

# Superior Materials, Advanced Test Methods, and Specifications in Europe



US Department of Transportation  
Federal Highway Administration  
International Technology Exchange Program

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# SUPERIOR MATERIALS, ADVANCED TEST METHODS, AND SPECIFICATIONS IN EUROPE

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This scanning study would not have been successful without the assistance of many individuals. The team particularly appreciates the outstanding contributions of the officials, engineers, technical personnel, and their staffs in the places we visited (Appendix A). These individuals and their organizations contributed countless hours both in front of and behind the scenes, responding to the team's amplifying questions, preparing and presenting technical information, arranging and guiding site reviews, and generously giving their time and expertise.

## FHWA INTERNATIONAL TECHNOLOGY EXCHANGE PROGRAMS

The Federal Highway Administration's (FHWA) Technology Exchange Program accesses and evaluates innovative foreign technologies and practices that could significantly benefit U.S. highway transportation systems. This approach allows for advanced technology to be adapted and put into practice much more efficiently without spending scarce research funds to recreate advances already developed by other countries.

The main channel for accessing foreign innovations is the International Technology Scanning Program. The program is undertaken jointly with the American Association of State Highway and Transportation Officials (AASHTO) and its Special Committee on International Activity Coordination in cooperation with the Transportation Research Board's National Cooperative Highway Research Program Project 20-36 "Highway Research and Technology – International Information Sharing," the private sector and academia.

FHWA and AASHTO jointly determine priority topics for teams of U.S. experts to study. Teams in the specific areas being investigated are formed and sent to countries where significant advances and innovations have been made in technology, management practices, organizational structure, program delivery, and financing. Scan teams usually include representatives from FHWA, State Departments of Transportation, local governments, transportation trade and research groups, the private sector, and academia.

After a scan is completed, team members evaluate findings and develop comprehensive reports, including recommendations for further research and pilot projects to verify the value of adapting innovations for United States use. Scan reports, as well as the results of pilot programs and research, are circulated throughout the country to State and local transportation officials and the private sector. Since 1990, FHWA has organized more than 50 international scans and disseminated findings nationwide on topics such as safety, planning, environment, pavements, bridge construction and maintenance, contracting, intermodal transport, organizational management, winter road maintenance, intelligent transportation systems and policy.

The International Technology Scanning Program has resulted in significant improvements and savings in road program technologies and practices throughout the United States. In some cases, scan studies have facilitated joint research and technology sharing projects with international counterparts, further conserving resources and advancing the state of the art. Scan studies have also exposed transportation professionals to remarkable advancements and inspired implementation of hundreds of innovations. The result: large savings of research dollars and time, as well as significant improvements in the nation's transportation system.

For a complete list of International Technology Scanning topics and to order free copies of the reports, please see the list contained in this publication, as well as: Website: [www.international.fhwa.dot.gov](http://www.international.fhwa.dot.gov) or Email: [international@fhwa.dot.gov](mailto:international@fhwa.dot.gov)

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European Bridge Structures (1995)  
Geotechnology – Soil Nailing (1992)

All publications are available on the Internet at  
[www.international.fhwa.dot.gov](http://www.international.fhwa.dot.gov)

## ACRONYMS

AASHTO	American Association of State Highway and Transportation Officials
APEL	Applied Process Engineering Laboratory
BASt	Bundesanstalt für Straßenwesen (Germany)
BBA	British Board of Agrément
BRE	Building Research Establishment (United Kingdom)
CEN	European Committee for Standardization
CRCP	continuously reinforced concrete pavement
CROW	Information and Technology Centre for Transport and Infrastructure (The Netherlands)
DBFO	design-build-finance-operate
DOT	department of transportation
DRI	Danish Road Institute
DWW	Dienst Weg-en Waterbouwkunde (The Netherlands)
EOTA	European Organisation for Technical Approvals
EPS	expanded poly-styrol
EU	European Union
FGSV	Road Transport and Research Association (Germany)
FHWA	Federal Highway Administration
FRP	fiber-reinforced polymer
HA	Highways Agency (United Kingdom)
HAPAS	Highway Authorities Product Approval Scheme
HITEC	Highway Innovative Technology Evaluation Center
HMA	hot-mix asphalt
HPC	high-performance concrete
IRI	international roughness index
JPCP	jointed plain concrete pavement
LCB	lean concrete base
NCHRP	National Cooperative Highway Research Program
NTPEP	National Transportation Product Evaluation Program
OECD	Organisation for Economic Cooperation and Development
PCCP	portland cement concrete pavement
PMS	pavement management system
RWS	Rijkswaterstaat (The Netherlands)
SHRP	Strategic Highway Research Program
SMA	stone-matrix asphalt
TRB	Transportation Research Board
TRL	Transport Research Laboratory (United Kingdom)
WIM	weigh-in-motion

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## EXECUTIVE SUMMARY

The Federal Highway Administration (FHWA) and the American Association of State Highway and Transportation Officials (AASHTO) conducted a study under the International Technology Scanning Program on the topic of superior materials, advanced test methods, and specifications. The study included visits to several European nations. During the visits, representatives of the United Kingdom, Denmark, Germany, and the Netherlands discussed their unique approaches to introducing, approving, and specifying new materials and manufactured products employed in highway construction. Issues discussed ranged from high-level policy issues to specific material evaluation procedures. The visits proved helpful in meeting the overall objectives of the scan, which ultimately will benefit the highway industry in the United States by identifying how processes for introducing new and innovative materials and products might be improved.

### OBJECTIVES

The scan focused on the use of superior materials in the highway infrastructure. For the purpose of this scan, “superior materials” were defined as those materials and manufactured products that do the following:

- Improve performance of the constructed facility significantly.
- Are cost effective from either an initial and/or life-cycle (whole-life) cost perspective.
- Improve safety for the traveling public and/or the construction worker.
- Reduce construction time.

Furthermore, projects on which the superior materials can be employed include the following:

- New construction.
- Reconstruction of existing facilities.
- Rehabilitation, repair, and preservation of existing facilities.

### KEY FINDINGS

#### Process-Related Issues

Over the past several years, most of Europe has seen a migration in process and specification. Many countries are transitioning from methods-based specifications, and are developing and adopting more functional requirements for their construction materials. Functional specifications are similar to end-result specifications used in the United States, but tend to incorporate elements of a performance specification. The objective of a functional specification is to ensure that the end product was constructed to meet the function for which it was intended (e.g., the noise level, smoothness, and safety that the public expects or demands). The use of these specifications and contracting methods has resulted in the introduction of more innovative materials, since a material that meets the specified function is deemed acceptable.

### ***European Union Standardization***

The formation of the European Union (EU) has had a profound impact on most facets of government. By working to eliminate barriers to free trade, the EU has created opportunities for vendors and owners to move toward standardized functional specifications rather than conventional prescriptive specifications. To assist in this effort, the European Committee for Standardization (Comité Européen de Normalisation, or CEN) was established to coordinate and manage the specification standards.

While the CEN standardization process is moving forward, it is not without difficulty. As part of the harmonization process, each member country must debate the details of its previously independent specifications. In addition to the CEN, the European Organisation for Technical Approvals (EOTA) provides a common testing and evaluation forum for products that do not have a standard specification.

