been? Projections that included separate commodity classifications proved to be sufficiently reliable for use in planning, initial phasing, design, and construction of facilities. Freight projections were generally much too conservative. Projections on the rate of sale or lease of land have been rare but relatively reliable.

2. What general range of reliability is required? Because the responses offered little useful information on this question, what follows is based on our own personal observations.

Facilities planning usually falls into two distinct categories: (a) public (general-purpose) terminal and (b) associated waterfront industrial park. The public terminal by its nature must be planned for a wide range of commodity classifications and, once the original waterfront facilities are constructed, expansions can rapidly be made to fit unexpected increases in certain commodities. In addition, wharf and mooring capacity usually exceeds other terminal capacity by so much that expansions do not require the per-megagram resources of original design and construction. Projections of amount of freight are more likely to be used to justify financing than to clarify detailed design and planning decisions for the public terminal.

From a planning viewpoint, the related waterfront industrial park resembles ordinary industrial subdividing except that it is also oriented to waterway transport. Both waterfront and nonwaterfront sites are essential. Planning, therefore, is more likely to focus on the sale or lease of the land than on commodity and freight projections, although these projections do constitute a broad indicator. Obviously, then, commodity freight projections need not be very precise from a planning viewpoint. Instead, they should indicate a median projection with a stated wide variation above and below that median, and this should in turn create a demand for physical plans that indicate minimum anticipated development as well as possible expansions.

The question of the general range of reliability required for purposes of physical planning merits additional research, including a larger sampling, more detailed responses, and the construction of a historical base for review at various time intervals.

3. To what source would the experienced port operator look today for reliable data on which to base projections of commodity freight? There appears to be no single reliable source for such data or, if there is one, it has not yet been proved by real-world testing. Port operators did not provide any new answers. Although this is a topic that does not currently merit any additional research, it would be appropriate to ask the question again because port operators are continuously gaining experience and exposure on the front line of the inland waterway transportation industry.

The center of gravity of research in commodity classes and freight projections is invariably national policy and how to influence it. But it is the local decision maker who must use projections because he or she must live within specifically or vaguely stated national policy. Local decision makers need more help than they are getting in this area.

4. Is more detailed investigation justified? We recommend researching a simple system for one federal agency, bureau, commission, association, or business to provide frequently updated box scores on projections. The how, who, what, and where would be part of the research. The initial cost should be low—perhaps $85 000—to encourage simplicity. Funding should be by a nonoperating research organization, one that cannot suggest it assume the updating role following initial research. The project should (a) suggest a format for minimum projection tabulation so that updated box scores can be meaningfully assembled, (b) show singly or in combination the sources of data and opinion that have proved most reliable, and (c) indicate a general range of projection development costs that has proved optimum, perhaps as a percent of project construction costs, to determine whether there is a point at which additional projection costs produce rapidly diminishing returns in the form of useful projections.

Commodity-Flow and Multimodal Transportation Analysis for Inland Waterway Planning

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The inland navigation systems analysis program of the U.S. Army Corps of Engineers is an integrated system of models, data, and planning procedures designed to explain, predict, and plan for U.S. inland waterway transportation. The program forecasts future waterway traffic by means of commodity-flow and multimodal network models. The commodity-flow model is similar to a multiregional input-output model with variable coefficients, in which market behavior and transportation costs determine location, composition, pricing, and level of output and the interregional commodity flows derived from them. The multimodal network model allocates these commodity flows to the several modes, based on transportation cost and performance criteria, and the allocations, as applied to the inland waterway system, constitute the waterway traffic forecast.

The inland navigation systems analysis (INSA) program of the U.S. Army Corps of Engineers (1) is an integrated system of models, data, and planning procedures designed to explain, predict, and plan for U.S. inland waterway transportation and to help planners reach thoroughly examined investment, operation, and maintenance decisions for inland waterways. The models are designed to mimic the national market system and the role of inland waterway transportation within that market system by simulating both inland waterway transportation and transportation markets within the national market system. The purpose of this paper is to describe the models and to explain how they are used to estimate demand for inland waterway transportation.

