

discontinuities from the earlier period<sup>2</sup>. Global and Virtual firms characterize the contemporary industrial scene. The transport activities and services offered today to the global and virtual corporations can be best described as *the logistical channel*. Transport logistics firms provide not only traditional material flow faster, cheaper, and more reliably than before; they also offer *new* types of transport and logistical services. These new services are in the form of reliability, timeliness, and strategic outsourcing of a corporation's distribution functions. Such services provide flexibility and new modes of operation, thereby offering strategic competitive advantages to their customers (the manufacturing and service firms). In this manner, the new transport logistics firms help gain system-wide cost reduction and value addition.

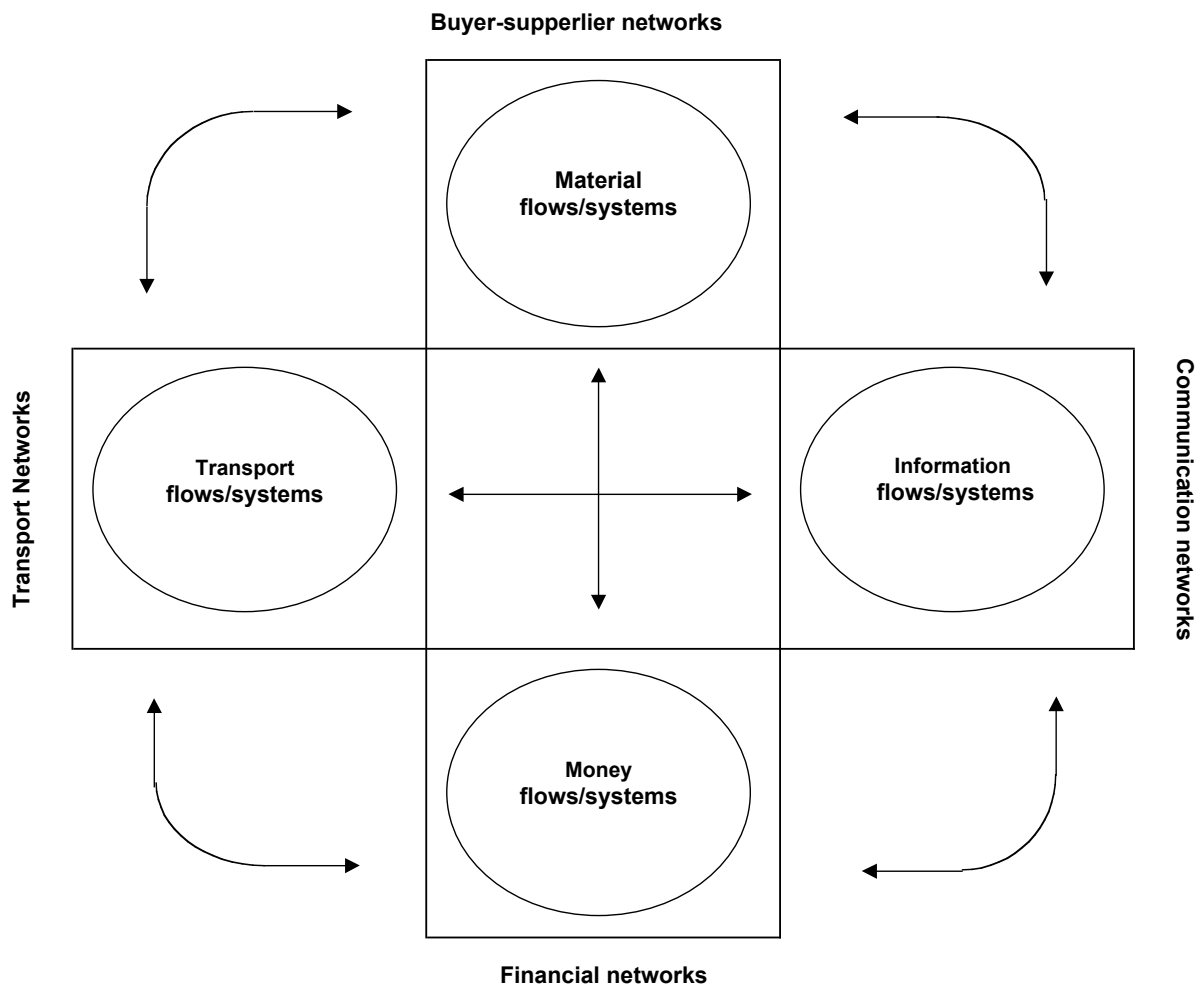
Further transportation and distribution concerns are increasingly integrated into the strategic decisions of firms, for example, where to locate their production and warehouse facilities, where to source their intermediate goods, and how to manage their value chains such as using Just-In-Time (JIT) systems, move into e-commerce and so on. Transport firms are actively involved in lowering order cycle times and in implementing the consumer demand oriented 'pull' system of logistics (FHWA, 1998). These changes are reflected in terms such as supply and value chain management or integrated logistics. The resulting integration blurs the boundaries between the various participants in the global supply or value chains.

Such chains in the global economic / transport system represent seamless linking of several separate but tightly linked networks (Figure 2). There are: transport networks (with transport flows), information networks (information flows), buyer-supplier networks (material flows), and financial networks (money flows). Transport flows are derived from demands expressed in buyer-supplier networks, with the transactions consummated when goods delivery is made in exchange of money flows from financial networks. The activities in all networks are coordinated by flows and exchanges of information from communication networks.

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<sup>2</sup> It must be noted that that the new attributes of the logistical system noted for the 'after 1990' period must have been incipient in late 1980s.

**Figure 2: Conceptual Model of Four Types of Networks or Systems Encountered in Business Logistics**



Source: OECD, 1996

The efficiency of operation of these networks is determined both by the emerging business practices and the public policies which are critical to the costs and delays of cross-border goods flow.

### **The Survey Document**

The objective of this survey instrument will be to identify, monitor and measure attributes of the new transportation and distribution system. A systematic documentation of these diverse and complex attributes of the contemporary transport sector can be made with a suitably designed

survey instrument. This report does not design that instrument. However, it spells out the scope and constituent parts of a desired survey instrument.

The conventional role of a public sector data agency has been to provide data to increase the efficiencies of its major clients, namely the Federal, state, and local levels of the public sector. However, the ability of the U.S. firms to increase their competitiveness during globalization depends on the attributes of the distribution and logistics firms that are influenced by the quantity and quality of public infrastructure and other public policies. If the public sector is to increase the competitiveness of US firms, the data needs of both public and private sectors need attention—the assumption being that the public sector has an enabling role with respect to the private sector activities. Conversely, user fees and lobbying by the private sector impact public policies and infrastructure supply. We can view the proposed survey instrument as a mechanism to address the joint data needs of both sectors particularly as the processes of globalization, privatization, and deregulation are being pursued vigorously by the U.S. government. Moreover, there is increasing interest in public-private partnerships, stakeholder voice and interactive cooperative strategies. Consequently, this report argues that the survey instrument should be administered to both the public and private sectors using different modules to capture the different behaviors. A significant portion of the instrument, however, will have issues common to both sectors.

The public sector respondents – the infrastructure supply sector - will include units at the national level (such as customs and cross border operators, port authorities); state and local levels who are responsible for adopting innovative electronic monitoring and source data acquisition technologies and for maintaining the infrastructure. The private sector actors - the infrastructure demand sector - should be broadly defined to include shippers, carriers, logistics firms and nonprofit transportation organizations. It will be desirable to administer the survey instrument to a range of provider and user groups due to the push in favor of a seamless distribution system. The case studies point out that one of the important institutional changes in the freight distribution system is the growing partnerships, for example, between shippers, railway operators and customs officials or between shippers, logistics firms and air and ocean terminals. Thus one of the early tasks will be to identify the respondent groups.

The major dimensions of the transport freight sector, which need to be monitored and measured, have been identified in a TRB Report (1999). The TRB report, however, examines business transportation issues and strategies to improve business performance and does not address information requirements. It also limits itself to the role of the public sector in these strategies (Table 2). Our point of departure is to assess how the public sector is responding to business needs, and what adjustments the private sector makes in response. For example, how are road incidents managed by the public sector? Do drivers have advance information on bottlenecks? Do they access GPS to bypass congestion points? In other words, what interactions are taking place between the public and private sectors in order to meet the tight schedules of transport logistical chains. Our interest is in the public-private interactions.

We organize the information needs in the survey into 4 modules of the survey. Module 1 will document the attributes of the range of economic actors—private and public—in the freight transport enterprise. Module 2 deals with the use of IT and Intelligent Transportation Systems (ITS). Module 3 covers intermodalism. Module 4 focuses on the logistical trend and the resulting new patterns of transport services. Additional modules on human resource attributes can be also conceptualized.

