TRB

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Transportation Data, Statistics, and Information Technology in the New Millennium
State of the Art and Future Directions

Perspectives from Eight TRB Standing Committees
January 2000

Committee on Freight Transportation Data (A1B09)
Committee on Urban Transportation Data and Information Systems (A1D08)
Committee on Statewide Transportation Data and Information Systems (A1D09)
Committee on Travel Survey Methods (A1D10)
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Transportation Research Board
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The Transportation Research Board is a unit of the National Research Council, a private, nonprofit institution that is the principal operating agency of the National Academy of Sciences and the National Academy of Engineering. Under a Congressional charter granted to the National Academy of Sciences, the National Research Council provides scientific and technical advice to the government, the public, and the scientific and engineering communities.

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Introduction

The Transportation Research Board's (TRB's) 180 standing committees cover all modes and areas of transportation. More than 3,000 volunteers—including experts from academia, industry, and government—serve on these committees, which guide much of the work of the Board. Their personal contributions to TRB and the transportation community are numerous and significant, albeit immeasurable.

To mark the approach of the new millennium, the committees mounted a special effort to capture the current state of the art and practice and to provide perspectives on future directions in their areas. The papers published in this circular present the efforts of the committees that focus on transportation data, statistics, and information technology. These committees are listed at the beginning of this volume, with their chairs and secretaries.

In his introduction to the CD-ROM, *Transportation in the New Millennium*, containing the full set of committee papers, Harold (Skip) Paul, Chairman of the TRB Technical Activities Division Council, wrote, "We hope the discussion of issues and challenges likely to be faced in the future will encourage readers to become major players as these issues and challenges are addressed by the transportation community."

If you would like to comment on any of the papers in this circular, please contact the committee chair, the paper's author, or TRB staff officer Thomas M. Palmerlee at 202/334-2907, e-mail tpalmerl@nas.edu.

TRB Committees Focusing on Transportation Data, Statistics, and Information Technology

A1B09 FREIGHT TRANSPORTATION DATA
Scope: The purposes of the committee are to identify and publicize sources of and needs for data on commodity movements, international trade, freight transportation activity, and the economics and organization of establishments engaged in freight transportation; to advise data collection agencies on cost-effective means of fulfilling essential data needs; and to assist analysts and decision makers in the effective use of freight transportation data.

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- *Secretary*: **Benjamin J. Ritchey,** Vice President & General Manager, Transportation Market, Battelle, Columbus, OH Office, 505 King Avenue, Columbus, Ohio 43201-2693; 614/424-5701; ritchey@battelle.org

A1D08 URBAN TRANSPORTATION DATA AND INFORMATION SYSTEMS
Scope: This committee is interested in the design, collection, analysis, and reporting of transportation supply and demand data needed to support urban and metropolitan transportation planning efforts. In particular, the committee is interested in developing the data requirements of new and innovative techniques for measuring and monitoring the performance of metropolitan transportation systems; and in evaluating changes in demographic and urban travel characteristics. In terms of household and other transportation surveys, the committee is concerned with the analysis, reporting, archiving, and dissemination of results and data products. The committee is interested in the effective use of census and other federal, secondary data sources in metropolitan transportation planning. The committee is concerned with advancements in information systems and information technology for the improved dissemination and sharing of knowledge about metropolitan transportation systems and urban travel behavior. The Urban Data Committee's URL is http://www.mtc.ca.gov/trb/urban/

- *Chair*: **Charles L. Purvis,** Senior Transportation Planner, Metropolitan Transportation Commission, 101 8th Street, Oakland, CA 94607-4700; 510/464-7731; cpurvis@mtc.ca.gov
- *Secretary*: **Jerry D. Everett,** University of Tennessee, 600 Henley Street, Suite 309, Knoxville, TN 37996; 423-974-8275; jeverett@utk.edu

A1D08(1) SUBCOMMITTEE ON CENSUS DATA FOR TRANSPORTATION PLANNING
Scope: This subcommittee is interested in census data matters as they relate to statewide and metropolitan transportation planning. The focus of this

subcommittee spans the entire spectrum of census-related activities including applied uses of the data, the content of censuses, collection procedures and dissemination programs all within the context of past, present and future censuses. The URL for this committee is http://www.mcs.com/~berwyned/census/

- *Chair*: **Ed Christopher,** Bureau of Transportation Statistics, 400 7th Street, NW, Washington, DC 20590; 202/366-0412; berwyned@mcs.com

A1D09 STATEWIDE TRANSPORTATION DATA AND INFORMATION SYSTEMS

Scope: Research and technology transfer activities pertaining to statewide transportation planning data and information systems for all modes of transportation. A primary concern is the capability of information systems to integrate various transportation related data sources into a strategic multimodal information database for statewide transportation planning. The committee is also a forum for discussion of current planning data activities. The URL for the Committee on Statewide Transportation Data and Information Systems is http://members.tripod.com/~TRBstate/

- *Chair*: **Ronald W. Tweedie,** Director, Data Services Bureau, New York State DOT, Building 4, Room 115, 1220 Washington Avenue, Albany, NY 12232; 518/457-1965; rtweedie@gw.dot.state.ny.us
- *Secretary*: **Tony Esteve,** Federal Highway Administration, 400 7th Street, SW, Washington, DC 20590; 202/366-5051; tony.esteve@fhwa.dot.gov

A1D10 TRAVEL SURVEY METHODS

Scope: The committee focuses on all types of travel or activity surveys, including those pertaining to motorized and non-motorized travel; household and commercial travel; travel involving single or multiple occupancy vehicles; and workplace, visitor, or recreational travel. The committee is concerned with survey design, sampling, instrument development, data collection, data processing, data analysis, and reporting of results. The URL for the Committee on Travel Survey Methods is http://www.fhwa.dot.gov/ohim/trb/trbpage.htm

- *Chair*: **Elaine Murakami, Community Planner,** Federal Highway Administration, Office of Highway Policy Information, 400 Seventh Street, SW, Washington, DC 20590; 202/366-6971; Elaine.Murakami@fhwa.dot.gov
- *Secretary*: **Robert E. Griffiths,** Director, Technical Services, Metro Washington Council of Governments, 777 N. Capitol Street, NE, Washington, DC 20002-4226; 202/962-3280; reg1@erols.com

A2A01 PHOTOGRAMMETRY, REMOTE SENSING, SURVEYING, AND RELATED AUTOMATED SYSTEMS

Scope: This committee is concerned with aerial, terrestrial and close range photogrammetry, digital mapping, surveying, remote sensing and automated systems, particularly those related to photogrammetry, mapping and surveying. The committee is further interested in the development of systems that apply advancing technologies such as computer-aided graphics, design and mapping, geographic information systems, automated surveying, global positioning systems, photologging, and automated data collection systems. The committee is active in the promotion of new applications and improved instrumentation, techniques and procedures.

- *Chair*: **A. Keith Turner,** Professor of Geological Engineering, Colorado School of Mines, Dept. of Geology & Geological Engineering, Golden, CO 80401; 303/273-3802; kturner@mines.edu

A5003 INFORMATION SYSTEMS AND TECHNOLOGY
Scope: This committee is concerned with reviewing and assessing the current state of the art in the development and application of computer technologies to problems in the transportation engineering (planning, analysis, and design) field for productivity improvements. Areas of emphasis include: (1) computer systems' user interfaces (i.e. interactive graphics, knowledge based, etc.) and data portability (i.e. neutral files); (2) utility of computer technologies use in the transportation field; (3) encouragement of common semantics and standards use in the transportation field; (4) delineation and prioritization of research, development and demonstration programs to augment and supplement work presently underway; (5) facilitating and monitoring technology transfer between transportation organizations, vendors and universities in the role of "user advocate"; and (6) evaluating the impact of computer technologies on transportation organizations, including the productivity gains provided.

- *Chair*: **Jeffrey L. Western,** Deputy Director, Bureau of Automation Services, Wisconsin Department of Transportation, 4802 Sheboygan Ave. Room 201B, PO Box 7982 Madison, WI 53707;608/264-8712; jeffrey.western@dot.state.wi.us
- *Secretary*: **Bin Ran,** Assistant Professor, University of Wisconsin at Madison, 2256 Engineering Hall, 1415 Engineering Drive, Madison, WI 53706; 608/262-0052; bran@engr.wisc.edu

A5015 SPATIAL DATA AND INFORMATION SCIENCE
Scope: The scope of this Committee includes all aspects of the spatial, locational and temporal data used in transportation. The Committee is interested in both research into and applications of this information and its associated information systems, commonly referred to as Geographic Information Systems in Transportation (GIS-T). The committee will provide a focal point for and promote coordination of GIS-T activities within the TRB committee structure. Relevant activities include the application of spatial data and spatial sciences across the entire domain of transportation information systems. The URL for this committee is http://www.ctre.iastate.edu/trb-sdis/

- *Co-Chair*: **David R. Fletcher,** GEODIGM, PO Box 40483, Albuquerque, NM, 87106; 505/833-3309; fletcher.d@worldnet.att.net
- *Co-Chair*: **Kathleen L. Hancock**, Assistant Professor, University of Massachusetts, Amherst, 139 Marston Hall, Amherst, MA 01003; 413-545-0228; hancock@kirk.ecs.umass.edu
- *Secretary*: **Reg Souleyrette,** Associate Professor/Associate Director, Iowa State University, Civil Engineering/CTRE, Ames, IA 50011; 515/294-5453; reg@iastate.edu

A5016 NATIONAL TRANSPORTATION DATA REQUIREMENTS AND PROGRAMS

Scope: The scope of this committee includes the development of nationwide and international data on transportation needed to support decision making, and data-related research in all sectors of transportation. All aspects of data development are of interest including design, collection, analysis, reporting, funding, administration, dissemination, and coordination of statistical programs. Of particular interest is the coordination of transportation statistical programs with non-transportation programs; coordination between national level and other programs, including international, private, state, and local systems; and the structuring of statistical standards and criteria that guide the development of comprehensive transportation programs.

- *Chair*: **Alan E. Pisarski,** Consultant, 6501 Waterway Drive, Falls Church, VA 22044-1328; 703-941-4257; pisarski@ix.netcom.com
- *Secretary*: **John W. Fuller, Professor,** University of Iowa, 340 Jessup Hall, Iowa City, IA 52242-1316; 319/335-0038; John-W-Fuller@uiowa.edu

A5017 LIBRARY AND INFORMATION SCIENCE FOR TRANSPORTATION*

Scope: This committee serves as a forum for transportation librarians and the transportation research community on developments in information science and their applicability to transportation. The committee facilitates diffusion of national library and information science innovations throughout the transportation community by monitoring the use of new resources and tools in the transportation arena, defining critical research and training issues relating to their implementation, and promoting the benefits of these capabilities.

- *Chair*: **Jeanne F. Thomas,** Manager of Information Services, Michigan DOT, Information Services, 425 Ottawa, PO Box 30050, Lansing, MI 48909-7550; 517-335-2350; thomasj@mdot.state.mi.us
- *Secretary*: **Daniel C. Krummes,** Director, Harmer Davis Transportation Library, University of California, Berkeley, Institute of Transport Studies, 412 McLaughlin Hall, Berkeley, CA 94720; 510/642-3604; dkrummes@library.berkeley.edu

* No millennium paper is included for this committee.

Freight Transportation Data

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The Transportation Research Board (TRB) Committee on Freight Transportation Data pursues several goals:

- To identify and publicize sources of data—as well as the needs for data—on commodity movement, international trade, freight transportation, and the economics and organization of entities engaged in freight transportation;
- To advise data-collection agencies on cost-effective ways to fulfill essential data needs; and
- To assist analysts and decision makers in the effective use of freight transportation data.

As the new millennium approaches, several challenges face freight transportation:

- Logistics in a changing regulatory and technological environment,
- Impact of freight transportation service on global competitiveness,
- Energy and environmental concerns,
- Safety considerations,
- National security requirements, and
- Continued pressure to do more with fewer resources (*1*).

Appropriate data are fundamental to addressing these challenges. These data support two functions:

1. The identification and measurement of the impact of freight transportation on the transportation infrastructure, and
2. Integrated transportation planning, which considers the needs of freight transportation as part of an overall intermodal passenger and freight transportation system.

SOURCES OF FREIGHT DATA

A variety of freight transportation data are currently available, from microscopic, local survey data to macroscopic, national commodity flow data and from hard-copy improvement plans to digital data sets stored on electronic media. Sources of data include individual shippers, forwarders, and carriers; private vendors and consultants; and public agencies (*2–9*). However, use and availability of this information are limited by several considerations:

- How can private companies provide information without compromising their competitive advantage?
- How do users identify the data needed to address their problems?
- How do users locate appropriate data?
- How do users decide whether the available data can be used to solve those problems?
- How can users link data sets?
- How do users acquire data that are not currently available or have not yet been collected?

Understanding these issues and the limitations of currently available data sets is the starting point. Several areas already have been identified as requiring new data or the new packaging of existing data; these are outlined below.

Small Area Commodity Flow Data

The degree of detail required to record small area commodity flow is necessary if data are to be modeled and assigned to regional highway and railroad networks. Currently, federal agencies are unable to release information for public use unless it is aggregated into multicounty zones; state and local agencies often do not have the resources necessary for gathering such detailed information.

Transborder Data

Under contract with the U.S. Bureau of the Census the U.S. government receives unpublished data on U.S. exports and imports, via rail, truck, water, and pipeline, with Canada and Mexico. Certain information, such as the Mexican state of destination for U.S. exports is coded and keyed by the U.S. Bureau of the Census. The U.S. Bureau of Transportation Statistics of the U.S. Department of Transportation (DOT) and the U.S. Army Corps of Engineers (water transportation) post public information files on their websites.

The major data element missing from information for U.S. exports and imports is weight. Obtaining weight data for surface modes of transportation will make it easier to compare the data against the water transportation data. This information is important to carriers, shippers, and others because freight weight is more useful and meaningful for transportation analyses than is freight value; it can more accurately and readily be translated into numbers of vehicles.

