FHWA International Scanning Report on Advanced Transportation Technology

INTERNATIONAL
TECHNOLOGY

FHWA's Scanning Program

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Advanced Transportation Technology

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Foreword

Team Members' Statement

Our Nation's existing highway system and traffic controls have served our country well and have provided the mobility needed to support the U.S. economy and everyday activities of the population. However, as a nation, we face the need to rebuild much of our existing infrastructure and to develop new traffic-control strategies and systems. To ensure that, in the future, the highway system continues to meet the needs of the Nation, it is necessary to investigate new, emerging, or advanced technologies that have potential for long-range application in the highway program.

To better prepare for the task of identifying advanced technologies that may be incorporated in future highway systems, a scanning team was assembled to survey European planning and applications of advanced technologies, seeking knowledge that might aid us in the United States. This advanced technology scanning team was drawn from our Federal and State highway agencies, the National Institute of Standards and Technology, and Carnegie Mellon Research Institute. Our group of experts in various advanced technologies met with experts in Denmark, Germany, France, and the Netherlands.

All seven participants agree with the following mission statement for the study tour:

> **The mission of the group is to review European plans and developments in evolving computer-based or computer-enhanced technologies to assist with the development of appropriate actions for enhancing our Nation's highway system, productivity, and economic future.**

Findings in Europe

- We found a cooperative attitude among the various components of the European highway community —researchers, government executives, government engineers, contractors, and others with commitments to sound planning and to excellence.
- We found a strong desire for fundamental understanding of the technologies, and the will to commit adequate resources to developing new systems.
- We found a strong commitment to research and development, including fundamental research.

Action Plan

A full report on the findings of our tour has been prepared and presented on the pages that follow. At this time we urge consideration of the following initial steps to help integration of advanced technologies in the United States highway system:

- Encourage closer interaction between highway agency engineers, researchers, consultants, and academics to promote better understanding and use of advanced technologies.

- Promote and develop cooperative research and technology transfer activities with our European counterparts on specific technologies.

- Organize continued training programs for researchers at Federal and State levels, engineers from highway agencies, and contractors to improve the understanding of new technologies.

Conclusion

To a significant degree, this tour of Europe offered a picture of applications, approaches, and opportunities for collaborative efforts that U.S. researchers should capitalize on. It is for us in the United States to take advantage of what we can learn from other nations and to identify what we can share with other nations, so that both can better anticipate tomorrow's needs and build the infrastructure and traffic control systems for the future.

Table of Contents

Appendices

List of Figures

1. Executive Summary

1.1 Background

New, emerging, and advanced technologies that have potential for long-range application in highway transportation are being independently investigated by transportation agencies worldwide. In 1989–1992 the Organisation for Economic Cooperation and Development (OECD) conducted a study of expert systems in the OECD countries that identified significant expert-systems activities in Europe. This study indicated the existence of many additional advanced-technology activities that may be of interest to the Federal Highway Administration (FHWA), but did not collect any information on these activities.

It is recognized that there are some technology areas that the U.S. highway community has not investigated, while European countries have. There are several other areas in which foreign countries have conducted investigations that could complement work conducted in the United States and where technology sharing would be mutually beneficial.

The Advanced Transportation Technology Team was organized by the International Programs Office of the FHWA, to survey European technology and to observe and document developments in evolving computer-based technologies such as artificial intelligence, expert systems, neural networks, computer-enhanced inspection, modeling and test methodologies, etc. More specifically to:

- Assess the state of ongoing research in evolving computer-based technologies such as artificial intelligence, data visualization, etc.
- Assess support for longer range, high-risk research ventures.
- Determine how European countries get innovations tested and into practice.
- Define technologies in which the United States can collaborate on joint research and development (R&D) efforts.

Thus, directions were to review European plans and developments in evolving computer-based or computer-enhanced technologies in order to assist with the development of appropriate actions for enhancing our Nation's highway system, productivity, and economic future.

The team consisted of seven people representing FHWA, State Departments of Transportation, NIST, and Carnegie Mellon Research Institute. Head of the delegation was James Wentworth of FHWA's Office of Advanced Research.

On November 8, 1993 the scanning tour started at Copenhagen, Denmark, and ended on November 19, 1993 at Delft, The Netherlands. Four countries were visited: Denmark, Germany, France, and The Netherlands. The team was hosted by representatives of the Ministries of Transportation in each country and visited research institutions, field applications sites, and private engineering offices.

1.2 General Observations

All of the European highway community that were met by the team were fully cooperative and made the team feel welcome. Representatives of the European transportation ministries candidly discussed problems as well as presenting technological successes and expressed the desire for mutual technology interchange.

European highway directorates appeared very willing to sponsor research, development, and implementation of advanced technologies in field test sites to validate their effectiveness. Through such programs as the Dedicated Road Infrastructure for Vehicle Safety in Europe (DRIVE), the European community is cooperating internationally to develop traffic monitoring and control systems that are compatible and transparent to national boundaries.

We have identified several technical projects that should be considered for followup either by long-distance communication or by additional trans-Atlantic visits by technologists (in both directions).

Sections 3 through 6 provide an overview of the entire tour in chronological order, country by country. Technologies are described briefly in those sections and more fully in Section 7.

1.3 Selected Highlights

In order to provide the reader with a flavor of the technologies that were observed by the team, a few projects are mentioned below. The reader is referred to Section 7 of this report for more extensive accounts of 11 technology areas observed by the team.

In Denmark, the team saw a new technology for investigating the condition of highway structural material. The National Road Laboratory (NRL) has a technique for preparing 20-micron thin slides of structural material (e.g., asphaltic concrete) and analyzing microscopic images of these samples by automated image processing. The number, size, and shape of the material voids are being related to the age and condition of the materials.

Germany has developed effective means of visualizing data regarding the condition of their highway network. They generate stylized maps that represent several different aspects of the condition of each road segment, according to a color code. These maps provide a rapid means of assessing systemic problems.

A valuable pavement management expert system has been developed in France. Known as ERASMUS, *Entretien Routier Assiste par Systeme Multi-expert* (pavement management system) is performing well above its predicted levels and yields savings of from 5 to 10 percent, in some cases. The cost-savings potential for the United States would be huge.

The Netherlands has been successfully employing automated sign changing. Drivers are provided with alternative-route advice based on traffic conditions detected by sensing stations.

Sections 3 through 7 provide information about research in materials, structures, sensing, data management and processing, artificial intelligence and other mathematical techniques, and traffic monitoring and control.

1.4 Followup

A list of technologies on which the team recommends additional technical interaction is provided in Section 8, but a few examples follow:

- Roadway weather stations are used to provide driving-condition data such as fog and icing conditions to traffic control centers that can alert drivers via automatically changeable warning signs, as well as alert maintenance crews when salting/sanding is appropriate.

- Several artificial intelligence applications, including pavement management and snowplow-route optimization, have been implemented or are in development.

- Each country is employing or developing an improved pavement-condition recording and evaluation system. Automated programs are being developed to schedule maintenance and reconstruction projects as far as 5 years ahead.

- Many European countries are cooperating on an international system for traffic monitoring and control. DRIVE is the European equivalent of the Intelligent Transportation System (ITS) program in the United States. (ITS was formerly referred to as IVHS, Intelligent Vehicle Highway System.) Exchange of information and technologies between these two programs would undoubtedly be of mutual benefit.

2. Introduction

2.1 Purpose

The Advanced Transportation Technology Team was organized by the FHWA International Programs Office to survey European technology to observe and document developments in evolving computer-based technologies, such as artificial intelligence, expert systems, neural networks, computer-enhanced inspection, modeling and test methodologies, etc. More specifically to:

- Assess the state of ongoing research in evolving computer-based technologies such as artificial intelligence, data visualization, etc.
- Assess support for longer range, high-risk research ventures.
- Determine how these countries get innovations tested and into practice.
- Define technologies in which the United States can collaborate on joint research and development (R&D) efforts.

Highway transportation research sites were selected based on a combination of criteria such as awareness on the part of FHWA of research strengths, availability of site representatives within the period of the team tour, time constraint of the tour interval, and geographic proximity so that the tour could be efficient. As this necessarily involved a brief visit to each of several sites, the team survey was an overview. In-depth mutual technology transfer will require individual followup in the future. It is anticipated that this set of visits by the team will stimulate exchanges of technology involving long-range communications, followup technical visits, coordinated or cooperative research projects, or, possibly, temporary exchange assignments.

2.2 Composition of the Team

The team was composed of seven people:

Mr. James Wentworth, FHWA, Office of Advanced Research, Team Leader

Dr. Charles Dougan, Connecticut Department of Transportation

Mr. David Green, New York Department of Transportation

Dr. William Kaufman, Carnegie Mellon Research Institute

Dr. Ernest Kent, National Institute of Standards and Technology

Mr. Thomas O'Keefe, Minnesota Department of Transportation

Mr. Huai Wang, FHWA, Office of Engineering, Bridge Division

2.3 Itinerary

The tour started in Copenhagen, Denmark, on November 8, 1993, and ended in Delft, The Netherlands, on November 19, 1993. To prepare the European hosts, team members compiled a list of specific questions to be addressed, which were transmitted in advance (Appendix A). Organizations met included:

Denmark

- Road Data Laboratory, Herlev
- National Road Laboratory, Roskilda
- Bridge Department of the Road Directorate, Copenhagen

Germany

- Ministry of Transportation, Bonn
- Bundesanstalt für Strassenwesen (BASt), Köln
- Hessisches Landesamt für Strassenbau, Wiesbaden
- Autobahnmeisterei, Rüsselsheim
- Technische Überwachungsverein Hessen GmbH, Darmstadt
- Ingenieurbüro Krebs und Kiefer, Darmstadt
- Dyckerhoff & Widmann, Munich

France

- Service d'Etudes Techniques des Routes et Autoroutes (SETRA), Paris
- Institut National de Recherche sur les Transports et leur Sécurité (INRETS), Paris
- Mairie de Paris, Direction de la Voirie, Paris

The Netherlands

- Institute of Spacial Organization (INRI-TNO), Delft
- Transportation Research Centre (AVV), Delft
- Philips Systems Project Center, Eindhoven

2.4 Format of Report

This report consists of:

1. An Executive Summary.

2. Introductory information.

3. Country summaries describing what was observed in each country in the following categories: management, design and decision-support tools, traffic management, data management, sensors, computational methods, and global positioning systems/geographic information systems (GPS/GIS) applications. (A subject area is not mentioned if no pertinent observations were made.)

4. A description of how various countries address specific technical subjects, such as traffic control, pavement management, materials research, etc.

5. An identification of areas and countries that should be followed up on through in-depth technical exchanges and cooperative or coordinated research.

3. Denmark

3.1 Management

Organization

Denmark's Road Directorate is the national agency for roads, corresponding to the United States Federal Highway Administration, but its function also resembles that of State Departments of Transportation because it manages construction, maintenance, and operations activities. Within the Road Directorate is the Danish Road Institute consisting of the National Road Laboratory (NRL) and the Road Data Laboratory (VDL). On November 8-9, 1993 the team visited three organizations in Denmark—the two laboratories of the Danish Road Institute and the Bridge Department of the Road Directorate. The Road Directorate is organized, as of this visit, as shown in Figure 1. (Reorganization was introduced January 1, 1994.)

A focal point of applications of computer technology at the Road Data Laboratory is their development of a Road Information System (VIS). This system is based on a Road Data Base (RDB) and software applications that make use of that data base. The first version of the RDB is 20 years old and uses Unisys DMS II software. Version 2 of the RDB is in an Oracle data base containing tables of attributes of sections of state motorways and will soon contain attributes of the county highways as well. The attributes include, but are not limited to, geometry, structure and materials, condition, maintenance history, accident history, and speed-limit data. The four cornerstones of the new VIS are a location reference system, standardization of data, sound operations management, and a well-designed and -operated computer platform.

Denmark's National Road Laboratory (NRL) is concerned with the materials and structure of roads. NRL staff are developing instrumentation and measurement systems and techniques to evaluate road conditions. Some examples include a vehicle that obtains road-surface longitudinal and transverse profiles and a separate system that records views of the roadway on videotape, then digitizes selected segments for incorporation in the RDB. Focus for their R&D for 1993 was on four materials areas: asphalt materials, cement-bound materials, unbound and stabilized base courses and subbases, and coatings for isolating and protecting materials (waterproofing concrete).

Major bridge maintenance and construction for the state are managed by the Bridge Department. This includes inspection of bridges, operation of a bridge-maintenance software system that optimizes maintenance planning in the face of financial constraints, and contracting with consultants for major construction and repair.

The Danish Road Institute has a research council that meets twice a year to review ongoing research projects and to provide guidance for future research efforts. This council has representatives from the national, regional, and local road administrations, the technical university, consultants and contractors, the public transport sector, associations (Automobile Association, Bicyclists' Association, etc.), and others interested in road research. This council strongly influences, but does not direct, research programs and projects and helps shape research policy.

NRL also places emphasis on cooperative research. The federal-industry-academic partnership is effective in both advancing technology and promoting business interests. Such a cooperative effort between the highway administration and the asphalt-paving industry led to the development of the models used in pavement-management systems.

Budget Considerations

The annual budget of the Road Directorate is DK2,081 million ($335 million U.S.). The annual budget of the Danish Road Institute is DK54.6 million ($8.81 million U.S.), approximately DK18 million ($2.90 million U.S.) of which is earmarked for research and development.

Budget allocations for bridge maintenance are determined according to results of inspections carried out as a three-tier process. At the local level, county inspectors conduct cursory inspections once or twice a year. Counties define and perform maintenance on specific bridges, based on these inspections, and use funds allocated by the state (nation) for this purpose. At the state level, personnel from the Bridge Department inspect bridges on state roads approximately every 4 to 6 years. There are about 2,000 bridges in the national system, of which 43 are major bridges. Bridges are rated by the inspectors. As ratings reach levels indicating worsening conditions, the inspection intervals are reduced. When the state bridge inspectors consider it appropriate, consultants are asked to do a "special inspection" and develop two estimates of the cost of repair. One estimate is the optimized cost of performing a planned sequence of maintenance actions over a 10-year period. The other is the cost of the repairs if delayed 5 years and then made. Both estimates must include the effective cost of traffic delays or detours caused by the maintenance plan, whether deferred or not. A bridge-management system software program (DANBRO) develops a 5-year plan based on these estimates for national bridge repairs that provides the best return on investment of the bridge-repair funds allocated by the government. Photographs taken during the inspection process are digitized and readily available for review by inspectors.

Technology Transfer

The Road Directorate carries out technology transfer in several ways. Some transfer is domestic, such as providing training programs and performing projects for the counties and municipalities for fees. They also sell services and projects internationally at the level of DK16 million per year ($2.58 million U.S.). For example, a project partially sponsored by FHWA to evaluate subgrade bearing capacity as a function of water content will be carried out at the NRL.

Another type of technology transfer is planned that will provide police with portable computers for entry of accident data.