Development of the CEN specifications can be contrasted with AASHTO specifications. While AASHTO has produced guide specifications that States may opt to adopt or modify, the EU is in the process of combining current specifications into a common binding specification for use across Europe. It should be noted that within the CEN, quality classifications allow for varying thresholds and tolerances on the material test results.

### ***Contract Mechanisms***

The Europeans used warranties and performance contracts as part of everyday practice. The specific elements of these contracts varied, ranging from short-term (1-to-3 year) materials and workmanship warranties to long-term (more than 30-year) design-build-finance-operate (DBFO) contracts. While these types of contracts were common, levels of comfort associated with them varied. Some agencies appeared more willing to relinquish control because they have seen an obvious increase in quality, while others appeared more cautious in their adoption. The same was sometimes true in a given agency, where one division was more receptive to using warranties, while another was more averse. Another interesting finding was that each of the countries visited employed a performance-based component in its contract award process. This, along with other decision-making criteria, meant that the low bidder on the job was not necessarily the successful bidder.

While an increase in quality often resulted, innovation through the use of superior materials was not always realized merely because of a warranty mechanism. Their use was more common on longer-term warranties in which the contractor had more latitude in the materials and processes it could use. Where superior materials were used, it was found that the specifications were much more performance based. It was also found, however, that some difficulty remains in how to define the performance standard, including what to measure, how to measure it, and when it should be measured.

### *Independent Product Evaluation and Certification*

The scanning team observed a variety of models for product evaluation and certification. While most countries had well-established systems in place, officials stressed that European standardization was changing this with the EOTA process serving as the coordinated organization for considering materials for which no standard exists.

In the United Kingdom, the Highways Agency (HA) uses an innovative process termed the Highway Authorities Product Approval Scheme (HAPAS). Administered under an independent certification agency, the British Board of Agrément (BBA), the HAPAS process involves working with the private sector to establish functional specifications to replace conventional method specifications. Existing performance and quality data for a product classification is gathered from the private sector to assist in functional specification development.

For certification, a vendor presents its existing product data to the BBA. A formal evaluation process is initiated that, if successful, results in a BBA certification that the product meets the quality and performance intent of the specification. In British terms, the product is deemed “fit for purpose.” Trade secrets such as constituents and manufacturing details are not released, but instead sealed by the BBA for use during subsequent quality audits. The HAPAS process appears to be successful, eliminating the need for routine on-site testing and continual surveillance for these material categories. It also provides the vendor with confidentiality as well. Certifications are available to the agency or owner on the Internet.

Other testing and evaluation organizations include the Building Research Establishment (BRE) and Transport Research Laboratory (TRL) of the United Kingdom, Danish Road Institute (DRI), Bundesanstalt für Straßenwesen (BASt) of Germany, and Dienst Weg-en Waterbouwkunde (DWW) and the Information and Technology Centre for Transport and Infrastructure (CROW) of the Netherlands. These organizations are prominent, well respected, and trusted in the highway community. When a vendor desires consideration of a material by an agency or contractor (e.g., on a warranty job), it many times will seek the approval of one of these organizations.

### *Roads to the Future*

In the Netherlands, transportation officials presented a novel approach to exploring long-range solutions for meeting future highway demands. A contest was held in which a number of highway functional requirements were defined, such as noise reduction and paving windows. To meet these demands, contractors were invited to offer solutions, no matter how unconventional. The agency was surprised by the tremendous response. It selected a small number of contractors for further evaluation on a highway test section. The contractors tried four techniques, including options with precast polymer surfaces that were laid down from rolls (like carpeting). This radical experiment resulted in a paradigm shift from the traditionally conservative thinking of the Dutch highway industry. Funding for this effort was equally divided between the agency and the contractors, resulting in

## EXECUTIVE SUMMARY

both shared risk and reward. One of the more notable aspects of this experiment was the timeframe. The idea went from concept to final placement in 2 years.

### Evaluation Techniques

#### *Performance Data*

The scanning team found that the highway community in the European countries, through the use of both accelerated load testing and various forms of field testing, evaluated superior materials for both properties and performance. The national testing laboratories with access to the requisite equipment and facilities, especially for the accelerated testing, commonly used these procedures. Vendors that wished to evaluate the performance of their product before seeking certification or specification sometimes initiated the demand for performance testing. Testing under accelerated loading allowed long-term performance to be assessed in a limited timeframe. In addition, because the conditions were carefully controlled, this eliminated much of the inherent uncertainty of a field trial on an active highway.

#### *Other Test Methods*

The various countries visited used a number of unique test methods for evaluating materials. While many have been used to some degree in the United States, the scan team believes that consideration should be given to a renewed evaluation. These methods include the following:

- Torque bond test
- Stripe wear
- Automated raveling assessment
- Hot-mix asphalt microscopy
- Polymer content evaluation
- Pulse (active) thermography

### Innovative Materials

The European hosts presented a variety of materials to the project team that met their definition of superior. Like the test methods, a number of these materials have been introduced in the United States already, but are listed here to highlight their more widespread use (in some cases) in Europe. The scanning team believes that some of these materials show promise for U.S. use as the pressure to better meet the needs and desires of the traveling public begins to dominate the decisionmaking process. Materials of interest include the following:

- Noise-attenuating pavements, including porous asphalt pavements, twin-layer asphalt, and Helmholtz resonators
- High-friction surfaces
- Waterproofing orthotropic decks

- Low-temperature asphalt mixes
- Semi-flexible asphalt
- Composite pavements
- Fiber-reinforced concrete inlays
- Rapid concrete repairs
- Dynamic road marking

### Other Issues and Considerations

Additional observations include the following:

- Two-course paving
- Noise
- Damage-based taxation
- Video monitoring of weigh-in-motion (WIM) stations
- Thaumaside
- External enclosure of bridges
- Sustainability

## RECOMMENDATIONS

### Roads to the Future

In the Netherlands, a novel approach to exploring long-range solutions for meeting future highway demands impressed the scan team. In a program called “Roads to the Future,” the government integrated long-term perspectives with short-term test projects and demonstrations through a cooperative, split-funded effort with industry. The intent of the program was to examine road surfaces of the future and to develop demonstrable concepts for tomorrow’s road surface. The agency’s other goals were to stimulate out-of-the-box thinking in both the agency and Dutch companies.

### Accelerated Pavement Striping Wheel Testing

Because of the expense and logistics associated with field-testing of lane markings (stripes), Germany has developed a laboratory facility for accelerated lane marking evaluation. This facility is capable of evaluating tape, temporary paint, and permanent paint markings, and hot and cold plastic systems.

### Innovative Product Development and Material Specification Processes

The scan team identified several key processes worthy of additional examination. They include the EU, the British HAPAS program, and the French Charter for Innovation. Each has potential merit for implementation in the United States.

## Functional Maintenance Contracting

The European public roads agencies face many of the same staff and funding cutbacks experienced by State departments of transportation (DOTs) in the United States. In addition, they seek both innovative and cost-effective execution of their maintenance operations. All four countries visited have experience with functional (performance-based) maintenance contracts. The United Kingdom is looking at awarding these contracts solely on quality. The Netherlands is working almost exclusively with these types of contracts and has moved to the second generation of specification. In Denmark, municipalities are beginning to use 10-to-15-year functional contracts for pavement surface renewal and restoration.