Currently, the Railroad Carload Waybill Sample required by the U.S. Surface Transportation Board does not retrieve data from most shipments that terminate in Canada (that is, on Canadian railroads). Few shipments from Mexico to the United States are recorded, and U.S. exports to Mexico are indicated as terminating at U.S. border points. With the growth of intercountry freight traffic under the North American Free Trade Agreement (NAFTA), a NAFTA waybill sample should be developed to record complete movements among the United States, Canada, and Mexico.

Small Railroad Data

Precise information about how many freight railroads operate in the United States is difficult to obtain. The American Association of Railroads conducted a survey of operating railroads in 1997 and received responses from 507 local and 34 regional railroads in addition to the Class I railroads. Is this the extent of this segment of the industry? Information about parameters such as trackmiles, the percentage of ties replaced, and major commodities hauled also would be useful.

Intercity Trucking Data

In addition to existing shipper-based surveys such as the Commodity Flow Survey (CFS), a carrier-based survey similar to that used for domestic water transportation might provide better routing information about origin, destination, value, hazardous materials designation, and weight. In contrast, shipper-based surveys are better linked to industrial activity. However, a carrier-based survey, or a national truck waybill sample, should be less burdensome and less costly as information technology improves. However, comprehensive trucking data are difficult to acquire either way, because a large proportion of fleets has fewer than 10 vehicles, is private, or is not the primary business of the owner.

Regional and Local Truck Trips

Data on truck trips from warehouses to retailers are needed to measure the demand on local infrastructure. The total number of trips to convenience stores, grocery stores, gas stations, and similar facilities might not vary greatly among cities with comparable populations. This pattern should reduce survey requirements.

National Freight Databases of Metropolitan Planning Organizations

Uses for these data include cordon-line checks, corridor travel, and inflow/outflow imputations.

Truck Trips

Two possibilities for quantifying truck trips include

- Vehicle inventory and use survey (VIUS) data-accessing procedures to make truck-trips-per-day data available to MPOs, and
- Conversion tables to determine the number of trucks from the number of tons by examining relationships between value and weight or between ton-miles and vehicle miles traveled.

A possibility for larger MPOs is the metropolitan statistical area-level data that will be provided by the 1997 CFS.

Time Dimension of Freight Data

Time recognition and tracking information could provide measures of our transportation system's productivity. Issues such as just-in-time and next-day delivery as well as time-sensitive commodities (fresh food) also must include temporal considerations in logistics and planning activities.

For many uses of freight data, linking data sets together could provide the requisite information to address issues. However, this task is difficult, if not impossible, to achieve because of limitations caused by several kinds of inconsistencies:

- In the terms, phrases, codes, acronyms, and collection tools between and across modes (locations, commodities, vessel and vehicle types, and facilities);
- In geographic codes and references across databases; and
- Between U.S. military, commercial, and public uses and time frames of the transportation infrastructure and the data collected to support evaluation and planning for those uses.

FREIGHT DATA COLLECTION

Current efforts to collect surface freight data consist primarily of surveys, whereas water transportation data are submitted by domestic carriers and by foreign shippers and carriers for each movement. CFS data are submitted by shippers in response to a survey from the U.S. Bureau of the Census. Rail waybills are submitted by rail carriers in response to a survey from the U.S. Surface Transportation Board. Local agencies and private consultants request information via surveys sent to local shippers, carriers, and forwarders. The burden is on the companies to provide freight data.

The potential for unobtrusive freight data-collection methods is very high, especially given the expansion of advanced technologies such as electronic data interchange (EDI), intelligent transportation systems for commercial vehicle operation (ITS-CVO), global positioning systems (GPSs), web site data retrieval and assembly, and automated freight-handling activities. Development and use of these technologies could provide several benefits, such as

- Less paperwork for survey-laded companies (e.g., shippers, carriers, consignees).
- Reduced burden from public and agency data collection requirements, while still maintaining the necessary data.
- Improved completeness, quality, and timeliness of data and statistics for decision making.
- Consistent information about hazardous materials, making it possible to link hazard codes and commodity codes.

FREIGHT DATA DISSEMINATION

Traditionally, freight data have been disseminated as hard copies of reports and tables, on magnetic tape and related media, and, more recently, over the Internet. As the Internet has become widely accessible to the public via the World Wide Web, it has become the preferred mode for providing users with data, either directly (as downloadable files) or indirectly (by informing users of data available for purchase).

For potential users, the biggest limitation of information dissemination via the Internet is knowing which data are available. For data providers, the biggest limitations are letting users know what is available and making hard-copy information accessible. One possible way to minimize these limitations is to establish processes across federal and state agencies to maximize the distribution of data and products. Such procedures would cover the assessment of distribution media and the creation of supporting interagency and international teams to establish and implement standardized terms, codes, access protocols, and sharing protocols.

FUTURE DIRECTIONS

Freight movement will continue to be an integral part of the evaluation and planning of the transportation infrastructure. Users will become more comfortable with the interrelationship between freight and passengers, the evaluation of a seamless intermodal transportation system, and an effective working relationship between private and public sector partners. Data needs, sources, dissemination, and use will become unambiguous, and users will have access to necessary information to support informed decision making.

With rapidly advancing technological capabilities, private-sector professionals are moving quickly toward the use of real-time information for managing and optimizing freight handling and movement to minimize costs, maximize service, and meet regulatory requirements. The same information could provide the data required for public evaluation and planning purposes. Information from EDI and GPSs includes what kind of freight is being moved and how much, how and why it is being moved, when and where it is moving, and who is moving it. The challenge is to harvest and disseminate this information in a way that does not compromise the confidentiality of individual firms—hence their viability, competitiveness, and existence.

Ideally, as shippers and carriers generate electronic data for their own logistical and operational needs, the data would be filtered automatically and sent to a regulatory clearinghouse. There, the data would be processed to meet federal, state, and local regulations and requirements, then forwarded to the appropriate regulatory agencies. The same data also would be filtered and modified for public availability and use. However, availability is an issue that requires careful exploration. Similarly, publicly gathered information, such as weigh-in-motion, ITS-CVO monitoring, and travel-time and volume data also would be collected and made available to users through a clearinghouse with data-filtering and -linking options.

As we work toward the ideal system, several efforts could lead to more and better access to freight transportation data. These include

- Expanding interagency access to all federally collected transportation and trade data and statistics;
- Increasing public access to nonconfidential public transportation and trade data and statistics;
- Identifying data elements and aggregations of proprietary data that can be disseminated to the public while maintaining the proprietary nature of the data;
- Ensuring federal legislation to improve availability of federal transportation and trade data and statistics, such as within the Trade Secrets Act and Freedom of Information Act and promoting awareness of such legislation;
- Increasing interagency coordination to minimize both the public reporting burden and total federal costs;
- Boosting interagency efforts to create integrated statistical products; and
- Developing and applying a range of sophisticated data-fusion techniques, including simulation and statistical modeling, to fill gaps in freight flow data (*10*).

Challenges that face users and providers of freight data include allowing the private sector to maintain proprietary information while maximizing public information, resolving turf conflicts, and providing adequate funding. One of many challenges to data providers is understanding the broad mix of existing and emerging business and public uses and users of freight transportation data. Reaching this goal will require increased dialogue and reliable feedback mechanisms. Next, users will have to be educated about the existence, purpose, and limitations of the data that are provided.

Improving our understanding of how to incorporate freight transportation data into the evaluation and planning processes will involve the use of data and statistics from all available sources. This in turn will increase the demand for improvements in the completeness, quality, and timeliness of the data; in their collection, processing, and distribution; in ways to minimize the associated costs; and in assigning confidence limits on publicly distributed transportation data and statistics.

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A1D08: Committee on Urban Transportation Data and Information Systems
Chairman: Charles L. Purvis

Future of Urban Transportation Data

EDWARD LIMOGES, *Southeastern Michigan Council of Governments*
CHARLES L. PURVIS, *Metropolitan Transportation Commission*
SHAWN TURNER, *Texas A&M University*
MARC WIGAN, *Oxford Systematics*
JEAN WOLF, *Georgia Institute of Technology*

The exciting opportunities technology is providing researchers in the field of urban transportation data come with equal challenges. These challenges include data privacy and confidentiality, fluctuating priorities on data needs, and problems for data collection budgets given the imminent need for modernizing the transportation infrastructure. Adding to these issues is the need to train a new generation of analysts to effectively analyze varying quantity and quality of data. Certainly new technologies promise to reduce the cost while improving the accuracy of collected data, but this benefit is countered to some degree by people's increasing reluctance to be monitored.

Members of the Transportation Research Board Committee on Urban Transportation Data and Information Systems lead the research community in many of the following areas:

- Using census data in transportation planning;
- Monitoring traffic and transit systems;
- Using ITS-generated data in planning;
- Using household survey data in describing traveler characteristics and metropolitan travel patterns;
- Combining data sources;
- Studying issues of data privacy and confidentiality; and
- Creating standards for meta-data (data about data) and meta-analysis (comparative data analyses).

This paper provides a perspective on these issues and a look at the opportunities and challenges that will face urban transportation planners in the 21st century. The several themes explored in this paper include

- The issues related to continuous data collection;
- The use of global positioning systems and other technologies in urban transportation data;
- The use of small area land use and socioeconomic data in metropolitan planning;
- Privacy and data ownership concerns; and
- The concept of "information from data."

CONTINUOUS DATA COLLECTION

Urban transportation planners in the United States are familiar with the "3-C" planning process—continuous, comprehensive, and cooperative. The "continuous" aspect of metropolitan planning, as envisioned by the 1962 Federal-Aid Highway Act, referred to the need to periodically update long-range transportation plans. Traditionally, traffic and transit system monitoring programs were the only continuous data collection programs in place within state and metropolitan areas. Other significant data collection programs, such as the U.S. decennial census or metropolitan area household surveys, were based on once per decade or an even more infrequent basis.

Three major trends in continuous data collection programs are of interest:

Continuous Census Data

The American Community Survey (ACS), a major initiative of the U.S. Census Bureau, is intended to eventually replace the traditional census "long form." ACS is a major change in the way transportation planners will collect census data in the 21st century. Planners will be able to get annual census data for large areas of 100,000 or more in population, and "rolling average" data for small areas such as census tracts and travel analysis zones. Understanding the statistical properties of rolling average data for small areas, and the creative and full use of such properties in transportation planning activities is an emerging research need.

Continuous Personal Travel Data

The typical large metropolitan area has experienced large-scale household travel, or home interview, surveys approximately once per decade over the past 40 years. The U.S. experience is that of shifting away from traditional in-home face-to-face interviews to more convenient mail-out or telephone surveys. These surveys were typically conducted during weekdays throughout the spring and fall of the survey years. An emerging international trend is the "continuous" household travel survey; data is collected every day of the year, every year. Examples include the Victorian Area Transport Survey in Melbourne, Australia, and a similar survey in Sydney, Australia. Other metropolitan areas are beginning to realize that "people travel throughout the year, not only during specific seasons" and are more willing to commit data collection budgets that treat travel as a year-round affair. Whether U.S. metropolitan areas can commit to a multi-year, continuous household survey collection effort, such as seen in Melbourne and Sydney, has yet to be determined.

Archiving ITS Data for Planning and Other Applications

Data collected and archived by intelligent transportation systems (ITS) offer great potential in expanding the scope and types of analyses conducted in transportation planning (*1*). Archived ITS data is already being used to a great extent for transportation planning, operations, and research. These activities include congestion monitoring (*2*), origin-destination studies (*3*), planning and traffic model development and validation (*4*), and traffic flow research (*5*), to name only a few. Given the potential of ITS, there are numerous opportunities as well as challenges in this rapidly growing area.

The continuous 24 hours a day, 7 days a week fine-grained detail typical of ITS data will eventually supplement or replace traditional traffic data sampling programs in many urban areas, resulting not only in cost savings but in a dramatic increase in the amount of data available for analysis. Additionally, the large amount and type of data available through

ITS will improve existing analyses and enable new types of transportation analyses, such as those focusing on travel reliability or actual discrete choices made by (anonymous) individual travelers or shippers. Numerous data user groups will be brought together because of their interest in obtaining archived ITS data. Therefore, archived ITS data has the potential to serve as a platform for coordinating diverse transportation agency efforts and to provide a feedback loop for various transportation disciplines.

Just as there are significant opportunities for using archived ITS data, so are there significant challenges. These include

- Formulating information use and sharing policies that encourage public and private sector partnerships that return value to the sponsoring agency and its customers, yet protecting individual's privacy rights while using ITS;
- Addressing data access and management issues inherent in sharing and analyzing extremely large databases in a distributed data user environment;
- Developing analytical tools and procedures that can be used to explore and analyze trends and relationships in large, complex transportation databases; and
- Developing and incorporating automated quality control procedures into data archiving practices to ensure that end users have data of sufficient quality and accuracy.

GPS AND OTHER TECHNOLOGIES TO ENHANCE URBAN TRANSPORTATION PLANNING

The automation of urban data collection offers some significant improvements in data quality by eliminating transcription errors and by introducing on-line error checking and improved form flow. At the same time, these new technologies eliminate the expense of transcribing written documents into electronic format. Automation further provides for the capture of once burdensome details about urban travel. For example, Global Positioning System (GPS) technology automatically records trip origin and destination, start and finish times, length and duration, and all travel routes. Finally, automation provides a means to capture urban travel data previously unattainable in a survey setting. On-board engine monitors and other vehicle sensors, when installed in personal vehicles, can provide much driver behavior-related data, including constant information for vehicle speed, engine speed, throttle position, and engine load. By gaining knowledge regarding these driver-vehicle-infrastructure interactions, transportation industry modelers and practitioners can better understand the contributions of driver behavior on traffic conditions and emissions.