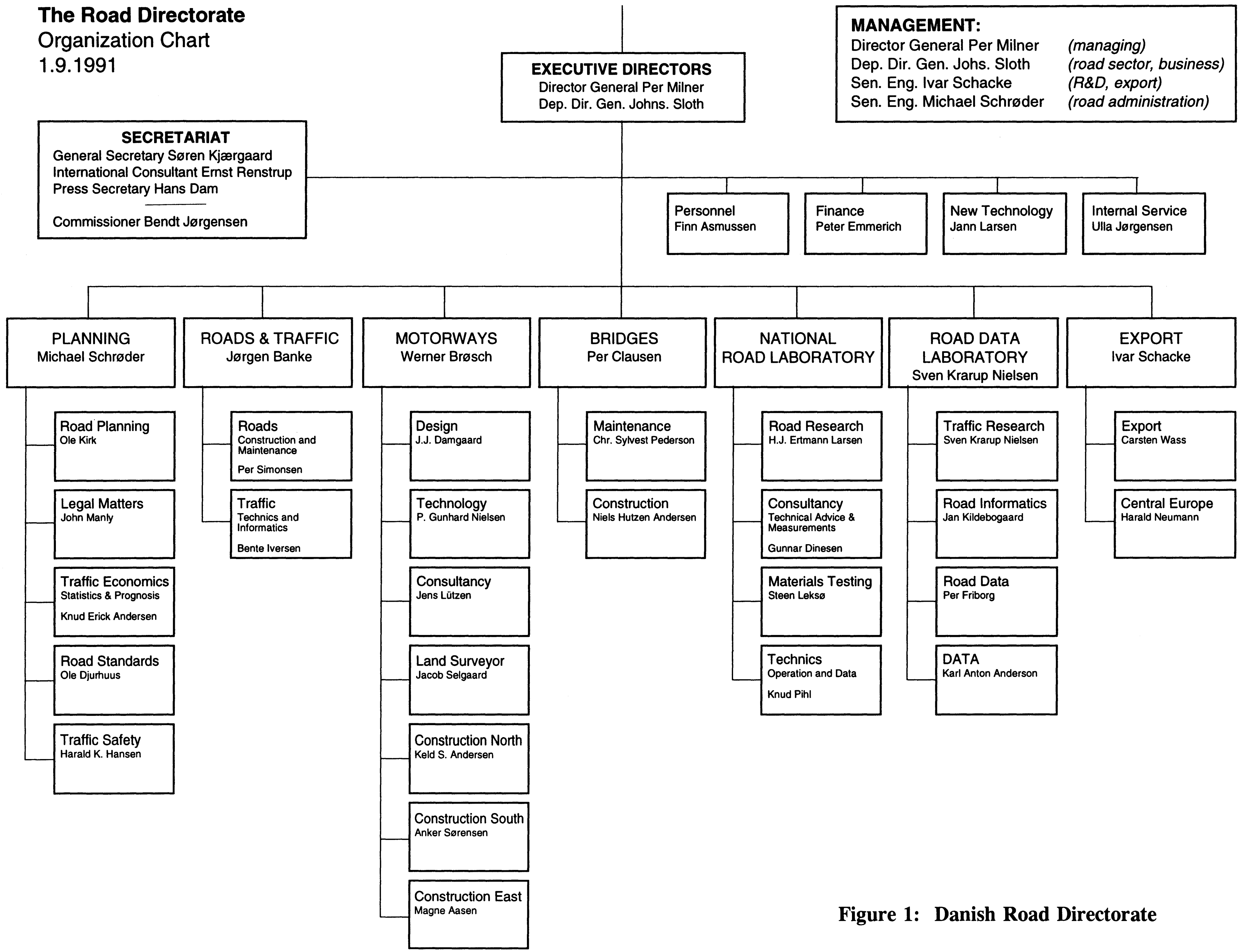


Figure 1: Danish Road Directorate

3.2 Design and Decision-Support Tools

Traffic modeling was used to justify the construction of a bridge/tunnel combination to link the highways of eastern and western Denmark. The model took into account the various ferry traffic between east and west.

The purpose of the VIS is that it serve as a decision-support tool. It is used as the basis for maintenance planning at the national level via PMS software. BELMAN, a similar but smaller, simpler tool, is used by the counties for maintenance planning.

Intergraph is used as a drafting tool. Moss is used for road design. Consultants do all designing.

3.3 Traffic Management

Experiments have been carried out with automated systems for traffic control, for example, a ramp-control system was used on one freeway ramp. A traffic light on the ramp was activated based on the traffic volume on both the freeway and the ramp, resulting in an increased rate of flow on the freeway. Unfortunately, the ramp backed up considerably and the system was not adopted for general use.

Another system that includes artificial intelligence in the selection of messages to be displayed provides route-selection guidance to drivers via changeable signs. This system will be tested at one location where a choice between a bridge route and a tunnel route across a body of water can be made by the drivers. As part of the experiment, the police will be given the choice to override the sign-change information. Known as QUO VADIS (Queue Obviation by Variable Direction and Information Signs), the system was planned to be in place in June 1994.

Currently, there are no road or bridge tolls in Denmark. Computer-based toll collection is contemplated for the east-west bridge/tunnel link to be constructed between Zeeland and Funen. The second toll-collection system will most likely be the bridge to Sweden that is under construction.

3.4 Data Management

Analytical Methods

The RDB is controlled and maintained by the VDL, and is updated continually by a special staff. Hard copy of data updates are received from the counties and input by VDL, though there is about a 2-month delay for the data to be entered. Eventually, they hope to receive data from the counties in electronic format. Individual counties have access to their portions of the RDB.

A pavement-performance model is used to predict future pavement condition, based on data in the RDB that are collected by visual and vehicle-borne automated inspection of roads.

Weigh-in-motion (WIM) is accomplished by interpreting signals acquired by load cells and loop sensors. By analyzing the wave shape of loop signals and combining information with load data, VDL can count, classify, weigh, and detect the speed of passing vehicles. A demonstration WIM system is available. VDL is also investigating measuring axle length and the footprint size of each tire using an array of load cells.

Communications

State motorways have a hard-wired roadside emergency telephone system. Phones are spaced 2 km apart and are located almost everywhere except where the motorway passes through a city, such as Copenhagen. Phones are located on both sides of the road so that motorists do not have to walk across the motorway.

Communication with drivers is just being tested using the changeable signs in the experiment mentioned above. Communication of information within the system is on X.25 (telephone lines), which will change signs automatically.

DRIVE, an international effort, is developing a system that will communicate with drivers through car radios. Coded messages advising drivers of specific conditions will be transmitted on a VHF band next to the commercial FM band. Car radios will have microprocessors that will decode messages and present them to the driver in the driver's language using a voice synthesizer.

Advanced Data Input Technologies

Images of roadway signs are obtained by digitizing video recordings of the roadways and are stored in the VIS/RDB; additional sign data are entered manually and updated as appropriate. Besides using these data to monitor the conditions of the signs, they are also used as evidence in court for accident cases.

Microscope images of thin-film concrete samples are digitized and entered automatically into a computer. Sample images are then processed to extract information about the number and shape of the material voids. Analysis of the voids supports basic studies of Portland cement concrete and asphaltic concrete.

Automated Data Acquisition

The Profilograph, described in the following section, and a skid-resistance measuring vehicle are used to collect surface-geometry data automatically.

Loops are used to collect data automatically for VDL's experimental traffic-routing guidance system and for an experimental freeway ramp-control system.

NRL wants to work on an automated surface-texture measuring system and also plans to do automated image interpretation of their roadway video images.

3.5 Sensors

Sensing loops are used for detecting the number and speed of vehicles and for classifying vehicles. Weigh-in-motion piezoelectric sensors are also used. Experiments were carried out on a fiber-optic load cell which, though successful in the lab, was unstable in the field.

Approximately 200 weather-sensing systems are in use. These consist of temperature and humidity sensors, and the data are processed to determine icing potential. Such sensors are also used to determine icing potential on bridges.

Humidity sensors are used to monitor and control the humidity inside steel box beams for rust prevention purposes so that they do not have to paint the interiors of the beams.

A laser-based Profilograph has been developed that measures road-surface geometry (roughness, rutting, faulting, etc.) through a series of laser distance-measuring devices on a transverse beam carried by an automobile. Lasers are pointed at the road surface, and an inertial platform establishes a reference plane for the distance-measuring devices. The system collects vertical-distance data (between the inertial plane and the road surface) at predetermined intervals along the road ranging upward from 3 mm and develops a road surface geometry profile. From this profile data they automatically determine roughness, rutting, crown shape, and faulting. Future plans are to sweep the beams of the two lasers laterally on the ends of the laser array so that a record of both road edges can be obtained.

NRL has developed an accelerated test-load facility that consists of a climate-controlled chamber and a rolling load that can be applied to a material sample. The loading is controlled hydraulically, and the chamber can present a controlled temperature in the range -20°C to +40°C.

NRL also has developed a falling-weight deflectometer (FWD) for road-compliance measurement in the field. Data from this testing machine are included in the VIS.

The Bridge Department uses a bridge pier movement detector similar to an inclinometer. If the movement is excessive, an alarm condition is indicated.

3.6 GPS/GIS Applications

Maintenance history for the last seven maintenance activities at each location is also stored in the VIS.

A few applications of GPS are being considered. NRL plans to install GPS on the Profilograph vehicle to automate collection of location information. VDL proposes to provide the police with GPS capabilities to determine the coordinates of an accident site.

Parallel with the effort to develop the new version of the RDB, the Road Directorate is undertaking an effort to complete 1:1000-scale mapping for the entire national highway system. The scale is the same as that used for their construction plans, and the mapping is necessary to complete plans for GIS development. Their GIS will incorporate the RDB information with the mapping, applying Intergraph's MGE, used by the Directorate, and MapInfo, used by the counties. Estimated cost of this effort is approximately DK10,000 per km ($1,612.90 U.S.), and it will take 3–5 years to complete.

4. Germany

4.1 Management

Organization

Scanning in Germany covered a wide range of organizations, starting from the Federal Ministry of Transport in Bonn, to a federal road research laboratory (BASt), to a länder (state) roads bureau in Hesse, to a local demonstration of traffic management near Frankfurt, to a länder engineering office in Hesse, to presentations by four private consulting organizations that support the federal and the länder bureaus with software and design engineering. This provided the team with a clear picture of the responsibilities and authorities of the various components of governance of the road transportation system in Germany.

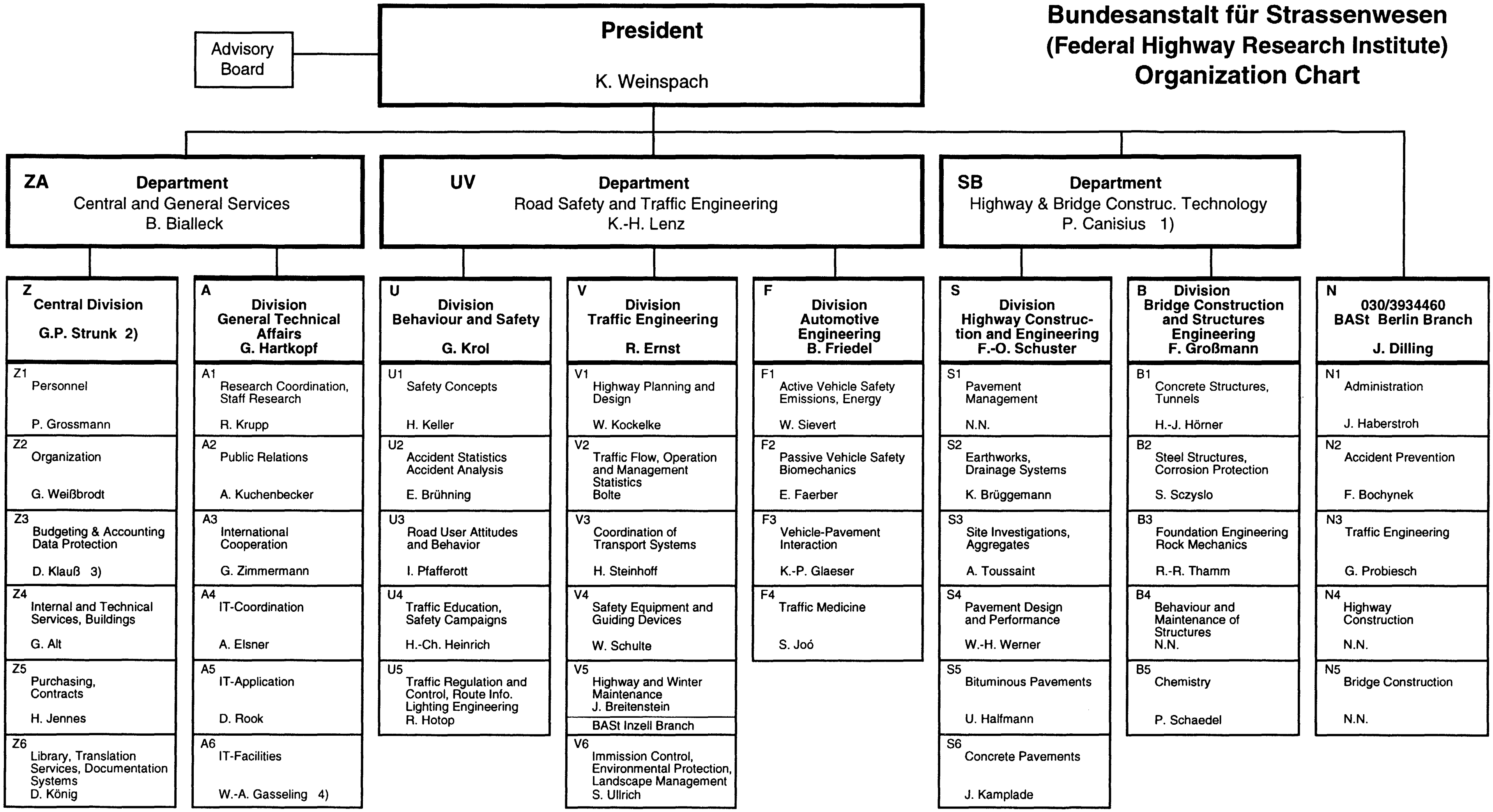
Germany's Federal Ministry of Transport is the equivalent of the United States Department of Transportation. At the Ministry, the team was presented an overview of the structure and activities of the Department of Road Construction and Department of Road Traffic. It was made clear that computer technologies are seen as the hope for the future to make up for their reduced budgets and corresponding downsizing of staffs at both the federal and länder levels. At present, the government agencies use computers most extensively for data bases, less as planning and decision aids. Private companies and consultants use computers for design and analysis and are experimenting with advanced concepts such as knowledge-based systems and neural networks.

BASt, the road research laboratory that reports to the Department of Road Construction, is organized as shown in Figure 2. Below the federal level, the länder have their own ministries of transportation and subordinate highway administrations.

Approximately 500,000 km of roads are in the entire country, including both the former East and the West. The Federal Ministry is responsible for approximately 50,000 km of federal highways, of these, approximately 11,000 km are motorways (autobahns). There are 34,000 bridges on federal highways.

Federal-industry-academic partnerships are strongly promoted in Germany. This allows transfer of technology efficiently throughout the system.

The Team visited the Dyckerhoff & Widmann Company in Munich, an international contractor for highways and bridges. This company has a 125-year history, 15,000 employees worldwide, and DM5 billion ($3.12 billion U.S.) in revenues in 1993. One percent of its revenue is spent on research [DM50 million ($31.2 million U.S.)], it is one of very few private companies in Europe that has its own research program, and probably the only one to invest so much capital in research. Dyckerhoff & Widmann is very active in improving design specifications and is represented on the Commission of FIP (*Fédération Internationale de la Precontrainte*).



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Date: Julyl 1993

Figure 2: German Federal Highway Research Institute

It has two subsidiaries, one in the United States and one in Canada, both named Dywidag Systems International (DSI). Dyckerhoff & Widmann constructed a tunnel in Denmark that was designed by the Japanese.

Prestressed concrete segmental bridges are very popular in Europe. Dyckerhoff & Widmann Company adopts the cast-in-place over precast construction method because, in the company's view, joints between segments could develop and cause problems at a later date. Free cantilever or incremental launching methods are preferred over other methods.

According to the company, on the federal highway system, 66 percent are prestressed concrete bridges, 20 percent reinforced concrete bridges, and 10 percent steel bridges. The firm's philosophy for prestressed concrete bridges is to build in controllable and exchangeable external tendons to allow repair or strengthening in the future. The external tendons are vulnerable to fire, and Dyckerhoff & Widmann holds a patent for fire protection of the tendons.

Budget Considerations

A combination of circumstances has put severe pressure on funds for highway construction and maintenance. In the last several years, there has been a very rapid increase in highway traffic. Projects of German Unity are special projects funded federally and, as a consequence, there is less money available for roads in the western part of the country. With unification, there is now a need to construct east-west oriented roads and to perform major maintenance on eastern roads.

Funds for major maintenance on roads and bridges are provided by the Federal Ministry of Transport, and minor maintenance is funded locally. A three-part pavement-management system is used as a budgeting decision aid; it consists of (1) a data base, (2) data collection, and (3) data analysis. During 1991 and 1992 all motorways were surveyed; in 1993, the Ministry initiated data collection from all the federal highways, including road-surface data. Currently, all the data are analyzed manually to make global generalizations of status for budget forecasting. Although the Federal Ministry of Transport is looking for global measures that can be used with automated data processing, deciding maintenance priorities in the face of limited budgets is still not easy.

Cursory bridge inspections are conducted annually, a more thorough inspection is performed every 3 years, and a detailed inspection is performed every 6 years. Annual bridge maintenance budgets are 1–1.2 percent of the values of the bridges. Approximately 30 percent of maintenance is for repair of salt damage, another 25 percent for waterproofing.

Technology Transfer

Germany is participating in the European effort to develop a driver information system. This system, referred to as RDS-TMC (Radio Detection System-Traffic Message Channel), will send coded messages to cars equipped with radios capable of receiving these broadcasts.

Technology developed by the Ministry is sold to the länder, if they wish to use it. Software developed by private consultants is also sold internationally. For example, the company that developed an optimized winter maintenance program is offering it for sale to municipalities. Consultants will install the system and train operators. Approximately 25–30 percent of engineers have PC's at their desks.

A barrier to technology transfer is the fact that the länder are not all organized and operated in the same way.

4.2 Design and Decision-Support Tools

The Ministry uses Urban Transportation Planning (UTP) to model traffic demand in order to forecast new road construction requirements.