## Rational Approach to Pavement Surface Design for Noise Abatement

Materials and pavement engineers need guidance on rational approaches to addressing noise in pavement design, mix design, construction, and maintenance. This and other scans have identified noise generated in the highway environment as a problem of significant concern in Europe that requires innovative and sometimes expensive solutions. While U.S. DOTs have established procedures for designing and installing noise walls, only a few have addressed noise attributed to pavement type, material, construction, and maintenance techniques. Several DOTs are now addressing this problem, using modified pavement surface texturing such as diamond grinding or longitudinal tine texturing, or modified mixes such as crumb rubber, stone-matrix asphalt (SMA), or open-graded asphalt friction courses as noise-attenuating surfaces.

Drivers' expectations and those of abutters to the highways are different in Europe than they are in the United States, but with an increasing number of DOT material and pavement engineers considering noise, a more rational approach to pavement and mix design is needed to address the issue.

## Innovative Products, Specifications, and Test Methods

The scan team identified numerous products, specifications, and tests that the European countries are using or developing that may be of interest to DOT engineers in the United States. For a select number of these, we believe that the logical step is to collect additional European background information. After reviewing this information and comparing it to U.S. practice, researchers can identify potential benefits and develop a plan for possible introduction and evaluation in the United States. Items the team believes show promise include the following:

- Concrete pavement advancements
- U.K. thin surface friction treatments (HAPAS approved)
- External enclosures of bridges
- U.S. demonstration of pre-fabricated, rolled-out, noise-reducing pavement
- Torque bond test

- Automated raveling assessment
- Microscopy
- Wet pressure aging vessel
- Polymer content testing
- Pulse thermography
- Cold-in-place recycling functional specifications
- Danish and German orthotropic bridge deck waterproofing
- Low-temperature asphalt



## CHAPTER ONE

# INTRODUCTION

The Federal Highway Administration (FHWA) and the American Association of State Highway and Transportation Officials (AASHTO) conducted a study under the International Technology Scanning Program on the topic of superior materials, advanced test methods, and specifications. The study included visits to four European nations. During the visits, representatives of the United Kingdom, Denmark, Germany, and the Netherlands discussed their unique approaches to introducing, approving, and specifying processes for new materials and manufactured products employed in highway construction. Issues discussed ranged from high-level policy issues to specific material evaluation procedures. The visits proved helpful in meeting the overall objectives of the scan, which will benefit the highway industry in the United States by identifying how processes for introducing new and innovative materials and products might be improved.

### BACKGROUND

For decades, we in the United States have strived for more efficient and effective ways of approving and specifying new materials and manufactured products within the standard highway construction practices of State departments of transportation (DOTs). Most people in the industry recognize the benefits that can be gained from recent advancements in commonly used materials, including metals, concrete, asphalt, coatings, composites, and semiconductor technology.

While many in the U.S. highway industry desire the use of more superior materials, other industries—including national defense, energy, and to some degree, commercial construction—have adopted them more rapidly. During the scan, the team compared highway materials practices in many European nations to those in the United States. The team found a more rapid and widespread adoption of superior materials in Europe, with a fewer number of obstacles to limit the process. The impact that both the European Union (EU) and use of performance contracting have had on this adoption cannot be overstated.

For the United States to remain competitive, it is necessary to explore not only the use of more superior materials when constructing the highway infrastructure, but also more rapid ways to assess and adopt those materials. As a result, the International Technology Scanning Program, jointly funded by FHWA and AASHTO, initiated this study to be conducted as part of the fiscal year 2003 program.

### SCOPE

The scan focused on the use of superior materials in the highway infrastructure. For the purposes of the scan, “superior materials” were defined as materials and manufactured products that do the following:

- Improve performance of the constructed facility significantly.
- Are cost effective from either an initial and/or life-cycle (whole-life) cost perspective.

## CHAPTER ONE: INTRODUCTION

- Improve safety for the traveling public and/or the construction worker.
- Reduce construction time.

Furthermore, projects on which the superior materials can be employed include the following:

- New construction.
- Reconstruction of existing facilities.
- Rehabilitation, repair, and preservation of existing facilities.

As part of the scan, the team asked the European hosts the following general questions:

- What do you define as a superior material?
- What is the process for approving these for use?
- How do you validate these materials as being superior after they have been in use?
- If proof of long-term performance does not exist for the material, what testing is used in its place?
- How are standard tests developed or adapted for a new material?
- If accepted for use, how is the material routinely tested to assure the required degree of quality?

The team asked specific amplifying questions, listed in Appendix C, of the various international hosts. Although not specifically answered, these questions were used as a guide to draw out the requisite information during dialogue.



### EUROPEAN HOSTS

Before the scan trip, research was conducted to identify countries that had demonstrated materials and processes that, if studied further, may prove useful in improving U.S. practices. The following table identifies the specific locations and organizations the team visited during the study.

Figure 1. The Scan Team in the United Kingdom.

Table 1. Countries visited during scanning study.

Location	Hosts and Participants	Dates
United Kingdom (London, England)	<ul style="list-style-type: none"> <li>• Highways Agency</li> <li>• Halcrow Group Limited</li> </ul>	June 9-10, 2003
United Kingdom (Watford, England)	<ul style="list-style-type: none"> <li>• Building Research Establishment (BRE)</li> </ul>	June 10
United Kingdom (Crowthorne, England)	<ul style="list-style-type: none"> <li>• Transport Research Laboratory (TRL)</li> <li>• British Board of Agrément (BBA)</li> <li>• Tarmac/Anglo Industrial Minerals</li> </ul>	June 11
Denmark (Copenhagen)	<ul style="list-style-type: none"> <li>• Vejteknisk Institut/Danish Road Institute (DRI)</li> <li>• LOTCON</li> <li>• Colas Danmark A/S</li> <li>• COWI</li> </ul>	June 12
Denmark (Herlev)	<ul style="list-style-type: none"> <li>• NCC Roade A/S</li> <li>• DRI</li> </ul>	June 13
Denmark (Roksilde)	<ul style="list-style-type: none"> <li>• DRI</li> </ul>	June 13
Germany (Bergisch Gladbach)	<ul style="list-style-type: none"> <li>• Bundesanstalt für Straßenwesen (BASt)</li> </ul>	June 16-17
The Netherlands (Delft)	<ul style="list-style-type: none"> <li>• Dienst Weg-en Waterbouwkunde (DWW)</li> <li>• Rijkswaterstaat, Ministerie van Verkeer en Waterstaat (Ministry of Transport)</li> <li>• Heijmans</li> <li>• Delft Technical University</li> </ul>	June 19
The Netherlands (Apeldoorn)	<ul style="list-style-type: none"> <li>• Ministry of Transport</li> <li>• Vermeer Infrastructuur BV</li> <li>• CROW</li> </ul>	June 20

## CHAPTER TWO

# GENERAL OBSERVATIONS

This chapter summarizes the presentations that representatives of the European host countries made during the scanning study. The presentations covered a broad range of topics and perspectives. From these presentations and subsequent discussions between the hosts and team members, the team gained further insight on various aspects of the technologies and philosophies covered.

### UNITED KINGDOM

#### Summary

The following summarizes findings from and comments about the presentations in which the scanning team participated in the United Kingdom. Scanning team comments are in italics.