**Table 2: Categorization of Potential Strategies to Address Business Transportation Issues**

To provide future opportunities for industries to improve their competitiveness by continuing to maintain lower inventories, increasing product delivery reliability, and improving speed of business travel, long-term short-term strategies include:

1. **Reduce Congestion and Bottlenecks**
  - assure adequate access to business during peak periods for employees and customers eliminate bottlenecks
  - efficient control of incidents
  - reduce congestion
  - real-time tracking of congestion
2. **Border-crossing / Gateway Development**
  - improve emerging corridors, borders ports of entry, international gateways, and other infrastructure to meet the emerging needs of international business and tourism travel and freight movement
3. **Improve Capacity and Efficiency**
  - assure adequate access for developed and developing commercial and industrial areas
  - facilitate intermodal connections (access to ports, rail stations, truck terminals, rail yards, and airports) and services
  - assure adequate capacity in emerging corridors, areas targeted to attract industry, and between airports / other terminals and manufacturers / retailers
4. **Introduce New Technologies**
  - introduce new technology (vehicles, facilities and ITS) that can result in further significant reductions in travel time and increase in reliability
5. **Address Institutional Roadblocks**
  - eliminate institutional roadblocks to more efficient, more reliable, and less costly services international increased airline connections
  - simplify laws and regulations, e.g. maritime deregulation and uniform truck size / weight regulations
  - customs and immigration clearance streamlining
6. **Standardization of Equipment and Processes**
  - Standardize equipment and other standards, e.g. EDI and uniform container standards for all modes
  - encourage international standards and regulations that make possible the use of the same equipment around the world and offers the opportunity to establish more integrated international and domestic transportation services

Source: Transportation Research Board (TRB), 1999

Module 1: Attributes of the Transport Service Providers and Users

The Module will gather data on the attributes of the transport infrastructure and transport service providers and users. Typical variables will be the size and location of firms by sector, warehouse location and types, past and current data input and data acquisition procedures, adoption of electronic data acquisition etc. by type (e.g. transponders, GPS, on board computers, scanners), use of logistics firms and so on. For example, not all firms or all divisions/levels of the

public sector have adopted electronic data acquisition technologies or have the same rate of usage of third party logistics firms in their supply chains. There are also several types of logistics firms differing in their functions and attributes. Some are dependent totally on public infrastructure, others have developed their own asset bases etc. Consequently there are a variety of practices and complexity of institutions in the emerging distribution system. The objective of the first module will be to provide a description of the decision units as they vary in their practices toward, and usage of, transportation services.

Modules 2, 3 and 4 will focus on assessing the trends in the ongoing transformations of the transportation systems. Only three trends – the Adoption of ITS, the Attributes of Intermodalism, and the Characteristics of Transport Logistics– are discussed here for illustrative purposes. This is only a partial list of trends; an important task will be to decide *what* data should be collected on *which* of the numerous trends currently occurring in the transportation system.

### Module 2: Adoption of Intelligent Transportation Systems

The National ITS Program Plan (NITSPP) emphasized user services as its core goal and focused on the development and deployment of useful ITS products to increase efficiency, alleviate congestion related problems and enhance productivity through improved mobility. Many of the ITS technologies are currently being deployed such as driver information, route guidance, and incident management information. The survey needs to collect data on: a) which ITS technologies are being used and the reasons for their adoption, b) what barriers and constraints are faced by the users, and c) how the productivity of the supplier and user is being enhanced.

Table 3 provides a modified list of user service bundles. These have been selected from a larger list identified in the report. The bundles were selected based on their relevance for increasing the productivity of U.S. firms. Some of the technologies suggested in the ITS program plan are still in their developmental stage, others in the pilot testing and demonstration phase and still others are being deployed by both public and private sectors. The survey needs, at the outset, to focus on the latter category. For example, in the Travel and Transportation Management bundle, we need to know how prevalent is the adoption of en-route driver information

technologies, which firms are adopting them, how is this technology impacting driver productivity, reliability and so on. What technologies are being used by the public sector to manage incidents? Are truck drivers being provided advance information on incidents, delays through congestion and bottlenecks? Do the drivers use GPS systems or have on board computers to bypass congestion points, that is, how do the public and private sectors interact with ITS to meet tight JIT schedules, to optimize fleet and driver use and so on?

A number of technologies in the Commercial Vehicle Operations bundle have been adopted and are currently in operation. For example, we need to assess the trends in the prevalence and usage of vehicle electronic clearance technologies. What is the reduction in transport times of the commercial fleet or reduction of congestion on the highway? Does the adoption of these technologies allow more efficient use of the road infrastructure, reduce time at border crossings and so on? What are the capital costs to the trucking firms and the railways? What are the gains in terms of system reliability and agility as mentioned earlier in the discussion of the rationale for the survey?

Vehicle accidents are a primary cause of damages to goods, delays on highways and lack of on-time reliability. Are longitudinal collision avoidance technologies being deployed to increase driver vigilance and their ability to increase vehicular control as identified in Advanced Vehicle Control and Safety Systems bundle? Who is adopting these technologies? Does this vary with the fleet size of a trucking firm, their asset base and so on? What are the associated capital costs and what have been the savings in operational costs and service qualities?



**Table 3: User Service Bundles: The Use of ITS**

<b>Bundle</b>	<b>User Services</b>
1. Travel and Transportation Management	<ol style="list-style-type: none"> <li>1. En-route Driver Information</li> <li>2. Route Guidance</li> <li>3. Travel Service Information</li> <li>4. Traffic Control</li> <li>5. Incident Management</li> <li>6. Emissions Testing and Mitigation</li> </ol>
2. Electronic Payment	1. Electronic Payment Services
3. Commercial Vehicle Operations	<ol style="list-style-type: none"> <li>1. Commercial Vehicle Electronic Clearance</li> <li>2. Automated Roadside Safety Inspection</li> <li>3. On-board Safety Monitoring</li> <li>4. Commercial Vehicle Administrative Processes</li> <li>5. Hazardous Materials Incident Response</li> <li>6. Freight Mobility</li> </ol>
4. Emergency Management	<ol style="list-style-type: none"> <li>1. Emergency Notification and Personal Security</li> <li>2. Emergency Vehicle Management</li> </ol>
5. Advanced Vehicle Control and Safety Systems	<ol style="list-style-type: none"> <li>1. Longitudinal Collision Avoidance</li> <li>2. Lateral Collision Avoidance</li> <li>3. Intersection Collision Avoidance</li> <li>4. Vision Enhancement for Crash Avoidance</li> <li>5. Safety Readiness</li> <li>6. Pre-Crash Restraint Development</li> <li>7. Automated Highway System</li> </ol>

Information that will allow the assessment of the ITS plan and be extremely useful to both public and private sectors for further development and deployment of ITS technologies.

In summary, the objective of ITS is to increase efficiency, alleviate congestion related problems, to enhance productivity of transportation firms and increase transportation service characteristics. The survey instrument should gather information on these attributes to assess its impact on private and public sector productivity.

Module 3: Attributes of Intermodalism

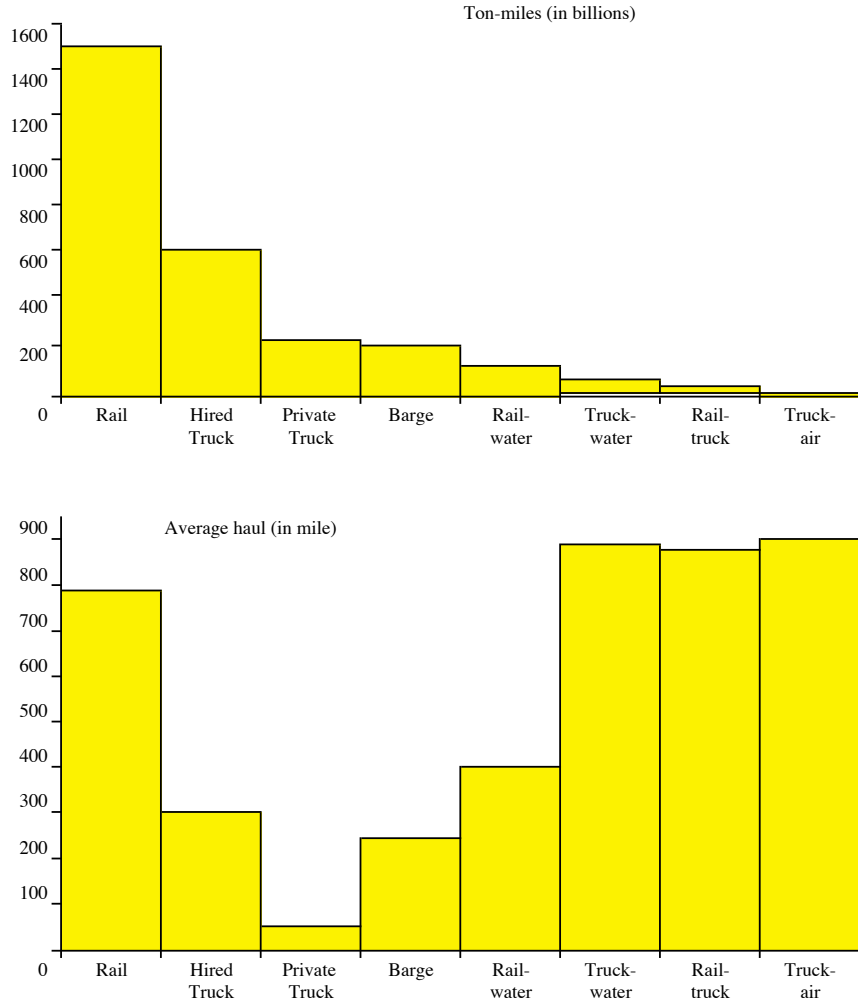
The ISTEA legislation sought to increase intermodalism. This module should include a whole set of dimensions that can assess the cooperation between various modes, and the use of multiple modes, in the shipping of a single product prior and post ISTEA and TEA-21.