In the länder of Hesse, the four-part DASTRA program (*Datenbank zur Auswertung der Strassenzustandserhebungen*) is used to assist in the evaluation of pavements. DASTRA-B is a photographic log that is manually interpreted for 15 pavement parameters. DASTRA-P processes automatically collected profile data and calculates a roughness index, water levels in ruts, and a texture measure that correlates with the sand-patch method of texture measurement. DASTRA-S is a statistical analysis package. And DASTRA-N is a graphics tool that draws maps that are color-keyed based on condition. Developed by the Technische Überwachung Hessen GmbH (TÜH), DASTRA is considered a standard for the evaluation of road-condition investigations and is widespread in the German road administration.

In general, highway and bridge design is done by private consulting organizations. The team visited a company that uses an extensive local network and employs modern commercially available CAD (computer-aided design), CAE (computer-assisted engineering), and computerized graphics tools. Considerable technical effort was put into the integration of the various software tools and development of specific applications for design and construction calculations. Some of the commercial systems used are Spirit, Autocad, Unicad, and Star (for a GIS data base). A consultant is developing a traffic-demand model, VDRM, for the Rhein/Main area.

4.3 Traffic Management

The Federal Ministry of Transport is developing a system for automated traffic control. The system will automatically compile congestion information and communicate this to drivers through radio broadcasts, variable message signs, an individual beacon system, and, eventually, the Radio Detection System (RDS). Currently, between 50 and 100 cars are equipped with radios for the RDS. Data are acquired via loop detectors, video cameras, some weather sensors, and police incident reports. This system is being tested on the motorway at Rüsselsheim near Frankfurt, where a major intersection is instrumented and variable message signs are used to manage traffic flow. A control center collects and displays data. Tests of the performance of this equipment lasted into early 1994.

In Berlin, in 1989, experiments were carried out to test individual vehicle management. This was done by infrared (I-R) beacons installed at traffic lights. I-R transceivers are mounted in front of the rearview mirrors of the vehicles. The driver transmits his destination to the system, and the system responds with traffic-density information, selecting the best route for the driver. Directions to navigate are given in both a visual display and by synthesized voice. At that time, the system was seen to provide additional information such as availability of parking spaces at the destination.

Automated toll-collection systems are being tested. The Ministry is constructing instrumentation bridges upon which various commercial equipment developers may mount their systems. Initially, 10 companies will participate. Two have I-R systems; the rest use radio, mostly in the 5.8 GHz band, though some use lower frequencies, as well.

4.4 Data Management

Analytical Methods

Fuzzy logic techniques are used with weather data in order to forecast weather and perform traffic-control recommendations at the Rüsselsheim test facility for traffic control. Expert systems are being considered for traffic-control applications.

Communications

Emergency telephones are in place on the motorways.

Berlin has a system in place that communicates with automobiles via I-R beacons located at selected stoplight installations. A limited number of test cars have I-R transceivers for communication with the traffic advisory system. The system under test near Frankfurt communicates to all operators via variable message signs and periodic (every 30 minutes) messages over commercial radio broadcasting stations. It communicates via the RDS to cars specially outfitted with RDS-compatible receivers. The RDS radio receiver obtains coded messages from the control center and synthesizes an audible message in the language of that specific radio. Plans are that RDS radios will be available commercially at the same cost as conventional car radios.

Advanced Data Input Techniques

Road and bridge inspectors have portable PC's to enter inspection data automatically in accordance with a prescribed format.

Ground-penetrating radar has been tried for determining subsurface conditions but not found to be effective.

Automated Data Acquisition

In Hesse, a continuous photo log of roads is acquired automatically by a camera on a vehicle that collects data at night. This log is scanned manually and data are entered into the data base manually. A vehicle is used to collect longitudinal profile data and another vehicle is used to measure skid resistance. Each segment of road is given a numerical rating based on a measure that is a weighted combination of surface-profile data and material-durability data. Loops collect volume and speed data. Video cameras are used in experimental settings to observe traffic flow.

4.5 Sensors

Loop detectors, weather sensors, profile, skid, and camera sensing have been mentioned previously. A road surface deflectometer is used occasionally to obtain bearing-strength data.

4.6 Computational Methods

Artificial intelligence (AI) techniques are being investigated at Siemens for the interpretation of data in various highway applications, but all are highly experimental. BASt is also watching the development of AI applications but is not currently pursuing any AI research projects.

5. France

5.1 Management

Organization

The Ministry of Planning, Transport, and Tourism corresponds, generally, to the U.S. Department of Transportation. There are five organizations within this ministry that correspond, generally, to the U.S. FHWA. They are INRETS (for a broad range of transportation research), LCPC (a laboratory mainly investigating materials, structures, geotechnology, environment, and safety), SETRA (for design, construction, environmental impact, maintenance, traffic management, safety, and accident analysis of roads and motorways), CETU (for tunnels), and CETUR (for urban transportation). The team visited SETRA and INRETS.

SETRA, *Service d'Etudes Techniques des Routes et Autoroutes* (see Figure 3), has a staff of approximately 400 people organized into four activities: Center for Major Structures (CTOA), Center for Information Technology (CITS), Center for Safety and Road Technology (CSTR), and an External Affairs Board for European standardization. SETRA's primary functions are to propose policies and develop fundamental engineering practices, perform technical reviews, advise and guide project owners on all major projects for roads and motorways, and develop and recommend technical tools and know-how to users.

INRETS, *Institut National de Recherche sur les Transports et leur Sécurité* (see Figure 4), has a staff of about 400 people distributed among 13 research units in four regional locations: Paris, at Arcueil; Lyon/Rhône-Alps, at Bron; at Villeneuve-d'Ascq; and at Salon-de-Provence. INRETS research covers a wide range of topics, such as traffic flow and information technology, guided transport, improvement of highway safety, ergonomics of driving, energy and the environment, technology of electrified railroads, use of micro-processors for control, advancements in and uses of artificial intelligence, and computer science.

LCPC, *Laboratoire Central des Ponts et Chaussées* (see Figure 5), is a central laboratory that interacts with 17 regional laboratories. The LCPC maintains major test facilities for soils, construction materials, structures, lighting and visibility, and a cold weather facility.

As of January 1993, France had 8,160 km of motorways and now plans to increase this to 12,120 km. There are also 29,700 km of national roads.

The team also visited Jean Muller International at Montigny, about 40 miles west of Paris. Mr. Muller has been an engineer, designing prestressed segmental bridges for 40 years. He has introduced many innovations, including match-cast dry joints, epoxy match-cast joints, multiple keys in the webs, the external prestressing concept, precast segmental piers, and transverse prestressed deck slabs. Mr. Muller's experience with segmental bridges and computer applications is described in Section 7.9.3.

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Figure 3: SETRA

THE FRENCH INTERNATIONAL INSTITUTE FOR TRANSPORT AND SAFETY RESEARCH

June 1992

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(2) INRETS Partner in the Regionl Authority Nord - Pas-de-Calais for Transport Research (GRRT)
(3) Associated Research Unit with INRETS/ Rhône-Alpes

Figure 4: INRETS

LE LCPC EN RÉSUMÉ

ORGANIGRAMME DU LCPC

Direction

• Directeur-Délégué du Centre de Nantes • Secrétaire général du Centre de Nantes	• **Directeur** • **Adjoints au Directeur**	• Délégué à l'action internationale • Délégué à la qualité et à la normalisation • Délégué à la communication • Chargés de mission

3 directions fonctionnelles

• Direction des Ressources humaines et des affaires financières	• Direction des Actions scientifiques et techniques	• Direction des Programmes et des actions de développement

11 divisions d'études générales et de recherches appliquées

• Méthodes et matériels de construction et d'entretien des routes • Gestion de l'entretien des routes • Matériaux et structures de chaussées	• Mécanique des sols et fondations • Géologie de l'aménagement et de l'environnement • Géotechnique et mécanique des chaussées	• Bétons et ciments pour ouvrages d'art • Métaux, armatures et câbles pour ouvrages d'art • Fonctionnement et durabilité des ouvrages d'art	• Exploitation, signalisation, éclairage	• Eau
Domaine Chaussées	Domaine Géotechnique	Domaine Ouvrages d'art	Domaine Exploitation et sécurité routières	Domaine Environnement et génie urbain

8 services scientifiques

- Chimie
- Physique (1)
- Mécanique (1)
- Mathématiques appliquées (1)
- Études et construction de prototypes
- Information scientifique et technique
- Informatique
- Études et recherches internationales

(1) Dont certaines sections constituent le Laboratoire des matériaux et des structures du génie civil (UMR 113 LCPC-CNRS)

• ***Dont l'activité est transversale aux cinq domaines***

LES CINQ DOMAINES D'ACTIVITE AU LCPC

Chaussées	Géotechnique	Ouvrages d'art	Exploitation et sécurité routières	Environnement et génie urbain
• Mécanique des chaussées • Dimensionnement • Matériaux • Liants hydrauliques • Liants hydrocarbonés • Granulats • Matériels de construction • Auscultation • Gestion de l'entretien	• Géologie • Élaboration des granulats • Mécanique des sols • Mécanique des roches • Géotechnique routière • Fondations • Soutènements • Ouvrages en terre • Géophysique appliquée • Risques naturels	• Matériaux: béton, ciment, métaux, armatures, câbles • Granulats • Fonctionnement des éléments de structure • Surveillance des ouvrages d'art • Durabilité des ouvrages d'art	• Équipement de la route • Éclairage, signalisation • Visibilité, lisibilité • Exploitation de la route • Aide à la conduite • Caractéristiques des surfaces de chaussées	• Eau, pollution • Assainissement • Hydrologie • Risques naturels • Décharges • Patrimoine naturel • Chaussées urbaines • Bruit routier

Sciences de l'ingénieur

• Mathématiques appliquées • Physique • Mécanique • Chimie • Informatique

Figure 5: LCPC

Budget Considerations

The national research policy allocated approximately $8.5 billion U.S. to civil research and development in 1993. Of this amount, by a combination of public research in universities, high schools, and national research centers and support of industrial research, about $150 million U.S. is spent on surface-transport research and $105 million U.S. on civil engineering research. In addition, approximately $35 million U.S. is expended in France by the European Communities Commission for Transportation and Materials programs.

Technology Transfer

INRETS transfers its technology primarily by means of technical publications, collaborative programs with other government, industrial, and educational organizations, and performance of specific studies for local authorities.

SETRA acts in an advisory capacity to specific construction programs and to local authorities, and the information developed by SETRA centers is used by the Ministry to support policy decisions. CTOA develops policy for construction and maintenance of bridges, and acts as a private consultant on bridge design. Contractors are responsible for the final design, though CTOA provides a first design and monitors progress during construction. Computer graphics systems developed by CTOA may be sold or licensed to private companies. Since "counties" are responsible for their own network of roads (similar to U.S. States), software developed by SETRA is available to all counties.

5.2 Design and Decision-Support Tools

CITS is currently providing CAD tools for standardization to verify that designs are in keeping with standards.

Two software design programs for bridges are CDS and PCP. These permit finite element calculations of stress in deck during each stage of construction, wind effects, and even modeling of collisions with ships.

Viper is a communication tool for graphic visualization. It is useful for demonstrating to local authorities how a new structure will appear in a site. The system inserts the image of a planned structure into an image of an existing site—even vegetation and shadows can be included.

Visage is a pavement-visualization system that presents charts of conditions for each section of pavement.

ERASMUS is an expert system for pavement management. In practice, ERASMUS is used more by laboratory engineers and less by field engineers, and has saved as much as 5–10 percent of the usual cost of maintenance and rehabilitation.

SAGE, *Schemas d'Amenagement et de Gestion des Eaux* (Diagrams for Management and Administration of Waters), is a rule-based expert system used to support the traffic control system of Paris. It operates on an HP8000 platform. Decisions are sent to the controller every 3 minutes.

5.3 Traffic Management

TIGRE, Travel Information and Guidance for European Roads, is an extensive traffic-management system used by eight Road Information Centers, one national and seven regional. The system is used to manage events, forecast traffic, perform analyses on historical data, and communicate traffic situations. TIGRE can also calculate recommended actions (e.g., installing a traffic light, restricting heavy-vehicle traffic, establishing detours, etc.) and provide recommended itineraries. The Road Information Centers are staffed around the clock to organize and distribute data about traffic conditions to road users.

SAGE, mentioned above, is a traffic-management system that accepts traffic data and presents control recommendations based on production rules. It has been operational in Paris since 1990. The Paris traffic-management system controls timing of traffic lights, and there are 1,500 light controllers, but only 500 are currently linked to the central control system. About 100 will be added each year. Traffic is monitored by an array of sensors (loop detectors, Doppler radar, video cameras); SAGE provides recommendations to the operator, and the operator makes the final decision on implementation of any traffic light timing changes.

INRETS is developing a system known as CLAIRE, which will upgrade SAGE. CLAIRE will provide a universal supervisory module capable of interfacing with SAGE and most other European traffic control systems. It will extend the functions of SAGE to include long-term memorization and learning so that optimal recommendations can be produced without the possibility of divergence inherent in many adaptive systems. SAGE will be in pilot operation during 1994.

Also in development at INRETS is an intelligent intersection. The system identifies and tracks vehicles, displaying the intersection in a graphical form that shows when internal areas are occupied for too long a time. Using video monitoring, traffic lights are controlled based on traffic flow.

5.4 Data Management

Analytical Methods

INRETS is pursuing research on a distributed AI system with multiple actors, an expert system coupled with statistical processing to diagnose the safety of infrastructure, a system combining operations research and AI to model a complex transportation system, and a neural network to provide automatic control of metro lines. They are also investigating various new analytical approaches to automatic incident detection including neural nets, filters, "catastrophe theory," and wavelet transforms.

Development of image-processing techniques to detect moving and stationary objects and classify them is also under way. Morphological markers and gradient markers are used to detect and classify. More than one characteristic per object is required to identify and classify it. So far, there has been difficulty in tracking vehicles that change lanes.

Communications

Communications are accomplished using telephone lines (X.25 and X.400 protocols) and radio telemetry. The Paris traffic-control system is hard-wired via cable through the Paris sewer system.

Real-time driver information is planned via "automatic phone," Minitel, variable message signs, and on-board car displays.

Automated Data Acquisition

All of the traffic control systems described above employ automated data acquisition. (Sensors are described in Section 5.5.) A new traffic-monitoring system named SIREDO (*Systeme Informatise de REcueil de DOnnées*) is a data collection information system on a national network of 1,500 stations. Loops and pressure cells are used to count vehicles and axles, and to record speed, vehicle length, headway, and mean speed. Some stations also collect weather information.

Automated systems are used to acquire information regarding the condition of the pavement. One system employs a vertically oriented camera to photograph the road surface. An operator views the film and manually enters codes relating to distress conditions. An inspection system called SIRANO collects road-condition data at 70 km/hr. It measures longitudinal profile, transverse profile, texture, and surface deterioration. Longitudinal profile is recorded in the wavelength range of 1–40 meters, with respect to an inertial platform. Lasers are used to measure texture and transverse profile. To detect ruts, the surface is illuminated at 15° from horizontal and observed at 90°—one photo is taken every 10 m.

Banking of the road is measured with respect to a gyroscopic reference. A camera is used to collect degradation information on photographic film, and morphological algorithms are used to classify the types of degradation.

5.5 Sensors

Traffic monitoring and control systems employ loop detectors, video cameras, piezoelectric and optical strain gauges, and Doppler radar.

Pavement inspection systems employ photographic and video cameras, lasers for distance measurement, mechanical feeler gauges, and inertial platforms based on accelerometers and gyroscopes.

5.6 GPS/GIS Applications

The TIGRE system used by the Road Information Centers includes a geographic reference system in association with a data base.

The automated freeway incident-detection system being developed contains a geographic data base as well.

6. The Netherlands

6.1 Management

Organization

The Ministry of Transport corresponds, generally, to the U.S. Department of Transportation. This ministry has directorates for Aviation, Maritime Shipping, Inland Transport, and for Traffic, Public Works, and Water Management. The Transport Research Centre (AVV) is part of the Traffic, Public Works, and Water Management Directorate. The organization chart of the Ministry is shown in Figure 6.

The Netherlands Organization for Applied Scientific Research (TNO) is a private institution that acts as intermediary between universities, industry, and government. TNO's Center for Highway Research coordinates the research being done in four TNO institutes.

Budget Considerations

Highway R&D staff at AVV consists of 300 people. The R&D budget for AVV is f.80 million/year ($15.38 million U.S.).

Payments by industry for its research services is TNO's primary funding source; it also receives a government subsidy to support its operation. In 1992, TNO was composed of 21 institutes employing 4,900 people. At the time of the team's visit, the staffing was at the level of 4,500 people. Its total budget was f.724 million ($139.23 million U.S.), of which f.457 million ($87.88 million U.S.) resulted from industrial programs. Approximately f.90 million ($17.31 million U.S.) is being provided by foreign contracts.

