Principles of Transport Systems Analysis

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Nine principles for the analysis of transportation systems are presented. The primary purpose of these principles is to identify the common threads underlying a great variety of seemingly disparate transportation problems, and so to stimulate the development of a "transportation science." The principles are equally applicable to urban transportation, megalopolitan transportation, developing country transportation, and strategic mobility.

The first five principles pertain to the scope of the system—the components of a transportation system, the modes and movements in a system which must be considered, and the nature of a transportation system as a particular form of "market." The second group of four principles pertains to the problems of analysis—the spectrum of potentially available transportation and non-transportation options, the objectives of transportation, and the relevant impacts.

To illustrate these principles, the paper concludes with a discussion of their application to two specific problems, urban transportation and strategic mobility.

•THE purpose of this paper is to present for discussion a set of principles for transport systems analysis. The accumulated experience of analysts, planners, and researchers working on many different transportation problems has yielded observations and insights which are applicable to a large number of such problems. These insights lead to new ways of looking at transportation systems problems. The principles proposed here have been developed in an attempt to summarize these insights and emphasize their generality.

The primary purpose of the principles is to identify the common threads underlying a great variety of seemingly disparate transportation problems, and so to stimulate the development of a "transportation science." A secondary purpose is normative—it is hoped that the principles will be useful as guidelines for analysis and will serve as a checklist for preventing the simplest yet most grievous analysis errors. However, like all generalities, these principles cannot be more than tests and guides; the realities of analysis are such that the analyst will always need to judge for himself what approximations and compromises may be necessary in the context of a specific problem. The principles can never be adhered to rigidly, but are objectives of analysis; whenever they are deliberately violated, the analyst should clearly so state.

The principles presented here should be considered tentative. Of course, they reflect the biases and experiences of the author. Through wide discussion and through testing against new transportation problems, they will be refined and amplified over time.

The principles themselves fall into two major groups. The first set, Principles I through V, identifies the system of concern—what must be incorporated in an analysis of a transportation system, and what significant interactions within that system must be considered. The second set, Principles VI through IX, considers the problem of analysis—what options or alternatives are potentially open to the analyst, and what factors must be considered in reaching a decision. The principles are summarized in Figure 1.

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GROUP A. THE SYSTEM

Principle I. The basic components of a transportation system are:
a. the persons and things being transported;
b. the vehicles in which they are conveyed;
c. the networks of links and nodes through which the vehicles move.

Principle II. All movements through the transportation system must be considered.

Principle III. Movements must be considered from their initial origin to their final destination.

Principle IV. All modes of transportation must be considered.

Principle V. A transportation system is a particular form of "market," in which supply and demand reach equilibrium within the constraining channels of the transportation network. Specifically:
a. a number of level-of-service variables are necessary to define the interaction between supply and demand;
b. the volume, composition, and time dependency of the demand for transportation depend upon the level of service at which transportation is supplied;
c. the level of service supplied by a transportation system depends (for given resource inputs) upon the volume, composition, and time variation of demand;
d. determining the level of service at which supply and demand are in equilibrium in a particular context is usually computationally difficult, because of the complexity of the transportation network and of the transportation demands.

GROUP B. THE ANALYSIS PROBLEM

Principle VI. The spectrum of potentially available transportation options includes decisions about:
a. routing and time schedule for a particular trip or shipment;
b. system operations, including routing and scheduling of vehicles, pricing, and types of service offered;
c. changes in non-fixed resources, such as vehicle characteristics and availabilities, and procurement of new equipment;
d. changes in fixed facilities, such as link and node characteristics, and network structure;
e. introduction of basically new transportation technologies, including vehicles, fixed facilities, and operating policies.

Principle VII. Transportation is not an end in itself.

Principle VIII. There are a variety of transportation-related options available; particularly important are those which can influence directly or indirectly the demand for transportation.

Principle IX. There is a spectrum of direct and indirect impacts of transportation relevant to the choice among alternative systems and policies.

Figure 1. Principles of transport systems analysis.