BACKGROUND

Figure 1 shows a schematic of the INSA structure. Forecasts of demand for commodity transportation are provided by commodity-flow analysis; then these forecast commodity flows are allocated to various modes by means of multimodal analysis, based on transportation cost and performance criteria. Allocations to the inland waterway system are input to the INSA waterway analysis and enable detailed estimates of future fleet requirements for the towing industry and operating characteristics of waterway systems. The cost and performance results of both the multimodal and waterway analyses are then used to evaluate systems and projects. Feedback from the multimodal analysis to the commodity-flow analysis indicates that INSA allows transportation cost and level of service to influence the spatial patterns, mixes, and quantities of commodity flows.

INSA commodity flow and multimodal analysis together constitute a model of transportation demand, which can be viewed at several levels during the analysis. Some of the dependent variables involved are defined as follows:

S_i = quantity shipped from region i,
D_j = quantity shipped to region j,
Q_{ij} = quantity shipped from region i to region j,
Q_{ijm} = quantity shipped from region i to region j by mode m,
Q_{ijmr} = quantity shipped from region i to region j by mode m via route r, and
Q_{ijmrp} = quantity shipped from region i to region j by mode m over network element (node or link) p of route r.

Simultaneous equation models and direct demand models that directly predict any of these variables can be formulated. A more typical approach is to take advantage of the hierarchical structure shown above by developing a chain of sequential models. Demand hierarchy and its implication for model building are discussed by Manheim (2) and Brand (3).

INSA uses the sequential approach. The first three variables, S_i, D_j, and Q_{ij}, are predicted by the commodity-flow model. Predictions of the other three variables are made in the multimodal network model, given interregional commodity flows (Q_{ij}). A discussion of both model systems follows.

COMMODITY-FLOW ANALYSIS

Model

The INSA commodity-flow model, accurately termed a regional economic activity and commodity-flow model, makes use of already well-known theory and empirical evidence but integrates them in a way that has been attempted only once (4). Typical of the overall structure of the model is the multiregional input-output approach (5, 6, 7). The elusive monetary coefficients normally present, however, are not relied on; instead, physical technical coefficients (8) are evaluated from regional production functions (9, 10). Given economic activity by region, flow patterns are analyzed by use of multiregional general equilibrium logic (11). The false security provided by some accepted models, such as physical analogs of mass attraction (12, 13), is avoided.

In the INSA commodity-flow model, the U.S. economy consists of a set of regions, each of which contains a set of economic sectors or industries. Each industry produces a product to satisfy domestic consumer demand, export demand, or demand from other industries. The production process requires that each industry combine raw materials, labor, and capital goods to produce its product; each industry, therefore, seeks the optimum combination of input. The mix and sources of items used in production depend on delivered input prices, including the price of transportation. Commodity flows occur within this system as raw materials travel to the industries demanding them and as what those industries produce travels to locations of domestic consumer demand, export demand, and other industrial demand.

The commodity-flow model is similar to a multiregional input-output model, in which market dynamics determine the location, composition, and pricing of output and the behavior of economic aggregates determines the level of output. Within this system firms and households select commodity suppliers and producers compete for customers on the basis of delivered price, which includes the price of transportation from supplier to consumer and the transportation cost built into free-on-board (FOB) price because of the transportation charge for gathering raw materials. The INSA commodity-flow model, therefore, generates a demand for transportation that depends in part on transportation price.

Brief descriptions of some of the major features of the model follow.

Economic Activity

Commodities are identified as output from an economic activity. Each activity consists of a production function type, a mix of required input commodities, and a unit of measure.

Sector

The basic unit on which the model operates is the regional sector for each activity. Each sector in a region has initial prices for labor, capital, and material and may have unique parameters for production function. Realistic levels of production may be set by placing output constraints on each sector. (Output constraints may reflect depleted mineral reserves or constraints imposed for environmental reasons.)

Region

The study area may be divided into regions by a standard approach such as that used by the Bureau of Economic Analysis (BEA), or by a variety of other means. If data needs are simple, states may be appropriate regional units, or counties can be used if greater detail is desired. A mix of definitions, such as BEA regions in the Mississippi and Ohio valleys and whole states on the Atlantic and Pacific coasts, can be used if economic activity near inland waterways is of primary interest.

Demand

All categories of demand for commodity requirements—foreign export, domestic final, and intermediate—are measured in physical units, such as tons or kilowatt-hours, rather than in monetary units. (The INSA model is based on U.S. customary units, and thus no SI equivalents are given.)

