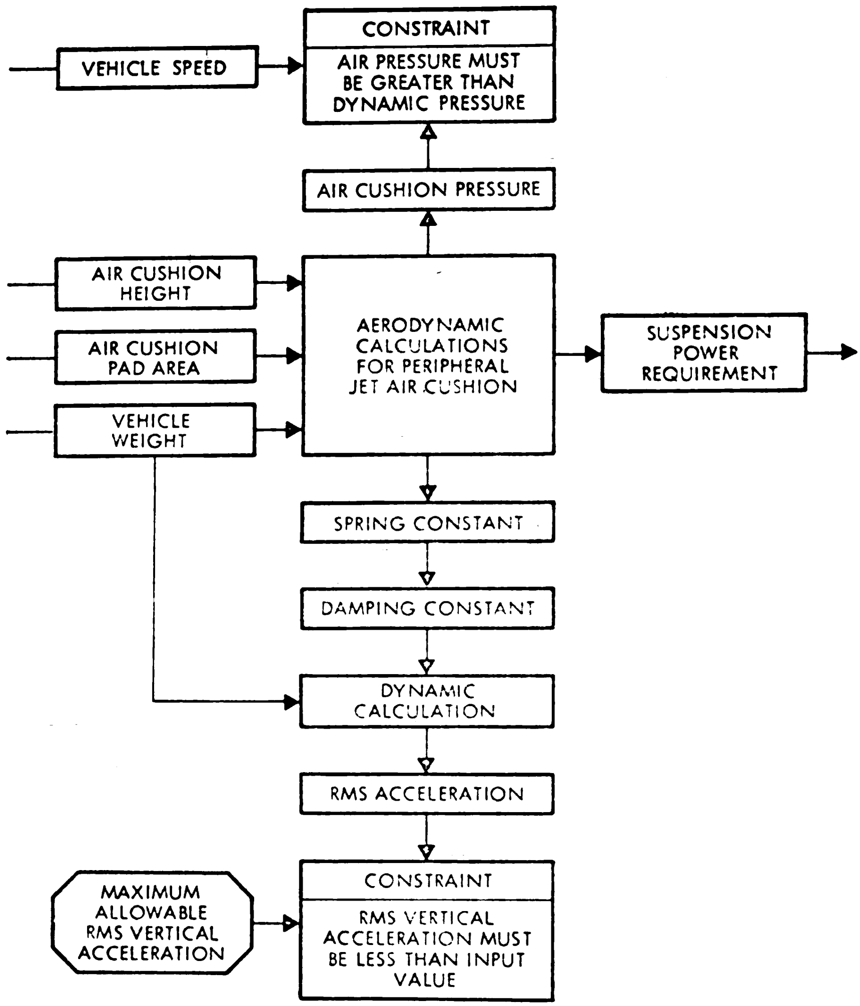

FIGURE 9
Suspension System Block Diagram

tems. They will further affect the overall system performance and schedule adherence capabilities through the impact on terminals location (and interfaces with the other regional transportation modes) and the complexities of the required service and maintenance facilities.

In final analysis each network alternative will, to a certain extent, affect the implementation schedule through the effects it would have on the system hardware demonstration public acceptability and certification processes. It can also be argued that the obsolescence and system removal costs (and/or policies) will reflect the network alternative chosen years earlier.