Intermodalism has been facilitated through the incorporation of a range of ITS technologies such as innovations in Automatic Equipment Identification (AEI) and electronic data gathering and transmission. Therefore there is a linkage between the modules 2 and 3. Thus the survey instrument should seek information on how intermodalism is being encouraged and is functioning.

Intermodalism is an ongoing process. A number of IT innovations have been adopted by the public sector in all modes - highways, railways, ocean freight, and airports – as well as by the private sector shippers, carriers and logistics firms. Have these IT innovations, adopted by the several levels of government fostered intermodalism? What IT technologies have facilitated intermodalism? Has there been an increase in time and cost efficiencies in the transportation sector through intermodalism? Some modes have cooperative relationships such as between the railroads and ocean-going international or maritime carriers. Others have virtually no interaction such as between rail and air freight due to the demand for their different service attributes (FHWA, 1998). What institutional practices are furthering or hindering cooperation between the modes?

Modes vary in their average haul distances due to cost advantages. Trucks have the potential for generating freight for the railroads and can be their intermodal business partners as depicted in Figure 3. For example, truck-rail intermodalism is occurring in sectors such as automobiles. However, the rail-truck intermodal transport has not exploited the full potentials of their complementarities (Eno, 1997). Road congestions could be significantly reduced if trucks provided the short haul connections between shippers, the railroad and consumers. What factors explain the competitive rather than cooperative relationship between railroads and trucking in some sectors and not in others? Greater system efficiencies can be gained if the public sector could provide information for enhancing cooperative behavior between the modes.

**Figure 3: Freight Shipment Characteristics**



Source: Eno Transportation Foundation, 1997

Figure 4 depicts some important forms of freight intermodalism by type of commodity. The survey should help us assess why rail-water or truck-air services work well. What were the problems faced by the different modes as they partnered to provide more seamless transportation services? We need more information on the process, costs, procedures and so on. Do the respondents use single or multiple modes? If so, what modes are combined, for what distances? Who combines them? What is the frequency of usage of multiple modes as a number and as a percentage of total shipments? Are multiple modes used for some products and not all, if so which, in which direction, by length of distance and so on? If multiple modes are used we should try to assess some of the problems faced, i.e. delays, damage/ loss, penalties paid, loss of

customers etc. What ways have the firms gained i.e. through market enlargement, lower transportation costs, increased profit making, more efficient management, faster turn around time etc? How has intermodalism increased the use of inland ports or intermodal transfer terminals? How do these changes compare with the earlier and traditional practices of shippers and carriers? The completed survey instrument should be able to capture some of these trends and enhance our descriptive and analytical capabilities. Such information could help decision support systems discussed in Section III.

**Figure 4: Forms of Freight Intermodalism by Commodities**

<b>Air</b>						
<b>Truck</b>	Express containers, JIT recovery					
<b>Rail</b>	NONE	Domestic intermodal DST and TOFC				
<b>Pipe</b>	NONE	Petroleum, gasoline	NONE			
<b>Barge</b>	NONE	Coal, grain, chemicals	Coal, grain, ore	Petroleum, chemicals		
<b>Ship</b>	Express containers, JIT recovery	International containers, automobiles	Containers, grain automobiles, chemicals	Petroleum, gasoline	Coal, petroleum, containers	
	<b>Air</b>	<b>Truck</b>	<b>Rail</b>	<b>Pipe</b>	<b>Barge</b>	<b>Ship</b>

Source: Eno Transportation Foundation, 1997

#### Module 4: Characteristics of Transport Logistics

Improvements in intermodal freight transport, combined with the digital information network, have given rise to the increasing importance of logistics in goods movement. Logistics refers to the synchronized delivery of goods for production and consumption. In the transportation sector, this translates into the coordination of information with physical distribution. Table 4 shows the linkages between the transportation and information technologies. While information technologies have catalyzed the logistics movement, such tight orchestration, speed and agility in the physical distribution system has been made possible by institutional adjustments in the transportation services sector. Inventory management, order tracking, warehousing, time sensitive responses to electronic information, trade facilitation through intermodal and international transportation management and like sub-processes are essential elements for the effective delivery of inputs to production centers and delivery of finished goods to the customer. The survey needs to collect information on these dimensions of ITS and intermodalism in order to assess how they are impacting the logistics sector.

There are also several types of logistics firms differing in their functions and attributes. Some are dependent totally on public infrastructure; others have developed their own asset bases etc. Consequently there are a wide range of practices varying by firm attributes. Table 5 shows stages in the evolution of logistics and the role of transportation in the extended supply chain. The logistics function is evolving from a department buried in the organizational infrastructure in stage one to the total supply chain integration by third party, asset based logistics firms as shown in stage four. Consequently, the transportation attributes vary with the maturation of the logistics function in the extended supply chain management. Which firms use in-house logistics, third party logistics and integrated logistics firms? How do these practices vary by size of firm, type of commodities transported and so on?

**Table 4: Characterizing Management Levels of Logistics Systems for Designing Information Systems**

<b>Management Level</b>	<b>Requirement</b>	<b>Information Technology Information System</b>
<b>Freight &amp; Logistic Management</b>	<ul style="list-style-type: none"> <li>• Picking &amp; dispatching planning</li> <li>• Load planning</li> <li>• Route planning (strategic)</li> <li>• Shipment status and delivery confirmation</li> </ul>	<ul style="list-style-type: none"> <li>• Freight status monitoring and response system for customers</li> <li>• Processing of transport documents</li> <li>• Software for optimizing picking, load planning, dispatching and route planning</li> <li>• Database (road map, Traffic regulation, statistics of road and traffic information, etc.)</li> </ul>
<b>Fleet &amp; Container Management</b>	<ul style="list-style-type: none"> <li>• Route planning (tactical)</li> <li>• Fleet monitoring</li> </ul>	<ul style="list-style-type: none"> <li>• Fleet monitoring (tracking &amp; tracing)</li> <li>• Mobile communication</li> <li>• Provision of road traffic information</li> <li>• Database (road map, traffic regulation, etc.)</li> </ul>
<b>Vehicle Management</b>	<ul style="list-style-type: none"> <li>• On road vehicle/cargo monitor</li> <li>• Automatic debiting</li> <li>• Emergency calls</li> </ul>	<ul style="list-style-type: none"> <li>• Mobile communication device</li> <li>• On-board information system</li> </ul>
<b>Infrastructure Management</b>	<ul style="list-style-type: none"> <li>• Customs clearance</li> <li>• Monitoring of special vehicles (heavy duty vehicle, hazardous goods)</li> </ul>	<ul style="list-style-type: none"> <li>• Mobile communication</li> <li>• Processing of documents</li> <li>• Monitoring system</li> <li>• Network system to link the operations at stations</li> </ul>

Source: OECD, 1996

Data can be useful for furthering the competitiveness of U.S. firms in the global supply chain. Table 6 provides one snapshot of some of the data needs useful for addressing the major issues critical for management of the global supply chain. For example what carriers are selected? How is this related to carrier management practices and other attributes? What percentage of carrier volume is LTL? Are inbound and outbound shipment volumes aggregated

to capture volume discounts? Are volume aggregates made of similar or complementary commodities? What metrics are used to monitor carrier performance?

Damage of goods and risk assessment is an important component of transport logistics effectiveness. How are damages assessed? When are the titles of shipments taken – at the supplier factory gate or at the delivery point? What forms of ITS are used in the transit tracking of goods or is there only tracking of the fleet? The survey can solicit information on annual volumes of logistics firms by mode or intermodal use, their reliability of on schedule deliveries and so on.

As the direction of technology and product innovation is moving towards customizing the product designs for the consumer, the pressure grows on the transport logistics provider to develop ever newer ways to offer the marketplace the level of choice demanded while keeping transport costs at affordable levels. Further, new forms of distribution such as the ‘Channel structure’<sup>3</sup>, and J4U distribution, and final destination choices put a premium on a high level of coordination among the participants in the transport chain. In turn, such coordination is a function of levels and ease of information flow among the spatially far-flung members of the network.