#### *Process-Related Issues*

- Highway Authorities Product Approval Scheme concept
  - The Highway Authorities Product Approval Scheme (HAPAS) is a means to approve and certify products by an impartial agency, the British Board of Agrément (BBA).
  - It reportedly works well when the product has a demonstration warranty.
  - Rapid implementation is a benefit.
  - *Can the Highway Innovative Technology Evaluation Center (HITEC) or a spin-off fill this role?*
  - *How does this program compare to the National Transportation Product Evaluation Program (NTPEP) and other programs? Can we give the U.S. programs more clout?*
  - *Is it possible to combine HITEC, NTPEP, and the Applied Process Engineering Laboratory (APEL) into one body similar to HAPAS? Emphasis could be placed on shifting responsibility to vendors for product development after certification by the new body. A minimum 2-year warranty could be placed on a product, construction system, etc.*
  - *BBA should be involved in implementing this concept to provide information.*
- Performance specifications as an incentive
  - A good example is the Transport Research Laboratory's (TRL) demonstration of its use of cold asphalt recycling, both in situ and ex situ.
- EOTA approval and reciprocity concept
  - The European Organization for Technical Approvals (EOTA) requires agreement among all agencies. Critical to its success is reciprocity of approvals.

- *A similar effort could be considered among the United States, Canada, and Mexico (with possible expansion to Central American and some South American countries). The new organization could set guidelines for product acceptance based on agreement by all participating countries. It could be called the North American Organization for Technical Approval (NAOTA) or North American Technical Organization for Product Approval (NATOPA).*
- *This concept could be further adopted across State boundaries and internationally.*
- Building Research Establishment third-party approval concept
  - *The Building Research Establishment (BRE) model may not be applicable in the United States until several prerequisite elements are in place.*
  - *Considerations must include the relationship with the construction industry and other public-private relationships.*
  - *BRE appears to be the preferred solution for many “higher science” problems.*
- Risk-versus-reward for trying innovations
  - *From the design-build-finance-operate (DBFO) experience, the Highways Agency (HA) learned it needed to get away from fixed-price contracts to achieve innovation. Financiers in fixed-price contracts stifled innovation because of the risks involved, and HA has no incentive to approve a deviation from the standard.*
- Manufacturer process certification
  - *This process requires the manufacturer to certify the contractor for selected products. The product may be excellent, but installation is critical.*
  - *This may be more properly termed “manufacturer certification of installer.”*
  - *It would be difficult to translate this directly to the low-bid concept, and differences need to be identified before the concept could be implemented.*
- Existing research data for product support
  - *A material developer can use research data developed by an approved laboratory or research institution as part of the 2-year evaluation required by HAPAS.*

### **Evaluation Techniques**

- Torque test
- Pulse (active) thermography
- Full-scale destructive testing for model calibration
  - *This involves testing of old structures (bridges) to calibrate and refine bridge modeling and assessment.*

## CHAPTER TWO: GENERAL OBSERVATIONS

- Non-destructive evaluation (NDE) of corrosion

### *Innovative Materials*

- Composite pavements
- NEWPAVE fiber-reinforced concrete inlay
- Thin surface treatments
- Fiber-reinforced polymer strengthening

### *Other Issues and Considerations*

- Sustainability considerations balanced with economics
  - *Lessons can be learned with the increasing use of recycled and reclaimed products based on economics. Specific factors include disposal costs and total energy balance, with economics as the driver.*
  - *BRE discussed whole-life costing as it relates to sustainability. We need to consider all costs. Is trucking fly ash 100 miles an effective environmental solution? We could develop material environmental sheets that look at the cost or investment in a product.*
  - *The concept of sustainability using an “eco-points” rating system and protocol was intriguing. It goes beyond traditional life-cycle cost analysis.*
  - *A previous scan on this topic found that European cost drivers are different. Sustainability falls under a division in U.S. transportation agencies, while in Europe pressure exists to integrate it throughout the agency.*
- Noise considerations
  - *How can we apply negative pavement surface texture and noise considerations to portland cement concrete pavements (PCCP)?*
- Design-build
  - *In European pavement design, contractors appear to have more flexibility in the decisionmaking process. We should gather more information about this and determine if a similar process can be used in the United States.*
  - *The Europeans include both an analytical consideration (e.g., counting a stiffer base when designing the surface thickness) and a procedural consideration (e.g., where the contractor can make the design decisions).*
- Contractor quality as a bid criterion
  - *The performance concept in bid approval and contract awards is one of the major reasons short-term warranties work on long-life products.*
  - *When awarding a contract, the Highways Agency puts 70 to 80 percent weight on quality and performance and 20 to 30 percent on price. The agency’s intent is to move toward awarding 100 percent quality-based contracts.*

- Warranty and other innovative contracting mechanisms
  - They involve coordination of DBFO and maintenance privatization contracts.
- Virgin aggregate tax
  - The tax is used to preserve this resource and fund research and implementation of alternate aggregate sources. It helps small companies with innovative ideas get into the marketplace.

## Highways Agency (London)

### *Introduction*

- Because of the need for reduced whole-life costs and greater durability, the Highways Agency is active in exploring new materials.
- The core business today is asset management, not new construction.
- To be able to maintain minimum control over initial quality, the agency probably will never go to totally performance-based standards.

### *Pavement Materials and Specifications*

- Proprietary materials always have been difficult to specify since they were believed to give an unfair advantage. The agency recognizes that some proprietary products offer benefits, but procurement regulations make it difficult to obtain them.
- British standards normally are broadly written and do not give incentives to newer and better materials, so cheaper materials are usually selected. New standards are developed with industry participation, but are sometimes technically driven by these participants.
- The Highway Authorities Product Approvals Scheme (HAPAS) is used to assess new materials for performance specifications.
  - The goal is to approve the product without necessarily developing a new materials standard.
  - The Highways Technical Advisory Committee was formed in the BBA to conduct testing for highway materials.
  - Several specialist groups have been established to look at specific materials, including high-friction materials (used on approaches to intersections), crack repair systems, thin wearing courses, bituminous binders and modifiers, repair materials for concrete pavements, color retention after weathering and wear, and resin-bound colored surfaces.
  - Before HAPAS was formed, materials were commonly recipe based, but with a number of other vendors identifying equivalent materials, a need arose to evaluate these alternatives.
  - The HAPAS process typically costs \$45,000 to \$60,000 per product.