Technology Transfer

TNO works closely with the European Community, its major involvements in highway research being with the DRIVE program, an effort to create an international traffic control system, and with Prometheus, an international industrial program aimed at developing "intelligent vehicles." Close association with the universities and performance of projects for industry and government is a natural means of transfer of new technologies. Further, TNO does extensive predevelopment for industry. Since TNO receives subsidies from the Ministry of Transportation, this predevelopment activity constitutes an example of public/private partnership to develop new commercial products. Such commercial development is a direct technology transfer from research to implementation. Within the country, technology transfer is facilitated by the centralized management of the roadway network while outside the country it is pursued aggressively through a public/private marketing program.

6.2 Design and Decision-Support Tools

TNO is performing research in traffic modeling and decision support for traffic-control applications and serves as the international coordinator for forecasting in the DRIVE program. Research includes development of driver-decision support and both short- and long-term forecasting

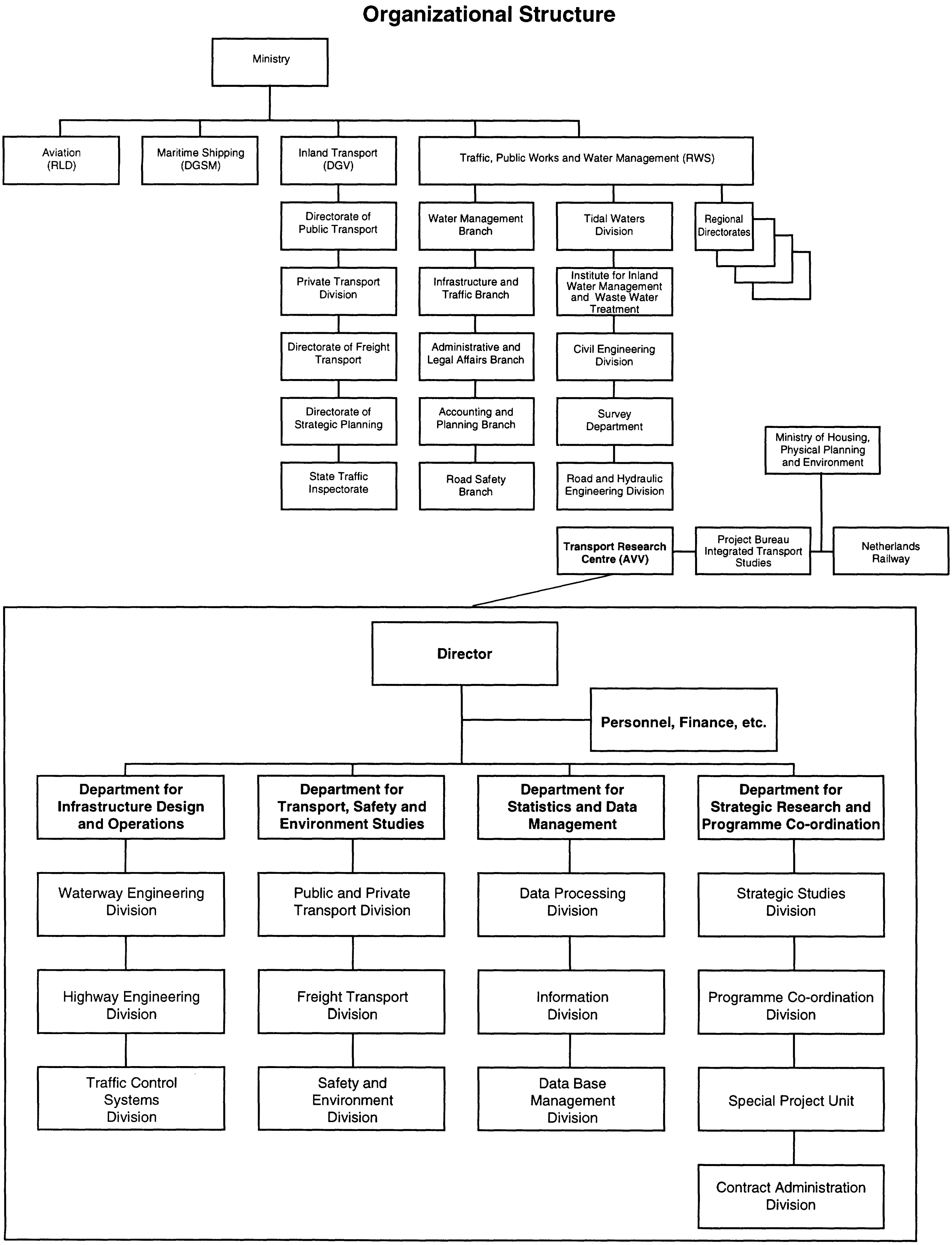

Figure 6: Netherlands Ministry of Transport

techniques. Implementation involves providing drivers with travel-time estimates and route selections based on current and forecasted traffic between origin and destination.

TNO is also developing noise propagation models to predict noise when planning new road construction. The method is based on empirical data and adapts to the local geography of the proposed route.

SOCRATES (System of Cellular Radio for Traffic Efficiency and Safety) is part of the DRIVE program. Information on traffic conditions will be sent to each car and routing decisions will be made in each car for its own destination. Philips Systems Project Center in Eindhoven is participating in the development of equipment for this system. For SOCRATES to operate, vehicles must have on-board systems that calculate the "best" route based on on-board maps and can adapt routes based on traffic information received by radio from traffic-message broadcasting centers.

6.3 Traffic Management

A motorway-signaling system of changeable signs is in place over 200 km of motorway, the size of which will be increased over time. Loop detectors provide input to the Automatic Incident Detection (AID) subsystem that changes speed signs and provides route suggestions in textual signs that advise drivers based on detected traffic congestion. Roadside-visibility sensors are in place to detect fog conditions, and these are reported on warning signs and speed limits are automatically adjusted. Traffic and system data are displayed at operator terminals so that the system can be run manually.

SOCRATES will be a vehicle-by-vehicle traffic management system. The on-board subsystems receive input from the on-board odometer, a compass, the steering wheel, and the antilock braking system (ABS). Once initialized, it computes vehicle location by dead reckoning that is regularly updated to the on-board digital map by comparing distance and direction changes with anticipated maneuvers. The system is also capable of using satellite-produced GPS signals as an alternative method of vehicle location. Drivers enter a destination and the on-board computer calculates the best route, advising drivers of maneuvers that should be taken at each intersection. This is done both audibly and visually on a small display screen. Traffic-condition messages will be received by the on-board system which, if necessary, will modify the selected route in real time.

Drivers will be able to query SOCRATES to obtain useful information, such as the availability of parking spaces, and will be able to signal for help in an emergency. Vehicles will be able to identify their location automatically and will serve SOCRATES as probes of traffic conditions, based on their speed and location.

6.4 Data Management

Analytical Methods

TNO is pursuing computer-integrated construction. In development are models for civil engineering and construction robots.

A neural network was developed by TNO for real-time forecasting of traffic speed, volume, and occupancy 5, 15, and 30 minutes ahead. Correlation coefficients of forecast with reality are 0.97, 0.92, and 0.88 respectively. The 30-minute forecast accuracy is accurate enough for trend purposes.

Philips has a proprietary algorithm for optimum route selection based on a road map stored on a CD ROM. This algorithm typically can select an optimum route within 10 seconds.

Communications

SOCRATES will use the existing cellular-phone infrastructure, while the AID system uses cables that are in place along the highways.

The General European Road Data Information Exchange Network (GERDIEN) serves as a framework for dynamic interurban traffic management. GERDIEN also provides a standard for common-world model definitions and language and provides a standard for equipment interfaces.

Automated Data Acquisition

AID and SOCRATES involve automated acquisition of data from sensor stations and vehicles. Sensor data is automatically sent by cable to the AID system central computer every minute. SOCRATES will automatically receive data from "floating cars" that will be equipped with transmitters and will serve as probes of traffic conditions.

6.5 Sensors

Traffic monitoring is done mainly with loop detectors. Weigh-in-motion (WIM) load cells and weather sensors (fog, etc.) are used for traffic management information. Video cameras are used less frequently.

The on-board system of SOCRATES employs input signals from a compass, the odometer, the ABS, and the steering wheel. The GPS signal is an option for SOCRATES in Europe (approximately 100 m accuracy), but would be mandatory if SOCRATES were to be introduced in the United States. When available, differential GPS will be used.

6.6 GPS/GIS Applications

TNO uses a GIS as a basis for much of their transportation modeling and simulation. For example, for noise modeling and prediction, the noise-propagation model is being modified to interact with GIS rather than to require manual input of geographical conditions.

As mentioned in Section 6.3, SOCRATES on board a vehicle will be able to use GPS to locate the vehicle on the digital map stored within the on-board computer.

7. Technical Subjects

7.1 Pavement Management

Each of the countries visited is working on pavement management (PM) systems. The systems and instrumentation involved address the unique needs of individual nations, but are generalized for export purposes to the European and other markets. An example of this concept is the Danish Road Profiler, a laser-based system providing data on the road profile in Denmark and now in Germany. Probably the best known system is the falling-weight deflectometer (FWD), a Dutch development and current Strategic Highway Research Program (SHRP) standard.

All of the nations employ video technology in their PM efforts; however, most of the video is used to document the overall view of the highway or road, and limited data are being extracted from the video images. The Danes are an exception. They digitize and obtain data from the digital images on type and location of roadside signing. High-definition television (HDTV) is being carefully researched in France. French researchers are also developing video imaging to secure data from HDTV systems for both road and train transportation.

The Dutch are probably the most advanced in the use of PM concepts on the network and project levels. The other three countries visited seem to focus on networks' needs and funding while the Dutch have developed and are using algorithms that address both project- and network-level needs. In Holland, a 5-year plan and cost estimates are being developed using remaining-life concepts. The needs assessed are grouped into projects and prioritized. Subsequent data obtained at the project level refine the project, again using remaining-life concepts. Based on the subsequent data and analytical results, the 5-year plan can be revised automatically.

7.2 Weigh-in-Motion (WIM)

All nations visited are interested in WIM technology and its applications for pavement design, management, and systems, as well as traffic-control strategies. All are obtaining data and inputting by various means into their operations.

Notable technological improvements in WIM systems are under way in Denmark and France. Danish researchers are employing various mathematical transforms to accomplish data smoothing and reduce random signal noise. In this way, data accuracy and transmissibility will be improved.

In separate activities, the French and Danish are examining fiber-optic cable to improve WIM technology. The Danes have been successful in the laboratory using fiber-optic cable to measure a substantial weight spectrum with high accuracy. Optical transmission is decreased when the fiber is stressed, and field trials have been unsuccessful to date. French researchers at INRETS also view the benefits of fiber optics for WIM applications favorably. Laboratory tests are being completed with field trials to follow.

7.3 Materials Analysis

The team reviewed limited efforts in the materials area. Noteworthy Danish research focuses on membrane waterproofing for use on portland cement concrete (PCC) structures. The Germans also are stressing membrane systems to reduce bridge-deck deterioration problems. Twenty-five to thirty percent of the research monies of these countries are devoted to membrane protective systems.

Danish work with thin-section technology was supported by SHRP. This technique employs pressurized epoxy injected into asphalt and concrete samples to form thin slices of these materials. Scanning microscopes are then employed to measure and analyze the internal crystalline and void structures. Further development of this system/technology sets forth promise to better understand the basic construction materials of the highway industry.

During an overview presentation in Germany, it was stated that the Germans are using a "vibrational system" to analyze bridge-bearing capacity. Further discussion revealed that the concept is similar to the Wave Equation Demonstration Project of FHWA. At BASt the introductory remarks cited work in the instrumentation and measurement areas now under way. Unfortunately, time limitations precluded subsequent briefing.

7.4 Road Data and Associated CAD/GIS Data Bases

Road Data

Collection and analysis of road data are essential to the success of all programs and technological applications aimed at improving service to our customers—the road users. All four countries visited emphasized the importance of data and expended considerable resources in the collection and analysis processes.

Denmark had established a national perspective toward data and had developed a "corporate" view in terms of managing the data. They define four "cornerstones" for success:

1. A common reference system.

2. A state-of-the-art computer system.

3. Strong operational management principles for data collection and use.

4. Standardization.

These concepts have been used for 20 years with data being made available to the counties who do much of the collection. A new system based on more current technologies is in the process of being implemented. A common reference system has been established using well-defined kilometer/mile markers and offset distances from those markers as mechanisms to record all data. A corporate data base manager has also been defined using Oracle in a client/server environment running Novell and SQL Net. The old system ran on Burroughs DMS II. They also have a directive to GIS capabilities using Intergraph's MGE products, including Map Info, at the local level. Photogrammetric techniques at 1:1000 scale with GPS ground control are being used to establish the digital base map for use in both GIS and automated mapping

PLEIADES	Paris-London corridor Evaluation of Integrated ATT and Drive Experimental Systems
PM	pavement management
QUO VADIS	Queue Obviation by Variable Direction and Information Signs
RDB	road data base
RDBMS	relational data base management system
RDS	radio detection system
RDS-TMC	radio detection system-traffic message channel
R&D	research and development
rf	radio frequency
RHAPIT	Rhein-Main Area Project for Integrated Traffic
ROSES	Road Safety Enhancement Systems
SAGE	Schemas d'Amenagement et de Gestion des Eaux
SETRA	Service d'Etudes Techniques des Routes et Autoroutes
SF	Sjaeiland to Faroe Bridge, Denmark
SHRP	Strategic Highway Research Program
SIREDO	Systeme Informatise de Recueil de Données
SOCRATES	System of Cellular Radio for Traffic Efficiency and Safety
SQL	system query language
TCP/IP	Transmission Control Protocol/Internet Protocol
TELAID	Telematic Applications for the Integration of DSN
TIGRE	Travel Information and Guidance for European Roads
TITAN	Traitement d'Images de Trafic et Analyse
T/m	tons per meter
TMC	traffic message channel
TNO	The Netherlands Organization for Applied Scientific Research
TRB	Transportation Research Board
TÜH	Technische Überwachung Hessen
UTP	Urban Transportation Planning
VDL	Danish Road Data Laboratory
VDRM	German traffic-demand model
VHF	very high frequency
Viper	French communication tool for graphic visualization
VIS	Danish Road Information System
Visage	French pavement-visualization system
VMS	variable message signing
WIM	weigh-in-motion

FWD	falling-weight deflectometer
GDF	Graphic Data Format
GERDIEN	General European Road Data Information Exchange Network
GHz	GigaHertz
GIDS	Generic Intelligent Driver Support
GIS	Geographic Information Systems
GPS	Global Positioning Systems
GSM	Global System for Mobile Communication [pan-European standard cellular radio, TTEC ed.]
HDTV	high-definition television
hr	hour
Hz	Hertz
INRETS	Institut National de Recherche sur les Transports et leur Sécurité
INRI-TNO	Institute of Spacial Organization, The Netherlands
INVAID	Integration of computer Vision techniques for Automatic Incident Detection
I-R	infrared
IRTE	Integrated Road Transport Environment
ITS	Intelligent Transportation System
IVHS	Intelligent Vehicle Highway System
KAT	German routing algorithm for winter maintenance
kN	kilo Newtons
km	kilometer
LIAISON	Linking Autonomous and Integrated Systems for On-Line Networks
LCPC	Laboratoire Central des Ponts et Chaussées
LTPP	Long-Term Pavement Performance Program
m	meter
MACAO	Management de Projet Autoroutier Conception Assiste par Ordinateur
M/C	maintenance over construction
Melodie	traffic-display software
MELYSSA	Mediterranean-Lyon-Stuttgart Site for ATT
mm	millimeter
MN	Mega Newton
MSB	most significant bit
MUSE	Multi-User Simulated Environment
N	Newton
NCHRP	National Cooperative Highway Research Program
NIST	National Institute of Standards and Technology
NRL	Danish National Road Laboratory
OECD	Organisation for Economic Cooperation and Development
OSI	Open Systems Interconnect
PC	personal computer
PCC	Portland cement concrete
PCP	bridge-design software

Appendix B: Glossary of Acronyms

ABS	Antilock Braking System
AI	Artificial Intelligence
AID	Automatic Incident Detection
Alert-Strada	Traffic and Travel Data Dictionary
ARIAM	Automatic Broadcasting Information by Actual Measurement
ATT	Advanced Transport Telematics
AVV	Transport Research Centre—Ministry of Transport, Public Works, and Water Management, The Netherlands
BASt	Bundesantalt für Strassenwesen
C	Celsius
CAD	computer-aided design
CAE	computer-assisted engineering
CBD	Central Business District
CD ROM	Compact Disc Read-Only-Memory
CDS	bridge-design software
CEN	European Committee for Standardization
CID	Conception Intelligence de Diagramme de Faux
CITS	Center for Information Technology (division of SETRA)
CLAIRE	context-free artificial intelligence-based supervisor for traffic control
CNIR	French national road information center
CRICR	French regional road information and coordination center
CSTR	Center for Safety and Road Technology (division of SETRA)
CTOA	Center for Major Structures (division of SETRA)
DANBRO	Danish bridge-management software system
DASTRA	Datenbank zur Auswertung der Strassenzustandserhebungen
DK	Danish Krone
DM	Deutsche Marks
DNT	communication protocol
DRIVE	Dedicated Road Infrastructure for Vehicle Safety in Europe
DSI	Dywidag Systems International
DSN	drivers with special needs
DTM	dynamic traffic management
EDRM	European Digital Road Map
ERASMUS	Entretien Routier Assiste par Systeme Multi-expert
ESRI	Environmental Science Research Institute
f.	Netherlands guilders
F	Fahrenheit
Ff	French francs
FF	Faroe to Falster Bridge, Denmark
FHWA	Federal Highway Administration
FIP	Fédération Internationale de la Precontrainte
FM	frequency modulation

Do you have new optimization approaches and algorithms?