Within the past several decades, the traditional paper-and-pencil interview for travel diary data collection has been supplemented or replaced with computer-assisted-telephone interviews. Most recently, computer-assisted-self-interview methods are being evaluated. There are numerous references available that review the traditional diary instruments and the transition to automated data collection (*6–8*). Two recent European research projects have examined handheld PCs (*9*) and Internet-based websites (*10*) for long distance travel data collection. As the cost of handheld computers with large storage capabilities continues to fall, computer-assisted travel diaries should become increasingly commonplace.

GPSs add a new spatial dimension to trip-making data by tracking actual route choice. Research projects investigating automated diaries with GPS include the Federal Highway Administration's Lexington study, and travel surveys in the Netherlands (*11*). These projects are among the first to combine electronic travel diaries with GPS receivers to gain exact temporal and spatial details of each trip. Several other projects have installed passive GPS receivers in automobiles and trucks (*12*) to capture travel route information. Various recent research projects have evaluated GPS receiver performance in London (*13*), Paris (*14*), and Atlanta (*15*). The cost of GPS technology has also continued to decline, making it quite feasible for a GPS component to be included in travel surveys. In fact, a number of major travel surveys scheduled for the year 2000 will contain GPS elements.

Within the last several decades, the need for accurate vehicle fuel consumption and pollutant emission models has forced both researchers and practitioners into developing automated means for capturing second-by-second vehicle and engine activity data. These projects include research conducted in France in 1983 and 1990 with 55 instrumented vehicles (*16*); a Canadian project using that country's "Autologger," a vehicle-mounted data collection device (*17*), and several instrumented vehicle studies conducted by the U.S. Environmental Protection Agency (*18*, *19*). A vehicle instrumentation package is scheduled for implementation as a sub-sample to the year 2000 Atlanta Metropolitan Regional Travel Survey (*20*). Not surprisingly, such technologically advanced data collection brings challenges. Common concerns include instrumentation costs, ease of installation, and data storage requirements.

SMALL AREA LAND USE AND SOCIOECONOMIC DATA

Transportation planning requires data that is organized and tabulated by small geographic areas, usually called traffic analysis zones. Patterns of land use and transportation systems are the two key determinants of small areas. Boundaries are drawn to separate differing land uses, to identify major traffic generators, and to fit within and relate to the transportation network. Other considerations include natural features and governmental boundaries. The boundaries and patterns of these small geographic areas form a somewhat abstract mosaic that outlines the spatial structure of large regions.

Space and Activity

The physical aspect of land use and transportation is facilities and spaces, and the functional aspect is activities and occupants. The common understanding of the interrelationships between form and function is more advanced for transportation, with its roads and other publicly owned facilities, than for land use. These interrelationships represent an integration of systems and flows that include measures of capacity, levels of service, and functional classifications. However, although land is largely privately owned, it is still publicly monitored and measured for space activities. Three areas of government oversee this monitoring—the U.S. Census Bureau; state employment insurance agencies; and municipal departments that oversee building construction and property assessments. These agencies create and maintain data concerning residential and nonresidential buildings and the occupants of those structures.

There are problems with all three sources. Several key questions in the decennial census present difficulties for questionnaire respondents because concepts are unfamiliar or facts unknown. These include two key housing items: number of units in a structure (attached or multi-unit buildings can generate confusion) and year structure built (many respondents, especially renters, do not know). Deficiencies in workplace location result from workers who do not know their workplace address, but only how to get there. Aside from address problems and missing establishments, in some states insurance files of employers cannot be released to other public agencies. Also, construction permit data may not be tabulated in "geocodable" form, and assessment records may not be computerized or may lack street addresses.

Recent Developments

Several recent developments represent substantial advances for socioeconomic and land use data. These developments are

- The replacement of the Standard Industrial Classification (SIC) system by the North American Industry Classification System (NAICS)(*21*). NAICS will better reflect the current structure of the national economy and incorporate some land use differentiation. However, NAICS in Census 2000 presents multiple challenges. One issue is how to assure correct assignment of the new classes; another is how to effectively bridge data to link 1990 SIC employment and 2000 NAICS employment at the same level. Finally, a third issue is how to create a full land use breakdown of employment using post-processing (*22*).
- The initiation of ACS. During the coming decade ACS will provide continuous census sample data, eventually including small areas. It will also form the basis for a nationwide Master Address File (MAF) of residential addresses, and facilitate completion of the multi-dimensional Land-Based Classification System (LBCS) model for classifying land use based on property characteristics. LBCS will replace a system developed in the mid-1960s (*23*). Also, the Census 2000 assignment of workplaces to small areas will be improved through the use of better coding resources, including an updated TIGER file, a more complete business establishment list, and an improved geographic allocation procedure.

Future Possibilities

On the horizon is the promise of full integration of census data (both 2000 and ACS), state employer data, and local construction and cadastral parcel assessment data. The central concept will be to use data drawn from the cadastral file, which will be continuously updated to reflect construction and demolition and provide a complete count of buildings and characteristics. Choosing several large geographic areas that already have the required data files could test these possibilities. Operationally, each address in the study area's MAF would be given housing characteristics drawn from the parcel file. The Census Bureau would match these addresses to Census 2000 and ACS addresses to create small area summaries of census population and household data by housing class. The study area's housing records would be populated by the census summary data through random assignment of household characteristics. An equivalent process, using relevant files, would be used to populate nonresidential buildings and floor space. The ultimate goal of such data integration is to maximize the usefulness of public information through multiple public services.

PRIVACY AND DATA OWNERSHIP CONCERNS

Society is rapidly becoming highly dependent on extensive data exchange, and substantial actions have been taken by the United States and other major countries to privatize and secure many of these data streams. These efforts are creating pressure to withhold information in hope of economic incentives, and pitting personal privacy against the desire to be included in the data flow. Eventually, data will come to be owned solely by the individual it involves (*24*).

A major challenge for the transport and data communities is to participate and guide this process of information management and ownership to the best community outcome. Having people freely providing their own data and opinions must be balanced with the public accessibility to aggregated results that are in the community's interest. The rapid rise in GIS data has the potential to upset this delicate balance, and ways of involving the community in the ownership and use of its data must be found.

Privacy is a separate issue, but it is becoming closely linked through the identification, surveillance, and charging systems now moving towards integration through GIS databases, GPS use, smartcards, and the growth of ITS data interchange standards. Only if the two major issues of data ownership and privacy can be navigated successfully will transport and traffic data become more targeted, appropriate, reliable, and efficient.

INFORMATION FROM DATA

Even before the wave of massive future information flows became apparent, the value of digested data had become obvious through books focusing on the implications of transport data (*25*). Twenty years later the flood of inaccessible and disorganized transport data has only just been met and matched by the Bureau of Transportation Statistics in the United States, and has flowed on to the user community with some isolated examples of similar forms of interpretation. The mindset that links metropolitan planning organization data flows to transport planning is shifting and will continue to do so.

The big growth areas will be in traffic, land use, and economic activity data as transport data balance more directly with community needs. Methods have yet to be found for digesting such data and then communicating it to the general and professional communities in a way that will allow for informed response and understanding. This objective has barely been met in transport, although GIS should permit such communication within several years.

The new types of data will place great pressure on the transport and planning communities to widely increase research efforts through the use of interactive tools. As this occurs, transportation and planning leaders will come to respect the opinions and expertise available in the general community.

CONCLUSIONS

In *Data Smog: Surviving the Information Glut*, author David Shenk offers his "first law of data smog"—"Information, once rare and cherished like caviar, is now plentiful and taken for granted like potatoes" (*26*). Urban transportation planners and data analysts in the 21st century will be faced with data that is more continuous in nature as well as more conflicting. Reconciliation of conflicting data sets will be more important in the decades to come. Equally important will be the need to effectively reduce and synthesize data from various sources, including continuous census data, continuous data from ITS efforts, and other emerging technologies that will collect data on traveler behavior and transportation systems.

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Data, Data, Data—Where's the Data?

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Transportation is changing throughout the nation. More people need to reach multiple destinations and achieve multiple objectives in one trip. Many of these trips cross jurisdictional and modal boundaries. In major urban areas, existing and new users are making increasingly complex trips that put higher demands on the transportation infrastructure and services. For example, travel to jobs, shopping, medical facilities, educational institutions, entertainment, and other neighborhoods requires seamless transitioning from one mode of travel to another.

These demands require a major new transportation strategy that responds to the issues facing each state and the nation for the next 20 to 30 years and well into the new millennium. Transportation leaders understand that this new strategy must include all aspects of the nation's vital infrastructure—air, water, housing, education, and more. The strategy must include an intergovernmental approach for accommodating growth in already heavily populated urban areas. This would involve a partnership with private entities and officials who make land-use decisions. Finally, the strategy must address the needs of an aging but active population.

Accurate, reliable, and readily available data is the essential tool for making this new transportation strategy a reality. Transportation professionals must find better ways to meet federal, state, and municipal needs for modeling, data systems, traffic counts, and performance measuring. The first step must be more reliable data. However, this will be a "tough sell," because data is more elusive than blacktop.

Many of the points in this article echo the poignant statements of Alan Pisarski, the 1999 TRB Distinguished Lecturer, made in his speech at the TRB Annual Meeting in January 1999 (*1*).

DILEMMAS OF TRANSPORTATION DATA COLLECTION

Transportation leaders have established little guidance regarding what data to collect, in what detail, precision, and frequency, or even for what reason. The most important aspects of transportation are time and cost. Yet little or nothing is known about these two factors. For example, think of performance measures without time or cost elements. Transportation data collection is literally a moving target. It is difficult to think of instances where it has been measured well. The single exception may be the airline industry — air travel is certainly the most data intensive transportation industry—but it also has problems.

The cost-benefits of transportation data have not been established. Officials who invest in a data collection program are probably investing in something from which they will derive no benefit. They are generating a bequest to their successors.

Large-scale statistical programs take lots of time and money. Most programs or agencies don't have the money to sustain the needed data programs. Most programs do a bad job of justifying the need for data expenditures.

But being "irrelevant" is a delicate concern. Gauging relevance is like sitting around the campfire: too far from the policy "flame" brings the risk of irrelevance and being frozen out; too close carries the risk of being singed.

The key to solving this dilemma is the anticipation of data needs. Transportation statistics programs, like most other statistics programs, are approximately five percent statistics and ninety-five percent logistics. These programs are complicated exercises in organization and planning. But the most central professional aspect to these efforts is not the statistical skills involved nor the logistical capabilities, but the ability to anticipate the policy and planning data needs of the future: What policies will be significant? What planning horizons matter in the future?

When policy issues arise for the U.S. Department of Transportation (DOT), metropolitan planning organizations (MPOs), state DOTs, or the private sector, it usually is already too late to begin data collection. They cannot respond, "Hold on for a year or so, we'll be right back!" When a policy question arises, data professionals usually can answer in

- Three minutes, if it's on the shelf;
- Three hours, if a little searching is required;
- Three days, if some manipulation is required;
- Three weeks, if a computer program is involved;
- Three months, if major data processing is required; or
- Three years, if new data collection is required.

In other words, transportation professionals are forced to work with what they have in the data "cupboard" when a policy issue arises. Therefore, all policy will be made with the extant statistical data set. That must be the goal of all design.

Following are the experiences and discoveries of two states, Kentucky and California, that took a comprehensive look at the need for transportation data.

KENTUCKY'S DATA COLLECTION ENHANCEMENT EFFORT

Kentucky transportation professionals are assessing their state's needs, issues, policies, and gaps with regard to data. They are aggressively pursuing video logging and other technology-oriented, data-enhanced collection efforts.

Accurate and complete information is essential for today's fast-paced decision-making processes. Technology has responded to the increased demand for information by providing sophisticated database management that includes visual and spatial analysis tools. These computerized tools demand better data content and accuracy. Just as the highway infrastructure is necessary to meet the demands of transporting people, goods, and services, a data infrastructure is required to support transportation planning. If data is treated like an asset, the rewards will follow in such areas as productivity and accountability.

Many factors are involved in highway data collection. For example, safety must be considered as field personnel collect data in the presence of the traveling public. There are also a variety of physical characteristics that must be observed over a large expanse of highways. In an attempt to capture more roadway features in one pass, Kentucky has proposed spreading the use of video logging throughout its transportation agency, as follows:

- Pavement conditions, Division of Operations;
- Roadway features inventory, Division of Operations;
- Traffic signs and signals inventory, Division of Traffic;
- Bridge maintenance system, Division of Operations;
- Roadway characteristics inventory, Division of Planning;
- "Rideability" index, Division of Operations;
- Passing zones, (possibly), Division of Operations; and
- Digital mapping references on data features, enterprise-wide.

In addition to better descriptive data, videotaped record and digital photographs could provide visual inspection capabilities in the office. Using a computer, it is possible to simulate driving on every highway throughout Kentucky. Digital photographs for geographic information systems (GIS) will enhance digital mapping analysis efforts. In summary, new technologies provide the following benefits:

- An asset management tool;
- Safer data collection methods;
- In-office data collection;
- An enhanced GIS;
- In-office view of all state highways; and
- One enterprise-wide database.

Additional future data issues identified by Kentucky include:

1. **Performance measures**. Training and retraining is essential to this area. The mobile work force creates an employee retention problem. Changing technologies make training critical to any new data initiative. This training needs to be updated continuously.
2. **Intelligent transportation systems (ITS) data integration**. ITS planning should become a standard part of all highway projects, similar to right of way and other line item aspects of project development. ITS will require serious quality control efforts to handle the enormous amount of data generated. Released data probably should have a standard disclaimer about its accuracy. Also at issue is what piece of data represents the average, and who is responsible for the data. For example, if a newspaper requests information about data at a given point, what should be used? A random day, perhaps?
3. **Data access**. Privacy issues already emerging with truck data will continue to arise. TRB and the Federal Highway Administration (FHWA) need to address this issue aggressively, to make the fullest use of the available technology. For example, transponders could be used universally on truck fleets; however, there is no political will to mandate it.