Because foreign export demand is given externally to the model throughout simulation, price elasticity of foreign demand must be exogenously estimated. Domestic demand, as estimated by the model, is assumed to be unitarily elastic with respect to price, but the analyst may use values based on alternative assumptions for estimated domestic demand.

Production Function

The aggregate production and consumption behavior of firms in a given sector is described by a production function, the form or type of which is activity specific, although the parameters may vary between regions to reflect technological differences. Firms within a region are treated as a group because (a) the likely behavior of every firm in the nation cannot be computed and (b) data needed to fit production functions for individual firms are generally not available.

A production function represents the quantity, cost, or price of output in relation to the quantity, price, or mix of input. In the commodity-flow model, it is assumed that the sector will produce the quantity consumers desire. Demand, however, depends on price mechanisms. Two fundamental types of production functions are available to the analyst using the model: fixed input proportion and a wide range of variable substitutions. Fixed proportion is the easiest to estimate because the only data needed are those such as the ratio of labor input to unit of commodity output and units of material input per unit of commodity output. Thus, when demand is given for a commodity in a sector, the factors and individual materials required are solved directly.

Figure 1. INSA system.

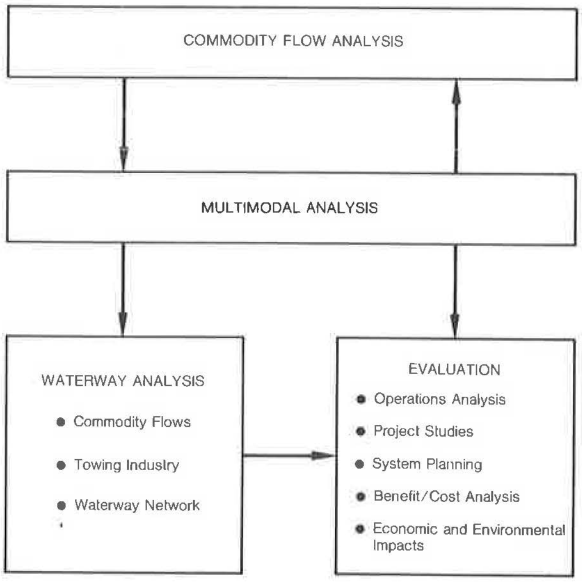
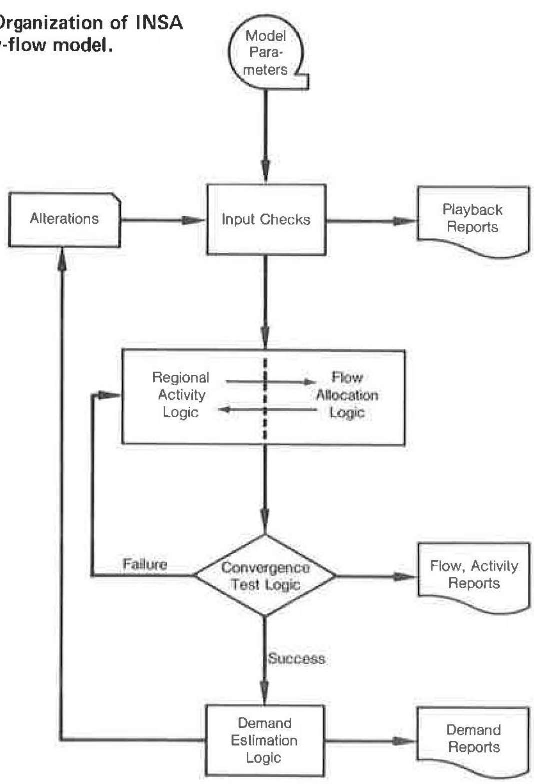


Figure 2. Organization of INSA commodity-flow model.



Model Organization and Logic

The commodity-flow model iterates through a series of calculations to arrive at predicted annual commodity flows for the current year and demand estimates and new parameters for the following year. Organization of the model is shown in Figure 2.

Because calculations of regional economic activity and flow allocation fluctuate for every sector, the logic for both calculations is shown in the same box. The model uses successive approximations to forecast commodity flows and tests for convergence between the last two approximations; failure to converge leads to additional processing. A successful test computes domestic commodity demand for the coming simulated year.