What is being done in "convoying" and other computer-controlled approaches to enhancing highway capacity?

V. GPS/GIS Applications

Do you maintain a geographic data base of accidents?

Do you maintain historical maintenance data in a geographic data base?

What use is being made of GPS and GIS in incident detection/accident data base, maintenance profile, integration with CAD, and traffic control?

How are the following aspects of GPS/GIS systems handled: system design, systems management (I/O, etc.), data controls and standards, distribution of errors for resurveys, maintenance or upkeep, and problems?

Do you use automated machine translation of speech for multilingual communications?

D. Automated Data Acquisition

Do you have automated inspection systems for roads, pavements, bridges, tunnels, and traffic control devices?

What applications do you have/propose for automated inspection? Please explain any applications and hardware/software used.

III. Sensors

Do you have sensor systems to detect traffic congestion?

Do you have sensor systems to detect accidents?

Do you have unique sensors for any inspection tasks?

Do you have sensor systems for bridge condition (loading), pavement condition, highway right-of-way, signing, etc.?

Are radars, lidars, flirs, and other technologies being used in addition to television systems?

What new/unique sensor technologies are being applied/proposed? HDTV, laser devices, etc. Possible applications: incident detection, traffic monitoring/control, weather, pavement-condition assessment, ice and snow detection, inspecting roads, bridges, tunnels.

Do you use ground-penetrating radar for preconstruction or inspection activities?

Do you have applications of WIM technology?

IV. Computational Methods

Please identify advanced mathematical concepts or technologies being applied in research or planned for inclusion in your programs. Topics might include applications of fuzzy logic, emergent behavior programs, chaos theory, constraint-based reasoning, fractals, generic algorithms, and other advanced concepts.

What AI technology applications are existing or proposed for highway research, planning, design, and operations? Please explain applications in expert systems, virtual reality, artificial neural networks, voice recognition/synthesis, and machine vision.

E.g., Multiuser Simulated Environment (MUSE) and similar approaches.

What use is being made of Transputer technology?

Are virtual reality techniques being employed for simulation, visualization, and analysis? Are they being used in real-time operations?

What is being done in data-fusion techniques?

B. Communications

Do you have a roadside communication network so that a motorist can call for help?

Do you have means, such as radio or changeable signs, to alert drivers to changes in driving conditions that are ahead, for example, weather conditions, traffic congestion, or accidents?

Do you use spread spectrum transmission of radio frequency (rf) signals, for example, in data networks?

Can signs change automatically, based on sensor systems?

What automated control technologies are employed for real-time management of traffic systems?

C. Advanced Data Input Technologies

How do you convert images for PC processing and analysis? (Video to digital and back.)

What are your uses of video? Please explain applications and hardware/software used in the following areas: incident detection, traffic monitoring, weather, pavement conditions. What other technologies do you use/propose for these applications (both dynamic and static images)?

What use is being made of dynamic properties in scene analysis? E.g., image-flow analysis, structure-from-motion, recognition of spacio-temporal behavior patterns, etc.

What special-purpose architectures are being employed for real-time, front-end image processing, or signal analysis?

What new techniques are being employed for image segmentation? Do you use high-definition television (HDTV) and existing video formats to obtain field data and information?

Do you employ automated speech interpretation for data entry?

Is optimum design of bridges used? In what respect is it used? Is the girder spacing of the number of girders optimized? Is the structural depth optimized (either constant depth or variable depth)? Is the span layout optimized by arranging the piers' positions?
How is a computer used to achieve the quality control in the shop and onsite? The geometry control?

Is contingency-driven automated planning and scheduling being applied in construction and maintenance tasks?

Are JIT (Just-in-Time) scheduling technologies being used in construction, maintenance, and operations?

D. Automated Systems

Do you have automated systems for controlling traffic flow, for example, control of entry ramps, variable speed limit signage, and lane direction control or restrictions?

What kind of computer-based toll-collection facilities are used?

What use is made of robotics and teleoperated equipment in highway construction and maintenance?

II. Data Management

A. Analytical Methods

What advanced data base management and analysis methods are used/proposed? Please explain any applications and methods used (including evaluation of inspection data) in the following areas: data fusion, virtual reality, expert systems, artificial neural networks, special-purpose architectures.

What analytical methods do you use to evaluate inspection data?

How do you integrate existing and new data sources into data bases?

How are computer programs updated to current specifications?

How are the bridge data updated by bridge inspections?

What kind of data base management methods and systems do you use? Are there any applications of multimedia data bases?

Are object-oriented, multiuser interactive data base technologies being employed?

Appendix A: Advanced Transportation Technology Questionnaire

I. Management and Design Systems

A. Budget Considerations

What percentage of the total highway budget is devoted to research?

Approximately what percentage of the highway research budget is devoted to computer-based technologies?

How are limited resources allocated to maintain bridges in a sound fashion? What theory is used to rank bridges in the order of maintenance, rehabilitation, or replacement? Is the bridge maintenance program the central or the provincial government's responsibility?

B. Technology Transfer

What are the avenues through which your computer technology is put into practice by government and industrial groups?

What are some of your organizational issues attendant to implementing new technologies, management systems, etc.? Are there barriers to technology transfer?

C. Design and Decision-Support Tools

Do you use model traffic demand in order to plan new construction requirements?

Is weather forecasting used in budget planning and maintenance planning?

What types of decision-support software are used by highway managers?

What CAD programs do you use for design of roadways and structures?

How is the final design of a major structure achieved? Is it through automatically recycling with the computer-generated new parameters, or through a manual input for repeated runs? Does the computer-aided drafting do most of the drafting when a design of a bridge is finalized by the computer?

In the process of a design and its review, do the engineers at the hierarchical levels, including the client, review the design and make comments through a computer monitor? Or is it still done through shipment of drawings?

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- All countries' open-system architecture—an exchange of definitions and guiding philosophies should be sought, as these vary widely among users.

- All countries' data base management concepts and systems.

The mechanisms for achieving cooperation and exchange for these items has not been addressed. Details should be developed in cooperation with the FHWA International Programs Office.

use in harsh environments. Expansion joint systems are still a problem, especially on curved and skewed structures. Follow up with BASt in Germany would be beneficial in these areas. TRB is currently establishing a subcommittee to address bridge joint systems. Joint development efforts in this area could be fruitful.

Danish Data Base

The common, integrated data base of Denmark is very progressive and appeared very successful. More detailed information should be obtained, particularly as it relates to data security, ownership, networking, common reference systems, and GIS interface. State and federal data base guidelines appear beneficial from a data-exchange point of view.

The Netherlands' Weather Stations/Maintenance System

The system employed in The Netherlands to collect weather information and translate that into notification of the road-maintenance crews when deployment of salt and sand is warranted should be further detailed. Related research on "brine" should also be included.

Study Team Followup Recommendations

- Danish laser-based road profiler—followup should be coordinated with States' Profiler User Groups. South Dakota should be contacted to take the lead on this.

- Danish work on thin sections for materials analysis.

- Danish work on WIM—both the use of fiber optics and signal smoothing should be coordinated through the FHWA LTPP Group and various planning groups within the States.

- French work on video imaging—information sharing between FHWA and France should be encouraged.

- French use of fiber optics for WIM.

- Dutch use of remaining life in pavement management—this concept is also being addressed in the United States. Followup should be coordinated with the National Cooperative Highway Research Program (NCHRP) and subsequent FHWA efforts.

- Dutch use of roadway sensors (ice and weather) and subsequent data analysis and display—followup through TRB Committees and various States involved with implementing ice and weather-sensing technologies should be promoted.

- Dutch use of GIS/GPS for maintenance—followup through TRB Committees and various States involved with GIS/GPS technologies should be promoted.

- Dutch real-time traffic data and analysis.

- All countries' use of graphic displays—exchange of ideas and progress should be sought as visualization is a rapidly advancing technology with unlimited opportunities to share successes and failures.

8. Areas for Followup

Automated Toll Collection

A bridge/tunnel combination is being planned in Denmark linking the eastern and western road systems. While no decisions have been made, there may be an opportunity to share technology/experience as automated toll collection is intended to be a component of the Intelligent Transportation System (ITS) in the United States. Denmark may implement this technology before the United States, and the net flow of technology could be from Denmark to the United States.

Germany is also experimenting with automated toll-collection systems. A joint or cooperative program among all three countries may be possible.

Fundamental Understanding of the Behavior of Paving Materials

The Office of Advanced Research of FHWA will assemble an interdisciplinary project aimed at understanding the controlling factors of crack initiation, crack growth, and large-scale material behavior of pavement materials (nano-scale, micro-scale, and engineering scale). The thin-section analysis (20 micrometer) developed at the Danish National Road Laboratory might be useful in checking analytical results. Denmark should be briefed fully on this R&D project and invited to participate at a level to be mutually determined. State and university research efforts can take advantage of this technology.

AI/Neural Networks

There is interest and concern about the use of artificial neural networks to analyze weigh-in-motion sensor data. FHWA should share theoretical analyses and proposals developed on this topic.

Open-System Architecture for ITS

Given the potential commercial impact of ITS, every effort should be made to ensure that development adheres to open standards. In areas where standards do not exist, efforts should be undertaken to develop standards cooperatively. These efforts should include not only ITS and the European DRIVE program, but also the Japanese VICS program. These areas include but are not limited to:

- Traffic/Travel Data Dictionary (DRIVE Alert-Strada).
- Roadside System Communication (DRIVE GERDIEN).
- In-Vehicle Communication (DRIVE SOCRATES).
- Location Referencing [DRIVE European Digital Road Map (EDRM) for mapping].

Structures Technology

There is interest in paintless (weathering) steel and expansion joint systems. After the first use of weathering steel in the 1960's, there are still concerns about its

intelligent highways are very promising and are expected to be introduced in the future.

Vehicle-control systems are expected to be very powerful traffic management tools. Introduction, however, is expected only in the long term. Developments are being monitored, but pilot demonstrations and full-scale implementation are not yet planned.

pilots plan to have 330 vehicles equipped with the technology by the end of 1994. The SOCRATES core project also has responsibility for ensuring standardization of the appropriate elements and for furthering development in new areas.

SOCRATES' features include:

- Dynamic route guidance in-vehicle using real-time traffic data.
- Driver information including local warnings and congestion information.
- Traffic management.
- Park and ride/public transport information.
- Emergency call, including requests for service.
- Automatic vehicle location.
- Tourist information.

The advantages of GSM are:

- Preexisting European standard.
- Bidirectional communication.
- Cellular structure helps localize messaging.
- Contact anytime/everywhere.
- Sufficient data-transfer capacity.

7.11 The Prometheus Program

In the Prometheus program, initiated by the European automobile industry, intensive research is proceeding in the field of intelligent vehicles on intelligent roads. Initially, on-board computer-aided systems will inform the drivers; later generations will provide more active support. A significant improvement in traffic safety is expected from these systems. Examples are:

- Vision-enhancement systems based on infrared or radar that could enhance the drivers' range of sight in darkness or under adverse conditions like rain, snow, and fog.
- Intelligent cruise control, distance- and lane-keeping systems, and obstacle detection and warning systems.
- Road/environment monitoring, vehicle monitoring, and driver monitoring.
- Heads-up display could be a suitable and safe human/machine interface for presentation of supporting systems information.

Increasing traffic efficiency with less impact on the environment is also an objective of Prometheus. Cooperative vehicle/roadside systems are under development for better use of the road capacity. Vehicle/vehicle and roadside/ vehicle communication form the bases for most of these systems. From a traffic management point of view, the possibilities of driving in convoy are very attractive. A large increase in traffic efficiency and safety is expected from this concept. By redividing the available road space, a small guide lane could be added for this purpose on the left of the road. Such concepts of intelligent vehicles on

GIDS—Generic Intelligent Driver Support (Proposed DRIVE Project)

GIDS is a program of human-factors research related to driver-support systems, including navigation aids and collision avoidance systems. Responses to various VMS strategies are being tested.

For physical feedback systems, the best feedback in response to excess speed in foggy conditions is increased resistance in the gas pedal. The best feedback for wandering between lanes is increased resistance in the steering wheel, but by making an autonomous process less so, the work involved in driving is increased significantly.

Responses to voice navigation systems are also being tested. Questions include: What semantic structure should a directional message have? For collision avoidance systems, at what moment should the warning be given, what kind of warning, what should be done about conditions of fog or ice?

ROSES—ROad Safety Enhancement Systems (DRIVE Project V2045, Areas 2, 4, & 5)

An overall goal of ROSES is to reduce the number of traffic accidents under adverse weather conditions. Its operational goal is the implementation of a fully integrated monitoring system for traffic, weather, and road condition to support drivers, traffic management, and winter maintenance. Dutch testing will evaluate the effectiveness of integrated roadside and in-vehicle systems. It will combine information from in-vehicle friction, visibility, and safety-margin monitoring systems, developed as a part of the Prometheus program, with information from road and weather monitoring and forecasting systems. Included in the project will be indoor testing using a simulator in controlled environments. Studies of adaptive driving behavior under poor weather conditions and the effectiveness of driver warning systems will also be made.

TELAID—TELematic Applications for the Integration of Drivers with special needs (DRIVE Project V2032, Area 5)

Deliverables for this project have been defined as:

1. Critical issues and a survey of past research and development work for drivers with special needs (DSN).

2. Existing aids for DSN.

3. Identification and grouping of requirements for DSN. Much of the research will be carried out by a human-factors laboratory working with simulators and testing vehicle adaptation strategies, including information aids and adaptable controls.

SOCRATES—System Of Cellular RAdio for Traffic Efficiency and Safety (DRIVE Project V2013, Areas 2, 3, 4, 6, & 7)

SOCRATES was a successful DRIVE 1 test project involving transmission of real-time traffic information to vehicles through European Standard Cellular Radio (GSM). The current SOCRATES project includes coordination of four pilot projects involving use of the technology. These the property of the ticketing line and are not distributed to lines being transferred to. Image processing is being tested as a means of measuring transferring passenger volume.

SIREDO—Traffic data gathering, recording, and disseminating devices. (Proposed DRIVE Project, decision due in 1994)

For each vehicle, the SIREDO devices measure and record: site identification, time of passage, vehicle speed, time to pass, length of vehicle, time of occupancy, number of axles, vehicle weight, axle weight, and headway. The SIREDO devices are linked to PC's at traffic information centers, communicating with the X.25 protocol. The objectives of the SIREDO program are to develop a national statistical traffic data base and to provide real-time information to the Traffic Information Centers.

Melodie—Integration and display of data from SIREDO devices

Melodie allows for real-time display of traffic, including modeled vehicles with cars, vans, and trucks of different sizes. Melodie can summarize and report from the relational data base populated by the SIREDO devices. Melodie is Windows 3.0-based and utilizes SQL Windows.

The Netherlands

Dynamic Traffic Management (DTM)

The DRIVE program as implemented in The Netherlands fits together with other related activities under the umbrella of DTM. Research and advisory themes for DTM include traffic-flow modeling, mobility models, transportation policy, freight transport modeling, telematics, infrastructure and economic impacts, logistics, and regional development.

GERDIEN—General European Road Data Information Exchange Network (DRIVE Project V2044, Area 4)

The primary objective of GERDIEN is to develop specifications for an open telecommunications infrastructure for the Integrated Road Transport Environment (IRTE). These specifications must allow for flexible exchange of data between applications. These applications include in-vehicle systems, roadside systems, traffic centers, demand-management systems, and the traffic information-collecting systems. The second objective of GERDIEN is to implement a part of the framework in a real-world environment.

Data communication architecture for GERDIEN is being developed on top of the seven-layer Open Systems Interconnect (OSI) reference model. Like MAP for manufacturers, DRIVE participants are developing DNT, a communication protocol, for the IRTE on top of the OSI model. Challenging aspects for the protocol development include the fact that mobile communication is necessary, and current OSI models do not have features for assigning priority to messages, which would be necessary for planned RDS-TMC applications.

Traffic information exchange necessarily must include standard location referencing, and GERDIEN has adopted the DRIVE GDF 2.0 digital road map for this purpose.