**Table 5: Stages of Organizational Growth in Supply-chain Management Competency**

<b>Stage 1</b>	<b>Stage 2</b>	<b>Stage 3</b>	<b>Stage 4</b>
<b>Stunted Logistics Performer</b>	<b>Neophyte Logistics Performance</b>	<b>Internally Integrated Performer</b>	<b>Externally Integrated Logistics Performer</b>
Logistics buried at lowest levels of corporate organizations	Stovepiped logistics; each function acts in relative autonomy (e.g., purchasing decisions are detached from transportation or warehousing decisions). In addition, each operating unit or strategic business unit acts separately. There is an unsegmented supply base with no formal supply-chain partnerships	Internal cross-functional teams spanning physical distribution functions such as transportation warehousing, and customer order management; the start of segmenting the supply base and organizing core suppliers	Integrate networked logistics teams and shared performance management information systems enable the corporation to manage its web of supply-chain relationships more in real time. Far closer alignment between production / service logistics and patterns of actual customer demand.
Logistics defined as shipping function	Logistics defined as shipping and warehousing functions	Logistics defined as shipping, warehousing, and customer service functions	Logistics defined as total supply-chain integration: purchasing, shipping, warehousing, customer service, and collaborative planning / forecasting functions
Run by shipping clerks with little authority outside the immediate shipping area	Run by military-style logisticians who exercise more authority to monitor performance of processes across a limited lateral span of control and take a range of improvement actions	Run by a chief logistics officer with a high level of formal control over a greater lateral span of related logistics functions	Run by a VP for supply chain with determinate strategic influence over supply-chain functions conducted by both internal operating units and externally owned operating units

Source: Boyson, Corsi, Dresner, Harrington & Rabinovich, 1999.

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<sup>3</sup> where manufacturers interact electronically with customers and use home-delivery bypassing retailers

**Table 6: Major Steps and Issues in Global Supply Chain: Data Needs**

<b>Designing and Managing an Effective Global Supply Chain is Very Complex and Addresses a Wide Variety Of Issues</b>	
<b>Internal Local Transportation</b>	<b>Consolidator</b>
<ul style="list-style-type: none"> <li>• Which mode to use?</li> <li>• Which carriers?</li> <li>• Who has what responsibility for shipping?</li> </ul>	<ul style="list-style-type: none"> <li>• Where to consolidate?</li> <li>• Perform in-house or use third party?</li> <li>• What levels of service?</li> <li>• Extent of consolidation?</li> </ul>
<b>Export Documentation</b>	<b>U.S. Customs</b>
<ul style="list-style-type: none"> <li>• Which port to use?</li> <li>• Which mode?</li> <li>• Which carriers?</li> <li>• Use freight forwarders or deal directly?</li> <li>• What levels of service?</li> </ul>	Clearance <ul style="list-style-type: none"> <li>• Which brokers?</li> <li>• What levels of management / coordination with U.S. transportation?</li> </ul>
<b>Deconsolidatory</b>	<b>Domestic U.S. Transportation</b>
<ul style="list-style-type: none"> <li>• Where to deconsolidate?</li> <li>• Perform in-house or use third party?</li> <li>• What levels of service?</li> <li>• Warehousing versus cross-docking</li> <li>• Store-ready versus repacking</li> </ul>	<b>Factories</b>

Source: McGowan, 1997

In summary, the survey instrument should attempt to identify and measure the key technological, institutional and economic forces driving transportation logistics.

### **Operationalization of Variables**

The earlier discussion provides a flavor of the types of information that can help the public sector assess and monitor the current trends in the evolving transportation system and to identify which variables are critical for enhancing the competitiveness of firms in the global market place. It is too premature, in this report, to operationalize variables as the dimensions of the new transportation services have not been prioritized. We have only limited at this stage at the potential scope of a survey instrument. In fact, we suggest that the *first actionable task*

should focus on workshops with Inter Agency, academic and private sector participation to design such a Survey. Consequently, we list some variables for only illustrative purposes.

#### Speed.

Can be measured as a time /distance ratio in transportation hauls, time spent at terminals, time spent on the last mile and so on.

#### Reliability

Can be measured as the ratio of consistent delivery on scheduled time relative to delayed deliveries. Delays can be measured in actual times or in averages. Reliability can also be measured in terms of the monetary value damage/loss of merchandise. It can also be measured in terms of client responsiveness such as information updates provided to customer when delays occur due to accidents, adverse weather and so on.

#### Tracking

Can be measured as real time information on the location of the vehicle from point to point. Tracking can also be measured in terms of the location of the merchandise, that is, the content of the container or vehicle. The method of tracking can be identified in terms of technology.

#### Safety of Mode

Can be measured as the number of accidents, safety of merchandise during shipment in terms of frequency of damage by merchandise type, amount of loss in monetary terms, by cause of damage, insurance costs and so on.

#### Flexibility

Can be measured as the ability to switch between alternate routes, to respond to unscheduled changes in destination due to unforeseen/unplanned incidents and so on.

### Agility

Can be measured as the ability of the carrier to respond at a short notice for picking up new deliveries. This can be measured by types of merchandise, proximity of the new delivery site to the new planned site, adaptation to alterations in schedule and so on.

While we cannot answer these operationalization questions now, the survey document will need to address what units of observation will be most appropriate for measuring these dimensions. Should these be measured in terms of individual shipments, or as averages, for example? Many such decisions will need to be taken before the survey instrument is finalized.

## **III. TRANSPORTATION DECISION SUPPORT INFORMATION FOR BTS**

### **Rationale**

A major mission of BTS is, as suggested by ISTEA and TEA 21, to develop the information needed to support effective transport decisions in the public sector at the Federal, state, and local levels. The report “Data for Decisions” prepared by TRB just prior to the formation of BTS identifies the types of such data. The dominant focus of these data needs pertain to transport decisions concerned with infrastructure expansion and locations, though issues relating to safety and environmental quality receive attention.

In the last decade or so, paralleling the explosive growth of international trade and the globalization trends, there have developed new transport policies that have been supportive of these trends in the U.S. Three such recent developments in the U.S. in the transportation public policy environment suggest a potential expansion in the information needs of BTS.

First, novel ways of expanding infrastructure capacity through the public sector promotion of the deployment of Intelligent Transportation Systems (ITS) are one development. In such systems, the use of Information Technologies (IT) increases effective infrastructure capacity by augmenting supply and manipulating the spatial and temporal aspects of transport

demand. Perhaps there are categories and items of relevant data needed by BTS to support public decisions in this evolving world of ITS.

Second, in the last decade or two of rapidly increasing role of international trade in the U.S. economy, a host of new supportive transport policies have come to the fore. As noted earlier, these policies include transport deregulation, promotion of modal competition, intermodality, lowering the costs of cross-border goods transit, regional and local, economic growth incentives, etc. Such policies, by altering the institutional structure of transport, have led to logistical organizational innovations and enhanced productivity in the U.S. and elsewhere (Lakshmanan and Anderson, 2000). To the degree these policies have influenced the evolution of the freight transport sector, there is both analytical and policy interest in these transport policy decisions. What kinds of data needs arise in this context for BTS to pursue?

Third, the recent rise of accountability concerns in the public sector has spawned a variety of management innovations in government. In the U.S. they derive from the requirements posed by The Government Performance and Review Act (GPRA), which requires regular monitoring and measuring of performance of government programs. Performance indicators, when defined and measured appropriately, are needed to ascertain the progress towards objectives. In Europe benchmarking, as a private sector tool for managing and improving policies for achieving the potential of economic activity in a global economy, is being applied in the transport public sector.

In summary, it appears that the combination of transformational changes in the freight sector and the recent parallel development of supportive public policies in the U.S. is likely to impact upon the transport decision information agenda of BTS. What new decision informational needs arise in the evolving freight sector and the transport policy environment?

### **Information Needs Assessment**

Since this task deals with a core mission of BTS, it warrants careful and prudent analysis. The determination of data needs for decision support at BTS cannot be lightly or frequently made the rationale presented here for a new determination of BTS data needs at this stage is

threefold: there appear to be major changes in the functions and operations of the freight transport sector, in its transport policy environment, and in the ‘transport governance structures’. If it is true that a significantly different world of freight transport is emerging, the case for a fresh effort to identify BTS data needs becomes stronger.

The conduct and interpretation of the results of the survey of the freight transport sector recommended in the previous task should provide a realistic picture of that sector—its composition, functions and services, organizational structures, and its policy environment. Inferences can be drawn about the degrees and kinds of differences between that sector and the traditional vision of the freight sector (for example, the attributes of the U.S. freight system implied in the Commodity Flow Surveys of 1993 or 1997, with their emphasis on commodities, modal composition, origins and destinations).