- Case study 1: high-friction surfacing
  - The original material for high-friction surfacing was used to calibrate the HAPAS test procedures, since the performance of this material was known. Test apparatuses were developed to look at various properties, such as scuffing, wear, bond, skid, texture, adhesion, and freeze-thaw.
  - Sometimes it was not known in advance what values to use in the test procedures. Trial and error was used to refine the tests.
  - When a new product comes along, a 2-year field trial is usually performed. The vendor wants this pre-testing because HAPAS testing is costly and the vendor will not want to do it unless it knows the product is likely to pass.
  - If the new material passes, the specification may change and, in many cases, be significantly reduced in length.
- Case study 2: thin wearing course systems
  - Noise, a big issue in the United Kingdom, has been identified as a priority by politicians.
  - Porous asphalt friction courses were not robust when first used, but eventually a specification was developed. At first, it was considered an expensive and generally high-risk material that did not last long. When the material began to ravel, it deteriorated quickly.
  - A compromise material was sought with both low-noise and durable characteristics. HA approval was provided only after field proof was demonstrated on half a dozen projects.
  - Since the HA was not set up to evaluate these new materials, the BBA was used instead.
  - Since the BBA has begun certification, the use of thin surfacing has increased dramatically.
  - HAPAS certification includes the approved traffic level for each material, and a site classification (difficulty of application).
  - Sixty percent of all English trunk roads are targeted to be quiet. Concrete is no longer used as a surface, but continuously reinforced concrete pavement (CRCP) surfaces for structural support are increasing in popularity. The concrete paving lobby advocates the use of this composite system.
- All British standards for aggregates will be abolished soon, and the European standards will be used instead.
- The HA likes the use of performance specifications. Shorter guarantees are being used, although contractors are not asked to guarantee underlying layers of the roadway. Some contractors have objected to building on poor substrates as a result.
- Case study 3: high-modulus base.

- A hard binder was attempted a number of years ago (15 Pen) with premature failure on three or four out of 20 contracts. As a result, a new test for asphalt durability was developed (pressure aging vessel with water/autoclave testing of hot-mix asphalt cores at 85° C, 2.1 megapascals, for 65 hours, which is believed to equal 8 to 10 years of aging in the presence of moisture).
- Binder is recovered and a master curve developed to compare the impacts of the aging process.
- It appears that the hard bitumens may be produced differently than in other countries, which would explain performance differences.
- The European standard includes national options.
- U.K. officials believe the country may be vulnerable to receiving inferior materials because the national specification will be less strict than other countries' specifications.

#### *Pavement Design and New Materials*

- Recent problems have led to the need for new solutions. The new procurement procedure is less prescriptive and more flexible in allowing contractors to use their own materials.
- For pavement structural design, requests have been made to use designs that lie somewhere between more traditional fully flexible and flexible composite structures. This requires design procedures beyond those traditionally used by the HA.
- An ongoing project with TRL includes identifying foundation classes and new formulae.
- The resulting procedure will allow the contractor to make the surfacing thinner if it uses a better support material.
- This demonstrates that materials are being considered along with other costs in an attempt to find the best solution.

#### *Discussion*

- The HAPAS process has generated more polymer-modified binders, largely as a result of the durability requirements.
- The BBA uses two or three labs for this process, and others can come online if the demand is there.
- The specifications look at key properties in addition to the expected traffic and other, more performance-based factors.
- Independent testing labs do evaluations for warranty work.
- On warranty jobs, the properties are measured only if failure occurs before the end of the warranty period.

## CHAPTER TWO: GENERAL OBSERVATIONS

- Vendors recognize that their reputations are on the line on proprietary materials. If a failure occurs in a trial site, the site often is removed and not reported. It is not until the vendor has success that it seeks HAPAS approval.
- HAPAS is tough on quality control. It takes 6 months to a year for HAPAS certification, depending on the amount of field data submitted.
- Typically, contractors acquire pavement design experience by hiring a consultant from one of about six firms with qualified pavement designers. The HA also hires a consultant to check pavement design. If the design follows HA procedures, approval is nearly automatic. If the design deviates, it may require additional engineering checks before being approved.
- Some bridge products have been suspended from HAPAS certification, but no highway materials.
- Given the movement toward normalization, a European technical approval process will likely replace HAPAS.
- The European standards include many tests and levels for material quality. Countries can choose acceptable levels, and a national application document outlines the qualifications unique to each country.

### *Geotechnical Issues*

- Earthworks, as managed by the HA, includes management of materials, most highly variable. A wide range of materials is available in the United Kingdom, although the climate is more consistent than in the United States.
- In the 1970s and '80s, the specification was largely methods based, an approach believed to be effective for most materials.
- Recently, pressure has been on changing specifications, particularly for more modular materials.
- Questions have been raised about the required level of design (life) required from the material, and what modes of failure and degradation must be resisted.
- Sustainability is another consideration. A typical scenario includes reducing construction vehicle movements, meaning fewer imports and more local materials.
- A scarcity of high-quality materials has led to pressure on using local materials.
- Risk sharing is another consideration, with new forms of contracts shifting responsibility to contractors. Although methods specifications have been low risk, they do not necessarily spur innovation. With new contract types, however, innovation is a consideration.
- Whole-life costing has also put more pressure on ensuring long-lasting materials.
- Newer testing equipment, such as the nuclear testing gauge, has allowed for more rapid assessment of earthwork quality.

- Tradeoffs also are being recognized. For example, the desire for improved ride quality sometimes conflicts with other targets, such as drainage.
- A Web-enabled data management system is used to track design, construction records, and appraisal of the asset condition. It also will be used for risk analysis and maintenance prioritization.
- Widening of the M2 and the Channel Tunnel is an example of innovative work in this area. On the M2, a shortage of material existed for constructing the embankments. The channel tunnel had material, but it did not meet traditional specifications. The specifications were reviewed and meetings were held to discuss how the material would be transported and placed. The material was approved with provisions on its application.

### *Innovation in Structures*

- Composites are commonly used for strengthening structures, such as decks, abutments, and columns. They correct bending deficiencies and, to some degree, shear.
- Bridge strengthening is a new application. To test this application, a trial bridge was retrofitted with various strengthening materials. At the same time, testing was conducted at TRL.
- Testing the success of a strengthening application traditionally has been done with crude methods, such as sounding with a hammer, but interest is growing in exploring more advanced non-destructive evaluation methods.
- Preliminary observations have shown some failures. Some are attributable to poor quality in the manufacture of the composite, rather than an installation failure.
- Glass-reinforced plastic has been used on some lighter structures. The applications are precast and incorporate some recycled materials (rubber used as the wearing course of the deck is made from recycled tires). The cost was higher than more conventional forms of construction.
- TRL has tested composite decks using a wheel-loading machine originally designed for expansion joints.
- For concrete application, recent emphasis has been on durability.
- Self-consolidating concrete has been used, but technical problems have occurred. In one case, the material did not go through the alternate procedure required for materials not covered by the standard specification. In another, a high column (35 to 40 feet) was poured, based on a change order requested by the contractor. Placement occurred quickly, resulting in segregation and other issues. The result was a failure.
- Lightweight and recycled aggregates are also being evaluated.
- A 120-year design life is used for structures, which limits use of poor-quality materials.

## CHAPTER TWO: GENERAL OBSERVATIONS

- Experts are looking for ways to eliminate joints and bearings, which are weak points in structures.
- Catastrophic failures on post-tensioned structures a number of years ago led to a moratorium, which was lifted after further research. The cause of the failures was inadequate grouting.
- A structures management information system is being developed to inventory structures in the highways network.
- The strengthening program is triggered when a given structure is being designed. Knowing the current loading and the design code, engineers can identify a need for strengthening.
- Working with industry is important, especially since HA staff is limited.