The main features of model logic are as follows:

1. Calculating minimum cost and location—The model first calculates minimum delivered price of each commodity by consumer region and supply region (delivered price is defined as FOB price plus transportation cost).
2. Allocating demand—Demand or purchasing regions (aggregations of individuals and firms) are treated as rational, economic decision-making units. Domestic or foreign market demand by location is satisfied by production regions offering the lowest delivered price. The allocation of demand to production regions defines a portion of commodity flow as well as the demand for the output of each regional sector. No direct checks are made to determine if new demand exceeds the capacity of a sector; in such a case, the model increments FOB price until demand does not exceed capacity.
3. Estimating transportation cost—Detailed models such as the INSA multimodal network model may be used to estimate transportation cost because cost is entered into the model externally. Any set of costs may be entered to analyze potential policies or unusual events.
4. Forecasting economic activity—Production in any sector is composed of and driven by export demand, domestic final demand, and demand created by other economic activities. Given prevailing production price, a minimum cost mix is used to produce desired demand, which defines, by sector, such production factors as the amounts of commodities the sector requires from other sectors. The price and amount of what is consumed determine the FOB price of that sector's commodity.
5. Allocating commodity flow—Materials required for production by a sector are allocated to other sectors for production. The criterion used is minimum delivered cost—FOB price in the producing sector plus transportation cost between regions.
6. Computing consumption—Wages paid by each sector contribute to the income of consumers in a region. Household income, derived from distributed returns on capital, is allocated to regions on the basis of per capita

earned income. Regional income is then spent or converted to demand for commodities and services by using a function for aggregate household consumption.

The principal output of the model is a set of region-to-region commodity flows that can be used in the planning process, and additional outputs include regional economic activity, national income, and value added.

MULTIMODAL ANALYSIS

Figure 1 shows the pivotal role of multimodal analysis in the INSA model. One of the major purposes of INSA multimodal analysis is to translate interregional estimates produced by the commodity-flow model into estimates of port-to-port waterway traffic. Because inland waterways are only one element of a multimodal transportation network in which waterways compete for freight traffic with other modes, forecasts of waterway transportation demand must be made within this complex framework. Analysis of intermodal competition is necessary if forecasts of waterway commodity flows are to be accurate.

Network Model

The INSA multimodal network model is based on standard techniques of transportation systems analysis (14, 15, 16, 17, 18). The model differs, however, from most freight transport demand models, such as those developed by Silberberg (19), Sasaki (20), Baumol and Quandt (21), Herendeen (22), and the National Bureau of Standards. The difference is that the INSA model does not use a separate modal-split model but combines modal share and network routing analyses. A complete treatment of the theoretical base and logical structure of the model is available elsewhere (1). The main features of the model are described below.

Transportation Network

The multimodal transportation network is a set of connected links and nodes for which the descriptive format is similar to that developed by the U.S. Department of Transportation (24). Links representing line-haul transportation facilities are described by nodes at each end of the link, length, transport mode, capacity, and transit time and cost parameters. The nodes have attributes such as name, number, location (coordinates), mode, capacity, and time and cost parameters. A special class of links called access links represent local transportation and connect commodity origin and destination regions to the network. Another special class of links representing intermodal transfer facilities and operations unite the modal subnetworks into an integrated multimodal network.

Performance Functions

The operating characteristics of links and nodes are represented in abstract form as functions that relate the cost of traversing a link or node to the amount of traffic that uses that link or node. These costs are intended to be fully allocated and may not equal the transportation rates paid by shippers. (Because the formulation of the model is general, rates can be used if desired.) Capacity functions are similar functions that relate transit time to shipment volume. Cost and capacity functions for intermodal transfers and for regional access are also used.

Commodity Movements

Each item for transportation is described by region of origin and destination, commodity type, and tonnage. Optional specifications of historical or estimated modal-split percentages and desired route from origin to destination are also permitted. Commodity types are defined by two-digit classification, value, and inventory factor (sensitivity to shipment time).

Routing Cost

Least cost routes (from the shipper's viewpoint) from origin to destination are found for all shipments. Both perceived and economic costs are allowed to vary with shipment volume on each link, and features that help to achieve equilibrium are included.