Our view is that the first step towards further defining and elaborating BTS’s data needs in the emerging world is to review the survey results and develop a statistical and interpretive narrative of the freight transport sector. Inferences can be drawn on the interactions among the participants in the transport logistics chain, the flows of information and decisions among participants, and the types of transport-related decisions made by public sector actors in the regional or global supply chain. Further, a paper outlining ‘Lessons Learnt’ from the survey can be generated.

The next step is to build on the report documenting the knowledge gained from this survey task and interpretation of results. Specifically, a Discussion Paper on ‘Changing Information Requirements for BTS’ will be prepared. This discussion paper, along with the ‘Lessons Learnt’ need to be presented, discussed and reformulated at an invitational workshop organized by BTS. The expected outcome is an advanced version of the Discussion Paper on ‘Changing Information Requirements’.

The final step involves the finalization of the paper into a report along the lines of ‘Information for Decision Support at BTS’. This report will be the outcome of a broad technical consultation with the broadest possible group of stakeholders organized by a conference.

## **IV. TOWARD A TRANSPORTATION INFORMATION SUPERHIGHWAY**

### **Rationale**

Throughout this report there has been an emphasis on the need for BTS to document the vast changes brought about by the expansion of Information Technologies into the Transportation Sector. We have also argued that *knowledge about* the activities of the public and private sectors in transportation need to be linked, as the activities of the two sectors are already interactive in practice. This interaction between the two complimentary sectors is increasing the competitiveness of U.S. firms in the contemporary world of globalization. In a rapidly changing world, access to contemporary, particularly, real time information has accelerated the efficiencies of scale and scope in production, distribution and service delivery

Data agencies, such as the BTS have key roles to play in pushing the knowledge envelope forward for decisions in the evolving networked knowledge society. Surveys are accepted methods for data collection; they are still the standard staple of data agencies and are valuable for deriving baseline information for benchmarking and monitoring of system performance over time. However, the National Performance Review (NPR) report emphasized the need to move away from the hierarchical data design structures, developed in the 1930's. They are *unsuitable* for and *unable* to keep up with the customer demand for information and the wide range of Government services in the new decision environments.

BTS has done a commendable job in listing and compiling transportation databases. Report Three of this project, submitted earlier to BTS, lists a large number of data bases available from the BTS and from other federal and international agencies (Tsai and Chatterjee, 2000). However, there are serious limitations in using these data sets due to the inconsistency between items, plethora of definitions, different metrics of measurement and so on as highlighted in that Report. These limitations cause the databases to be incompatible and thus difficult (if not incorrect) to use. As these databases were developed for the needs of the different modes, and

reflect what they do, they are representative of the increasingly obsolescent hierarchical design structure of decisions.

To address the problems of the networked society of the contemporary globalized world, we need to develop data architectures that are horizontal. In such frameworks, metadata can permit data users – public and private sectors- to easily access data from diverse sources. While data can be collected and maintained by numerous organizations and government agencies, they need to possess compatible data structures. Just as the World Wide Web increased global efficiencies and integration through an information system that is international in scope and context, we can visualize a similar approach to networking and interconnecting all production, service delivery and transportation related data. As noted in our Report Three to BTS (Tsai and Chatterjee, 2000), this needs to include both transportation and non-transportation data from diverse public and private sources.

The internet has already demonstrated how information technology can speed up and increase the efficiency, not only for accessing information for the sake of knowledge, but also in its practical dimensions of increasing business productivity and consumer options. Globalization and e-commerce are examples of sweeping structural changes greatly enabled by ready access to information. Not only has the electronic world increased user access to government data, it has also increased the public and private sectors' ability to assemble data more easily and increase the effectiveness of their operations. In summary, advances in information technology have expanded the potential for cost-effective and user-friendly data assembly and access. It is possible to extend such an outcome to the transportation sector.

Due to the diverse data management schemas an initial step will be to determine the status, and the identification of, equivalent entities in all databases that can potentially contribute to the data warehouse. (For example, in the Tsai and Chatterjee Report (2000c) we identified the numerous databases but we have no idea of their interrelationships.) This requires sensitivity to data relationships in heterogeneous systems if they are to be moved into the data warehouse. Current advances in fuzzy matching are making such integration increasingly feasible. This will mean developing data transformation tools that will extract data from operational sources. Data

warehouses have already developed such capabilities, the task will be to identify and refine the capabilities from the existing knowledge base.

To summarize, increasing globalization, intermodalism and pressures for time compression in production and transport are making this approach to data acquisition increasingly desirable. Just as the internet and the world wide web have rapidly increased the efficiency of individual users and organizations in all sectors of the economy, we can conceive of a Transportation Information Superhighway (TIS) with onramps that can increase the efficiency of transport users in the traditional and virtual economies through easy access to networked data.

### **A Transportation Information Infrastructure (TII)**

Our presentations of the concept of a TII will be facilitated by a brief review of the experience of National Information Infrastructure (NII). The NII successfully laid the groundwork for the efficient creation and diffusion of information. Three of the seven goals articulated in the NII vision are also relevant for the TII envisaged here. The three common goals are:

- 1) Enhance the competitiveness of the manufacturing base.
- 2) Increase the speed and efficiency of electronic commerce, or business-to-business communication, to promote economic growth.
- 3) Provide government services to the public faster, more responsively, and more efficiently.

The public sector's role in the NII included the following:

“Set rules for competition and enforce them”

“Ensure that improvements in public communication benefit all Americans rather than a select few”

“Promote the adoption of standards that allows systems to interoperate”

“Ensure that intellectual property rights are respected”

“Support research to improve information systems and make them easier to use”

“Be a wise purchaser of information technologies and services”

“Reduce uncertainty and risk by funding pilot projects that demonstrate the usefulness and

economic efficiency of new services and applications”. (NII, 2000)

Table 7 has listed the nine principles and goals delineated by the NII as guiding its action for the information infrastructure as these principles will be relevant to the TII initiative, which their profiles are listed here, as well. They were spelled out in detail by the NII. For example the promotion of private sector investment called for tax and regulatory policies to encourage long term investment in innovation. The universal service principle called for policies that would encourage access by all including linking of libraries to the web. The goal of seamless, interactive user driven network ensured that information could be smoothly transferred across the network. These principles have already been embedded in the current NII.

At the outset, the NII noted that they “must tightly couple federal initiatives and programs to the goals, priorities, and activities of industry, academia and labor” for the social and economic objectives of the nation could only be furthered by drawing on the complementary strengths of these sectors. The NII was spectacularly successful in meeting these goals; it laid the groundwork for a global system commonly known as the Information Superhighway. The NII has also paved the way for providing a workable model for application to the specialized sectors. Since transportation provides extremely important linkages among social actors (with efficiency and equity considerations), it is time to consider and explore the potentials of a Transportation Information Infrastructure (TII).

It is our view that there are analogous roles for the public sector in the case of the TII. Among these roles, perhaps the most important task will be the setting of standards for information content, display and exchange; to encourage coordination among standards so that private, voluntary acceptance of these standards optimize efficiency. The acceptance of a common standard would enable more rapid infrastructure development and interfacing between technologies and services.

The task of the TII will be to provide a “network within this network” that can promote seamless, user driven access to all information relevant to those who use the transportation infrastructure – physical and institutional- for business and personal purposes. The system

efficiencies of the transportation sector will increase by ensuring universal access to all users, irrespective of size and monetary resources of firms.

**Table 7: The Initial Agenda for NII**

- 1). Promoting Private Sector Investment
- 2). Extending the "Universal Service" Concept to Ensure that Information Resources are Available to All at Affordable Prices
- 3). Promoting Technological Innovation and New Applications
- 4). Promoting Seamless, Interactive, User-Driven Operation
- 5). Ensuring Information Security and Network Reliability
- 6). Improving Management of the Radio Frequency Spectrum
- 7). Protecting Intellectual Property Rights
- 8). Coordinating with Other Levels of Government and with Other Nations
- 9). Providing Access to Government Information and Improving Government Procurement

*Source:* Information Infrastructure Task Force , <http://www.iitf.nist.gov>.

Vast amounts of transportation information currently exist in public agencies, shipper, carrier and logistics firms, information vendors, not for profit transport, member organizations and laboratories. Applications and software – existing and to be developed - have the potential for integrating these vast amounts of information collected by diverse groups and making them available to all those who need them irrespective of size of organization and their income constraints for data access. The TII can permit the transportation sector to enable us to more

fully capture the promise of the Information Age. For example, one of the major constraints faced by e-commerce firms is their ability to get their products to their customers on time during periods of high demand. Real time information on available capacity of carriers will go a long way to address these transportation and shipping problems.