### *Superior Materials in Highway Structures*

- The network includes 9,700 bridges and 16,000 structures.
- Assets on the network are valued at about £62 billion (highways and structures).
- External enclosures have been used on some structures to protect them from the elements, adding 10 to 15 percent to the cost.
- Access is provided to the enclosure so the roadway underneath does not need to be closed during inspection and maintenance.
- So far, enclosures have been used only on steel structures. Because of the enclosure, painting the steel is not always needed.
- Some European nations use composites of various steel strengths to make beams smaller.
- Weathering steels also are used for difficult access, but they can cause staining on the structure and adjoining features.
- Whole-life costs are an important consideration, and include a number of inputs. Whole-life costs are used much more often in identifying the optimum techniques to use.
- Standard design for a bridge deck wearing course is 5 inches of hot-mix asphalt (HMA). None of the wearing courses on bridge decks under HA control is concrete. The HA is trying thinner HMA courses, but has yet to achieve good adhesion with the waterproofing membrane.
- Bridge deck waterproofing systems have evolved over time. Some waterproofing solutions have joints, but spray solutions are preferred.
- Chloride ion testing is used to measure and monitor the performance of these techniques. The process involves penetrating the membrane, running the test, and then patching the membrane.

- Many newer projects are design-build, but the HA will run a whole-life cost analysis of the recommended design, comparing it to the original design.

### ***Paint Certification and Quality Assurance***

- Formulas of all paints used must be reviewed by the HA, which guarantees that the formulas will remain confidential.
- The paint formula is compared to the requirements by testing. If approved, it is added to the pre-approved database.
- In addition to the specification sheet, the manufacturer must submit a performance history.
- HA is shifting the certification process to BBA (HAPAS).
- DBFO projects are one source of innovation. The contractor makes a request to use a new material. If the HA agrees, it shifts responsibility for failure the contractor.
- This process is considered more a recipe specification than a method or performance specification system. The BBA waterproofing certification is derived from laboratory testing. The master plan includes the possibility of a performance requirement.
- A mixture of method and performance specifications is now used, but the intent is to move toward performance specifications in the future.
- If a vendor approaches the HA with a new material, first steps typically include technical dialogue, where the burden of proof is on the vendor to show the product is beneficial.
- Moist cure paint systems are used at night.
- Water-based paint systems have not been used.
- Generally, warranties have not been used on paint. Some believe that warranties have little use because if problems arise they are likely to become legal matters.

### ***Procurement Strategy***

- HA procurement strategies include procurement of both maintenance and DBFO contracts.
- Before 1990s, procurements with the agencies were ad hoc, on a county-to-county basis. About 90 agreements were formed. Since then, a formal procurement strategy has been put in place, and the 90 agreements have been consolidated to about 20.
- Many agreements also transitioned from the local authorities to the private sector. The result is more customer-oriented goals, less public impact, and better consideration of costs.

## CHAPTER TWO: GENERAL OBSERVATIONS

- The roles of management and execution of maintenance are being combined under a single entity to improve efficiency.
- The agency is more involved in assessing performance, but leaves operational decisions to the contractor. The agency also looks for improvement in operations over time.
- Contract duration is typically 5 base years plus 2-year options for maintenance contracts. DBFO contracts are typically 30 years plus a 10-year option.
- For capital works, design-build contracts are used. Early contractor involvement is encouraged, including bringing the contractor in at the design stage to identify potential problems.
- To date, nine DBFO contracts have been let for a total of 380 miles at a cost of £700 million (about 5 percent of the network).
- DBFO contracting is nearly a 100 percent risk transfer. An example of the few risks that the agency retains is archaeological finds.
- The DBFO takes responsibility for motor crashes, and the agency is indemnified. Under the Highways Act, the agency is responsible, but it is allowed to shift responsibility to a competent party (such as a DBFO). The only situation in which the agency can be held responsible is if it is found negligent in the selection of the third party (DBFO entity).
- Overall, 96 percent of the work on the network is carried out by the private sector.
- Two new DBFO projects are being let. On these contracts, the DBFO will be penalized if its activities affect traffic flow, although not if roadway demand exceeds capacity.
- The agency has found that by transferring 100 percent of the risk to the DBFO, it is difficult to impose future agency strategies on existing contracts. Some risk, therefore, may be transferred back to the agencies.
- An example is a recent policy shift toward minimizing noise. Existing DBFO contracts were steered toward high durability, with a preference for concrete pavements. The government now wants asphalt surfaces to minimize noise, leading to disagreement on how to achieve noise relief while maintaining durability.

### *Discussion*

- Maintenance includes cyclical activities, such as replacing surfacing and routine repairs. Major improvements to the network would not qualify.
- In old fixed-price contracts, the contractor could recommend additional improvements during construction, such as better skid or noise control, and the agency could decide whether it should be done under that contract.

- The 20 procurement agreements require a minimum of five bidders on each contract. Procurement is made by a notification in the European journal. This includes invitations to bidders from other countries. The French, for example, have several contracts.
- Reducing the number of contracts is not necessarily beneficial because of the reduction in government staff. It is better to take advantage of the economies of scale and strategic partnering.
- Where larger contracts are used, it is common for small companies to be bought out by larger companies. Framework consultants are sometimes used, however, that employ a number of smaller consultants and contractors.
- The new contract types have resulted in introduction of superior materials. The drive for thin surfacing, for example, came from DBFO contractors.
- Contracts usually include network condition requirements, and construction of the facility must follow the construction specifications in place. A high-speed van is used for periodic testing for structural distresses, roughness, and skid.
- Deflectographs also have been used, but TRL research determined that if a minimum level of structure is in place, structural deterioration is not a major consideration, so more emphasis is placed on functional condition. TRL is looking at traffic speed deflection assessment using a fifth-wheel device being developed by the Swedish.
- Under the first DBFO contracts, trunk maintenance guidelines were used, but were found to be largely prescriptive. The new DBFO contracts set benchmarks for specific functional indicators.
- For safety, the indicator is the personal injury crash rate. The number of deaths and seriously injured also may be an indicator. Obtaining this information is difficult, since it is collected by local police authorities and must be synthesized by the HA.
- Self-certified measurement is used for performance assessment, but audit requirements exist. Traffic speed and flow are also operated by the DBFO, but are monitored more closely at regular intervals. The laser vehicle is run periodically by the DBFO contractor
- At the end of the contract, provisions for joint evaluation of the facility provide an opportunity to learn. Also, a residual life assessment requires that pavement not have zero life (requiring immediate repair or replacement). No means for measuring this are specified, though.
- The highway agencies do not have a staff to inspect structures, but longer design life for structures (120 years) is ensured by following the design standards. A technical review process ensures that the design is done properly. The HA employs a consultant to ensure that the detailed procedures are followed.