Model Organization and Logic

Figure 3 shows the organization of the multimodal network model. The main operations of the model, which consist of algorithmic processes that select paths and assign traffic, are described below.

Path Selection

A principal function of the model is to determine the least cost path for each commodity movement by using data that include definitions of the multimodal network in terms of nodes and links and, for each commodity movement, origin and destination regions, tonnage, commodity type, and route restrictions, if any. The problem is to find the minimum cost path between the origin and destination regions for each commodity movement, a path being defined as a sequence of connecting nodes and links.

Determining routes between two points in a network is a familiar problem in transportation analysis, and the multimodal network model uses standard solution techniques (26, 27, 28) developed for finding the least time, or in this case least cost, route. The cost of traversing a network element is defined as the shipment cost (determined from the element's cost function) plus the cost of delay as perceived by the shipper, which is defined as the product of transit time, commodity value, and commodity inventory factor where transit time is determined from the element's capacity function.

The minimum path algorithm finds the path from origin to destination that minimizes the cost incurred for traversing the nodes and links making up that path. Decentralized shipper decision making is assumed; i.e., paths that minimize cost from the individual shipper's viewpoint are generated rather than paths that minimize total systemwide cost. The aggregate result of individual decisions should converge toward a global optimum if all parts of the modeled market system are truly competitive.

Path Constraints

If commodities are restricted as to transportation mode, nodes and links of the modes not used are not considered in the path selection process (e.g., nonpetroleum products are not shipped by petroleum pipeline). Individual shipments may also be restricted to a specified route from origin to destination. Links and nodes are limited to carrying flows below their capacities.

Circuity Constraint

To lessen computational problems, a constraint is imposed on the number of routes considered in the path-selection process by assuming that the location of each node is given in terms of geographic coordinates. An ellipse of given eccentricity is then constructed about the origin and destination regions for a particular commodity movement; the major axis of the ellipse is

Figure 3. Organization of INSA multimodal network model.

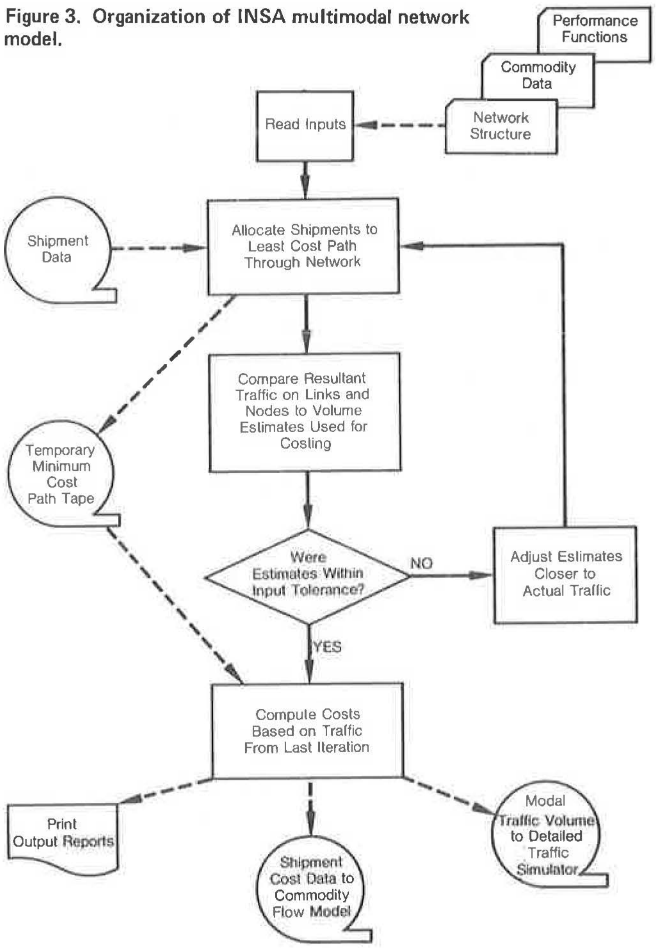
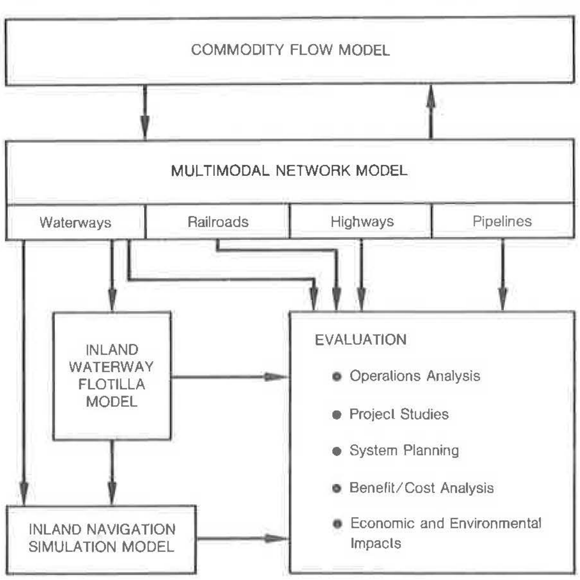