There is precedence for use of this type of pooled information. Segments of the transportation sector are currently using the internet and world wide web to pool information to increase system efficiency. Mergers and acquisitions are allowing logistical firms to capture efficiencies of scale and scope. New alliances between the modes, between shippers and carriers are becoming feasible due to the information exchange attributes of the internet. New organizational forms are emerging. For example, the Trucking Information Exchange Services ([tie-services.com](http://tie-services.com)) provides trucking companies, brokers and shippers with information on available trucks and loads, thereby, increasing driver and truck usage. The National Transportation Exchange ([nte.net](http://nte.net)) provides trading exchange opportunities to its member shippers and carriers. Tansplace.Com, the result of the merger of the logistics arms of 6 of the 10 largest trucking companies, was formed to provide shippers enhanced information about available capacity in truckload, intermodal and international services of the member firms. The internet has significantly improved the operational efficiency of sectors such as air freight, cartage and household delivery services as can be witnessed by FEDEX, UPS, Peapod, Homeruns and scores of like enterprises. However, these innovative organizational responses benefit a small segment of the shipper, carrier and logistics firms due to the high front end costs and access limitations of proprietary information management systems.

A greater flow of information on transportation services will allow smaller carriers to partner with these large alliances, thereby, fulfilling the universal access principal, currently valuable efficiency and equity attributes of the internet. A similar approach to TII will permit the smaller transportation firms to survive under the fiercely competitive pressures of globalized economies. It will increase system efficiency of the entire transportation sector through higher driver and vehicle utilization rates. Instead of inefficient market segmentations, free flow of information has the potential to foster alliances between small and large transportation providers. Seamless transportation opportunities can increase through load consolidation and

deconsolidation in all areas of the country – remote or urban congested. Since attributes such as cost efficiency vary with firm size, geographical location, type of ownership and so on, developing a TII stands to benefit the whole economy and U.S. manufacturing and service businesses through improving freight density and cost reductions.

In summary, the importance of pooling information is already being demonstrated in the private sector. However, the full potentials have yet to be captured. The public sector has an important role to play because this is an infrastructure issue. To realize this vision the following tasks are being suggested for the next stage. A combination of agencies in the public sector (familiar with the principle of a horizontal architecture of information) such as the NIST is the best candidate to partner with BTS, if the agency decides to follow on the promise of a Transportation Information Infrastructure Network.

The tasks are explored in the following section.

### **The Next Steps**

BTS can take a leadership role in expanding the quality and effectiveness of DOT information and participating in the development of a system that would permit users of information to tap into the various transportation databases. The National Information Infrastructure (NII) initiative, known as the “information superhighway” provides a workable model for sector based Information Infrastructure Initiatives such as the proposed Transportation Information Infrastructure (TII) initiative. Some lessons from its experience are relevant to the discussion of tasks.

The White House convened the Information Infrastructure Task Force (IITF), in 1993, to articulate and implement the vision for the NII. The IITF was charged with making the promise of NII into a reality. It not only stimulated discussion and dialogue on how improvements in modern communication could be made more effective, they identified “critical barriers, enablers and the tools of government action most effective in the applications of advanced communication technologies”. Quoting from the words of Alexis de Tocqueville, they noted that innovations in communication and transportation – from postal roads, railroads and interstate

highways to telegraph, telephone and communication satellites were among the proudest achievements of the US as they facilitated the movement of people and ideas. However, the IITF focused on the communication sector; the transportation sector has yet to catch up. While the transportation service sector is currently using communications innovations to restructure operations, bottlenecks continue to exist because of the deficiencies in flow of transportation information between modes, between service provided and so on. In the 21<sup>st</sup> century, the boundaries between transportation and communication are increasingly being blurred and the public sector has once again an opportunity to adopt an innovative guidance role to capture more of the potential of the internet.

The IITF successfully completed its mandate in partnership with the private sector in the space of approximately four years. It no longer convenes. However, the archival material is available for analysis and for drawing lessons for parallel initiatives in special sectors of the national economy.

Two immediate tasks are suggested.

1. A quick review and analysis of the archival material available on the President's Information Infrastructure Task Force, available in an archived site maintained by the Dept. of Commerce, will provide guidelines on how to proceed with the TII initiative. The U.S. National Information Infrastructure (NII) Virtual library, maintained by the Information Technology Laboratory of the National Institutes of Standards and Technology (NIST), contains current information on new developments. The review will have the following objectives:
  - a. Identify the sequence of steps followed by the IITF as they proceeded with their task. What problems did they face? How did they deal with the problems and what lessons does this provide for TII.
  - b. Analyze the composition of the NII Task Force.
  - c. Prepare a background document.

2. Form a Committee for convening a Transportation Information Infrastructure Task Force (TIITF), with the participation of the modal administrations and other Federal agencies (such as Commerce, HUD, EPA). The TIITF will play the key role in the application of information and telecommunication technologies for the design and implementation of the transportation information superhighway. The task of this preparatory Committee will be to finalize the composition of the TIITF, which should include members from the business community, state governments, academics from the IT and transportation engineering departments, the nonprofit transportation sectors, software vendors, systems integrators, CEOs from shippers, carriers and logistics firms among others. The composition of TIITF will require deliberations between BTS and other members of the Committee. The IITF deliberated and fulfilled its role in three to four years. We envisage a two year mandate for the TIITF to implement the TII as rapid advances have been made in horizontal, scalable data architectures for data warehousing in the last few years.

The task of developing a transportation information superhighway will be complex because of the enormous size of the databases and the incompatibility of the diverse sources of information. For starters, two issues – metadata and data warehousing- requiring consideration are discussed as illustrations of issues that will need to be addressed.

### **Metadata**

Metadata is data about data. Metadata is necessary to synchronize data gathered by different types of institutions and vendors. Metadata deals with characterizing and indexing data, specifying access protocol and so on. Because business data is assembled from various sources, private sector vendors have already developed products that can integrate data from diverse sources. Many options are available and there is active development in this area.

However, there are two problems with the current pattern of client-based development of software. It is expensive and the softwares are not compatible. Consequently, only larger firms can afford to buy these services from third party firms or to develop in house capabilities. The

products of these various vendors are different as they are customized for their clients. Thus there is considerable duplication and wastage and limited prospects for networking in the system.

An important role of the TIITF will be to review the products of various vendors, analyze their strengths in term of their applicability for the transportation sector and so on. The GIS community has spent resources on metadata as well. So BTS can play an important role in the TIITF's deliberation of standards that can be sensitive to GIS applications (as transportation is a spatial phenomena). Some of the relevant analytical issues concerned with GIS in transportation are discussed in detail in the Appendix to this report prepared by Prof. Raymond Dezzani of Boston University.

Establishing a common database structure and rules for conversion of data in heterogeneous systems to a common format will be an important role for the TIITF.

### **Data warehousing**

Data warehouses store vast amounts of data derived from diverse sources. The rapid reduction in the expenses for warehousing technology makes it practical to warehouse transportation data. Data warehouses can include historical/legacy data as well accurate updates by processing current data. For example, historical data on bottlenecks, congestion rates and time delays in specific areas, accident rates at particular points, toll booth congestion by time of day can provide valuable information for infrastructure development. Current data can help routing and thereby improve business performance. Swift and accurate processing of current data can also show how interventions are succeeding in reducing these historical problems and will allow users to adjust accordingly, thereby increasing efficiencies in the whole economy.

The hardware capacity needed is another constraint for data warehousing. Current improvements in dynamic, scalable architecture enables database servers to scale from gigabytes to multiple terabytes. Scalable architectures permit data bases to accommodate increased amounts of data and allow concurrent users. Informix, for example has developed such solutions. It is practical to develop management capacity at the federal level so that

consistent/uniform set of data transformation rules, error checking rules and so on can be developed.

## **V. CONCLUDING COMMENTS**

At the dawn of the 21<sup>st</sup> Century, a variety of technological, economic, social, and institutional changes have converged to create a new freight transport sector, whose reach, functions, and modes of operation are significantly different from those of its recent counterpart. The emerging freight transport sector not only offers speedier goods transport at declining costs, increasingly, it provides its customers a number of valuable services such as global time-definite delivery, ever increasing speed and frequency, lean inventories, strategic outsourcing of the distribution function, flexibility of destination choices, etc. Such services add value to the operations of its customers, conferring thereby strategic competitive advantages on customer U.S. firms operating in the global economy.

Since a major strategic objective of the U.S. Department of Transportation is the promotion of the economic growth and development, the enabling of the U.S. firms which operate in the competitive global economy has policy interest. The Bureau of Transportation Statistics (BTS) as a modal administration and a national statistical agency has a mission to develop the necessary transport and related information and knowledge, which would support transport decisions that enable American competitiveness.

This final and fourth report on the project, “Globalization, Transportation, and Competitiveness”, has presented and outlined a three-part approach for BTS to acquire the information and knowledge to help it to support U.S. DOT’s strategic goal of American economic growth and development. This approach was conceived in three parts.

The first part, an actionable step which can build upon the work carried out in this project, involves planning and carrying out, in the immediate future, a survey that documents the

interactive changes in the economy and the intermodal freight sector, so that one is able to arrive at a valid current picture of the scope, functions, and organization of the freight transport sector.