## CHAPTER TWO: GENERAL OBSERVATIONS

- When designers propose innovations, they are reviewed by the HA's technical staff. Under a recent overhaul of this process, requests are entered into a database. HA uses the database to rationalize future requests for acceptance or denial.
- One problem with the process is that little incentive exists for the agency to accept innovations. Not much credit is given if an innovative design does well.
- Many design departures have been to expedite construction rather than save money.
- If a new material is of interest, the interested party will usually track its performance. If the performance is found to be acceptable, it can be incorporated into a standard.
- DBFO contracts include core components and a number of options. The financiers drive many details since their investment is at risk, and they often are more conservative than the HA.
- A company that brings in a technology approved in another country has a better chance of getting it accepted, but it is not guaranteed. This will become less of an issue when the European codes take effect.
- The approval process continues to be refined. Precedents set by previous departure decisions are used in the decisionmaking process for future products. Follow-up is likely to see if technologies have met their claims.
- DBFO contracts must follow the laws of the United Kingdom, but no local or minority employment requirements are specified.
- In DBFO contracts, many routine activities are set by the contractor rather than specified by the agency.
- In maintenance contracts, the contractor performs safety inspections and defines defects. If it is a serious defect (Category I), it needs to be repaired as soon as possible. A less serious defect (Category II) can be corrected within six months (or longer if the company does a more encompassing repair).
- Courtesy boards are used to identify the DBFO operator.
- The agency performs a network needs assessment to allocate funding. As requests come in from the districts, they are prioritized. Each of three regions is allocated a portion of the budget, which is then distributed within the region. Five criteria are used to assess which project to select: safety, economy, environment, accessibility, and integration.
- About 50 percent of the budget is spent on new construction, but much of it is network widening and other improvements. Little is for new alignments.
- Innovation has vastly improved the condition of the network. It has created a more strategic view, rather than a fragmented approach by local authorities.

- In the past, the agency gave money to local authorities and had little control over how it was spent. This may have led to improper, or at least inefficient, use of the funds.

## Building Research Establishment (Watford)

### Introduction

- The Building Research Establishment (BRE) is a national research consultancy that performs research on building materials.
- Until six years ago, it was wholly a government organization, but after a gradual separation from direct government control it is now private.
- The Foundation for the Built Environment is a non-profit organization owned by the construction industry that oversees BRE activities.
- The BRE now conducts research, consultancy, and testing of the built environment.



Figure 2. Meeting with the Building Research Establishment in the United Kingdom.

- Six years ago, 90 to 95 percent of funding came from the government, but now it is about 50 percent. The remainder comes from industry.
- A sister company, BRE Certification, certifies the quality of products for which no standards exist. It also looks at installation standards. BRE Certification is separate from BRE to maintain objectivity.

### Concrete as a Durable Asset and Superior Material

- By taking a systems approach, an asset can be viewed in stages. For the asset to meet its intended service life, the materials and design processes must be more fully understood.
- Service life assessment uses a stochastic approach rather than a deterministic one, which accounts for known variables.
- The process of enhancing service life begins with the owner's requirements.

## CHAPTER TWO: GENERAL OBSERVATIONS

- Evaluation techniques are developed to meet a need. For example, ground-penetrating radar is a commonly used procedure for identifying voids beneath the road surface.
- Publication of summary documents and technical reports is key to putting results of studies into practice. Results include services such as identifying client needs, evaluating the asset, and developing a plan for renewing and repairing the asset.
- Researchers have used a wide range in the predictions of the various mechanisms. Selecting a probabilistic approach allows for a more rational means to account for the variability in the various predictive models.
- It is difficult to select materials for 120-year design life, since the service life of modern concretes is so short. The best option is to run tests that give some indication of long life.

### *Non-Destructive Evaluation of New Corrosion-Protection Systems*

- A number of repair paths can be used to achieve intended service life.
- Routine maintenance should be conducted at critical times to significantly extend the life with minimal cost.
- Non-destructive testing is a significant benefit when assessing the success of repairs.
- Active thermography uses a radiant pulse to heat a laminated repair. Differential heating occurs on bonded (versus unbonded) areas and can be viewed using infrared video imaging.
- Active thermography has not been used for determining pavement layer delamination because the overlays are too thick.
- To get a product considered for certification, such as lithium for alkali-silica reactivity mitigation, the first step is to approach certification officials. A plan is then developed to collect the information needed to make an acceptance decision.

### *Thaumasite as a Concrete Deterioration Mechanism*

- Thaumasite is a form of sulfate attack that occurs under special conditions, the most critical of which is lower temperatures. Most sulfate tests are performed at warmer temperatures.
- This problem was discovered on M5 as it was being strengthened to accommodate European lorries.
- Much of the sulfate developed as a result of the construction process. Pyritic clay was exposed to the air during construction, and the pyrite oxidized into sulfates.
- Type V cement does not mitigate this problem, but a mixture of 70 percent ground granulated blast furnace slag and 30 percent cement works well.

### **Geotechnics**

- Optimum designs to minimize differential movements (settlements and swelling) are being studied.
- U.K. officials have not used grouting extensively, but they have had great success with it where they have used it, typically in transition zones between highways and embankments.
- Officials are looking at horizontal grouting techniques, such as grouting through directional drilling. A PIARC (World Road Association) partner is also looking where the grout is going using resistivity measurements.
- Cone penetration testing has been used extensively for geotechnical evaluation.
- Reuse of pile foundations in central London is a challenge experts are trying to solve.
- Officials are interested in smart technology using piezoelectric ceramics embedded in concrete for stress levels.
- Polymer replacements are being used for bentonite clay, but questions have arisen about skin friction implications.
- Officials are not looking at lime-sulfate reaction since the soils that contain sulfates are stiff and do not need lime.
- The biggest issues they face involve correcting existing structures rather than preparing new materials.

### **Ferrosilicate Slag and Other Waste Materials as Superior Materials**

- The Waste Resources Action Program is a government-funded program to use more waste materials.
- A lot of ferrosilicate slag is available, and experts are looking for solutions on how to use these waste materials.
- The slag contains trace metals that make it an environmental issue.
- In concrete, leaching of metals is a consideration, as well as delay in the concrete set (delay of up to 6 days has been observed).
- This project was funded by landfill tax credits.

### **Environmental Management of the Highway Infrastructure**

- Many sustainability and environmental performance issues must be balanced with progress. When a material is studied, its environmental and social aspects must be considered.
- Environmental considerations also must be balanced with economic considerations.

## CHAPTER TWO: GENERAL OBSERVATIONS

- Processes such as cement production have unique impacts that can be measured and balanced against each other to determine which materials to employ.
- An addition to the “superior materials” definition could be materials of superior environmental performance. Not only is the material evaluated with these criteria, but also construction techniques and other activities during the life cycle (maintenance and salvage).
- A rational means has been developed to balance several criteria that are difficult to quantify. The “eco-point” process, a weighting process, was developed by surveying a range of individuals, including the public, contractors, environmentalists, and politicians.
- These techniques have been used for a number of civil engineering materials, including steel, concrete, asphalt.
- Officials have been looking at ways to integrate service life and environmental impacts.

### *Discussion*

- The goal in establishing priorities on technologies is to improve competitiveness and sustainability. The staff has the authority to accept or decline work in any particular area.
- Divisions are separate (e.g., geotechnical and concrete), but some crossovers occur.
- Before privatization, the money coming in was not pre-programmed. Now funding must be bid competitively, although some work is still sole-sourced.
- BRE profits go to the non-profit organization that oversees BRE and are commonly reinvested in projects that make the community better.

## **Transport Research Laboratory (Crowthorne)**

### *Introduction*

- At the Transport Research Laboratory (TRL), emphasis on international work, including World Bank projects, has increased
- Concrete roads have taken a back seat recently because of noise issues. A 10-year plan calls for overlaying all concrete roads on the trunk network, starting with the noisiest pavements. Concrete may be used as a long-life layer down in the pavement structure. A recently built private road north of Birmingham has continuously reinforced concrete pavement with a hot-mix asphalt overlay.