3. Automatic incident detection.

4. Road traffic and weather.

5. Information and control strategies for traffic management.

6. Privacy of personal information.

Application areas for pretrip and at-stop motorist information include information terminals, videotext systems, audiotext systems and travel services, and reservation systems. Cost-benefit comparisons for each application will be made. On-trip motorist information will be evaluated with VMS and with in-vehicle guidance systems, vocally and visually.

In the area of freight and fleet management, heavy vehicles will be guided by the traffic control centers as a means of improving overall traffic management, concentrating in particular on the movement of hazardous material.

CLAIRE—Artificial intelligence systems for traffic control (DRIVE Project V1015)

The purpose of the CLAIRE program was to propose a universal supervisory module capable of interfacing with most European urban traffic signal systems and to make that supervisory module capable of long-term learning.

CLAIRE reasons on three states of network arcs (i.e., roads between intersections): noncongested, congested, and unknown. In the noncongested state, CLAIRE imposes no commands on the traffic-signal systems, allowing them to operate conventionally. In unknown conditions given, for example, loop detector failure, CLAIRE makes a determination of road status and, if non-congested, restores control to conventional systems. In congested conditions, CLAIRE acts on the basic controllers until the non-congested state is restored. Generally this action, described as "holding" or "favoring" an arc, is accomplished by decreasing or increasing green time on the arc. Additionally, CLAIRE collects rough traffic data, converts them into qualitative states, and adds this information to its knowledge base, improving the models of network congestion propagation.

INVAID II—Evaluation of the INVAID (INtegration of computer-Vision techniques for Automatic Incident Detection) system in motorways and urban pilot projects (DRIVE Project V2015, Areas 3 & 4)

Motorway applications of image processing include:

1. Measuring volume, speed, and occupancy.

2. Measuring queues at toll stations.

3. Incident detection as indicated by stopped-vehicles congestion, slow-down, wrong-way vehicles, and pedestrians or vehicles on shoulders.

Urban applications include traffic measurement, incident detection, and bus detection. Additionally, for public transportation, image processing can be used for surveillance to detect fare cheating and other crime. It can also be used to determine passenger volume. On the Paris Metro, each line is a profit center. At present, there is no way to gauge transfer volume, so fare receipts are

6. Communication—part of this module checks incoming messages for integrity, duplication, and location ambiguity among other things. Part of this module is concerned with the messages sent to the road operators. Incoming messages use X.400, X.25, or TCP/IP. Messages sent to the road operators use these, or fax or telex.

7. External—TIGRE accesses a separate module that calculates routes and durations dynamically.

TIGRE uses Uriah as its GIS tool, Informix as its RDBMS, and Michelin mapping in GDF 2.0 format for mapping. The hardware includes Sun workstations and Bull servers for messaging.

PLEIADES—Paris-London Corridor Evaluation of Integrated ATT and DRIVE Experimental Systems (DRIVE Project V2047, Areas 2 & 4)

Objectives of PLEIADES are to integrate driver information systems with interurban traffic-management systems on the Paris-London corridor. The driver information systems will utilize travel information centers and their information systems, including TIGRE. Information will be disseminated to drivers by a variety of media including Travel Information Center displays, RDS-TMC, VMS, paging, cellular phones, and in-vehicle navigation systems.

In the area of interurban traffic management, two strategies will be employed. The first uses traffic monitoring information with a short-term forecasting tool to smooth flow on major routes. The second strategy will develop a model for operating VMS at critical nodes on the roadway network. PLEIADES also plans to study the impact of poor visibility on driver behavior and, subsequently, develop a means of categorizing visibility and warnings. For traffic information, PLEIADES will evaluate the use of image processing, and a portable incident-detection system based on acoustic detectors will be developed and tested.

MELYSSA—MEditerranean-LYon-Stuttgart Site for ATT (DRIVE Project V2040, Areas 2, 4, 5, & 6)

MELYSSA comprises four areas of interest:

1. Integrated interurban traffic management.

2. Pretrip and at-stop motorist information.

3. On-trip or enroute motorist information.

4. Freight and fleet management.

Evaluations and recommendations from a full-scale implementation are due at the end of 1994.

In the area of integrated interurban traffic management, six application areas are being investigated:

1. International and interurban information exchange, including the use of standard data dictionaries and transmission protocols.

2. Information exchange between urban and interurban areas.

lower. Germany will provide up to 10 sign bridges for 10 competitors with the best proposals.

France

TIGRE—Processing of Geographical and Road-Events Information

TIGRE is the information system for the seven Regional Road Information and Coordination Centers (CRICR) and the National Road Information Center (CNIR) in France. The mission of the Road Information Centers is to organize the distribution of information about traffic conditions to road users, to manage traffic on interurban road networks, and to forecast traffic conditions. TIGRE is related to the DRIVE program in that it is a part of two projects, PLEIADES and MELYSSA (described below), and TIGRE developers were part of the team creating the Alert-Strada data dictionary. TIGRE uses DRIVE standards, including GDF 2.0 (Graphic Data Format) and the ALERT C location codes.

TIGRE consists of two core data bases:

1. Its events data base is relational, adhering to the Alert-Strada data dictionary. Events include traffic jams and queues, construction or repair, accidents, road obstructions, incidents, meteorological events, and strikes or demonstrations.

2. Its geographical data base(s)—mapping in the scale of 1:1,000,000, developed by Michelin, is used in the CNIR. Mapping in the scale of 1:200,000, also developed by Michelin, is used in the seven CRICR. In both cases the mapping is in the exchange format GDF 2.0. Each event entered is located by way of the mapping, sometimes with the aid of the kilometer post network that includes posts placed at every 100 meters along the road network. Events can be point, linear, or zonal in nature, which the location reference reflects.

TIGRE has the following application modules in place:

1. Event management—allows the creation, modification, cancellation, and visualization of any or all events.

2. Traffic-control measures—allows the entry of measures to mitigate the events. Measures include recommended routes, seasonal load restrictions, detours, traffic signal placement, limiting access, lane narrowing or widening, and service vehicle presence.

3. Prediction—allows entry of expected events. Resultant events are predicted, and the operator has the option of validating, eliminating, or delaying the predicted events, as well as adding traffic-control measures.

4. Information—provides reporting on active events within a geographic area defined by the operator. Query can be on the basis of a route or for an event series, such as an accident followed by a traffic jam followed by a detour. Results can be displayed with mapping or by generating reports.

5. Historic—allows observation of historical events, including each of the states of a series.

translate the coded digital message into the selected language. Customer acceptance tests have been positive.

RDS-TMC allows for 20–60 broadcast messages per minute. It is expected that messages will be filtered for location; i.e., only those messages pertaining to the vehicle's location will be delivered by the in-vehicle radio, achieved by muting the volume on the selected broadcast station while the traffic message is played. While this rate of messages per minute represents an improvement over current technology, it is too small to be effective in an urban network.

Digitalization is central to implementing applications with mobile radio networks. Therefore, communications elements and data exchange interfaces between the control center and specially-equipped vehicles are being tested.

LIAISON Berlin—Linking Autonomous and Integrated Systems for On-line Networks and Demand Management in Berlin (DRIVE Project V2035, Area 3)

LIAISON is a system of two-way communication between vehicles and a traffic-management system using infrared beacons. The vehicle transmitter is attached to the rearview mirror, and the system transmitters are attached to traffic signals. System beacons transmit maps with route congestion information included. Vehicles transmit destination information, last system beacon, next system beacon, and elapsed time between beacons.

The system also calculates optimal routes. Route information is provided either by map display or voice. At the traffic signal beacons, vehicle locations are corrected. Between beacons, inertial methods provide vehicle location information for route guidance. Six hundred vehicles are being tested, but, for reasons of data privacy, vehicles are not identified. Findings include slight improvements in safety and some changes in use of routes. Passengers observe driver behavior—with verbal directions, a calming effect is noted based on less blinking by the driver. The system includes information on parking, provides indication of Central Business District (CBD) full ramps, and directs drivers to Park and Ride lots.

Automatic Toll Collection (Not currently a DRIVE project)

In Germany, there are at present no toll roads, though several motorways are being evaluated for placement of toll facilities. The motorways being evaluated do not have room for the wide, eight-station toll plazas common in the United States and elsewhere. The motorways being evaluated have frequent exits and entrances, with an average of 6 kilometers between interchanges, thus a system of toll facilities placed on ramps would be prohibitively expensive. Given these constraints, the decision was made to develop a bidding competition for automatic toll collection.

Specifications for the system require placement of the toll devices on a sign bridge over the motorway. For the competition Germany will construct the bridge, and the competing firms are responsible for providing devices and installation. Initial proposals include two infrared systems, with the remainder using radio, mostly in the 5.8 GHz band and

A remaining area for standardization within the DATEX framework is verbal descriptions of location. RDS-TMC and other traffic and travel information systems to be used by the public require location referencing by verbal description. The definition of the comprehensive location referencing system is being worked on by a European Committee for Standardization (CEN) subgroup.

Germany

RHAPIT—RHein/Main Area Project for Integrated Traffic (DRIVE Project V2055, Areas 1, 2, 4, 6, & 7)

RHAPIT is one of the largest and most complex DRIVE projects. It involves the cities of Frankfurt, Offenbach, Wiesbaden, Mainz, and Darmstadt, and the dense motorway network connecting those cities. The objective of this project, simply stated, is to improve the powerful in-place traffic management system. The existing traffic control center at Rüsselsheim is being enhanced and extended by the SOCRATES (see Sections 6.2–6.6) Service Center to provide further and better information to drivers/users via the Global System for Mobile Communication (GSM) radio link.

Though not directly related to the RHAPIT program, some systems currently in use or in development contribute to the achievement of RHAPIT's overall goals.

Collective traffic-influencing measures
In-place systems include directional signing systems at seven major interchanges. These interchanges are designed with variable numbers of lanes usable on entrance and exit ramps. Based on congestion, the number of lanes allocated to these movements changes. In-place systems also include variable message signs displaying speed limits by lane. These signs are intended to smooth traffic flow, increasing motorway capacity. The motorway network in this area includes 650 loop detectors gathering traffic volume, vehicle type, and speed information. Detectors are placed at intervals of 1 to 15 kilometers, and plans include interconnecting loop detectors to attempt to gather elapsed time for individual vehicles.

ARIAM (Automatic Broadcasting Information by Actual Measurement)
Also in place in the Rhein/Main area, ARIAM provides information to drivers by way of commercial radio on the basis of automatic incident detection. Analyzing information from the detector loops, ARIAM develops a suitable and complete text description of the incident and automatically transmits it to the broadcasting station. This system has a delay of 1 to 1.5 minutes between congestion and broadcast, compared with approximately 15 minutes for a system requiring manual intervention.

Bevei
In another field trial, known as Bevei, Germany is implementing, on a pilot basis, RDS-TMC in 50–100 vehicles. To use RDS-TMC requires FM-broadcast stations to change their signal from analog to digital to allow for sideband transmission. To receive the sideband transmissions will require purchasing an add-on for the automobile radio that is estimated to cost $400 U.S. or approximately the same as a compact disc player. The radio add-on will be a voice-synthesis module that will

planned for both the bridge and the tunnel. The system will also be useful for mitigating congestion due to traffic incidents such as accidents or stalls.

Its corridor system includes a network of loop detectors for traffic volume and speed information, and variable message signs (14 planned) tied to a central computer. VMS give information and guidance to drivers about the easiest way to cross the fjord given actual traffic conditions. Two different types of VMS information are being tested in the QUO VADIS project. The first gives delay-time information for both the bridge and tunnel, with the driver deciding the most practical route. The second is route guidance; for a few significant destinations, routes are recommended by directional arrows to either the bridge or tunnel. Computer and sensor facilities came on line in October 1993, with field trials taking place in 1994.

A significant objective of QUO VADIS is to gain success in predictions of driver behavior. Preliminary studies indicate that VMS have a success rate of 20–80 percent in influencing driver behavior. To narrow that interval, further studies, including the use of roadside interviews, questionnaires delivered by mail, and computer simulation of route choice, are planned. This simulator, called Vladimir, enables drivers to make trips through a realistic simulation of the network including road features and VMS information.

Two strategies for control of the VMS are being tested. The first strategy calculates travel time along the two routes. By comparing with travel time under normal conditions, the model dictates which signs should be activated and what messages displayed. The second strategy, knowledge-based, compares sensor-traffic measurement to criteria set for various situations. Based on these comparisons, the determination is made of which signs with which messages should be activated. Ultimate control of the system will reside with police and road authorities. As planned, the system will make recommendations that the police will have to activate.

In the long term, the VMS are intended to be part of an integrated traffic system in Ålborg. This integrated system is planned to be coordinated from a single control center and will include the optimization of traffic signals in Ålborg and traffic regulation on the tunnel approaches as well as additional VMS.

Cord—Strategic Assessment of Advanced Transport Telematics (ATT) Implementation (DRIVE Project V2056)

Cord is the program-management project for all of DRIVE; among its primary goals is identifying areas for standardization across DRIVE projects. Cord chartered a task force, known as DATEX, which included Danish membership, to develop a data dictionary for traffic and travel information systems, referred to as the consolidated Alert-Strada dictionary. One of a number of uses for this standardized information is Radio Detection System–Traffic Message Channel (RDS-TMC), which is FM-sideband transmission of traffic information for reception in-vehicle. Denmark is working on an incident-reporting pilot system for use by the police to input incident data in this standard format.

only one-quarter the costs of the cast-in-place bridges. Thus, in Mr. Muller's opinion, the former is superior to the latter in long-term performance.

Built-in Strengthening Design

Should requirements arise, built-in additional or larger ducts can allow for additional tendons. Anchor blocks and deviation saddles provide for external tendons.

Jean Muller International—Computer Applications

Bridge design and bridge construction programs are based on a plan frame for static-dead and live-load analysis, while the Hercule program is used for vibration and dynamic analysis of a complete 3-dimensional structure.

MACAO, *Management de Projet Autoroutier Conception Assiste par Ordinateur*, is a highway CAD program. Given the topography from the land surveyor, under the defined templates and superelevations, the program is capable of highway design including drainage, earthwork computation, automatic drafting of cross sections, and horizontal and vertical alignments. Additionally, the MACAO program provides 3-dimensional views of the finished roadway and existing terrain from a driver perspective. [MACAO was developed by the Commercial Society for Road Usage (SCETAUROUTE) of which Jean Muller International is a part. TTEC ed.]

These computer programs are all proprietary but are available from Jean Muller's organization.

7.10 The DRIVE Program

Each of the countries we visited has active projects within the DRIVE program. DRIVE is organized into seven areas:

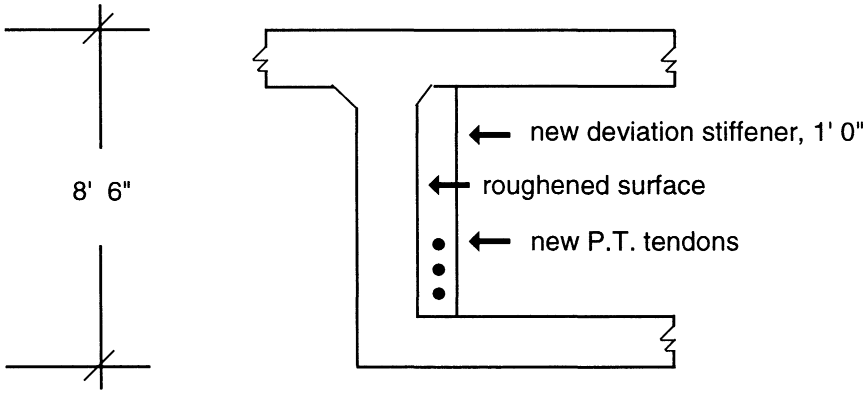
Area 1	Demand Management
Area 2	Travel and Traffic Information
Area 3	Integrated Urban Traffic Management
Area 4	Integrated Inter-Urban Traffic Management
Area 5	Driver Assistance and Cooperative Driving
Area 6	Freight and Fleet Management
Area 7	Public Transport Management

Many projects apply to more than one area, and many are interrelated; most, if not all, projects are cooperative efforts involving two or more countries, plus other public and private organizations. The DRIVE projects presented by each country to the team are reviewed below, including projects either proposed for DRIVE or otherwise associated.