The second part of the approach will need to analyze what implications these transformational changes in the freight transport sector pose for transport policy at the Federal, State, and local levels, and identify the transportation information requirements associated with the transport policies at various levels.

The third part calls for the development of a transportation information architecture (or framework), consistent with a Federal government role of promoting transport competitiveness in the global arena—by providing an informational ‘public good’, which can improve the overall efficiency of private transport companies and logistics providers, thereby enhancing the competitive advantage of the U.S. firms (both transport and non-transport).

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## **APPENDIX**

### **Geographic Information Systems and Transportation: An Overview and Evaluation for GIS-SC Development.**

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#### **Introduction**

Geographic information systems (GIS) consist of a system of computer hardware and software designed for the purpose of spatial data input, storage, manipulation and analysis, display and query of georeferenced information. Most GIS encompass all these tasks in a single environment with a graphic user interface (GUI) to facilitate data processing. GIS are extremely complex in that each task of spatial data processing must permit a wide variety of options for input and output. Georeferenced data exhibit special characteristics and require coordinate operations and graphic rendering of output in map-form that other database management systems do not require or possess. Some examples include map projection and coordinate system selection and computation as well as graphic real-time coordinate geometry editing and map presentation. In addition, for spatial data processing to explicitly model spatial relations, topological structures that provide exact relationships among the mapped objects must be modeled and stored for accurate reconstruction.

GIS employs a map-type model without generally storing maps in the vector data format. In the case of raster images and databases, maps are stored and topology is explicit as the raster database consists of an array such that every piece of spatial data is spatially related to every other. On the other hand, vector databases require the construction of topological relations among the discrete spatial data elements that are being modeled. Therefore, topological relations are implicit in the structure, storage and referencing of data elements in vector GIS databases (Burrough and McDonnell 1998). Raster spatial databases and GIS usually require more space

in the physical memory of the computer hardware and, often require more processing time. In contrast, vector spatial databases and GIS usually require less space but have stricter data structuring requirements and often use nearly as much processing time for analysis and manipulation as the raster data sets.

The important aspect of vector databases is that they are much better for modeling discrete spatial entities with exact locations on the face of the earth such as transport networks. This does not preclude the use of raster data such as satellite images for augmenting transportation analysis. Practically, GIS permits and facilitates the creation of large spatial databases using a wide variety of different types of spatial data. One of the strengths of GIS is the ability to combine both vector and raster spatial data with satellite images, aerial photographs and digitized map information to create a new spatial database.

### **Models and Perspectives**

The true value of GIS is the way that spatial data and their corresponding distributions can be referenced so as to represent a portion of the Earth's surface. Every data record is tied to a particular geographic entity with spatial extent and location characteristics. Topology is structured from both the type of geographic entity being represented in the GIS and the nature of the spatial referencing system. Given this arrangement, any phenomenon that can be mapped can be indexed with respect to a given coordinate system and any other mapped entity. The standard vector GIS transportation model employed is the network structure model that consists of network links (arcs) and nodes (turns/stops). Polygon or area data can then be related to the network model through the conventions of arc-node topology (i.e., where arcs and nodes provide area delimiters) as in the TIGER model developed by the United States Census (USDC 1997).

The use of GIS for transport modeling (GIS-T) is unique in that the primary concerns are the network link-specific movement or flow capacity attributes (Thill 2000). This means that the links carry all attribute information concerning traffic parameters such as rates of linear displacement (e.g., speed), flows, impedances and any other information concerned with the movement of the traffic utilizing the network or link. Nodes carry all information concerning stop, intersection and turn attributes and all topological information regarding link

interconnections. These characteristics apply to any and all infrastructure network frameworks. Networks constructed in this way utilizing linear referencing attributes can very accurately represent real-world road and infrastructure systems except for on condition (Petzold and Freund 1990, Thill 2000, Scarponcini 1999).

The standard network framework consist of a two-dimensional, planar description of the world. However, the condition under which this framework collapses occurs when it becomes necessary to force nodes at network intersections such as in the case of highway overpasses. The three-dimensional, non-planar model would provide the necessary realism for navigational databases as well as for dynamic flow models. The non-planar model is enabled through new definitions of connectivity as well as adjustments to the valid topological relations among link and node structures in the network. As such, GIS-T has some unusual topological refinements required for data analysis not common to standard GIS functionality.

A number of specific GIS model types can be used to capture real-world processes. Goodchild (1992, 1998) has suggested three classes of relevant GIS models useful for transportation modeling. These models can be arranged according to different topological necessities: 1) discrete models used to describe points, lines and polygons in a vector framework, 2) field models as representations of continuous phenomenon with spatially autocorrelated variation usually described/interpolated from point distributions, and 3) network models representing topologically interconnected linear structures set within a reference surface (Thill 2000). These models can be used in conjunction to provide a complete description of the transportation process using network models and discrete models, as well as analyzing the generation mechanisms using discrete and field models (e.g., households, destinations and cost surfaces/interaction potentials).

As transport systems document movement, GIS-T must be able to model displacement and change over time. Claramunt et. al. (2000) describe three methods for modeling change: 1) through the use of map series; 2) through the use of a map symbol, such as a directed vector-symbol, that indicates the direction and magnitude of movement; and 3) through the use of computer animation. In addition, they posit the development of very dynamic GIS (VDGIS) that

integrates micro and macro analyses to create a "layered" data representation model that is closer to the actual behavior of traffic (Claramunt et. al. 2000). Theoretically, this can provide a model of traffic behavior in a network from the level of individual automobiles up through aggregate traffic flow.

### **The Space-Time Location Framework**

While models exist to capture space quite well within GIS, time is another matter. Some of the procedures for time-capture have been described in the previous paragraph. The fact remains that the best methods for currently examining time or dynamic influences in GIS is through georeferenced overlay using binary set operators. The operators IDENTITY, INTERSECT and UNION are standard across GIS and used to determine spatial set inclusion. These operators generally work for both vector and raster type discrete models. Fields and network models must be either modified through buffering to create area relations or as is the case with fields, converted directly into discrete areas. Time effects are evaluated using overlay to examine displacements that occur between georeferenced network or context layers for a common discrete entity among the spatial "time slices" of the dynamic process. In general, a constant resolution is assumed. Space-time representation is an active area of GIS research as none of the applications models are truly representative to be able to capture the complexities of actual dynamic processes. In addition, problems have existed for the data partitioning problem associated with the standard overlay apparatus and result. This problem results when many new polygons are created as the result of overlay and a quantitative value from one or both of the original polygons must be apportioned to the many new polygons. Area adjustment is used but is unsatisfactory as it requires the assumption of spatial homogeneity for the original data/polygon set. Recently, Mugglin *et. al.* (2000) have provided a more statistically rigorous and parsimonious apportionment solution using Bayesian methods making overlay procedures more reliable.

Space-time modeling can be easily performed using the GIS structure so as to incorporate specific spatial dependence models. Grid or raster-based GIS are ideal for constructing both spatial and space-time dependence using a basic Markov random field structure (Besag 1974, Cressie 1991, Ripley 1988). These models become somewhat more difficult to implement using

vector, irregular polygon structures but are still workable with some additional statistical distributional assumptions. Such models have been constructed for innovation diffusion (Haining 1983) and for transportation modeling (**reference**). This class of models, based on spatial Markov dependence, will continue to prove highly fruitful for spatial-temporal analysis, modeling and forecasting.

### **Traditional Transport Modeling**

Traditional transport modeling occupies the three realms of analysis, policy formulation and performance evaluation (Quiroga 2000). GIS has been demonstrated to facilitate and enhance all three activities. Examples of GIS for transport analysis cover transit network development (Choi and Jang 2000) and travel time forecasting models (You and Kim 2000). Both Choi and Jang (2000) and You and Kim (2000) demonstrate that GIS is useful for policy effects simulation and evaluation. Arentze et. al. (1994), Quiroga (2000) and Taylor et. al. (2000) illustrate the use of GIS for evaluating accessibility, congestion and traffic flows using performance measures and the global positioning system (GPS). Given this range of opportunities for GIS applications in transportation modeling, it seems likely that GIS will only become further developed and incorporated into transportation studies and system evaluation.

Transport models based on the gravity framework have made use of location information only indirectly for calibration purposes. Aggregate models of transportation behavior using traditional gravity models can yield interaction surfaces from point data that can be used to infer travel behaviors to either an area or network context. These models lack detail owing to the often high levels that data is aggregated and limited by generalization to a surface. Desegregate models have exhibited difficulties arising from the complexity of interacting variables, locations and trip sequencing. However, recent studies incorporating GIS have shown that most of these difficulties with traditional transport modeling can be eliminated (Kwan, 1997, 1998; Li, 1994; Miller, 1991, 1999).

Kwan (2000a) has framed a disaggregated GIS study of activity-travel patterns coupled with a three-dimensional transportation network and point-kernel estimates to provide information on both household space-time activity paths and path densities. In addition, Kwan

(2000a) standardizes the space-time paths to provide mean and variance behavior for origin (i.e., home) based trips. Such an application alludes not only to the great utility of GIS for data storage of spatial information but also to its use as an instrument of policy analysis and evaluation.