The principles are enunciated with a spectrum of transportation system contexts in mind. These include: (a) urban transportation—the problem of providing integrated multi-mode transportation systems (with highway, mass transit, rail, and other modes) to meet the evolving needs of a metropolitan area; (b) megalopolitan transportation—the problem of providing high-speed transportation among the cities of a highly urbanized region; (c) developing-country transportation—the problem of determining appropriate investments in transportation facilities to best achieve overall socioeconomic development objectives; and (d) strategic mobility—the problem of determining the most efficient set of transportation capabilities to best achieve national strategic objectives through rapid deployment of military forces. Transportation analysts have been involved in analyzing problems in each of these contexts, and can expect to confront an even broader range of transportation system problems in the future.

After presenting the proposed principles, their application to two specific contexts, urban transportation and strategic mobility, is discussed. These examples will demonstrate, it is hoped, the applicability and utility of the principles to any transportation systems problem.

THE PRINCIPLES

Principle I

The basic components of a transportation system are (a) the persons and things being transported; (b) the vehicles in which they are conveyed; and (c) the networks through which the vehicles move.

The purpose of this principle is to establish what we mean by a "transportation system." One level of description is the pattern of flows of persons and things through the system. These flows are constrained by the channels of the network, but for many kinds of analyses we may conceivably ignore the description of the physical facilities and simply show the patterns of flow, as, for example, in the pattern of grain flows across the United States, or of work trips in a metropolitan area. [1]

[1]Edward L. Ullman, American Commodity Flow, Univ. of Washington Press, Seattle, 1957; Walter Isard, Methods of Regional Analysis, Ch. 5, MIT Press, New York, 1960; Chicago Area Transportation Study, Final Reports, Vol. 1-3.

Vehicles are the containers which provide the interface between the items being transported and the fixed facilities of the network, such as the roadway. In such modes as rail, highway, and air, the vehicles are obvious, and the distinction of vehicles from other facilities is highly relevant for analysis. In such modes as pipelines or conveyor transportation, or movement of pedestrians on foot, while there is no vehicle as such, there is still some kind of interface between the goods and fixed facilities.

Networks consist of nodes and of links connecting various pairs of nodes. Each link corresponds to a specific transportation channel. Links may be well defined, such as rail lines, highways, controlled airways, or sidewalks, or may be relatively diffuse, as in uncontrolled air or sea travel, or off-the-road vehicles. Some nodes may be interchange points between links of the same mode, such as highway interchanges or rail yards. Other nodes may be interchange points between links of different modes, as a rail, bus, or airline terminal typically is. The paths of vehicles in a network are through a succession of links and nodes.

This principle has several important implications for analysis. First, our primary concern is with the things being transported. Second, the consideration of networks emphasizes that vehicles interact over space and time, competing for the limited capacities of the links and nodes, and flowing through the networks in a variety of interacting paths. These implications are expanded in Principles II through V.

Principle II

All movements through the transportation system must be considered. The resources in the transportation system are used for the transport of a variety of persons and things. Changes in the movements of one set of items through the system will, in general, impact upon the movements of others. For example, design of transportation terminals for air, rail, and other modes must consider the flows of baggage and other freight, as well as passengers; urban transportation planners must consider the patterns of goods movements throughout a metropolitan area, not just person trips, and must consider trips for purposes of shopping and recreation, not just trips to and from work. Identification of the full spectrum of persons and things potentially or actually moving through a particular transportation system is an important task.

Principle III

Movements must be considered from their initial origin to their final destination. To study adequately the flows through the transportation system, the analyst must trace the full history of each class of trips. One example is intercity air travel, where attention has been focused on the air leg between airports, with the result that little consideration has been given to the problem of getting the traveler to the airport from his initial origin, and from the airport to his final destination. Another example is the rapid growth of containerization, and particularly container ships, due partly to recognition of this principle. Besides increasing utilization of the ships and other vehicles, containerization also achieves more effective service for the customer over the full origin-to-destination movement of the commodity.

More attention to this principle is essential to increased effectiveness of the transportation system. Clearly, more important than the speed of one particular mode or link is the performance of the transportation system as a whole in carrying the movement from initial origin to final destination. In particular, this principle focuses attention on the interface between modes—the interchange nodes and their characteristics. In the sequence of modes between origin and destination, increasing the speed of one mode may not reduce the total trip time significantly if the speeds of other modes are low or the interchange functions are inefficient.