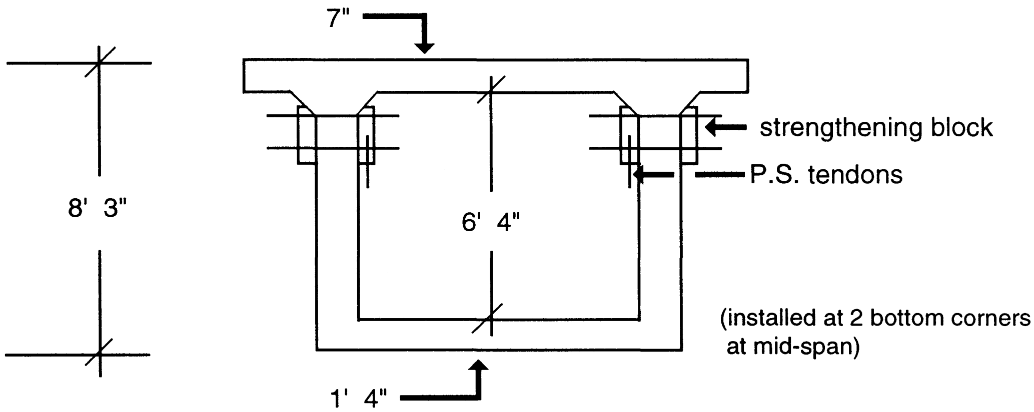
Denmark

QUO VADIS—QUeue Obviation by VAriable Direction and Information Signs (DRIVE Project V2042, Areas 2 & 4)

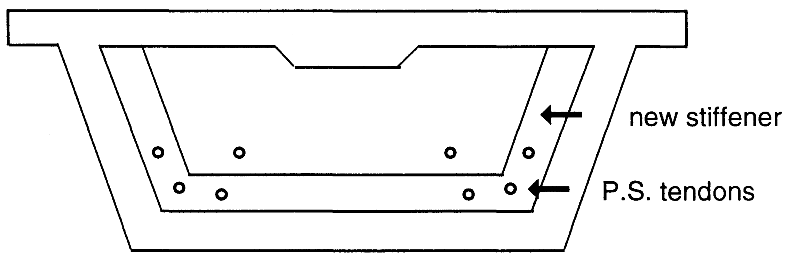
A primary objective of QUO VADIS is to determine the most effective methods for using variable message signs (VMS) to improve road-network capacity. QUO VADIS is being researched in Ålborg, Denmark, and in Scotland. It is aimed at distributing traffic over two crossings, a bridge and a tunnel, of the Limfjorden Fjord. This will become particularly important in the coming years as major repairs requiring lane restrictions are



Brest Bridge



at Pier
Choisy-Le-Roi Bridge



at Mid-Span
Brotonne Bridge

Bridge Prestress Strengthening

Figure 10: Jean Muller International, France

pier before the pylon. Then, the concrete segments over the pylon are constructed by the balanced-cantilever method toward the access span and the main span. With a closure pour at 6 m near the last approach pier, the concrete segments in the main span continue up to 116 m past the pylon where the steel segment begins.

Steel segments are shipped to the site by barge. A segment is lifted, anchored to a cable stay, and welded to a previously erected segment. This procedure continues until the main span is completed.

Jean Muller International—Segmental Bridge Construction

With a lifetime of experience in prestressed concrete segmental bridges, Jean Muller has many valuable lessons, some of which are described in brief below.

Temperature Gradient in Bridge Decks

Temperature gradient should not be ignored. In a single day, the temperature differential may reach 30°F, causing internal stress. Stress could be aggravated when the structure is over water where the bottom flange of the box is kept cool while the deck absorbs solar energy.

Long-Term Deformation

Joints at the closure pour may open up as a result of long-term deformations. This condition can be retrofitted by providing additional external post-tensioning. This method has been used for the Brest Bridge, Choisy-Le-Roi Bridge, Brotonne Bridge, and the Givors Bridge. The strengthening methods used for the first three bridges are illustrated by Figure 10.

Shear Force and Keys

Cracks may develop in the center web of a two-cell box. This happens when the transverse distortion of the box is neglected, or the straight-line theory, if used, underestimates the shear force developing at the center web. The integrity could be restored by a prestressed bar planted in the web, or two bars on either side of the web.

Multiple shear keys in the web and shear keys in the top and bottom flanges are essential for the transmission of shear and torsional stresses across the segment.

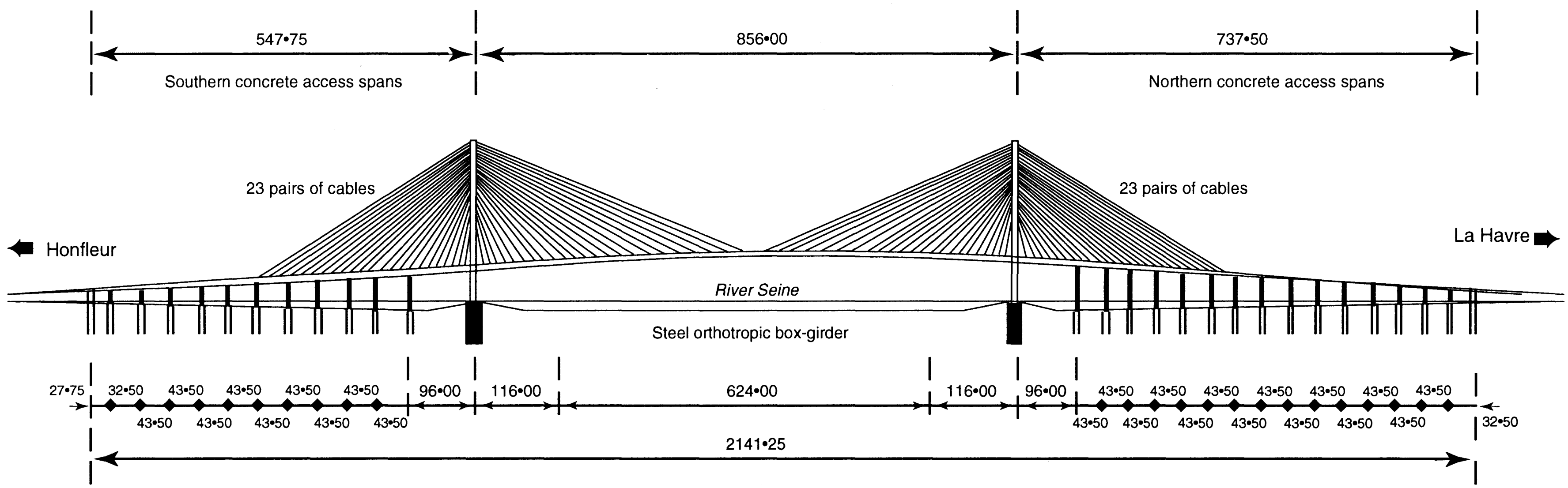
Heat Curing

To reduce a construction cycle and rotation of casting machines, the box segments may be heated. The ratio width/length for short or intermediate spans is 2 to 3; for a wide deck or long spans, the ratio may reach about 10. To avoid handling and construction problems caused by temperature gradients, the cast segment and the match cast segment should be cured simultaneously.

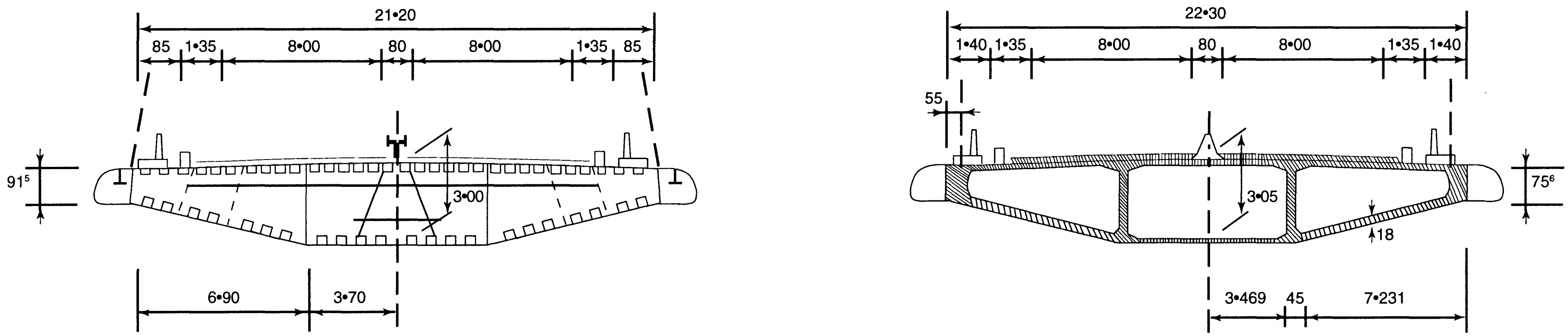
Prestressed Concrete Segmental Construction

A survey of 64 such bridges that were designed and built from 1962 to 1986 showed that the cumulative cost of maintenance over construction (M/C cost ratio) is 1.54 percent. The average age of bridges surveyed was 14 years old; therefore, the average maintenance cost per year was 0.11 percent of the original construction cost.

As far as maintenance cost is concerned, the precast segmental bridges incurred



Longitudinal view of Normandie Bridge (all dimensions in m)



Typical cross-sections in concrete access spans (right) and in steel part of main span (left) (all dimensions in m)

Figure 9: Normandie Bridge, France

6. Expansion joint systems of rubber, metal, or a hybrid of rubber and metal on steel members.

7. Regulation on long-term unpainted steel.

8. Waterproofing membrane for tunneling.

9. Reinforced earth.

7.9.3 France

Normandie Bridge

One of the longest of this structural type in the world, Normandie Bridge is a cable-stayed bridge with an 856-meter main span over the Seine River near the town of Honfleur. SETRA is the leading agency, among others that, between September 1986 and February 1988, performed the preliminary design of the bridge.

Contrary to practice in the United States, SETRA's preliminary design only provided the span configuration, transverse structural sections, principles for prestressing, and reinforcing (see Figure 9). Bids were opened in August 1988 and the project let in 1990. The contractor completed the detailed design before construction, which was to be completed during 1994.

Wind effects have governed much of the design and erection. This is a unique and unusual structure; some interesting information is highlighted below.

Span Configuration and Structural Sections

Overall length of the structure is 2,141 m. As far as structural material is concerned, the 624 m center portion of the 856 m main span uses a steel box girder while the remainder is of concrete. In this arrangement, the weight of the steel main span is 13 T/m including equipment, while the concrete spans are 45 T/m.

To provide torsional resistance, box girders are used with a constant 3 m depth for both steel or concrete segments. This streamlined shape aims to reduce the wind effect and vortex shedding. In the steel orthotropic box girder, the top plates are 12 or 14 mm thick while the inclined webs and bottom plate are 12 mm thick. The stiffening ribs are 240 mm deep, 7 or 8 mm thick, and at 1 m spacing.

Relatively short approach spans, mostly at 43.5 m, produce a counterweight effect so as to stiffen the center span, to reduce pylon deformations, to reduce live load deflections in the main span, and to limit fatigue damage as a result of reduced stress variation in the cables.

Pylons and Cable Stays

An A-shaped pylon is used to resist wind forces, and the deck is rigidly connected to the pylon. Stays comprise 15 mm-diameter parallel strands that are hot-dip galvanized for corrosion protection. Each individual strand is protected by a 1.5 mm-thick polyethylene sheathing, and voids are filled with petroleum wax. The cables are composed of 31–51 strands, depending upon their locations in the structure.

Span Construction

Approach spans are built by the incremental launching method from each of the abutments to 6 m beyond the last approach that spread the wheel load to the adjacent ribs when the wheels were moving. Therefore, the stiffened rib would have a longer life, compared with the laboratory test, when there was no asphalt pavement between the load and deck plate. Research results also indicated that with an increase in temperature and a resulting decrease in rigidity of the asphalt pavement, the effective distribution of wheel loads decreases.

2. Structural torsion and the force of the stays.

A truck of 500 kN was placed at the edge of the roadway at the mid-span of the cable-stayed bridge; the rotation was measured as 0.06 degrees, very close to the calculated value.

Cable force before grouting was determined from frequency measurements, using a stopwatch and counting the cycles when the stay was brought into oscillation manually. Stay force, P, was then calculated from the following equation:

$$P = 4f^2l^2m/n^2$$

where:
f = measured frequency
l = distance from the supports (sockets)
m = mass per unit length (the strands and the duct)
n = 1 for first-order oscillation, 2 for second-order oscillation.

Computed forces checked well with the oil pressure measured by the hydraulic jacks in the stays.

Cable force was also determined from the sag measurement. This method was time-consuming and strenuous, but the results were good, except for the short and nearly vertical cables. A carriage with a fixed reflector was drawn up along the stay. The sag was calculated from the measured distance and horizontal angle of three points along the cable. Cable force, P, is calculated from the equation:

$$P = (dL^2/8f)(1 + (h + 4f^2/L))^{1/2}$$

where:
d = vertical load per unit length
f = calculated sag of the cable
h = vertical distance between the top and bottom points
L = horizontal distance between the top and bottom points.

Force from the sag checked very well with the force from the frequency method mentioned previously.

7.9.2 Germany

At BASt, the ongoing bridge-research projects include:

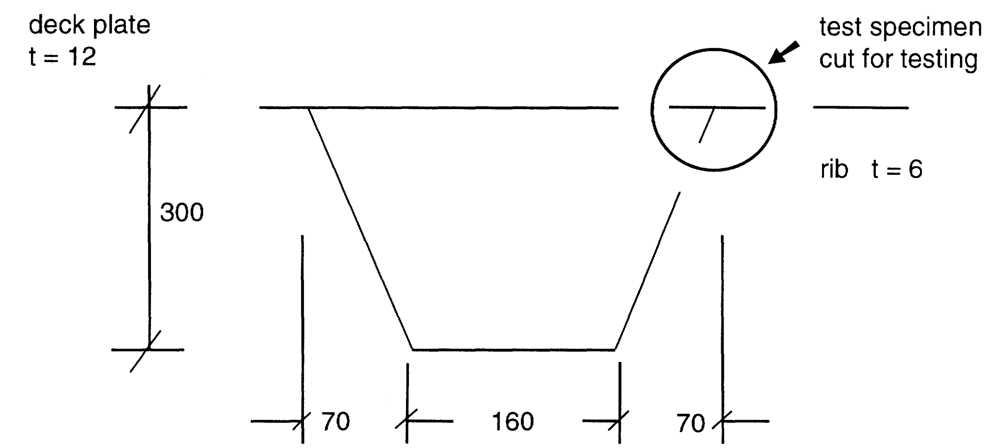
1. Bridge bearing.

2. Prestressed concrete cracks.

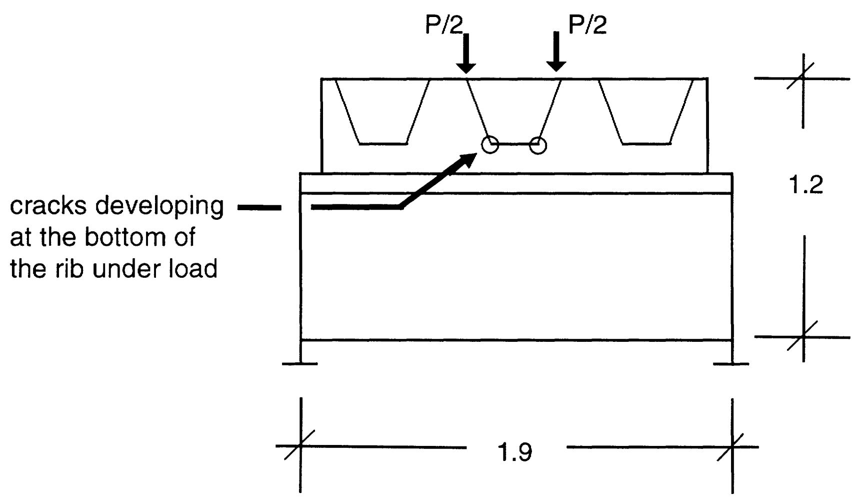
3. Temperature effects on a concrete deck through a welded layer of metallic sheet on top of which the asphalt is heated to 270°F.

4. Carbonation and chloride contents of concrete deck.

5. Corrosion protection such as cables of cable-stayed bridges.



Rib/Deck Connection Plate (mm)
Flexure Fatigue Test



Deck Panel Test (m)
Longitudinal Spans at 2 m and 4 m

Figure 8: Faroe Bridge, Denmark

100 million cycles, which was equivalent to 2,730 such trucks per day in one direction for 100 years.

To test the deck/rib panel connection, 10 specimens were cut from a manufactured deck plate at the welded rib (see Figure 8). The flexure test was performed by a high-frequency pulsator until rupture at the welded seam. Results indicated the stiffened deck-plate capacity was almost double the design moment of 0.7 kN/mm at 2 million axle cycles.

Additionally, a fatigue test was done on the deck beam having an area of 12 m^2 (see Figure 8). Three stiffening ribs were supported on three diaphragms at spans of 4 m and 2 m. The load was applied at the center rib. At 5 million cycles, the first two cracks appeared with a 2.37 mm deflection at the rib joint in the bottom part of the rib (see Figure 8). At 5.5 million cycles, the cracks had extended to the full width of the rib bottom. At this point the welds were repaired and the test continued until 7 million cycles were reached, causing an additional 0.07 mm deflection at load P = 153 kN.