Performance evaluation of transportation systems can be greatly facilitated using GIS. Quiroga (2000) demonstrates that real-time evaluation can be performed seamlessly on a transport link in a linearly referenced network using distance-measuring equipment (DME) and real-time input from a global positioning system. Taylor *et. al.* (2000) illustrate the use of real time GPS data feed into GIS with information on distance traveled, position, speed, acceleration, fuel consumption, engine performance and air pollutant emissions. Such databases provide a rich source of information for vehicle transportation studies. Similar studies for rail, light rail and air transport systems could yield a similar complex, rich and useful source of transportation information. Furthermore, with acceptable data standards and internet data sharing this information could be made available to researchers with minimal time lag via internet servers.

GIS has extended the capability of traditional transportation modeling through its ability to incorporate more realistic modeling procedures and more complex data sets tied to spatial indices (Kwan 2000b). Given the capabilities of GIS to integrate and coordinate many different types of spatially-referenced information into increasingly complex model forms, it is likely that transportation modeling will become dominated by disaggregated studies of household behavior incorporating both census and transportation survey data. Thus, GIS facilitates much greater realism in model results.

### **Areas and Networks**

A classic problem of GIS is relating areas to network components. The problem is present in trip generation models when areas/polygons are assumed to generate network flows to other areas (i.e., destinations), where trip attraction characteristics are located. In addition, another problem of general economic interest is delineating market areas for networks; which, is important for facility location and spatial decision-making. Miller (1994) addressed this problem specifically using a Huff visit probability model with GIS so as to provide a more realistic

solution using street networks rather than presenting an isotropic planar result summarizing visit probabilities. Miller (1994) demonstrated that within GIS, functional areas can be delimited using network and flow criteria. This research portends future research that will relate transport networks to fixed areas, landuse types, land values, area productive capacity and agglomeration formation. These relations are critical for supply chain modeling that require both network flow and mode information as well as point and area information regarding warehousing costs and availability, productive capacity and market load or supplier demand for commodities and goods.

### **Intermodal and International Freight Networks**

As previously stated, the ability to delineate and model supply chains requires both network as well as area information. Only GIS provides the spatial data integration and topological referencing characteristics to capture spatial objects such as supply chains (Porter 1987). Southworth and Peterson (2000) construct an intermodal and trans-national freight network model using GIS. In their case, the GIS was used to organize and maintain the database while the routing algorithms were performed external to the GIS. However, this is usually not a great difficulty as most GIS possess a true programming macro-language. These macro-languages facilitate the creation of both graphic user interfaces and data interchange procedures that ease the transition from database creation and spatial query, performed in GIS, to data analysis, performed using other algorithms and routines. The data analysis routines may be either called within the GIS or remain external as stand-alone programs or packages. Ready-made interfaces such as the SPLUS Spatial Data Analyst is designed to provide ready access to relatively high-level spatial modeling through the ArcView modules of Arc/Info.

The requirements of supply chain and international intermodal freight and transport models are very similar. A multilayer arrangement of polygons, points and line networks are needed to capture spatial information on market areas, administrative regions/country boundaries, factory and warehouse locations, transshipment points, and modal line networks representing transport structures. Links between layers occur at common points where commodities and goods are transferred among transport modes or factories representing stages in the manufacturing process. Transfer links within terminal/transfer points indicate the direction and level of movement at a particular node. Data can then be coupled from a variety of sources

to capacitate the GIS model. Destinations and origins can be located and optimal cost/routing algorithms can determine solutions either internal or external to the GIS. Routing structures must be organized by commodity, manufacturer, shipper, and destination. Through the use of structuring the chain this way, chain can be referenced as objects within the GIS.

Such a framework would provide information on alternative transport modalities for specific manufacturers and commodity types. Data and GIS provided for this purpose would be extremely useful for determining the influence of transport services and policies on general economic development within and across regions. Such an instrument would be normally useful for transport policy evaluation and for directing funds for transport system investment. By structuring spatial GIS models to incorporate multiple regions and modalities, transport system impacts can be evaluated for a variety of industries and purposes. However, a general set of consistent data standards and quality reporting mechanisms must be instituted for an integrated transport GIS to be constructed and used by a variety of agencies.

### **Spatial Decision Support Systems and Metadata Needs**

A common set of data quality and map-based parameter indices are required for the fully integrated use of transportation GIS. At the very least, a common set of reporting data standards to a variety of users on a potentially varied set of platforms is required. Criteria of standardization include: coordinate system consistency, a minimum set of topological standards for point, line and polygon data reported as minimum "fuzzy tolerances", a common set of map objects defined as data for referencing and constructing map entities. Each of these are relatively self evident. Coordinate system consistency refers to a common set of map projections that can be defined with minimum-distortion characteristics. These map projections should be selected so as to avoid problems with cross-zone adjustments often associated with state-plane and UTM systems. Topological standards would ensure that errors do not accrue as spatial extent is increased. For example, if a seamless map of the continental United States is used for the construction of a transport base map, the minimum resolution reported, as fuzzy tolerance, should apply to the entire coverage. If variations occur, then this information should be made available to users as it will influence analysis. Finally, a common set of map objects referring to

the structural and data elements of analysis needs to be developed that will serve the needs of a variety of users.

When these goals have been achieved, an end purpose such as the construction of spatial decision support systems (SDSS) can be developed for groups of users (Armstrong, 1993). The purpose of SDSS is to provide an integrated analytical instrument that can interface directly with the GIS database and address a variety of simulation and analytical issues relating to user needs be they policy or performance oriented. Integrated transport GIS will be used by transport specialists but also by other groups such as university researchers, urban and regional planners, planners at the level of national decision-making and perhaps by other non-governmental organizations and groups. As such, spatial decision support systems developed by governmental agencies and paid with using public funds should serve many needs. In general, location and flow management problems should be addressed directly but Armstrong (1993) identifies several stages for SDSS development. The first step involves strategizing and the formulation of an initial solution process. The SDSS developers must decide what types of data resource the majority of users will need and then create an adaptive system for other potential users. The second stage will involve exploration of main problems in an attempt to identify solution spaces of the key problems a number of different ways. GIS is particularly adaptable for this purpose. The third step involves narrowing the range of the solution set so as to evaluate the possible solutions. The developers can then choose to incorporate solution algorithms for the majority of problems addressed and allow the minority of users to explore solution methods using an adaptive program. If the spatial database is created with sufficient care and attention to user detail, the SDSS should be able to solve the vast majority of simulation and analytic problems that users may put to the database.

Spatial decision support systems require data sets that can be manipulated through the application of a particular model or decision framework. Depending on the model, the data requirements will vary. However, the data should be available at the basic resolution of the minimum geographical units for the study. For network models, this means flow data or network characteristic data must be accurate at the level of the individual links and nodes that constitute the spatial system. With special regards to supply chain decision support systems, nodes must

consist of information concerning the node type, (e.g., manufacturing, storage, break point/modal change location, port, rail terminal, airport, etc.), production and warehousing characteristics, costs and throughputs by commodity type, manufacturer and storage facility. The nodes in such a support system must contain information on flow capacities and values by link and commodity, durations and resistances to flows by commodity and throughput mode as well as specific costs involved in movement. One purpose for such a supply chain SDSS may well be the determination of cost contribution to total cost allocation for each link and node by commodity and manufacturer so as to mitigate inefficient options by individual users.

The epitome of such a supply chain SDSS would be an object-based GIS system where specific commodities or manufacturers, or specific classes of commodities may be selected and traced, queried and analyzed for their spatial extensions, costs and profit contributions. This same system would provide adequate coverage for economic analysis of regional agglomeration, trade and specialization. A host of information provided by an object-based GIS SDSS would enable users to integrate information regarding network characteristic density at different scales for manufacturers, commodities and transport modes. In this way, the entire trace of the product supply chain from raw material to final market sale may be examined. When sufficient spatial data is coupled with a SDSS as described, then the true contributory role of transport in the economic growth process for regions, states and countries may rigorously be assessed.

Geographic information systems has much to offer transport analysis through the development of purely object-based systems and the addition of appropriate, high-quality data. Proper development of finer-resolution economic analysis demands extending analysis to transport networks and directly incorporating the supply chain paradigm (Porter, 1987). These systems would permit an examination of economic growth at a variety of scales and permit analysts to evaluate logistical efficiency by commodity, manufacturer and route selection. Currently, the data are not available to operationalize these tasks with GIS. The purpose of this survey has been to provide evidence that GIS is the appropriate tool for combining economic and transport system analysis but that the necessary data and SDSSs are missing. The next step is to begin assessing data requirements for large and small scale logistical analysis and establish the best means of data capture so as to be able to implement a functioning GIS-SC SDSS in the foreseeable future.

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