Principle IV

All modes of transportation must be considered. In order to analyze movements from origin to destination, we must include in the transportation system under study all modes actually or potentially utilized by the full set of movements. Thus, if our problem

Time

total trip time
reliability—subjective estimate of variance in trip time
time spent at transfer points
frequency of service
schedule times

Cost (to user)

direct transportation charges
other direct operating costs (loading, documentation, etc.)
indirect costs (warehousing, interest, insurance, etc.)

Safety

probability of fatality (or destruction of cargo)
probability distribution of accident types (shock vibration, damage, etc.)

Comfort and Convenience

number of changes of vehicle
physical comfort
psychological comfort (status, privacy, etc.)
other amenities (baggage handling, ticketing, etc.)
enjoyment of trip
aesthetic experiences

Figure 2. Level-of-service variables.

deals with intercity air travel, we must include not only the inter-airport leg, but also the ground transportation distribution system within both the origin and destination metropolitan areas, and the flows within the air terminals themselves.

Obviously, the conception of "mode" here is very broad. The various modes will include the full range of technologies, from air, rail, highway and water, to pipeline, conveyor, and pedestrian, and whatever variants and new technologies may potentially be applicable.

Principle V

A transportation system is a particular form of "market," in which supply and demand reach equilibrium within the constraining channels of the transportation network. Specifically: (a) a number of "level of service" variables are necessary to define the interaction between supply and demand; (b) the volume, composition, and time dependency of the demand for transportation depend upon the level of service at which transportation is supplied; (c) the level of service supplied by a transportation system depends (for given resource inputs) upon the volume, composition, and time variation of demand; and (d) determining the level of service at which supply and demand are in equilibrium in a particular context is usually computationally difficult because of the complexity of the transportation network and of the transportation demands. This principle identifies a major source of difficulty in transportation systems analysis, namely, the peculiar characteristics of the market for transportation. It has long been recognized in some areas of transportation[2] that predicting the flows in a transportation system is a problem in the prediction of the equilibrium between supply and demand. However, the simple textbook examples, such as the "cobweb" computation for determining this equilibrium,[3] are far from the complex realities of the transportation market.[4]

Whereas, in simple economic theory supply and demand are given as functions of a single variable, "price," in transportation the equivalent variable is in general multidimensional. The supply of and demand for transportation depend upon a number of characteristics of the transportation service provided, not just direct price in dollars. A sample of these "level-of-service" variables is shown in Figure 2. Generally, users of transportation in making their decisions consider several characteristics. An air traveler considers not only cost and expected travel time, but also safety, comfort, and possible variations in travel time. Automobile drivers may often pay higher tolls to save time, or may take longer, more scenic routes for greater driving enjoyment.

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[2] For example, Haskel Benishay and Gilbert R. Whitaker, Jr., An Empirical Study of Transportation Supply and Demand Relationships, Papers Fourth Annual Meeting, Transportation Research Forum; or, Ralph E. Rechel, Issues in Pricing Metropolitan Area Passenger Service—Public and Private, op.cit.; and many others.

[3] See, for example, William J. Baumol, Economic Theory and Operations Analysis, Prentice Hall, Englewood Cliffs, 1965.

[4] For a discussion of some aspects of these computational difficulties, see Alan Hershdorfer, Predicting the Equilibrium of Supply and Demand: Location Theory and Transportation Flow Models, Papers Seventh Annual Meeting, Transportation Research Forum, 1966.

Because of the spatial characteristics of transportation, demand is also spatially distributed. Further, the magnitude and composition of that demand will vary over time as well as over space. For example, consider the variation in intercity air travel demand among the following cases: Monday morning on a normal workday, eight o'clock on a Saturday night, or the Wednesday before Thanksgiving at a major U. S. airport.

Similarly, the level of service at which transportation is provided will vary spatially and over time; level of service responds to demand in a highly complex way because of the many interactions among flows in their movements over the transportation network. The interactions of autos in an urban road network during rush hours are a good example. In such a saturated and unstable system, a minor bottleneck quickly cascades over the system, causing breakdowns in service over a wide area.