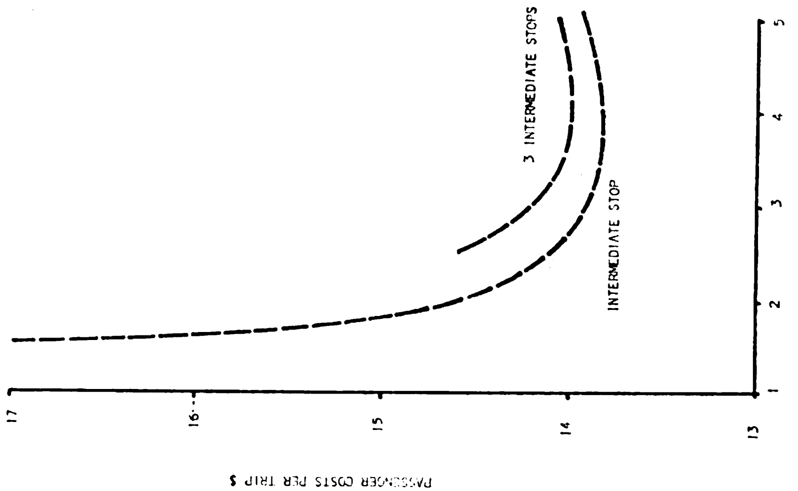

FIGURE 10
Optimization Problem Results

5.2 Operating Constraints

There are sets of operating policy alternatives associated with the various network alternatives just described, whose effects on given systems needs evaluation. They are just as likely to have a major impact on the selection process and hardware configurations as the former network alternatives. They include scheduling policies, ranging from the simple uniform schedule, through the common, fixed but peak load/seasonal sensitive type, to the sophisticated demand adaptive variations. Other operating policy alternatives apply to definitions of acceptable system safety factors, comfort and convenience levels, effects on the surrounding environment (such as the alternative of an enclosed and buried guideway in order to eliminate danger and nuisance to the adjoining communities, etc.

5.3 Study Results

The analysis of the system response to the environmental and operating constraints will result in system definitions for sufficiently wide ranges of alternatives to permit meaningful decision-making conclusions to be drawn. Whether or not the examination of network and operating policies requires iterative hardware system analysis depends on the degree of detail and representativeness of the assumptions used in the two earlier study phases. Presumably, practical limitations in the early analysis will require that some iterative evaluations be always required.

Within these constraint ranges the ranges the results of the combined efforts of all study phases should, however, provide a picture as complete as possible of the systems' characteristics. This should include not only the typical hardware and operational specification items shown in Figure 6 but also realistic estimates of:

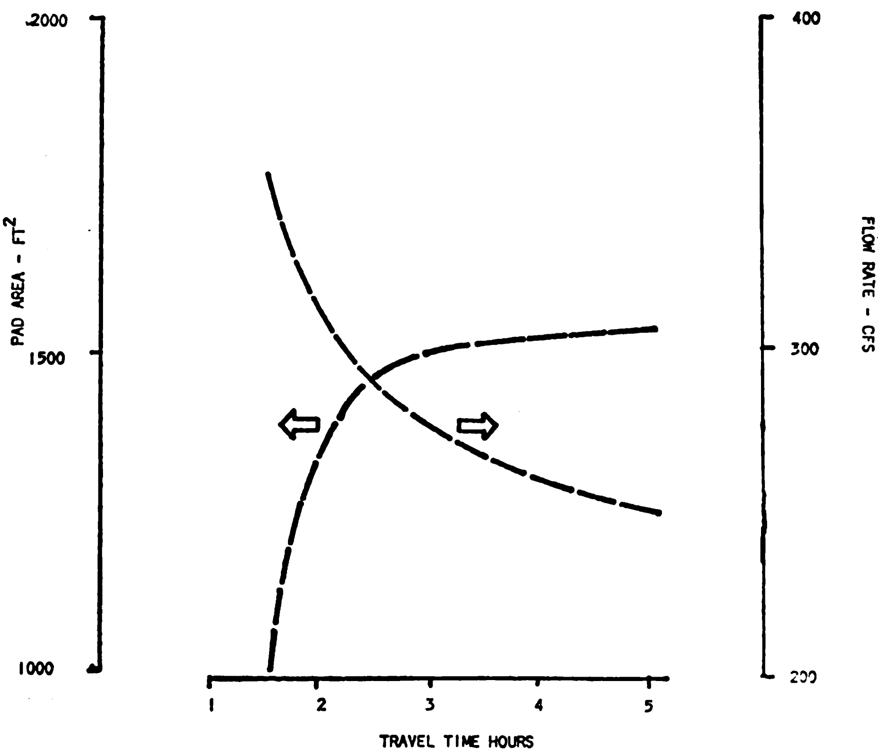

FIGURE 11
Organization Problem — Engineering Outputs

- Technology and operations R&D (including costs, projections and risk estimates),
- Implementation processes including hardware and passenger acceptability demonstrations, and
- For the truly novel systems, the hardware and system operation certification processes necessary to insure the systems' adherence to standards as well as the maximum protection to the public and private sectors.