Figure 4. INSA system as a set of interrelated models.



the straight line connecting the centers of the two regions. The path-selection algorithm then considers only those routes between the two regions that lie totally within the ellipse. In effect this ellipse constitutes a circuity constraint that greatly shortens the amount of computer processing time required, although the price paid is that circuitous routes that may be less costly than the selected route are ignored.

Inertia Effect

An optional inertia effect included in the model may be used to constrain a specified portion of any commodity shipment to observe modal-share percentages input by the user for that shipment. Least cost paths are built for tonnage constrained by mode by using only nodes and links of the specified mode. The remainder of the shipment is free to select the best route. This feature reflects the realities of long-term shipper contracts and other commitments and also prevents the modal results from oscillating in response to small cost differentials among modes.

Assignment Algorithm

An iterative procedure is used to assign shipments to the network. For a base-year case, link and node costs are set by entering the performance functions with flow volumes equal to the practical capacity of each element (volumes for which delays are normal) or some other user-supplied estimate of volume. Shipments with fixed routes are assigned by increasing the loadings on each link and node in the route by the amount of shipment. Shipments with a fixed mode choice are assigned by using the path selection routine. All elements in the path must be of the selected mode. All other shipments are assigned by using normal minimum path logic, and all costs are updated to correspond to the total assigned traffic. This process is repeated in an iterative fashion until assumed and final volumes (and costs) agree within some specified tolerance. For succeeding time periods, volumes and final costs from one period are used as the base volume and cost estimates for the next period.

Output Processing

Standard types of output reports produced by the model are listed below.

1. Optional path traceback for each shipment, which displays nodes along the selected path through the multimodal network;
2. Network flow and cost, for each link and node in the network, including (a) tonnage assigned, (b) transit time, (c) average shipping cost, (d) average inventory cost, and (e) average total cost;
3. Network flow and cost summary, for each mode by node and link class, including (a) average kilotons and kiloton miles (links only), (b) total kiloton days, (c) cost per kiloton mile (links only), and (d) total cost; and
4. Network flow and cost summary by commodity, for each commodity class by mode, including (a) modal share of kilotons, kiloton miles, and kiloton days and (b) modal share of shipping, inventory, and total costs.

In addition, the model provides interface data files for input to other models. Average transportation costs are generated for each commodity and origin-destination pair to be used by the INSA commodity-flow model. For any designated mode, the model keeps track of which nodes were used to enter and leave that modal subnetwork and produces a file of traffic by node of origin and destination and by commodity. This feature may primarily be used to produce port-to-port commodity flows for input to the INSA inland navigation simulation model. It was to determine these prospective waterway traffic flows that the model was originally developed. The additional planning information listed above is generated in the process of obtaining these flows.

INTEGRATED COMMODITY-FLOW, MULTIMODAL, AND WATERWAY ANALYSIS

Figure 4, which is an expanded version of Figure 1, shows the overall structure of the INSA system in the form of a set of interrelated models. In comparing the two figures it may be noted that waterway analysis is expressed in the form of two models, the inland waterway flotilla model and the inland navigation simulation model. In Figure 4 the commodity-flow model serves as the main driving force of the other models, prescribing the kinds and amounts of cargo to be transported. The multimodal network model allocates commodity flows to the four principal modes of intercity cargo transportation and represents these modes at equal levels of abstraction. Waterway freight traffic, as determined by the multimodal network model, is then input to the two waterway models. The inland waterway flotilla model represents the structural aspects of the waterway system in detail but represents waterway traffic flows in the abstract. This model is used primarily to generate fleet forecasts that are consistent with expected commodity flows and characteristics of the waterway network. Forecasts of fleet and waterway traffic are then input to the inland navigation simulation model, which in comparison with the other models contains a detailed representation of the structure and operation of the waterway system. The models collectively provide measures of the cost and performance characteristics of transportation resources used to satisfy the demand for commodity transportation.