4. **Data quality**. Expert programs must be pursued aggressively. But these programs have been slow in developing. The amount of data generated is increasing geometrically, and the quality of the data is suspect. It is essential that data be "tagged" with information showing the source (e.g., the equipment or the collection team), the statistical level of confidence, and the availability of archival data. Data quality has great potential as a new training program in engineering schools.
5. **Modeling and traffic simulation**. A clearinghouse should be established for data used for statewide and regional planning efforts such as statewide traffic models. Interjurisdictional data currently is difficult to obtain and compare. A national database could solve this problem. The database could contain such attributes as volume data, vehicle classification data, origin-destination data, and employment data. The tool-kit approach is better than the one-size-fits-all approach represented by FHWA's decision to promote the new model TRANSIM, which may or may not be a good tool for demand modeling.

Kentucky concludes that with leadership from key states and case studies showing how data collection and management have saved large sums of money, it will be possible to implement forward-looking ideas. The political barriers are more severe than the technological barriers.

CALIFORNIA'S EFFORT TO MEASURE SYSTEM PERFORMANCE

California, along with several other states, has undertaken an effort to develop transportation system performance measures that will provide a systematic approach to planning and decision making. Transportation policy makers recognize the need to consider improved system management options before more costly capital expansion projects are developed. However, decision makers are hampered by a lack of tools designed for system analysis. The 1998 Updated California Transportation Plan addressed this handicap by affirming the system approach and calling for performance assessment at the total system level (*2*).

California State Senate Bill 45 of 1997 split authority between the state and municipalities with regard to transportation improvement program funding. But the bill also made it possible for the regions and the state to suggest projects to be funded at either level of decision making. In effect, California can recommend projects at the regional level, and the regions, in turn, can recommend projects for state funding. The process requires a consistent method for comparing projects and programs. System performance measures provide some of the tools for making these comparisons.

The question remains as to what system performance measurement will do. Performance measurement is a standard management function that will enable managers and other stakeholders to determine if their goals and objectives are being met. A sound performance measurement framework involves three key components:

1. A clear direction or purpose, often enunciated as a vision;
2. A simple set of metrics based on readily obtainable data; and
3. Routine, readable reports.

The purpose of performance measures and indicators is to show where a project stands and what the next step should be. Performance measures and indicators provide a benchmark for comparing performance against best practices, identify opportunities for improvement, and guide resource allocation. The measures and indicators must be understandable to government officials, planners, and the public. The information or data provided should be obtained at a reasonable cost and with reasonable effort. Finally, the measures must be reported regularly so that the progress of transportation projects can be continually monitored.

Performance measurement can assume perspectives as rich and diverse as the transportation system itself. Total system performance depends on subsystem performance from such individual modes and programs as transit, highway, inland waterway, rail, airport, and shipping. The system works well when these subsystems and individual components execute well. There are different levels at which the transportation system and subsystems can be measured:

- **System outcome**. System outcome performance is focused on the benefits and costs accruing to society from a transportation system. Outcomes represent the values that society deems important but are often difficult to measure directly, thereby requiring indicators that can be measured using available output. Outcomes may be positive or negative. For example, a positive outcome of a rail construction project may be the reduction of traffic congestion. A negative outcome may be noise and the localization of air pollution around train stations.
- **Organization**. Organizational performance is the assessment of how well an agency or entity provides its service. Organizational performance is linked to system performance. If every organization and service provider performs well, the system will work better.
- **Individual mode or program**. Individual mode or program performance is clearly linked to system outcome performance. Moving from outcome performance to individual mode performance requires a greater need for detailed information. However, the added detail does not detract from the usefulness of each level of performance measurement. Using public transit as an example, it is important to know how many riders are utilizing each route within a transit authority's domain so that line managers are able to allocate resources to meet travel demand. Data collection for such an analysis may require the use of extensive surveys and line-by-line rider counts. Therefore, this degree of detail would be more appropriate at the state rather than regional level, where the cost of collecting such information would not likely be justifiable.

Desired Outcomes of a Performing Transportation System

The transportation programs that ultimately deliver services to foster mobility are designed to produce results benefiting society. In getting results that society values, there must be continuing vigilance to avoid unwanted side effects.

Nine transportation system outcomes have been identified; they fall into one of two categories: (a) system effectiveness and efficiency; or (b) system responsibility.

The outcome category of system effectiveness and efficiency focuses on providing reliable and cost-effective mobility and accessibility and on contributing to a strong economy. The outcome category of responsibility focuses on ensuring that those key deliverables are provided without unwanted consequences.

As some stakeholders have commented, there might be too many outcomes and some might overlap. However, the outcomes represent different regional and interregional priorities for decision makers. Some regions might focus on only a subset of the outcomes.

California recognizes that some of these outcomes cannot be used consistently for both system performance monitoring and forecasting. This becomes evident when specific measures and indicators are reviewed and evaluated. A list of the system performance outcomes under evaluation follows; though interrelated, the outcomes are not prioritized.

Effectiveness & Efficiency

- **Mobility and accessibility**—Reaching desired destinations with relative ease, within a reasonable time, at a reasonable cost, and with reasonable choices.
- **Reliability**—Providing reasonable and dependable levels of service by mode.
- **Cost-effectiveness**—Maximizing the current and future benefits from public and private transportation investments.
- **Customer satisfaction**—Providing transportation choices that are safe, convenient, affordable, comfortable, and meet customers' needs.
- **Economic well-being**—Contributing to California's economic growth.

Responsibility

- **Sustainability**—Preserving the transportation system while meeting the needs of the present without compromising the ability of future generations to meet their own needs.
- **Environmental quality**—Helping to maintain and enhance the quality of the natural and human environment.
- **Safety and security**—Minimizing the risk of death, injury, or property loss.
- **Equity**—Fair distribution of benefits and burdens.

A continually evolving "state of the system" report is critical to the success of the California initiative. Once again, data is key. System data on all modes, regions, markets, and other aspects of state transportation will be critical.

TRB's Role in Data Collection

As states from Kentucky to California prepare for transportation in the new millennium, it is important that TRB remains in the forefront. The findings of TRB's 1997 Spring conference—Information Needs To Support State and Local Transportation Decision Making into the 21st Century—were landmarks in the effort to address transportation data needs (*3*). Those findings must guide future efforts. The content and the methodological and institutional improvements listed in the conference findings will provide state transportation officials with the data and technology for remaining effective at their jobs.

CONCLUSION

The future of data in transportation decision making lies along one of two divergent paths. One perpetuates a greater reliance on good, high quality, statistically relevant, timely, and useful data for decision making. This comes at a high cost that often outweighs the near-term benefits. The other path, and the one often followed for budget reasons, leads to a "data-free analysis zone" in which decisions are made without the benefit of sound data.

The customer deserves the best. Data professionals must lead the transportation industry along the right path.

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Travel Surveys

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Travel surveys will continue to be one of the most important ways of obtaining the critical information needed for transportation planning and decision making in the new millennium. Not only will these surveys be used to gather current information about the demographic, socioeconomic, and trip-making characteristics of individuals and households, but they will also be used to further our understanding of travel in relation to the choice, location, and scheduling of daily activities. This will enable us to enhance our travel forecasting methods and improve our ability to predict changes in daily travel patterns in response to current social and economic trends and new investments in transportation systems and services. These travel surveys will also play a role in evaluating changes in transportation supply and regulation as they occur.

In the last half century, travel survey methods have undergone tremendous change. Originally, travel surveys were conducted primarily through face-to-face interviews, typically conducted in respondents' homes or at intercept points along major roadways and transit routes or at major transportation nodes. The surveys produced high-quality data that provided a sound basis for the development of the first generation of travel forecasting models. Significant changes in modern urban lifestyles, however, made the large-scale use of traditional face-to-face survey methods extremely costly. In response to these societal changes, travel survey methods have adapted to better fit contemporary lifestyles and have become much more economical to conduct. Thus, travel surveys are now an integral part of the continuing transportation planning process and are frequently used in many different types of transportation studies.

CURRENT STATE OF METHODOLOGY

Current state-of-the-art household travel surveys rely extensively on the use of mail and telephone to obtain information on the daily travel and other activities of a representative sample of the population. Typically, eligible persons in randomly selected households are mailed survey diaries in which they are asked to record all travel or activities conducted during a randomly assigned 1- to 2-day period. Retrieval of this information is conducted over the telephone or by the mailing back of the survey diaries. Households participating in these surveys are generally given postcard or telephone call reminders about their upcoming travel survey day and the need to promptly provide their survey diary information to the survey interviewers. To ensure the accuracy of the data collected, the retrieved information is checked for missing, invalid, or inconsistent data. Persons providing incomplete or inconsistent diary information are prompted, or are recontacted, by survey interviewers to obtain the missing the data.

After the information collected in state-of-the-art travel surveys has been reviewed and edited, it is keyed into computer data files, geocoded, weighted, tabulated, and analyzed. If a computer-assisted telephone interviewing (CATI) system is used, the survey information is directly entered into computer files and processed as it is collected. Also, if the CATI system is linked to a geographic information system (GIS), real-time geocoding of trip ends occurs. Next, technical reports summarizing the major findings and documenting the survey results are prepared. The documentation includes data dictionaries for all survey files produced, a complete description of all survey procedures, and full disclosure of survey response rates at each stage of the survey interviewing process.

Although household-based travel surveys are one of the most comprehensive means of obtaining data for transportation planning and decision making, they are by no means the only way to obtain such information. Workplace surveys, license-plate surveys, licensed driver surveys, transit on-board surveys, and other types of travel intercept surveys are used to supplement and enrich the data collected in household travel surveys. In addition, analysts are beginning to use travel survey data within increasingly integrated data systems containing information such as detailed land use attributes, economic activity, or the patterns of air pollution, road accidents, and noise.

Regardless of the method of data collection being used, state-of-the-art travel surveys place an important emphasis on a total design survey process that follows a series of logical, interconnected steps. The steps include preliminary planning; selection of a survey design; selection of a survey sample; development and pretest of the survey instrument and all administration procedures; administration of the survey interviewing; coding, editing, validation, and processing of the data collected; the analysis and weighting of survey data; presentation of survey results; and the documentation and archiving of the cleaned data.

Throughout the total design survey process, quality control procedures are implemented to ensure the accuracy of the survey results. The quality control procedures include a complete pretest of all survey procedures, the review and editing of survey data for missing and invalid data, the recontacting of some travel survey households and imputation of some data items from other survey responses, comparison of survey results with the latest census or other secondary source data, and adjustment of survey weights to account for identifiable response biases. Also, in the very best travel surveys, quality control subsamples or follow-up interviews with survey nonrespondents are conducted to determine and correct for biases associated with unit nonresponse (from nonparticipation) or item nonresponse (from items that a participant refused or left incomplete). Only by a full consideration of all sources of error and deliberate design decisions to minimize or correct for these errors can high-quality data collection result.

The biggest problem faced in conducting high-quality travel surveys today is nonparticipation. Although most travel surveys start with a random sample of households or individuals selected for participation, many of the selected individuals simply do not respond. Such nonparticipation negatively affects the quality of data collected. Much research in recent years has focused on techniques for improving participation in travel surveys. In state-of-the-art travel surveys, presurvey letters, toll-free survey hot lines, cash incentives, and refusal conversion techniques are used to encourage participation.

SURVEY ENVIRONMENT

The environment within which travel surveys will be conducted will be characterized by policy makers' demands for more frequent and reliable information to respond to:

- A continued concern with greenhouse gases, air quality, and urban congestion, and the need to address these issues with more policy-sensitive travel forecasting models, including activity modeling and microsimulation;
- A resulting emphasis on sustainable transport systems, requiring greater use of nonmotorized transport, new public transport options, and nontransport solutions to transport problems;
- A need to give greater consideration to urban freight and commercial vehicle movements in addressing traffic and environmental problems;
- The desire to use and enhance the effectiveness of intelligent transportation system (ITS) technologies;
- A greater concern with various forms of user-pays solutions such as toll roads and other road pricing schemes; and
- Increased trends toward privatization of road and public transport systems, creating a greater commercial need for timely and accurate market data on travel patterns.

At the same time that policy makers are demanding more information, survey practitioners will be faced with some of the following challenges in the new millennium:

- Higher levels of multiculturalism, and multiple languages, within urban areas;
- Greater pressures on the free time available to individuals, reducing their willingness to use this time to participate in surveys and other "public service" activities;
- Advances in personal communications technology that will make it much easier for people to have greater control over whom they choose to communicate with and how, when, and where these communications take place;
- Introduction of more restrictive "privacy legislation" in many countries, reducing what data can reasonably be collected and how it can be used; and
- Continued restrictions on the public funds available for the collection and analysis of travel survey data.

FUTURE DIRECTIONS

The basic conflict between the need for increasingly detailed and frequent data on daily travel patterns and the growing difficulty in contacting and interviewing persons about their travel will require continued improvements in travel survey methods. Some of the likely improvements are discussed in the following subsections.

Conversion of State-of-the-Art Travel Surveys into State of Practice

The most urgent need for travel surveys in the new millennium is to convert today's state of the art into tomorrow's state of practice. Pressing on with improvements in the former in a small number of surveys is somewhat pointless if the lessons learned are not transferred to the latter in a large number of surveys. Another important component of raising the quality standards of travel surveys is a full and honest documentation of the survey processes.

Mixed-Mode Survey Designs

State-of-the-art travel surveys use some combination of telephone and mail methods to recruit, interview, and follow up on persons asked to participate in the surveys. In most of these designs, however, almost all of the interviewing of survey respondents is conducted exclusively by the mailback of the survey diaries or the retrieval of the diary information over the telephone. We know from experience that some respondents respond better to mail methods, others to telephone methods. Further, we know that some potential respondents will respond neither to mail nor to telephone interviewing techniques, but that they will respond if properly approached and asked questions in a face-to-face interview. To obtain acceptable response rates for travel surveys in the new millennium, practitioners will need to resort to the use of mixed-mode survey designs, rather than relying on a single method of interviewing. This will entail giving potential survey respondents greater choices over how, where, and when to be interviewed. Certainly, this will require some negotiation between the survey interviewer and respondent, but the essential point is that survey practitioners are going to need to view survey respondents as their customers and adapt the interviewing method used to the personal preferences of each potential customer.