In recent years, increasing attention has been paid to the problem of predicting the equilibrium flows in multi-mode transportation networks.[5] Approaches range from the purely predictive to the prescriptive. The "traffic assignment" techniques of urban transportation planning[6] attempt to predict the equilibrium distribution of flows resulting when each traveler is free to make his own decision about his path through the multi-mode network. On the other hand, such techniques as linear programming, Ford-Fulkerson network flow theory and scheduling algorithms attempt to prescribe the flows so as to achieve some type of overall "optimum."[7] Aside from the problems of obtaining functional representations for demand and supply, the problem of predicting equilibrium still remains a difficult one, in spite of these advances.

Principle VI

The spectrum of transportation options potentially available includes decisions about: (a) routing and time schedule for a particular trip or shipment; (b) system operations, including routing and scheduling of vehicles, pricing, and types of service offered; (c) changes in non-fixed resources, such as vehicle characteristics and availabilities, and procurement of new equipment; (d) changes in fixed facilities, such as link and node characteristics, and network structure; and (e) introduction of basically new transportation technologies, including vehicles, fixed facilities, and operating policies. By this principle, we attempt to summarize the range and variety of transportation options open to decision-makers in various contexts. The individual traveler or potential shipper sees the transportation system as essentially fixed; by and large, he can only choose his own particular routing and time schedule through the system. In the area of operating policies and decisions, the carriers have the options of establishing the routings and schedules of the vehicles, pricing, and a variety of other factors such as meals, cleanliness, handling procedures, and reliability which determine the level of service available to the user of transportation, including time, cost, comfort, and other characteristics. (These carrier options are of course often subject to regulatory or other institutional constraints.) The next level of options adds the additional dimension of vehicle procurement—options about what types, numbers and availabilities of vehicles there will be in the system. Purchase of new equipment, modification of old equipment, repositioning (basing) or leasing options fall under this general heading.

Beyond the level of vehicles, there are the options of changes in the structure and characteristics of the network—additions of new links or abandonment of old ones; changes in the operating characteristics of links, such as highway widening or resurfacing, signalization of a rail line, or dredging of a river; and changes in the basic structure of the network, such as adding a subway system to a metropolitan area, or implementing the Interstate and Defense Highway System nationwide, or assigning a new type of carrier operating rights in a certain market. Finally, the broadest set of options relaxes everything, and allows the introduction of basically new transportation technologies—new vehicles, new networks, new operating policies, etc., such as the

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[5] Hershdorfer, op. cit.

[6] Brian V. Martin, Frederick W. Memmott, and A. J. Bone, Future Demand for Urban Travel, MIT Press, Cambridge, 1966; Brian V. Martin and Marvin L. Manheim, A Research Program for Comparison of Traffic Assignment Techniques, Highway Research Record 88, 1965, pp. 69-84.

[7] Hershdorfer, op. cit.; L. R. Ford and D. R. Fulkerson, Flows in Networks, Princeton Univ. Press, 1962.

new technologies being investigated for the high-speed ground transport system in the Northeast Corridor of the United States.[8]

The objective in voicing this principle is to prevent the analyst from unduly constraining his analysis to a restricted set of options. However, the full set of options will rarely be open to one single agency or organization. Then too, types of options differ in the time frame in which they can be implemented; specific trip decisions can be implemented rapidly, but network changes and the introduction of a new technology may take years to accomplish. Still, it is up to the analyst to insure that the potential options are explored and pointed out to the relevant decision makers. For example, consider a shipper, who will ordinarily choose among a number of available routings together with their associated time and other level-of-service characteristics. He has the option of negotiating new rates, or, over the longer run, attempting to develop in coordination with a carrier new equipment more suited to his traffic.

Principle VII

Transportation is not an end in itself. This principle emphasizes that the ultimate objective in providing transportation is to fulfill some broader public or private objectives. The cliché that transportation adds "place utility" to an object expresses this. The broader objectives of transportation may be to stimulate economic development, to channel the growth of a metropolitan region, to bring goods to the market, or to deliver military forces where they can be an effective instrument of national policy.