Experimentation was continued to the ultimate load of the deck team, and the proportionality limit was reached at 290 N/mm^2. At an 11 mm permanent local deflection, the ultimate load reached an axle load of 2 MN, a value 20 times the normally permitted axle load.

Danish research indicated that the orthotropic deck was superior in fatigue loading and ductility than was indicated by the research done in the United States, possibly because of better Danish quality control and a better welding procedure.

Wind Response of the Cable Stayed Main Crossing

Measurements at the tip of the cantilever of the main crossing were taken to determine wind effects before and after the closure pour was made.

The natural frequencies registered were:

	Before closure	**After closure**
Vertical bending	0.42 Hz	0.46 Hz
Horizontal bending	0.36	0.47
Torsion	2.0	1.2

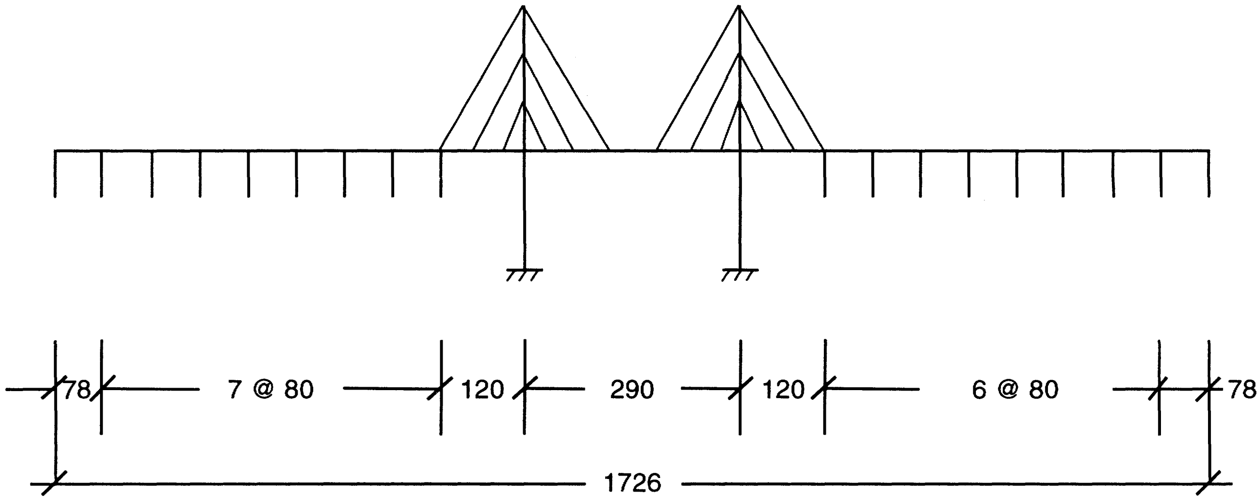
The largest oscillation amplitude was 40 mm and 25 mm before and after the closure pour at a wind speed of 15 m/sec perpendicular to the bridge.

Full-Scale Testing

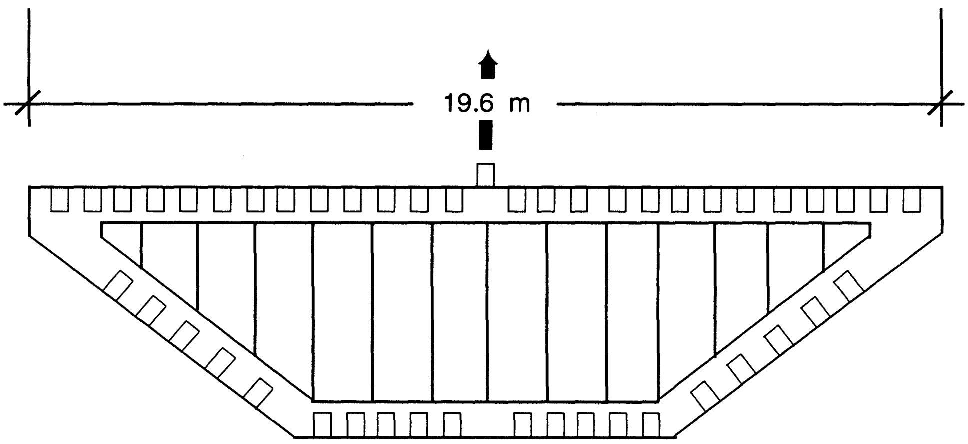
1. Bending stress of the stiffening rib.

Using a loaded truck, static tests and dynamic tests at 10 and 40 km/hr at a temperature of 15°C were conducted with strain gauges attached to the bottom of ribs. The measured bending stresses at the rib bottom both at the diaphragm and mid-span were very close to those calculated for the static test, but only about three-quarters of that calculated for the dynamic test.

Research indicated that the decrease was due to the existence of asphalt pavement



Span Configuration (m)
the Cable-Stay Main Crossing



Steel Orthotropic Box Girder with
Stiffening Ribs

Figure 7: Faroe Bridge, Denmark

network is 1.3. Thirteen items of bridge quality are rated. Large bridges have a routine inspection every 2 or 3 years. Maintenance is performed by counties (provinces) funded by the federal government, and principal inspection is conducted by contractors every 4–5 years.

DANBRO is a bridge-management program, containing the data base of all bridges on the national network. The DANBRO system contains a 5-year strategy, which prioritizes the bridges for maintenance for the first year and for the fifth year, if so delayed. At the fifth year, the maintenance cost is higher as a result of the increased scope due to aging and from the traffic cost due to delays. In between, the estimated costs to maintain from the second to fourth years are linearly interpolated.

This system contains construction costs of all bridge items from the bids of the past contracted projects, automatically generating a price-increase index. Construction costs in the data base are kept updated when new projects are bid on. Based on the data, the estimated maintenance costs in the DANBRO system are usually close to target values. Spreadsheet output shows the yearly estimate for a 5-year plan as compared to the available allocations of the 5 years.

Operation of the program is interactive on a PC terminal to access the computer center. If any increase or decrease of the allocation for any year is keyed in, the spreadsheet responds with a new priority ranking.

Faroe Bridge

The Faroe bridge was designed, constructed, and completed between 1980 and 1985. It connects the "South Motorway" from Copenhagen over waterways between Sjaeiland and Falster via the small island of Faroe. Therefore, it comprises two bridges: one, referred to as the SF bridge from Sjaeiland to Faroe; the other, called the FF bridge, from Faroe to Falster.

Steel orthotropic box-girder construction was used throughout the entire Faroe bridge project with transverse diaphragms spaced at 4 m. The SF bridge, 1,596 m in length, contains 20 continuous spans at 80 m on a slight horizontal curve. The FF bridge contains a cable-stayed bridge over the main channel (Figure 7).

The Danish Ministry performed extensive testing on this bridge for research purposes, including laboratory testing of the steel deck, wind-tunnel tests, field monitoring of wind response in the prototype cable-stayed bridge, and pavement tests. Steel orthotropic construction is not commonly used in the United States due to welding and fatigue problems, and it is not economically competitive. The team found the testing procedures and results very revealing and absorbing. This scanning report outlines the major tests (except wind-tunnel and pavement tests), with appropriate figures.

Laboratory Tests on the Steel Orthotropic Deck Section

The fatigue loading simulated a truck with 3 axles spaced at 1.5m, and consisted of

ERASMUS: Entretien Routier Assiste par Systeme Multi-expert, an expert system for pavement management developed in 1985–1989 and now installed in approximately 40 sites in France. This system is estimated to save up to 2 percent per year per site with a total estimated savings of Ff200 million (about $36 million U.S.) per year. Some sites have yielded up to 10 percent savings.

SAGE: systeme pour la surveillance et le controle de la congestion, a rule-based system that became operational in Paris in 1990.

CLAIRE: systeme independent de supervision de systeme de regulation, a rule-based system finalized in 1992 and currently installed in Toulouse.

Carrefour Intelligent: controle d'intersection par traitement d'image, an object-oriented program for intersection control based on visual images (image processing), which is undergoing testing and evaluation in Valence.

CID: Conception Intelligence de Diagramme de Faux, a constraint-based reasoning system for intersection design with the prototype system currently being tested in Paris.

TITAN: Traitement d'Images de Trafic et Analyse, a vehicle-detection system based on processing and analysis of images. The feasibility of this concept was established in 1987.

The Netherlands

The Netherlands has an active artificial intelligence program. An expert system for incident support and a neural network for traffic forecasting based on sensor and historical data have been developed. Efforts toward computer-integrated construction and robotics are under way with the focus on moving advanced technology and AI into construction and maintenance operations. Future efforts are planned in incident management, variable-message signing (VMS), traffic information broadcasting, control-center operator support, and other intelligent traffic systems.

7.9 Bridge Management

7.9.1 Denmark

Denmark has a very thorough bridge management system. Inspection and rating have the following three categories:

1. Condition rating, from 0 to 5.

2. Maintenance rating, where "+" means good and "-" indicates a problem.

3. Special inspection, to be done by a contractor.

The bridge-rating scale is from 0 to 5; 0 is good and 5 is poor. From the latest statistics, 8 percent are poor, 32 percent, fair, and 60 percent, good. The average condition of bridges on the national

The steps in the algorithm, known as KAT, are:

1. Generation of a graph with even-degree nodes.

2. Decomposition in cycles.

3. Formation of the cycle graph.

4. Calculation of a spanning forest with the most significant bit (MSB) algorithm.

5. Improvement of the spanning forest with simulated annealing.

6. Construction of the tours.

It is claimed that the KAT algorithm overcomes the lack of flexibility of known algorithms for arc-routing problems. Most of the relevant constraints on applications are considered. Besides the minimization of deadheading distance, other objectives are optimized. There is proof that this flexibility is not obtained at the expense of deadheading distance, and that the KAT algorithm is even superior to other algorithms in this respect. The algorithm can be run effectively on PC-based equipment.

7.8 Artificial Intelligence

Denmark

Denmark's Road Institute has taken a pragmatic approach to investigating and developing artificial intelligence systems. An expert system for pavement-maintenance management has been developed and evaluated, and the development of neural-network tools is under consideration. AI systems will be considered as the technology is required to address specific problems, and other applications of advanced technologies will be developed as needs are identified.

Germany

AI technologies are being incorporated into operational systems as needs are identified. While there are some doubts about their usefulness, knowledge-based systems have been developed in the areas of traffic control, incident management, and highway information systems. In control systems, fuzzy sets and neural networks are considered to be applicable. Constraint-based reasoning is being developed for traffic flow representation. Voice synthesis will be an integral part of the Ali-Scout system for roadside-vehicle communications. In some cases artificial intelligence will be embedded in hybrid systems invisible to the user.

France

France has a progressive artificial intelligence research program conducted under the *Service d'Etudes Techniques des Routes et Autoroutes* (SETRA) and the *Institut National de Recherche sur les Transports et leur Sécurité* (INRETS) Department of Applied Mathematics and Artificial Intelligence. SETRA and INRETS have developed operational AI-based systems in pavement management and traffic control and have significant research accomplishments in several areas, including constraint-based reasoning, image processing, and computer vision.

is a grid-based scheme that attempts to classify squares on a fixed grid as containing or not containing moving objects.

The indirect method employs markers, based on gradients and morphology. The morphological markers are based on features and extract morphological sizes, of which combinations are recognized as aggregations for shape-detection. The gradient markers are edge-features extracted through gradient-detection techniques. The cooperative attributes approach employs both types.

The Carrefour system employs these methods in an AI-based system for surveillance and control at intersections. Spatial dimensions and categories are used to define objects and relations, using a real-time inference engine.

7.7 Advanced Mathematical Techniques

Routing Algorithms for Winter Maintenance

The Hesse Administration of Traffic Safety in Darmstadt, Germany, has made use of advanced algorithms for optimization of winter maintenance. The algorithms were developed by Durth Roos Consulting, GmbH, and the system is commercially available.

Route optimization for plowing vehicles is performed on the basis of a model network consisting of nodes and connecting edges. An edge-oriented procedure appropriate to servicing roads is sought, rather than a node-oriented procedure appropriate to delivery of goods. A flexible, random-based algorithm has been developed for this purpose, approached in the following manner:

1. A list of constraints and definitions is created, containing:

   - Network definition: nodes and edges, functions, etc.
   - Traffic definitions: road category, traffic density, special problems.
   - Operative constraints: depot locations, number, type, and capacity of equipment.

2. Each edge of the network is assigned a level of priority with respect to the sequence of servicing.

3. The optimal objective is defined. This is a weighted combination of factors, such as minimal deadheading distance, equal distribution of tours, minimum service time, and maximum priority; the weightings can be reselected at any time.

4. Tours are organized corresponding to the number, capacity, and maximum service time of the vehicles. Possible routes are determined for each tour, which are rated by a point-evaluation system, dependent on the optimization objective.

5. The best solution (highest point rating) is then found by the search algorithm. Multiple schedules considering various criteria may be produced in parallel.

7.6 Image-Processing Applications

The principal image-processing applications observed were those associated with the French efforts. The SETRA Macadam program seeks to apply image-processing techniques to detection of cracking in road surfaces, while at INRETS the Carrefour program applies image-processing techniques to the analysis of traffic flow.

Macadam

An inspection vehicle is employed with a variety of sensors to assess pavement conditions. Currently, the vehicle employs a vertically oriented camera to take pictures that are viewed and analyzed manually for crack detection. Work is well under way to develop an automated computer-vision system to perform the crack-detection analysis task. At the present time, an algorithm has been developed that can detect cracks adequately in the laboratory, but not under field conditions. The algorithm analyzes the film that is taken at 2–3 km/hr with a slit camera. Other sensors on the vehicle assessing other road characteristics can operate at up to 70 km/hr.

In its present form, the algorithm is capable of finding linear features as narrow as 1 mm. Like most French approaches to machine vision, the algorithm is based on the Mathematical Morphology approach of J. Serra. The basic procedure is to subtract the average value, and then use erosion and dilation operators matched to models of selected types of pavement deterioration, such as cracking.

At present, the performance of the algorithm in the field is limited by film quality available in actual road runs. It is difficult to control illumination due to variations in pavement reflectance, and this, in turn, has been found to interfere with the thresholding step. Efforts are under way to improve the illumination system and the film quality; a new video system is under consideration that will give a line-width of 4,000 pixels.

Carrefour

At INRETS, a team of five to six persons is working on machine-vision applications for surveillance and measurement of traffic. The applications include volume, speed, and occupancy, queues at toll stops, and incident detection on freeways. At this time the incident-detection application is the most advanced. Traffic-control applications include incident detection and bus detection in urban areas, and applications to volume and surveillance for mass transit systems are also in development.

Several approaches are employed, most based on mathematical morphology, and are currently capable of running on PC's at a rate of 5 images (10 frames) per second, with 512×512-pixel images. The methods employed were categorized as "direct," "indirect," and "cooperative."

In the direct method, motion analysis is employed. The method is further divided into a surface-detection approach and a breaking-up approach. The surface-detection approach is feature-based and relies on edge-detection to delineate moving objects. The breaking-up approach applications, once again demonstrating their commitment to integration.

The other three countries visited equally recognize the importance of data and their integration. Excellent techniques and significant resources exist for the collection of the data; however, their state of integration is not as far advanced as in Denmark. Most data appear to reside in application-specific data bases. They do recognize the importance of proceeding toward the goal of full integration and sharing of data.

CAD/GIS

The four countries' common philosophy on responsibilities for the highways significantly affected their use of computer-aided design (CAD). Only preliminary design was done by the government agencies, whereas the final designs were done almost exclusively by the consultant community, which seems to act like a true partner with government. Design review was done by the government but did not take much advantage of CAD to do so. Based on this approach, there was no real standardization of CAD, as each consultant used what he or she believed to be most cost effective. A wide variety of in-house and vendor products were mentioned. The two consulting firms visited were very advanced in the use of engineering automation and the multiple use of common data from phase to phase.

Some very interesting uses of "design visualization" were observed to be employed by consultants in Germany and by the government in France. "Spot imagery" as a backdrop for communicating the impact of a project to the public was quite good.

Use of geographically based information systems was more evident because of the natural tie to the analysis and display of data mentioned above. Three of the four countries demonstrated these capabilities with two using the Intergraph products and one the ESRI (Environmental Science Research Institute) products. The more integrated the data were, the more successful the use of this technology.

7.5 Epoxy Rebars

Epoxy coating of rebars has been recognized as beneficial to the life of concrete components for some time; however, some problems exist concerning the durability and adhesive characteristics of the coating. A design/build firm in Germany has done significant research in this area, resulting in new processes being used to improve the quality control of the application. Improvements included:

1. Pre-bending and fabrication of reinforcing-bar components in a "manufacturing facility."

2. Sandblasting of the reinforcing bars in a controlled environment, prior to coating, to reduce the potential for corrosion.

3. Application of a thicker coating than is used in the United States.

This appears to have increased the durability and reduced the potential for internal corrosion.

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