The components of the INSA system described above are designed to permit navigation planning to be carried out in a multimodal context by providing four general capabilities:

1. Analysis of the effects of transportation costs on future commodity flows,
2. Estimation of the modal split of freight traffic,
3. Evaluation of the intermodal impacts of waterway improvements, and
4. Comparison of waterway investments with equivalent investments in other modes.

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Inland Navigation Systems Analysis

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The objectives of the inland navigation systems analysis program are to develop within the U.S. Army Corps of Engineers the capability to optimize the design and schedule for implementation of future improvements to U.S. inland waterways and improve the operating efficiency of inland navigation. The program is an integrated system of four computer models, data, and planning procedures to (a) forecast commodity flows, (b) predict modal shares of traffic, (c) simulate and monitor inland waterway transportation, (d) predict economic impacts of inland waterway improvements, and (e) select the best size, location, and timing of inland waterway improvements.

The inland navigation systems analysis (INSA) program of the U.S. Army Corps of Engineers is designed to help Corps planners make the best possible decisions concerning the development of the inland waterway system and specifically to help them achieve two goals: to operate and maintain the inland waterway system as efficiently as possible and to select the best size, location, and timing of inland waterway improvements.

INSA essentially provides a planning capability and comprises an integrated system of four models, data, and planning procedures. Because the program recognizes that waterway transportation is a dynamic physical system embedded in an equally dynamic multimodal transportation market and national economic system, the system of models is designed to mimic the national market system and the role of inland waterway transportation within that market system. INSA simulates the market forces by use of a commodity-flow model and a multimodal model. The commodity-flow model is a multiregional input-output model designed to reproduce the market conditions of the U.S. economy, and the multimodal model gives modal transportation supply conditions. When these models operate together, they simulate the interplay of the national economy and the modal transportation system in bulk commodity movement.

Another pair of models simulates inland waterway transportation. Interaction among commodity traffic, the towing industry, and the waterway are simulated by a flotilla model and a navigation simulation model. The flotilla model represents the towing industry's response to commodity traffic, physical waterway characteristics, and operating delays caused by congestion. Given the waterway network, commodity traffic patterns, and expected operating delays, the flotilla model generates a least cost fleet or mix of towboats and barges required for the movement of commodities. The inland navigation simulation model is intended to represent inland waterway navigation as a large interacting system and to test by simulation the local and systemwide performance impact of a replacement structure, a new channel configuration, or an entirely new waterway. The navigation simulation model can also test new lock operating policies, variations in lock design, changes in channel depth, and many other controllable factors. Together the two models can estimate waterway network cost and capacity for providing freight transportation, and those estimates in turn can be used to estimate economic impacts, costs, and benefits.

The four INSA models are shown schematically in Figure 1 and described below. These four models can be operated together as a unit or as individual models by using any means or models other than those of INSA as input.

This paper summarizes the results of several years of intensive research. Because of the extent and complexity of the study, it is not possible to present more than the general concept of the models.

COMMODITY-FLOW MODEL

The purpose of the INSA commodity-flow model is to forecast the demand for interregional bulk commodity transportation. The commodity-flow model is largely concerned with predicting the size and shape of particular sectors of an economic system. In the model, an economy consists of a set of regions, each of which contains a set of economic sectors or industries. These economic sectors produce an output product to satisfy perceived domestic and export demand. The production process in each sector requires using a combination of inputs (raw materials, labor, and capital goods) to produce the output product. The mix and sources of inputs to the production process depend primarily on delivered input prices, including the price of transportation, as each sector seeks efficient input combinations. Commodity flows occur in this system as raw materials travel to production sites and commodities move to satisfy domestic and export demand.

The commodity-flow model is a multiregional input-output model in which market dynamics determine the location, composition, and pricing of output and the behavior of economic aggregates determines the level of output. In this system consumers select commodity