Principle VIII

There are a variety of transportation-related options available; particularly important are those which can influence directly or indirectly the demand for transportation. As soon as it is recognized that transportation is not an end in itself, then clearly transportation decisions must be accomplished in concert with decisions in a variety of transportation-related areas. In particular, many types of non-transportation decisions will have significant effects on the demand for transportation. For instance, the distribution of demand over space, over time, and by type of transportation service desired, will be affected by national economic policies, in the case of the demand for freight movements; by influences on differential regional growth, in the case of intercity air travel; by staggering of work hours, and land use controls such as zoning and the provision of public utilities, in the case of metropolitan commuter transportation; and by distribution and inventory policies, in the case of military and industrial logistics systems.

The degree of influence which the transportation analyst can exert over such non-transportation variables may vary widely. However, the analyst must clearly recognize the existence of such variables, and must carefully explore their potential use in the context of his particular transportation problem.

Principle IX

There is a spectrum of direct and indirect impact of transportation relevant to the choice among alternative systems and policies. Clearly, as a consequence of Principle VII, impacts beyond the bounds of the transportation system must be considered.

The spectrum of impacts of transportation can be broken down into dollar-valued and non-dollar-valued, and further broken down by their incidence among different groups or elements in society. One useful set of distinctions is:

1. dollar costs
    a. capital investments in vehicles and fixed facilities
    b. dollar-valued operating costs
    c. dollar-valued changes in costs borne by users of the transportation system (shippers and travelers)

[8] Edward Ward, Prospective New Technologies, Papers Seventh Annual Meeting, Transportation Research Forum, 1966.

2. non-dollar-valued costs
   a. borne by the users of the system—aspects of level of service variables other than dollar-valued
   b. impacts on non-users of the system

ILLUSTRATION OF THE PRINCIPLES

We will now briefly illustrate the application of these principles to two specific transportation systems problems.

Example I: Urban Transportation

The last 15 years have seen a major growth, not only in the transportation facilities of urban areas, but also in the outlook and frame of reference of those professionals charged with planning urban transportation systems. The evolution of urban transportation planning has brought about a major stimulus to the development of a comprehensive transportation system approach. The following discussion illustrates the role of the principles in this problem area.

In metropolitan transportation, the frame of reference historically has shifted from a concern solely with highways to integrated planning for highways, arterial streets, and rapid transit systems. The complete metropolitan area transportation system (Principle I) includes the intra-urban modes, such as highway, arterial, and local streets, buses, commuter rail and rapid transit, and also the interfaces with inter-urban modes, such as rail, air, and bus. The movements through the system are both people and goods (Principle II). Person trips of interest are primarily commuting trips between home and work, but recreational and shopping trips are also significant. Except for relatively minor consideration of truck traffic, metropolitan area transportation planning on the whole has been deficient in considering goods movements within the urban area, and the intra-urban distribution function for inter-urban goods movements by rail, truck or air has received little attention. For that matter, little special attention has been paid to the intra-urban trip of the inter-urban traveler, from airport or train station to office or home, for example.

With respect to highway and rapid transit, there has been some consideration of the total origin-to-destination trip (Principle III). Again, it is primarily on the intra-urban legs of intercity trips that this principle has been violated. In most current studies, all currently available modes of transportation are being considered, including rail commuter, highway, subway, and bus, though sometimes the option of express bus on separate right-of-way is not evaluated (Principle IV). In the Northeast Corridor (but not to my knowledge in any metropolitan area study), attention is being given to basically new technologies, such as VSTOL.[9]

The major development in urban transportation planning in the last decade has been the development of techniques for computing the equilibrium between supply and demand (Principle V). These are structured in a way which leads to some significant computational and conceptual difficulties, but the sequence of steps involved—trip generation, calculation of zonal interchange volumes, modal split, and traffic assignment—is well developed[10] and institutionalized, perhaps too institutionalized. The level-of-service variables used are commonly out-of-pocket costs including tolls and parking charges, travel time door-to-door, and some measure of "comfort and convenience."