Other types of mixed-mode survey designs will address a familiar problem: the trade-off between the level of detail and the size of the sample. Is it better to ask many people a few questions or a few people many questions? We expect that layered strategies will become more commonplace: within a large representative sample, a subgroup is targeted for more in-depth data collection, and in some cases more than two levels may be involved.

Use of the Internet and Multimedia Methods

Increased use of the Internet and multimedia computer technology can improve state-of-the-art travel survey methods to better serve potential customers. Use of the Internet and the e-mailing of survey materials between survey interviewer and respondent provide a means of giving some survey respondents greater choice of when and where to be interviewed. Increased use of multimedia methods and computer technology, whether provided via the Internet, CD-ROM discs, or videotapes, could also greatly simplify the asking of complicated survey questions and make it much easier and faster for some survey respondents to respond to these questions. Whereas the Internet and multimedia methods will be immediately useful in some circumstances, such as the conduct of surveys with businesses, the widespread use of the Internet for the conduct of general travel surveys must await the more widespread penetration of the Internet into households.

Use of Monitoring and Remote-Sensing Technologies

Further advances in automatic monitoring and remote-sensing technologies, such as vehicle instrumentation and global positioning systems (GPS), when linked to well-developed GIS databases, will offer substantial opportunities to improve the amount, detail, and accuracy of the data collected in 21st century travel surveys. Some new automobiles already include GPS-based in-vehicle navigation systems. With some slight modifications, these in-vehicle navigation systems could be used to record information on vehicle trip origins and destinations and the exact routing of these vehicle trips through the transportation network by time of day. Vehicle speeds and travel times by network link would also be available. Because many of the new vehicles instrumented with in-vehicle navigation systems also are equipped with wireless phones, obtaining real-time survey data about the other characteristics of this travel would be possible.

The use of GPS technology to record daily travel patterns may not be limited to in-vehicle travel in the longer-term future. If GPS equipment can be sufficiently miniaturized, it may be possible to integrate its use with wireless phone technology and further reduce respondent burden. All that may be asked of the potential survey respondents is that they wear or carry around with them a small remote-sensing device for a few days and answer a few simple questions. Whereas this could almost completely eliminate respondent burden, there would still be the questions of whether a significant number of individuals would agree to have their daily activities and movements tracked so precisely and whether such a situation would cause them to change their travel and activity behavior.

Another source of monitoring data that holds great promise is the use of data from automatic ticketing machines on public transport systems. Such machines can provide information on every trip made on these vehicles in terms of origin, destination, time of boarding, and ticket type. Once smart cards become the standard "ticket" used by all passengers, there is the promise of sociodemographic data encoded on the smart card also being recorded for every trip. By analogy, individualized data may be collected automatically from ITS, including electronic toll collection and traffic monitoring systems.

Increased Attention to Urban Freight and Commercial Vehicle Surveys

The increasing role of commercial vehicles in urban congestion and environmental problems means that more attention must be focused on measuring travel patterns for such vehicles. Such surveys have been difficult in the past because of the quantity of data that must be collected and the lack of cooperation that has been obtained from drivers and vehicle owners. However, the advances in GPS technology described above promise major improvements in the ease of data collection and the quality of trip data that can be collected. Substantial improvements in urban commercial vehicle surveys can be expected in the future.

Continuous Travel Surveys (Including Panel Surveys)

Another likely direction will be greater use of continuing travel surveys, including long-term panel surveys. The advantages of continuing surveys are that they give more timely data, rather than sporadic data every 10 years or so, which is much more useful for monitoring the effects of projects and policies. In an era of continuing public finance austerity, it is also politically easier to obtain a relatively small continuing budget allocation than a massive allocation at various points in time. Managerially, continuing surveys have the advantage of keeping the survey team together, so that continuous improvement is possible and the skills developed are not dissipated.

Whereas longitudinal panel surveys have been used in some transportation studies, few panels yet span more than a few years. Longitudinal panel designs provide the opportunity to ask questions of the same individuals on repeated occasions about how and why their daily travel has evolved over time. They can provide transportation modelers and others with unique insights into how personal and household lifestyle and life-cycle factors influence daily travel behavior and into the turnover of membership in particular population segments, such as transit users. Panels raise complex sampling and analysis issues, especially concerning strategies used to deal with attrition, but wider use of panels can be expected to the extent that methodological improvements address these issues.

Greater Emphasis on Collecting Information on Activities

Given the needs of emerging activity-modeling approaches, it is likely that future travel surveys will pay more attention to the measurement of the activities at the end of trips and to how and when the respondent chose to do them. Some attention is already paid to activities, but often it is only as a way of having respondents remember more about the trips they made to those activities. In the future, new types of coding frames will be needed for the characterization of activities and the activity-scheduling process.

Widening Range of Stated-Response Techniques

Greater use of stated-response (SR) data collection strategies and techniques in travel surveys is also likely in the new millennium. SR techniques refer to methodologies for obtaining information about user responses and decision processes in new situations. The most widely used SR survey technique is stated-preference (SP) choice experiments, but a wide variety of other techniques exists to allow respondents to explore and experiment with aspects of hypothetical situations. Policy makers will increasingly want information about potential transportation services and regulatory measures that have not been tried before. The evaluation of novel transportation solutions such as ITS, alternative-fuel vehicles, and congestion-pricing alternatives is problematic to the extent that individuals are asked about their likely responses to situations of which they have little or no experience. SR data collection might also be combined with the use of long-term panel surveys and new multimedia computer technology to obtain information on the effects of new transportation services and policy measures. SR survey methodologies, together with virtual reality simulation of various transportation alternatives, will certainly offer exciting insights into how various types of travelers might respond to innovative transportation solutions.

Two provisos are in order. First, SR survey questions must be subjected to full testing under cognitive laboratory conditions to ensure that respondents understand the SR task in the way that the survey designer intends them to, so that unrealistic SR questions are not used, as has often happened in the past. Second, the SR, and particularly SP, questions must be designed in such a way that models other than conventional compensatory choice models can be tested with the data, so that we are to extend our understanding of choice processes.

Use of Travel Surveys as a Specific Instrument of Transport Policy

In the past, travel surveys have been used almost exclusively to collect information about how people travel. However, it has long been known in the physical and social sciences that the mere act of measuring something will often change the very thing we are trying to measure. Such a phenomenon has now been recognized in transport, and a number of studies in Europe, Australia, and Canada are using the survey as a way for respondents to become aware of their travel and explore opportunities for change, notably ways to undertake their current activities in a more sustainable and less transport-intensive manner. In some cases, respondents go on to report on trial changes in their behavior. This use of both revealed and stated travel surveys as positive policy instruments is an area of great promise.

CONCLUSIONS

Travel surveys will be undertaken in an environment characterized by several conflicting features:

- There will be an increasing need for accurate, timely, and cost-effective data for public- and private-sector planning in passenger and freight transport.
- However, there will be increasing difficulty in obtaining such data from respondents who may speak many different languages, who will have less free time to participate in surveys, and who will be subjected to many other surveys and marketing approaches by various organizations.
- New technology will provide new options for obtaining data from respondents but will also give them greater opportunity to block those attempts.

In such an environment, we expect that the major advances in travel surveys will come about by:

- Application of the best survey practice of today in such a way that it is common practice tomorrow;
- The use of mixed-mode survey designs to meet the data needs of the surveyor in ways that create the least burden and the greatest respect for respondents;
- The judicious use of new technologies to augment existing survey techniques, especially in the automatic recording of time/space trajectories of vehicles and people;
- A move toward more continuous surveys to provide more timely data in an economical manner, which would also develop and preserve technical and managerial skills in the conduct of complex surveys;
- Increased use of longitudinal surveys, activity surveys, and SR surveys to provide a better understanding of decision-making processes by travelers; and
- The use of surveys as direct instruments of transport policy, as a means of bringing about behavioral change.

The biggest challenge for travel surveys will be to balance the need for increasingly detailed, accurate, and timely data on daily travel patterns with the need to minimize respondent burden and protect personal privacy. The continued success of travel surveys in obtaining information needed for decision making in the new millennium will require that travel survey methods be continuously adapted to the changing lifestyles and personal preferences of the individuals who will be asked to participate in them.

Spatial Data Technologies

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The efficient planning, construction, and operation of transportation facilities depend on access to the right spatial data, in the right format, and at the right time. The provision of spatial data—traditionally the domain of surveyors; engineers; and various mapping specialists, such as photogrammetrists, geographers, and aerial photographic and remote sensing specialists—has undergone a series of profound technological changes.

The purpose of technology is to serve people. The evolution of methods for acquiring, processing, and distributing spatial information provides an excellent example of how technology can serve transportation professionals. The unprecedented explosion in use of the Global Positioning System (GPS) clearly demonstrates that the provision of accurate and reliable remotely sensed and acquired spatial information is one of the major innovations.

Already being used to precisely map facilities, count cars, or locate accidents, new spatial data technologies have become a fundamental component of the transportation information system. Such applications are enabling transportation professionals to function more effectively by allowing them to make decisions more quickly and with better data. Moreover, it can be anticipated that the most dramatic results of having inexpensive, accurate, and readily available spatial data are yet to be realized. Access to even better data will result in enhanced services to more people at less cost.

Changes in spatial data capabilities are continuing at a rapid pace. Methods for the collection and use of the data are being defined largely by the convergence of a number of widely used technologies that include the following:

- High-resolution commercial satellites capable of resolving features as small as 1 meter;
- High-altitude airborne sensors;
- Low-altitude airborne platforms, including helicopters;
- GPS for location;
- Economical and robust high-resolution digital cameras;
- Improved digital image processing, distribution procedures, and media;
- Widespread acceptance of geographic information systems (GIS) technologies;
- Increased sophistication of database management and information systems;
- Expansion of the Internet and the World Wide Web, and the globalization of information sources; and
- Increasing availability of large public information sources at little or no cost, at least in the United States.

The new millennium will herald an era of spatially referenced data that are not merely a *little* better than those presently available, but *much* better. These advances are coming at a very important time for many transportation agencies. This will be the era of multidisciplinary teams and integrated technologies. The anticipated advances offer the promise of enabling the transportation community to evolve into a cross-agency enterprise through the power of accurate, timely information.

THE FUTURE IS NOW

Regardless of how exciting one might find the technical details of the new remote sensing devices and information technologies, the real story revolves around their applications—and the applications involve people. The following are some existing advanced applications undertaken by forward-looking people and organizations.

Until GPS became available, a metropolitan planning organization (MPO) in Georgia had no detailed paper maps of its area other than the traditional U.S. Geological Survey topographic maps. The members of the MPO are now constructing accurate maps on their own. Agencies without the funds to obtain their own GPS equipment are trading the data they acquire for time with a GPS receiver. The MPO conducts a half-day training session in a town, and the town then gets to use the equipment for 3 days. The data are valuable because they are accurate, and they can be obtained at low cost.

In another example, about 70 people showed up for a recent workshop sponsored by Arizona State University concerning the use of GPS data for building a spatial referencing system, even though the workshop had had virtually no advance publicity. The attendees wanted to know how to do things themselves. One of the organizers commented that the experience was singular in that professionals from three or four levels of government, the private sector, and academia were collaborating for the good of the citizens of the state. The scope of the technological experiments is growing. A rural Arizona county is among the first to have a three-dimensional (3-D) referencing system generated entirely from GPS data. There have also been several statewide efforts to adopt a 3-D referencing system. Those involved are excited about creating something of value that is new.

Jefferson County, Colorado, includes much of the western portion of the Denver metropolitan area. The county extends into the Rocky Mountain foothills and is subject to considerable development pressure in complex terrain. The county has entered into a development agreement with one of the providers of the new 1-meter-resolution commercial satellite data and a software firm to obtain a capability for producing extremely rapid photorealistic 3-D renderings of any location in the county. Current tests are based on existing 10-meter U.S. Geological Survey Digital Elevation Model (DEM) data and scanned county-owned orthophoto maps (see Figure 1), which have a slightly lower resolution quality than desired and cannot show present conditions. Both of these constraints will be removed once the new data sources become operational. The county plans to use the new technology to support technical studies and to provide displays for county commissions and public hearings on site evaluations, site planning, zoning applications, transportation improvements, and viewshed analyses. More information on these applications can be obtained from the Jefferson County GIS Web site: http://co.jefferson.co.us/dpt/gis/gis.htm.

Figure 1: Jefferson County 3-D visualization model—view south along Dakota Hogback west of Denver. C-470 is left of and parallel to Hogback. Interchange C-470/US-285 lies just beyond lakes. Colorado Highway 8 connects US-285 with town of Morrison, a portion of which is visible in lower right.

An even more ambitious program is under way in Los Angeles. The Urban Simulation Team of the University of California at Los Angeles is creating a real-time virtual model of the entire Los Angeles Basin. Combining aerial and terrestrial digital images within 3-D computer-assisted design geometries creates accurate 3-D models of small areas. The results are photorealistic urban images, even down to the graffiti and signs (see Figure 2). These local models are then linked to create models of larger areas. The intent is to create a single unified virtual model that can be used to help solve a multitude of civil engineering, urban design, and planning-related problems. Similar experiments are under way in several other urban areas. All are pushing the current technological and economic envelope.

CURRENT TRENDS

The cost of spatial data is declining rapidly because there is competition in all aspects of the technology—data acquisition, processing, and distribution. This competition is spurred by increasing acceptance and use of spatial data, which causes unit costs to fall. These trends are evident today, and transportation practitioners are the beneficiaries.