The metropolitan transportation studies have focused primarily on options with regard to changes in networks—more particularly, stimulated by legislative requirements, highway network changes of significant magnitude (Principle VI). Relatively little attention has been given to links of other modes, except mass transit, or to the inter-modal interchanges or terminals. Some consideration has been given to options

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[9] See, for example, Robert Simpson, Future Short-Haul Air Transportation in the Northeast Corridor, Papers Seventh Annual Meeting, Transportation Research Forum, 1966.

[10] Martin, Memmott and Bone, op. cit.; Hershdorfer, op. cit.

of new technologies, though not much, and almost no attention to changes in the characteristics of the existing automotive vehicles (though minor changes in both mass transit and rail commuter vehicles have been addressed and implemented). No attempt has been made to explore ways of controlling the routes taken by private autos or the times at which they travel; occasionally pricing, to the extent of tolls and parking charges, has been investigated.

For many years, much verbal attention has been paid to the idea that transportation is only one instrument of metropolitan planning[11] and that the objectives of transportation planning are to contribute to the guiding of metropolitan growth in desired directions (Principle VII). In practice, however, there is some question as to the actual extent to which this philosophy has been implemented. More often than not, independent projections of land use development are used to define the needs for a transportation system, and no explicit attempt is made to test transportation system plans to choose that one which steers growth in the desired direction (Exceptions: Penn-Jersey, Southeastern Wisconsin). Although staggering of work hours and segregation of traffic, including prohibitions of vehicles from key central areas, have been discussed, in general they have not been put forward and analyzed as transportation-related options (Principle VIII). However, some studies have addressed possible uses of land use controls (zoning) and provision of public utilities (sewer, water, electricity) as ways of shaping demand through channeling metropolitan growth.

In evaluating transportation alternatives, there has been a strong emphasis on cost-benefit analysis. This has encouraged analysts to address only those impacts of a proposed system which could be relatively easily transcribed into dollar equivalents for decision-making. With just a few exceptions,[12] the difficult, non-dollar-valued impacts, such as disruption of neighborhoods, have been left out of the transportation planning calculation with the result that the issues have become part of the political arena (Principle IX).

To summarize, in urban transportation planning, we do see some adherence to the principles. Furthermore, by applying these principles, we get an indication of possible gaps in the way current analyses are being accomplished.

Example II: Strategic Mobility[13]

The basic problem in "strategic mobility" is to deploy large military forces to selected areas of the world as rapidly as necessary to achieve strategic objectives. At first glance, the strategic mobility problem would seem to be totally different from that of urban transportation. Yet they are both transportation systems problems and so the principles apply.

In strategic mobility, the transportation system is potentially the entire worldwide transportation system, including military and nonmilitary vehicles and networks, all modes—air, sea, rail, highway, etc., and in the United States as well as around the world (Principle I). The movements through the system which must be considered in

[11] William W. Nash, Roland B. Greeley, and Marvin L. Manheim, Interdependence of Transportation and Land Use Planning, Staff report to the U.S. Bureau of Public Roads, Joint Center for Urban Studies of MIT and Harvard, Cambridge, 1960; John R. Meyer, John F. Kain, and Martin Wohl, The Urban Transportation Problem, Harvard Univ. Press, Cambridge, 1965.

[12] William W. Nash and Jerrold R. Voss, Analyzing the Socio-Economic Impacts of Urban Highways, HRB Bull. 268, 1960, pp. 80-94; Marvin G. Cline, Urban Freeways and Social Structure: Some Problems and Proposals, Highway Research Record 2, 1963, pp. 12-20; Donald Appleyard, Kevin Lynch, and John Meyer, View From the Road, Highway Research Record 2, 1963, pp. 21-30, also published by MIT Press, 1964.

[13] Marvin L. Manheim, An Overview of Strategic Mobility and Its Implications for the Design of Analysis Systems, paper presented to the NATO Advisory Panel on Operations Research Conference on the Analysis of Military Transportation Systems, Oxford, England, July 1966; Lawrence E. Lynn, The Analysis of Strategic Mobility Problems, Papers Seventh Annual Meeting, Transportation Research Forum, 1966.

analysis (Principle II) are the troop units being deployed, including personnel and equipment; individual personnel enroute to or from the various theaters; and supplies and equipment to support the deployed forces after arrival, and to support forces already stationed around the world.