New Satellite Data Sources

Several satellites and space missions scheduled prior to 2005 may be useful for transportation studies. The National Aeronautics and Space Administration (NASA) launched Landsat-7 on April 15, 1999, and several commercial firms are planning to

Figure 2. Virtual Los Angeles model—view of downtown.

deploy additional satellites. There is a great deal of such activity, and it appears likely that in the next few years many new data sources will emerge. Competition among the various purveyors of space-borne sensors will keep prices attractive.

An important trend is toward high spectral resolution, as well as high spatial resolution. When the electromagnetic spectrum is divided into a large number of segments, discrimination among materials becomes possible. In response to expressed needs, NASA has created a scientific payload that will be carried on a Space Shuttle mission in late 1999. ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) is capable of collecting 14 bands of data at 15- to 90-meter resolutions. The scheduled launch of the Orbview4 satellite in 2000 will provide a 200-band hyperspectral capability with an 8-meter resolution. Not only will the resolution be even better than that of ASTER, but the capability will be operational for several years.

Improved Spatial Location Procedures

The GPS revolution is well under way. In the United States, federal and state agencies are cooperating in making differential GPS (DGPS) readily available to all users. DGPS allows locations to be determined with submeter accuracy—an essential requirement for many transportation applications.

New motion sensors that will further revolutionize the accurate identification of spatial positions are coming to the market. These new fiberoptic gyroscopes are so sensitive that if left on one's desk for a day, they would determine that the earth had made a full rotation and would read 360 degrees. The devices have no moving parts and will be much less costly than existing systems. They will increase by perhaps an order of magnitude the spatial accuracy achievable by moving data-collection platforms, such as logging vans, while driving the total price of the vans down by perhaps 30 to 50 percent. The low cost, light weight, and inherent accuracy of these devices will also result in their being incorporated into new forms of personal locator devices.

VISIONS FOR 2010

Advances already under way in information technology, communications infrastructure, microelectronics, and related technologies will provide unprecedented opportunities for information discovery and management, and new ways to conduct research. Following are some visions of how spatial information might be used by transportation professionals in the year 2010.

Recent rains have caused a small landslide on a new earthfill. A geotechnical engineer working for the New Mexico Department of Transportation dons a headset as she leaves the site office. The headset provides an enhanced reality system that combines glasses, earphones, and a tiny microphone, yet weighs little more than a pair of sunglasses. When the engineer reaches the site, she issues a simple voice command, and the microtopography of the earthfill slope is superimposed as a red wire-frame display on the landscape before her. Where there has been significant erosion, the designed surface appears like a net stretched above the ground. In areas where deposition has occurred, the original surface lies below the current one, so the planned surface is obscured. The engineer takes out a hand-held device and begins to point at the current surface in various places while clicking the pointing device. A green mesh appears as she quickly collects sufficient points to make the digitized data fit the current microtopography. Her new slope data appear simultaneously in the division office, allowing a colleague to undertake slope stability calculations. Using these results, the engineer is able to discuss with the earthfill contractor steps necessary to repair the slope erosion damage and prevent a recurrence.

* * *

The Minneapolis Airport is experiencing a mid-December snowstorm. The snow is fairly light, but drifting to cause extensive visibility problems for ground crews. Modern air traffic control systems allow aircraft to land and depart on a nearly normal schedule, but the runways, taxiways, and ramps must be kept clear. The snowplow operators are able to continue by using the heads-up graphical displays in their vehicles, which project an image of the pavement edges onto the windshield. The system is based on a detailed 3-D model of the entire airport and on real-time GPS vehicle location technology. The central dispatch office and control tower are able to coordinate the snow clearing with aircraft arrivals and departures with perfect safety.

* * *

In New York City, the emergency measures coordinator is overseeing a training drill of an evacuation of the RCA Building in downtown Manhattan. A simulated fire on the 44th floor requires coordination of several groups, including helicopter pilots from the Air National Guard, representatives of the City of New York, and the New York State Police. The simulation is using the recently completed New York Virtual Reality Model, which allows multiple users to interact in real time. Pilots can operate their virtual helicopters in individual simulators while controllers monitor an overview of the operation. The photorealism of the simulation is uncanny. Flames and smoke from the fire can be seen, and the smoke plume can be adjusted to reflect different and changing weather conditions. The test is completed without disturbing the public and at a fraction of the cost of the old-style training.

* * *

In the Denver suburb of Lakewood, a public hearing on a new transit stop on the proposed western light rail corridor is under way. The planners display photorealistic 3-D simulations of existing and proposed conditions on a large screen. Citizens protest the style and scope of the proposed parking structures. Several small-group discussions are organized around graphical workstations operated by facilitators. Alternatives are suggested and incorporated in rough form into the displays as the discussions progress. At the end of the meeting, two new alternatives are selected for further detailed analysis and presentation on the local Jefferson County website at the end of the following week. These alternatives will be the subject of an additional public hearing at the County Planning Commission in a month.

These scenarios may sound like science fiction, but much of the technology needed to support them—including high-speed wireless information links, real-time multimedia satellite transmission, high-performance computing, GPS chips, and methods for content-based retrieval from digital libraries—is already under development or available in prototype form.

CONCLUSION

As can be seen from the scenarios presented above, the impact of the new spatial data technologies will be profound. These technologies will change completely the way transportation professionals view their roles and responsibilities. The technologies will be not only inexpensive, but also easy to use and ubiquitous. Thus they will enable transportation analysts to manage change proactively and thereby better meet the needs of society.

Virtually all of these new technologies are inherently three-dimensional. No longer will transportation applications be isolated and limited by one- or two-dimensional modalities. The new 3-D information will support integration and interoperability in ways not envisioned by most current practitioners. Making such applications a reality, however, will require substantial advances in technical knowledge; in understanding of human–computer interactions; and in the development of appropriate models of environmental, physical, and social processes that shape our geographic world. Major investments in information infrastructure will be required. Yet these advances will influence the way people work, communicate, teach, and learn—perhaps even the way they think.

Information Technology in Transportation
Key Issues and a Look Forward

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State-of-the-art computer technology has undergone an almost incomprehensible transformation, analogous to the evolution from Morse code to e-mail. Although the rudimentary scope, goals, and objectives of the transportation community have not changed significantly, the challenges of technology today are greater than ever before. Within a generation, computers have transformed the everyday tasks of the workforce—computer use has infiltrated almost everywhere. Data management capabilities have greatly enhanced resource management. However, accompanying the positive effects are the challenges of implementing, supporting, and funding these technologies in the world of transportation.

Narrowing the gap between cutting-edge technology and its applications, as well as identifying the missing links for applying technology in transportation will be the ongoing challenge. This paper briefly documents the state-of-the-practice in information systems and technologies for transportation, as well as the developing role of information technology (IT) in the 21st century. This assessment points to potential solutions for technological challenges in such areas as

- Applying information systems and technology in the transportation field;
- Applying system-user interfaces (e.g., interactive graphics) as well as data management and data sharing;
- Using web technologies (Internet, intranets, and extranets) in transportation;
- Prioritizing research, development, and demonstration programs to augment work presently under way;
- Encouraging the use of common information system and information technology semantics and standards in the transportation field;
- Facilitating and monitoring technology transfer as a "user advocate" among transportation organizations, vendors, and universities; and
- Evaluating the impact of computer technologies on transportation organizations, including gains in productivity.

The growing concerns about the application of advanced computer technology in transportation involve the following issues:

- IT,
- Management,

- Data sharing and interoperability,
- Transportation applications, and
- Information dissemination.

IT ISSUES

Transportation Applications of Web Technologies

In applying web technologies, the focus in the new millennium will be on advances in real-time technologies, such as "zero-latency" and push technologies.

Internet, Intranet, and Extranet Information Technologies

The transportation community should emphasize the applications of the Internet, intranets, and extranets in the design, construction, and operation of transportation facilities, specifically in the following areas:

- Data exchange and communication over the Internet or extranets;
- Cross-platform integration of transportation information sources;
- Dynamic generation and presentation of transportation information on the Internet;
- Information dissemination and management using organizations' intranets; and
- Integration of transportation databases with the Internet, intranets, and extranets.

Anticipating Future Revolutions in IT

The transportation community should identify and prepare for future revolutions in IT that will have an impact on transportation. One revolution is the likely "near future" transition to 64-bit "Wintel" systems. This transition will have a tremendous impact on distributed computing (such as the web) and on data management applications. Many organizations were caught off-guard and were unprepared or unwilling to make the initial investment in the 32-bit Windows 95 revolution and have lagged behind ever since.

Mobile Computing

The market penetration of hand-held and in-vehicle computers will provide a platform for many transportation applications. How can we take advantage of these new technologies?

Virtual Reality

Virtual reality may be useful for facility design and prototyping and should be investigated further.

High-Bandwidth Wireless Networks

How can high-bandwidth wireless networks be used effectively in transportation technology?

Consumer Electronics Explosion

The consumer electronics (CE) market is poised for explosive growth. Market-ready products supporting mobile computing and electronic commerce, and wireless communications supporting E911 locations, smart cards, and the like have made their debuts already. What impact will they have on public and private transportation services? Which CE technologies offer major opportunities for reengineering? For example, how can motor vehicles exploit e-commerce? We barely understand the dynamics of the boundary between the public and private sectors and are about to be overcome by technologically savvy consumers.

New Philosophies and Techniques for Systems Development

The interaction among interoperability, consumer electronics, and in-house software development is already undermining the entire concept of "enterprise" computing. Where is the transportation enterprise in a globally connected, consumer-driven, component-based universe? Enterprise solutions are just more "stovepipe" thinking, as isolating ultimately as the stovepipe applications they were intended to replace. What new philosophical and technical foundations will guide the development of new systems? Is the whole concept of "system" artificial and self-limiting? How should the ideas of nonlinearity, complexity, autopoeisis, and cybernetics be introduced into transportation systems? Institutions of higher education and the National Aeronautics and Space Administration (NASA) are exploring these areas. New applications derive from nonclassified military air and space technologies. The gathering of transportation data (for vehicles, rail, and aircraft traffic), analytic processing, and information presentation to transportation operation centers might be vital in the 21st century. Many of the large companies that have contracts with the military and NASA, such as Boeing, Northrop Grumman, and Lockheed-Martin, can be resources for the transportation community. This kind of engagement could allow research facilities, using U.S. Department of Transportation (DOT) grants, to develop processes, techniques, and management systems using high-altitude reconnaissance and ground surveillance aircraft equipment, geosynchronous satellite sensors, and data collection and telemetry programs. The Transportation Research Board should help develop consortiums among the states, universities, aerospace and aviation companies, and DOTs to discover solutions for tomorrow's needs.

Other topics and types of IT that will be of increasing interest to the transportation community include

- Software and hardware security,
- Mobile communications,
- Automatic equipment identification,
- Electronic data interchange,
- Global positioning systems,
- Geographic information systems (GIS),
- Visualization and animation,
- Electronic funds transfer,
- Voice recognition,
- Sophisticated bar-coding,
- Airborne ground surveillance,
- Satellite ground surveillance and tracking,
- Very large-scale computing,
- Distributive and client-server technologies, and
- Advanced analysis and modeling computing.

MANAGEMENT ISSUES

Standardized Methods for Benefit–Cost Analysis

It is important to develop standardized methods for benefit and cost (BC) analysis for the implementation of IT in transportation agencies. BC analysis traditionally has been difficult for IT. Managers and politicians are less patient and less willing to accept the "intangible" benefits of IT.

Software Safety

As software becomes a more integral part of transportation systems, software safety issues arise. We must ensure that the software does no harm if it should fail. We do not want the equivalent of the Thorac X-ray machine accidents, in which several patients died due to defective software, to occur in transportation. But safety is not the same as security, although they are interrelated; safety goes beyond security. Safety considers such issues as "What happens if someone breaches the security barrier? Can the system still be safe?" Even without a security breach, software can fail because of a bug, hardware failure, or another similar internal problem. It is important to ensure that if the system software does fail, there is no resulting injury or loss of life. Some developers go even further, maintaining that it is important to ensure that the software does not cause any highly undesirable situations—for example, all the traffic lights turning green simultaneously as a result of a failure in the traffic management system. On the other hand, it also could be argued that all lights turning red at once also is unsafe—or at least highly undesirable.

Software Systems

With the good old days of "roll-your-own" software systems gone forever, how does an agency obtain new systems and components? How do you design and build systems from components? What new skills and roles does your information system (IS) staff need? How do you acquire, benchmark, deploy, operate, upgrade, and retire systems in this new environment? The last generation of systems managers witnessed the hardware "appliance." What is the software equivalent?

Standards and Guidelines

What are the specific standards and guidelines that IS leaders in the transportation world can rely on for practical application in a dramatically changing environment? The transportation community should support standards development—such as *Standards on Software,* Carnegie–Mellon's *Software Engineering Institute Capability Maturity Model, ISO9000-3,* the Project Management Institute's *Guide to the Project Management Body of Knowledge*, and other documents providing standards and guidelines.

Technical Concerns

What are the realistic, long-term costs and risks associated with enterprise resource planning implementations?

DATA SHARING AND INTEROPERABILITY

Management of Transportation Data

Management of transportation data from an IT point of view, or data storage and data delivery in a non-data-specific way should be considered.

Exchange and Sharing of Transportation Data Sets

The exchange of ideas and experiences is important in the advancement of transportation facilities. Good ideas and experiences can be exchanged through conference presentations and journal publications. These good ideas and experiences come mostly from analyzing or studying real-world data. These data sets, however, are rarely available. At present, even if authors who publish their work would like to share their data, there is no well-established place to organize and disseminate them. Furthermore, data are expensive to collect. If we know that relevant data are available, we do not have to collect them again, or we only need to supplement the data that already exist. This would save both money and time. The transportation community should encourage the following activities related to exchanging and sharing transportation data sets:

- Determine what types of data are useful in terms of planning, design, operation, safety, and maintenance of transportation facilities. Determine how to classify the data.
- Determine the format and standard for publishing data sets. For instance, the data should be saved and published in standard formats. The data should then include a description of how they are collected, what and how to use them, where to get them, and so on. Since data are collected in the real world, we also might require each data set to specify at least one location reference suitable for GIS geocoding, making it possible find out what data a particular location has by clicking on a map.
- Define standards for disseminating the data.

Interoperability

Now that the "Holy Grail" of integrated systems has been abandoned, it looks like the next goal is interoperability. What is a good, working definition of interoperable? Is it practically achievable? How does interoperability differ from compatibility, interfaceability, and substitutability? What is the role of standards in achieving it? Which standards are we going to use? What is the difference between component-level interoperability and system-level interoperability? Where are the early examples of interoperability in transportation?

TRANSPORTATION APPLICATIONS

Aging and Disabled Drivers

The transportation community needs to investigate how IT could provide assistance to the increasing population of elderly and disabled drivers.

Intelligent Vehicles

How IT will affect the deployment of intelligent vehicles and how telematics will change the operations of transportation agencies and the behavior of motorists needs to be evaluated.

Vehicle and Highway Automation

Where do we go from here? How do we start with partial automation and advance to full automation?

Collision Warning and Avoidance Systems
The transportation community needs to evaluate how well collision warning and avoidance systems and crash mitigation systems could work, what percentage of the annual 40,000 accident deaths could be prevented by such systems, and whether such systems should be mandatory.

Information Dissemination
Public expectations about the transportation industry, particularly how the public interacts with government organizations, should be assessed. This is especially important as people become accustomed to the availability of a high degree of timely information in their daily lives.

We also should consider how the timeliness of information applies to the following categories of people:

- End users traveling along the transportation infrastructure (en route IT);
- End users preparing to enter the transportation infrastructure (credentialing and trip planning);
- Government staff employing gathered information to improve the infrastructure (operations, planning, enforcement, etc.); and
- Governments communicating with each other.

BEYOND 2000
As we move into the 21st century, we need to identify the areas of transportation in which IT innovations might develop; we then can begin to solve problems and meet challenges proactively. By reviewing and assessing the state of the art in information systems and technologies, the transportation community might be able to predict directions that technology will take and to identify the skills that will be necessary to support the future expansion, integration, and productivity of transportation systems. We will see more advanced technologies with direct or indirect uses in transportation. It is important to provide trend forecasts for management, especially when the proposed changes require a long lead time and significant effort. One example is the need to rely increasingly on contracted work, which generates a need for effective contract management training and coaching for IS project managers.

To meet the IT challenges in the new millennium, we should increase awareness in state and local agencies of formal techniques to increase the margin of safety of the systems they procure. In the future, it will be possible to have considerably more intelligence in the infrastructure (for example, "smart highways" procured by state and local transportation agencies) and in communications between vehicles and the infrastructure.

In the new millennium, the transportation community should take a much more integrative and coordinating approach to IT applications for transportation, such as GIS, global positioning systems, and intelligent transportation systems. Finally, the transportation industry should strive to be a leader in IT. To do this, the transportation community must monitor developments in other sectors of the economy.

Geographic Information Systems for Transportation
A Look Forward

DAVID R. FLETCHER, *Geographic Paradigm Computing, Inc.*

> I have no way of judging the future but by the past.
> —*Patrick Henry, Orator*

> You can never plan the future by the past.
> —*Edmund Burke, British Statesman*

The following story could be true: It's late and you're driving on an unfamiliar country road. Suddenly, without warning, a deer leaps out from the side of the road. You swerve violently, missing the deer but not the ditch. Shaken, but not seriously hurt, you wait as your car contacts E911 and requests emergency service. Within minutes, the patrol deputy nearest your car is on-scene, and a possibly serious situation is quickly avoided. Some weeks later, a safety analyst working for your insurance company observes that your incident was one of many involving animals along that same stretch of road. Reviewing recent satellite images of the area, the analyst determines that roadside vegetation has grown too close—obscuring the vision of both driver and deer. The analyst forwards a maintenance request to the Department of Transportation (DOT) and within days, the brush cutting—scheduled to coincide with other routine maintenance along the same section—is complete.

Is this story true today? No. Can this story be told within the next ten years? It depends. The outcome of this story and many similar scenarios depends on meeting significant institutional and technological challenges. One of the most fundamental is developing the ability to communicate, understand, and use information about place and time consistently across jurisdictional, institutional, and technical boundaries. The recording of places and their changes over time goes under many names—geographic information, geospatial data, geographic information systems for transportation (GIS-T), the digital earth. These digital records take many forms—maps, images, measurements, and observations—and are stored in vector, raster, and alphanumeric databases. However, for simplicity's sake, our opening story illustrates GIS-T.

GIS-T are interconnected systems of hardware, software, data, people, organizations, and institutional arrangements for collecting, storing, analyzing, and disseminating information about areas of the earth that are used for, influenced by, or affected by transportation activity. Many trends, directions, and influences are shaping the next generation of GIS-T. Some of them come from within the transportation industry; most are exogenous to it. While these influences represent complex, interdependent technological, political, and cultural trends, several primary themes emerge that will likely shape GIS-T in the new millennium. They include

- The evolution of GIS-T products, services, and technologies, guided primarily by general technology and market forces;
- The application and use of these products in the public sector, guided primarily by political and institutional trends; and
- Emerging data and information issues that affect those who build or use GIS-T.

GENERAL INFORMATION TECHNOLOGY AND MARKET FORCES

The nature and explosive growth of the Internet is producing an entirely new computing model. Ample evidence exists that the computing and communications industries are constructing a distributed, component-based, global network. This high-speed, broadband architecture will ultimately allow access to any desired information service or resource on an international communications network, using a variety of "plug and play" devices. In this environment, central notions of clients, services, and access methods are rapidly replacing an earlier focus on applications, products, and platforms. In essence, extensions of current technologies allow transparent access to information resources regardless of their physical or logical location. This implies that architectural and infrastructure details will increasingly be hidden behind standard network appliances, impenetrable to all except a few very large technology vendors. Information users will no longer need to know or care about the new technical infrastructure. This major trend will affect every aspect of GIS-T hardware, software, and data development.

GENERAL TRANSPORTATION ADMINISTRATION TRENDS

Governments around the globe are outsourcing, privatizing, and decentralizing many operational responsibilities previously performed by in-house staffs. Many factors are contributing to this trend, including political pressures for smaller bureaucracies, increased competition from the private sector, and the increasing difficulty of attracting and retaining qualified staff. Consequently, the inexorable future of transportation management will lie in smaller, more decentralized agencies primarily providing regulatory oversight and intergovernmental services. The public sector employees that remain will be organized into multidisciplinary teams focused on policy formulation, planning, funding, and program oversight functions. Private organizations will continue to challenge the public sector as data and service providers. This significant trend in transportation services delivery will have a major impact on the people, organizations, and institutional arrangements associated with GIS-T.

GIS-T MARKETS, PRODUCTS, AND TECHNOLOGIES

New Products, New Markets

Present Outlook

GIS-T, once the sole domain of public sector planning and transportation agencies, will continue to diffuse into broad commercial and consumer transportation markets. New products—with a wide range of features, functionality, usability, and prices—will be developed for these much larger markets. In the process, while transportation-related spatial data and services will become commonplace, GIS-T will cease to be a meaningful label. By the middle of the next decade, interoperable logistics and dispatch systems will be standard throughout the commercial transportation sector. Mobile E911 connections, map-based yellow pages, trip planning and travel directions applets, vehicle tracking and routing applications, and other real-time products, services, and applications will dominate GIS-T consumer markets. The synergy between cellular telephones, mobile positioning systems (using either GPS or cellular location technologies), and thin client computing will create entirely new markets and spatial data consumers. The next generation of personal device assistants will provide voice, e-mail, web browsing, computing, and mobile-positioning services. Mobile IP addresses, coupled with GPS circuitry attached to vehicle data buses, will provide the same set of services to vehicles.

Challenges

Although universal network connectivity is becoming a reality, serious issues remain concerning geographic data interoperability. As of now, no universally accepted data structures, formats, syntax, terminology—which constitute semantic content—or quality standards exist. Without significant progress towards standards in these areas, emergent markets may fail or, more significantly, may succeed but necessitate a much higher threshold for spatial and temporal data quality than exists today.

A major emerging issue is how to operate effectively in a world with millions of spatially enabled, Internet-attached travelers, shippers, carriers, and vehicles—each collecting and processing real-time positions locally. Users of each of these nodes will demand and expect connections to hundreds of geographic-data reference sites, including those maintained by state and local transportation agencies.

Waning Role of Public Sector

Present Outlook

Public sector (particularly federal and state) customers will wield far less influence over GIS-T products and their vendors in the future. As spatial technology vendors begin to compete for much larger commercial and consumer markets, successful GIS-T products, services, and technologies will be those that fade into the background of ordinary use. Intuitive, easy-to-learn products accessing plug-and-play data will characterize market leaders. The esoteric, complex packages on the market today will not penetrate consumer markets.

This mass "commoditization" of spatially enabled, consumer-oriented applications and utilities will be provided by vendors who have the critical capabilities—distribution channels and marketing mechanisms—required for capturing large markets. While such vendors will address consumer markets, they will not focus on transportation-specific data capture, maintenance, warehousing, and dissemination. These areas will remain the primary interest of public sector customers, offering new opportunities for the currently dominant GIS-T vendors.

Whereas today GIS-T is perceived to be too costly relative to its benefits and too difficult for the average person to use, this assessment is changing. The widespread availability of inexpensive, consumer-friendly products and services, coupled with increasing market demands for better data and better constituent service, will be embraced by public sector organizations. This will stimulate a second-generation GIS-T renaissance within agencies.

Challenges
Most public sector agencies today are encumbered with major GIS-T legacy investments and cumbersome procurement practices. Better ways must be found to create agile processes that accelerate the introduction and integration of these new GIS-T products, services, and technologies.

High Demand for Skilled Workforce
Present Outlook
A consequence of this widespread diffusion is that while spatial data and technology will be commonplace, effective knowledge about the principles underlying them will not be. Although the demand for GIS-T technologies and services will increase, the supply of formally educated spatial experts (for example, geographers, cartographers, and surveyors) will not be sufficient. Because of the difficulties in creating a "smarter" user, the tools themselves will become smarter. Consequently, most GIS-T consumers will not even know they are using GIS-T tools. More and more GIS-T functionality will be found in standard desktop software and Internet-based browsers and applets. There will be a growing number of canned applications with spatial processing components. However, this suggests that the majority of general users of GIS-T services will be content to use geographic browsing and map visualization utilities with only limited understanding and use of more complex spatial analyses.

Challenges
Although the major benefits of GIS-T arise from the application of spatial analysis techniques, relatively few people will be able to conduct these analyses with confidence. There is a critical need to create both smarter consumers of geographic information and smarter tools. A likely scenario is the emergence of two GIS-T markets: one characterized by new advances in the mapping and geographic sciences accelerated by the next generation of high-end products, and the other driven by low-end "point and click" applications. The GIS-T community needs to recognize both and bridge the gap between them.

While the emergence of high-end spatial-processing software is stimulating a revolution in the educational curricula of mapping and geographic sciences, civil and transportation engineering educators are still struggling to absorb this impact. A serious debate is needed within the profession about the role of GIS-T in undergraduate, graduate, and continuing education programs. A continued shortage of knowledgeable staff will limit the benefits inherent in GIS-T.

New User Interfaces to Spatial Data
Advanced user-interfaces will become increasingly available, particularly in high-end products. Virtual and augmented reality approaches using 3D, synthetic speech and voice activation, and other haptic devices (for example, force feedback joysticks, pressure pads, and head-tracking displays) will begin to supplant existing 2D map-oriented presentation metaphors.

GIS-T APPLICATIONS AND SERVICES

Spatial Data and Transportation's Changing Mission

Public sector GIS-T applications and services will increasingly reflect the shift in national transportation policy, from infrastructure development to asset preservation and transportation operations. While early applications of GIS-T supported project-level engineering or program-level transportation planning activities, future efforts will focus on dynamic performance evaluation and resource allocation on a system-wide basis. The Intelligent Transportation System (ITS) vision of a seamlessly integrated mix of concrete and digital components will be supported by a GIS-T foundation.

As the planning field moves more to micro-simulation models, the worlds of planning and operations will move closer together. Systems planning will become more meaningful to operations staff, and operational information will be used directly in the planning process. Planning will increasingly become an exercise in simulated operations and a new life cycle paradigm (Operate-Plan-Improve-Operate) will begin to emerge. Such changes will require implementing unified, interdisciplinary representations of real-world features and events, subsequently requiring interoperable, comprehensive, high-quality data with location and time as central dimensions. With this increasing need for current and accurate data, inconsistent or out-of-date information will no longer suffice.

Spatial Data and the DOTs

Present Outlook

The primary missions of the DOTs are evolving as well. Although they were once primarily engineering organizations closely tied to the design and construction industry, they are increasingly becoming multipurpose information providers serving a number of constituencies, including other agencies, commercial carriers, and individual citizens. The heterogeneous services they provide—engineering, mobility, retail, and intergovernmental—will be scrutinized by elected officials, the press, and the public and evaluated against a set of explicit public policy goals and objectives.

State DOTs will implement GIS-T systems to support the new services that are truly mission critical. These include systems for performance monitoring, traffic management, property management, tort cases, environmental mitigation, maintenance, setting project priorities, and scheduling.

Challenges

This unified approach to transportation system management will require major investments in transportation data warehouses that are accessible to various operational and decision-support applications. It will also require a high degree of change between operational systems and decision-support systems. Much research will be necessary to reconcile this transportation management model and GIS-T terminology and perspectives.

The need for much-higher-quality data highlights the present lack of efficient data-update and maintenance procedures. New methods of identifying changes, updating spatial databases, and communicating the changes to information service providers and end users are essential.