For the majority of elements to be transported in a rapid deployment, the initial origin is a home station in the United States and the destination a location in the objective theater (Principle III). While the airlift and sealift phases of these worldwide moves have received much attention in analyses, the phases of movements through the United States and other surface transportation systems have not been adequately studied. This historical fragmentation of concern is only now being overcome by a "from-origin-to-destination" approach, with due consideration of all potential modes (Principle IV).

The market aspects of strategic mobility are much more subtle than in urban transportation (Principle V). Here there is no set of independent consumers, creating through their aggregate behavior a demand function for transportation. Rather, in current practice, a theater commander or other strategic planner will formulate his requirements for movements of troops and supplies at a fixed level; that is, demand is set exogenously. The problem of the transportation analyst, then, is restricted to simply determining whether available resources are sufficient to deliver the movement requirements by the specified times. However, in practice, when the theater commander who submitted the plan finds that there are insufficient mobility resources to meet his requirements, or that there is excess capability potentially available to him, he will in fact go back and reformulate the movement requirements. Thus, the basic idea of finding an equilibrium is present, except that the demand is moved up and down by the deliberate actions of the theater commander, not by uncontrolled aggregate behavior. In this case, the level-of-service variables are predominantly (a) time of arrival in theater relative to time required (in accordance with the desired strategic response), and (b) the time it takes to marry up all the components of the fighting force (when personnel and equipment travel separately).

The spectrum of transportation options in strategic mobility is indeed wide (Principle VI). In the time frame of current operations, the vehicles and networks are fixed, and the problem is to achieve the most effective utilization of the given transportation resources to deploy the force. Over longer time frames, there are options about procurement of new vehicles, assignment of vehicles geographically and by command jurisdiction; and the introduction of new technologies such as the C-5 heavy-lift aircraft or the Fast Deployment Logistic Ship.[14]

Clearly, in strategic mobility, transportation is not an end in itself (Principle VII). The objective is an appropriate and adequate response to real or threatened aggression through rapid deployment of an effective fighting force. Transportation is obviously secondary to considerations of strategy and of national policy.

The transportation-related options (Principle VIII) include, first and foremost, the nature of the strategic response, as expressed in the requirements for movement—the forces, equipment, and supplies to be deployed, together with the origins, destinations, and desired times of arrival at the destination for each element. In addition, there are other options which directly affect the demand for transportation resources; for example, the option of prepositioning equipment and supplies overseas, or of changing the readiness of units to be deployed so that they can become available for movement at earlier times, or of redesigning the equipment to be transported to improve its transportability.

The relevant impacts of alternative strategic transportation plans are relatively obvious (Principle IX). First of all, there are the dollar costs—the costs of having men and vehicles available on a standby basis to provide support to a deployment, as well as the costs of operating them during a deployment. The dollar-valued revenues are the savings in using these vehicles for peacetime logistic support of the armed forces overseas. The non-dollar-valued costs are the many aspects of military effec-

[14] Lynn, op. cit.; Ernst Frankel, Planning the Design, Production and Operation of an Integrated Ship System, loc. cit.; Franz A. P. Frisch and W. Donald Weir, Analysis of Mission and Design Concepts for a Logistics Ship, loc. cit.

tiveness—buildup rate of forces in the theater, ability of the units to become an effective fighting force (as affected by length of time in transit, time available for training before departure, and marry-up with equipment), flexibility, reliability and vulnerability of the deployment plan.

CONCLUSIONS

We have presented several principles of transport systems analysis. We argue that these principles express guidelines or checklists which every transportation analyst should observe, to help prevent the most obvious types of errors in any problem of transportation systems analysis. To demonstrate the applicability of these principles, we showed their relevance in the context of two major transportation problems of current interest, urban transportation and strategic mobility.

Undoubtedly, these statements of principles require further clarification, testing, and modification. The author looks forward to spirited discourse about these principles, as part of a common effort to evolve a solid foundation for transportation science.

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