The application of spatial technology today is often opportunistic and tangential to core agency missions. New agency missions and objectives will require delivery mechanisms with major spatial components. GIS-T needs to become more core-mission focused, driven by critical agency needs and not by technological imperatives. This requires a degree of technical robustness and performance rarely achieved today.

SPATIAL DATA, INFORMATION, AND KNOWLEDGE

Global Data on Demand

Present Outlook

The influence of the major technological and institutional trends is also determining the future of spatial data and information. The widespread adoption of distributed object technology, plus increased software components and pervasive models of network computing using tools such as Java, will create an "on demand" environment allowing dynamic reconfiguration of spatial information. Subsequently, the type and character of data will become less important as access, viewing, and analysis methods will link transparently to a variety of data types. Spatial and other data will be dynamically allocated and organized to meet user requests; usage requirements will dictate the mix of data types and tools used in a particular problem-solving setting.

Although this will provide rapid, near-global access to unlimited spatial data, it will not do much to improve the context of resource delivery. The global spatial data infrastructure will contain a bewildering number of free and for-fee databases. Some of them will be tightly coupled to particular applications; others will be multipurpose. Users will still have to wade through all this available data searching for meaning. This creates the need for universally understood metadata or "data about data," catalogues, and other searching strategies.

Challenges

Recent lessons from existing data-intensive domains suggest that as the amount and diversity of data increases, its marginal value paradoxically decreases. Indeed, adding more data to already information-saturated situations tends to obscure issues rather than clarify them. Too much information raises extraneous issues and poses too many choices. Ultimately and ironically, the result of an expanding global spatial-data universe may be less knowledge and greater uncertainty about the world. While the promises of artificial intelligence, expert systems, virtual realities, agents, filters, and data miners are seducing us into acquiring and applying more complex and expensive information systems, we must develop better approaches to managing information glut.

Interoperable Systems

Present Outlook

Interoperability strategies, architectures, and technologies will continue to replace integrated ones. That is, the strategy of using enterprise GIS-T as a transportation information and institutional integrator will be modified to reflect more interoperable approaches. Location will continue to be an essential data dimension, along with time. However, scale and resolution differences will become less important. At the same time, data quality issues, including defensible statements of uncertainty and error, will become increasingly important. Data warehousing will accelerate these approaches, and location determination will differentiate new data-warehousing technologies necessary for transportation information processing. These will include space, time, and attribute transformations, not merely simple projection or scale adjustments. Primary data stewardship will remain with current jurisdictions, which will be using mostly existing legacy systems for data capture and maintenance.

Challenges
Metadata and public data interface standards are the two most crucial factors for determining the success of interoperable systems. Although several agencies and organizations are working on these issues, no universally adopted mechanisms exist. Metadata creation and use will be critical for true interoperability.

Location Reference Schemes
Present Outlook
Because transportation systems are essentially linear phenomena, the need to manage, analyze, and understand transportation information in a linear context will persist. However, linear referencing methods must be interchangeable with other methods of location referencing. The current trend is to collect data using two- or three-dimensional devices—such as GPS—and transform the coordinates into path-oriented or linear locations. These measurements are referenced to a standard ellipsoid model instead of base maps or linear field monuments. This allows for new economies in the field and the continued use of existing legacy and it supports path and network models, applications, and displays.

Challenges
The implications of having two fundamentally different location models—geographic and linear—are profound. Data warehouses must be able to manage both models. Improved transformation algorithms and utilities will be necessary to perform on-the-fly transformations of spatial data.

High-Spatial-Resolution Data
Present Outlook
The next generation of high-spatial-resolution satellite imagery will provide a global data source of unprecedented accuracy, scope, and availability. Since fusing vector, raster, and video spatial data structures in the application layer will no longer be a technical challenge, these images will be widely used. Specific transportation applications include creating new spatial databases, updating existing map bases, and using the images as backdrops for virtual and augmented reality displays or as control frameworks to register multiple thematic map layers.

Challenges
Widespread use of this new data in public sector transportation will depend on creative, flexible licenses; pricing strategies, plug-and-play data and applications, and "open" software and data architectures.

CONCLUSION
The transportation community has an unprecedented opportunity over the next few years to obtain, use, and distribute spatial data using many spatially enabled technologies. If utilized intelligently, the data will provide a wealth of information about transportation and its relationship to the quality of life on global and local scales. The way that we respond to

today's trends, opportunities, and challenges will determine whether stories like that in our introduction come true or remain merely fables.

> The barbarians are in the line of mental growth, and those who do insist that the ideal and the real are dynamically continuous are those by whom the world is to be saved.
> —*William James, Philosopher*

National Transportation Statistics

ALAN E. PISARSKI, *Consultant*

There are three central elements of national transportation statistics:

- Content;
- Institutions; and
- Technology.

At the century's end, significant changes are occurring in all three elements. These changes can be expected to modify the ways we will function, changing the nature of statistical programs in the new era ahead.

CONTENT

As the new century dawns, we are operating in a post–regulatory mode for data content. Extensive economic deregulation of most of the transport modes began 20 years ago. Transport statisticians still operate in the aftermath of the former regulatory environment, seeking to reestablish systems of data that were gradually abolished as the regulatory warrants for the data disappeared. Many transportation operators resist government data-collection efforts for fear of renewed regulatory control. As a result, data are missing because no statistical programs have yet been put in place to replace information once provided by federal and state regulatory agencies for such modes as air freight and intercity bus. Transportation modes that have risen in importance in the meantime, such as regional or short-line railroads, have little data collected.

The emerging world of the new millennium will have new data needs as we shift our focus in transportation. Among the concerns will be

- Demographic extremes;
- Globalization;
- The niche society;
- Impact analysis; and
- Economic measurement.

Demographic Extremes

There are major stabilizing forces in personal travel that suggest a decline in historic rates of growth. These include the relative saturation of driver's licenses, vehicle ownership, and labor force participation.

The history of our era since World War II can be seen as effects of the baby-boom generation working its way down the age-cohort decades. Between 1995 and 2005 the number of people in their fifties in America will grow by 50 percent, exemplifying the dramatic shifts we will undergo as a society. These changes, from the final playing out of the baby boom, will affect almost every facet of our transportation environment. In 2010, the first of the boomers will reach 65 and another dramatic turning point will be reached.

Globalization

International relationships are increasingly important in our very competitive world. The field of transportation statistics must expand its thinking beyond domestic boundaries and prepare our statistical systems to operate in a world environment. One important step has been the development in recent years of the North American Interchange on Transportation Statistics, in which Canadian, Mexican, and U.S. transportation and statistical agencies meet to share experience, coordinate programs, and develop comparable statistical systems. Early in the new century, we will have the first comprehensive North American transportation statistics report.

Today, the United States has little ability to describe the transportation effects of major trade flows, either domestic or international. In the last few years, the Department of Transportation Bureau of Transportation Statistics (DOT BTS) has helped resurrect the surveys begun in the 1970s that measured the intercity movement of both freight and passengers. However, these efforts will need to be extended to produce the information needed for an increasingly global economy.

The dominant focus in states and metropolitan areas is on the economy. The economic thrust today is globalization of almost everything—production, markets, and supply and demand. New economic arrangements such as the North American Free Trade Agreement (NAFTA) and the Common Market are creating new competitive and cooperative patterns. Both freight and passenger transport are affected. It is becoming increasingly clear that domestic markets are sharply influenced by international services and competition.

Among the fields where tremendous data gaps exist are

- Just-in-time patterns and trends;
- Current and prospective NAFTA trade flows;
- Intermodal freight movements;
- Urban goods movement;
- Internal movements of goods in foreign trade;
- Travel and tourism, both intercity and international; and
- Major new trade corridor flows.

Niche Society

We are shifting from a system emphasizing the measurement of large masses of travelers to public policy interests that focus on the smaller units of total travel demand, such as transit users, bicyclists, walkers, households without vehicles, those with low incomes, people with disabilities, people involved in the changing welfare system, and minority populations. These groups are difficult to monitor because they represent small subsets of the general population that are difficult to identify and measure with precision. Obtaining data for special populations of interest has become a major challenge for statistical systems.

Rising incomes will also be a factor, resulting in increasing auto availability and use, trips per household, and average trip lengths.

Impact Analysis

Transportation seems to be linked to everything and is often seen as the universal lever for many public policies. It is called on to support many other goals. There will be a critical need to construct analytical data capabilities to assess the impact of transportation in many areas. Policy makers will increasingly require sophisticated treatment of transportation's impact on safety, the environment, and society, in addition to its economic impact.

As more and more transportation development issues center on moving freight across America to our ports and borders, it is amazing how limited are the skills and resources available to the process. The ability to produce benefit and cost analyses in these areas, as we ask ourselves about trade-offs between modes serving very different functions, needs substantial development.

With diminished public consensus on the desirability of transportation investment, the need for rigorous, quantified, economic, and social arguments for new expenditures will increase. We will need to quantify the value of transportation to our communities.

Many performance measures in transportation fail the relevance test, either because the performance measure is not readily linked to real-world experience, or because the measure fails to capture the desired concept. The commonly used measure of ton-miles illustrates the former; few decision makers can visualize a ton-mile and relate it to an understood quantity.

Economic Measurement

It will be important to develop sophisticated levels of economic analysis so that appropriate evaluations can be made within and between modes. The ability to interpret global impacts of freight or passenger travel will be critical. As states and regions compete for jobs and new technological opportunities, the ability to make economic assessments will be essential.

Recent research has shown that America's future depends to a high degree on improved competitive access between suppliers, producers, and consumers. Two dominant factors in competitive success are communication and transportation. We will need tools to transmit the basis for investment decisions to the public.

INSTITUTIONS

It can be said that transportation statistics are in better shape today than at any time in recent memory, yet unprecedented demands are being put on those statistics by decision makers. As documented in several reports of the National Research Council, the transportation community requires more complete, detailed, timely, and accurate statistics than ever before. The demand for more thorough coverage of transportation activity recognizes that forms of transportation that are more difficult to measure may contribute as much social and economic impact as the forms we have traditionally measured.

In 1992, the Intermodal Surface Transportation Efficiency Act (ISTEA) reflected such great concern with the deteriorated state of information that a new national statistical agency, BTS, was mandated. In 1998, the Transportation Equity Act for the 21st Century (TEA-21) reaffirmed the programs launched under ISTEA and added new areas to be tackled.

BTS provides a focal point for the expression of data needs and concentrates the efforts to respond to those needs. But there are still institutional issues to resolve. Statistics coordination within the DOT and between agencies of the federal government will require continued attention.

TEA-21 requires BTS to maintain two databases. The Intermodal Transportation Database (ITDB) is to be a complete picture of transportation activity, measured in physical and economic terms. The National Transportation Atlas Database (NTAD) is literally the ITDB on a map, a recognition that transportation exists to overcome the barriers of geography.

TEA-21 and a report of the Committee on National Statistics emphasize the need to improve data quality and comparability throughout the transportation community. This will require the following:

- Adoption of common definitions of variables throughout the profession;
- Adherence to good statistical practice, particularly in the collection and interpretation of sample data;
- Replacement of questionnaires with unobtrusive methods of data collection, either through the use of administration records or remote sensing; and
- Validation of statistics used in performance measures and other applications.

One aspect of the new institutional need overlaps with new technology concerns. As intelligent transportation system (ITS) technologies develop as major sources of data, the institutions are not in place to process and disseminate ITS data. ITS is recognized as a valuable potential resource, but there are gaps in our institutional mechanisms to fully utilize ITS as an information resource.

TECHNOLOGY

Many tools of traditional data collection are failing just as new tools become available. Roadside surveys and household travel surveys are almost things of the past. As security concerns and poor response rates diminish the effectiveness of these traditional tools, new, less-obtrusive, technology-based tools will need to be employed using remote sensing, automated systems, or administrative records processing. ITS, the Internet, and computer-based technologies will all contribute to faster and less-expensive collection mechanisms. However, these new technologies will have their own problems. They may distort information in new ways and require new institutions to develop them, and they will certainly generate new statistical quality questions.

The demand for greater detail in transportation means a need for detail about geography and time, recognizing that congestion and other transportation problems are not the result of average conditions but of concentrating too much activity in one location during the same period. The demand for greater geographic detail also recognizes that transportation's benefits depend on where the flows of people and goods go and which locations are left behind. The demand for more-timely data indicates that the transportation system must respond to rapidly changing conditions, especially in a global economy, and that decisions cannot wait for measurement systems to be devised and put in operation.

FUTURE OF NATIONAL TRANSPORTATION STATISTICS

How policy and planning processes use data tells us a great deal about whether the processes are to be respected. If transportation policy and planning are to be taken seriously, then the statistical professions must address key concerns in the future. Some fundamental concerns are

- Transportation statistics systems will need to focus on objectively describing what exists and how transport relates to other elements of society and the economy.
- Those involved in transportation statistics will need to recognize that most transportation policy and planning is as much about other subjects as it is about transportation. What makes for viable policy and planning information is the combination of transportation *and* demographic data, transportation and economic data, transportation and resource data, etc.
- Transportation statistics will need a valid vocabulary with properly defined and demarcated meanings to aid in better communication in the transportation community.
- Transportation statisticians will need to learn how to justify their programs. There are few guidelines on what to collect, in what detail and with what precision, how often, and why. The ability to justify transportation statistical programs in cost and benefit terms is still in the distant future.
- Transportation statisticians must recognize that anticipating emerging issues is the key to success. The ability to anticipate the policy and planning data needs of the future will be the quintessential skill.
- Transportation statistical systems must be based on the recognition that policy makers are forced to work with what data are available when a policy issue arises, and data programs must be designed with that in mind.

* * *

The story goes that when the staff of first DOT Secretary Alan Boyd told him that his plans for national data collection would take years and that he would not likely benefit from them, he answered: "We'd better get started then, shouldn't we!"

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