### *Managing Infrastructure Assets*

- Once design standards are improved, existing structures need to be assessed to see if they meet the newer specification.
- In the United Kingdom, the rating is based on the strength of the structure.

- Sometimes researchers take a full-size beam from an existing structure for testing, such as beams from structures that failed in the field. They take other specimens from structures made of materials no longer used (e.g., cast iron and precast beams made without shear links).
- The goal of testing is to identify factors most significant to failure.
- Some testing has explored the benefits of fiber-reinforced polymer (FRP) strengthening.

Figure 3. Fiber-reinforced strengthening of structures in the United Kingdom. (Photo source: TRL Limited, UK)



- TRL built two half-scale bridges to test them under design loads, not loads seen in service (which are lower).
- Site tests have been conducted on bridges scheduled for replacement. This type of testing was routine 10 years ago when budgets were larger, but it is now uncommon.
- The Jack Arch Bridge failed at 3.2 times the load predicted by assessment techniques used at the time.
- Proof load testing has not been successful since the options are to extrapolate or load the structure to near failure, causing damage.
- More than half the bridges in the United Kingdom are arch bridges, although HA links do not have as many because the facilities typically are more modern.
- An improved method of assessing arch bridge behavior was developed by tests on models.
- A client has asked TRL to assess a proposed repair method, a strengthening technique that consists of stainless steel reinforcement and pins.
- Another company with a heflex stainless steel reinforcement system found a 60 to 70 percent increase in strength by adding the reinforced repair system.

- Infill decks are common in the United Kingdom. They are designed so that the precast elements carry the load. If loads increase, however, the cast-in-place concrete may begin to carry some of the load as well. Researchers are looking at how the prestressed beam and the fill concrete interact. They are more concerned about shear than bending moments. In shear failure, the precast beam fails in a different mode than the fill concrete.
- The most common use of FRP in the United Kingdom is for strengthening, and a standard guide has been developed.
- The Barnfield Bridge was built without enough reinforcement by today's standard. Application of FRP resulted in 30 percent reduction in stress. A two-person crew spent four days applying FRP, adding a new layer each day.
- For bridge support strengthening, another project was selected, and four consultants were invited to try their systems.
- Officials believe FRP should be compared to more conventional techniques, and that the costs and the benefits of both should be weighed.
- Modular FRP sections have been developed to create decks of a variety of cross sections. Two footbridges in the U.K. have used this commercial system already.
- A heavy-duty system has been developed to carry truck loads. A pultrusion process is used to manufacture the panels. Fatigue testing has been completed. An accelerated wheel-testing device was used to test an FRP box section under repeated loading, and no damage was observed at the end of testing. It took three months to run the test, representing 30 to 40 years of service life. Small deck sections were then tested under alternate kinds of fatigue loading.
- The goal is test procedures and tolerances that can be codified.
- While FRP is more economical for larger structures than small, not many large-scale applications have been done because people want proof first on smaller structures.
- Whole-life costs pick up on the advantages of FRP.
- Strengthening using FRP is more economical than conventional steel plate methods.

### *Materials Developments*

- Although not many concrete roads are being constructed, a few developments have occurred in this area.
- Continuously reinforced concrete pavement (CRCP) with an asphalt surface is considered one of the most economic alternatives from a whole-life cost perspective.
- A large truck is used to drop the longitudinal and transverse bars (in a mat).
- Exposed aggregate concrete is used when the concrete is left exposed to the traffic. The concrete is brushed 24 to 48 hours at 20° C.

- ECOPAVE is a European effort to study a strong, joint-free system.
- NEWPAVE is an inlay treatment of 2 inches of a dual reinforced system using fibers and conventional reinforcement. The original concept was a 1-inch layer with a cocktail of fibers. The NEWPAVE is rolled to develop a distributed microcracking rather than large working cracks.
- Driving forces in the United Kingdom include European harmonization and sustainability.
- New taxes have been enacted to promote sustainability, including landfill taxes (\$20 a ton now, and expected to increase) and taxes for new primary aggregates.
- New performance specifications are also under development for foundation layers.
- Thin surfacing products (less than 40 millimeters) are also being developed. To date, 32 thin surfacing products have been approved.
- These surfaces have negative textures with flat tops on the aggregates that lead to lower noise compared to positive textures.
- Most mechanistic models do not consider the change in material properties over time and depth. Modern thicker HMA pavement does not rut in the underlying layers. Most rutting is in the top layers of the HMA.
- Two methods have been developed to test rutting susceptibility and compared to field rutting measurements.
- In the past, a stronger foundation would not lead to a thinner structure. Newer design procedures must look at the pavement system and the contributions of each of the layers, including the use of various stabilization methods.
- The next generation of design should not include overly exotic testing. Future versions can begin to use more complex tests once they become more proven and cost effective.
- The Prima, a dynamic plate load system with a single geophone, was demonstrated. The cost is about US \$11,000.

#### ***Perspective of BBA/HAPAS***

- BBA assesses the use of products for a given purpose. It does not develop a specification around a material, but instead certifies that the material meets the stated properties.
- Litigation against the BBA is low because of indemnification.
- The BBA will withdrawal certifications on occasion.
- Only a small percentage of BBA certifications are HAPAS certificates.

## CHAPTER TWO: GENERAL OBSERVATIONS

- Agrément was started by the French as a means to assist the insurance industry. Agrément authorities are located throughout Europe, and they work together.
- In France, an organization similar to HAPAS certifies highway products.
- Development of the subject area panels has been easier than expected, particularly with industry cooperation.
- Materials must now comply with CEN standards or have EOTA approval.
- If many similar products have been issued European technical approvals, then a CEN standard is warranted.
- In theory, any material can be certified, as long as it meets the technical specifications.
- It is also important that the material does not change. Auditing of materials is built in to the process, allowing the BBA to suspend or withdraw a certificate if quality decreases. The BBA can perform surprise audits and site inspections.
- Two years of use is required before a material can be certified. If a vendor has well-documented data, it can be accepted in lieu of a two-year trial.
- One advantage of certification to the buyer is that an independent party has evaluated the product and deems it acceptable.
- An advantage to the producer is the ability to look more objective in its promotion of the product.
- A warranty is commonly required on the products during installation as well.

### *Perspective of a Materials Supplier and Contractor (Tarmac/Anglo Industrial Minerals)*

- Tarmac/Anglo Industrial Minerals is one of the biggest mineral operations in the world, but it is important to justify every decision made in the company. Reasons for new materials include changing customer needs, leading-edge technology, cost reduction, and increased use of secondary materials.
- Stone matrix asphalt (SMA) gets its resistance to deformation from binder selection. SMA has resistance through stone-on-stone contact. SMA is commonly preferred because of its lower cost, expedited construction, reduced spray, deformation resistance, and noise reduction. A key disadvantage is the need for large, high-quality aggregates.
- Tarmac uses a proprietary thin surfacing system called Thin-Surfacing Masterpave®. Masterpave is thinner than Masterflex®, which uses polymer-modified asphalt instead of a neat asphalt binder. Material cost of these surfacing materials is higher, but the cost per area is lower because of their thinness.
- The French introduced high-modulus base technologies several years ago. HMA's impermeability, including the high modulus bases and thin surfacing, is

critical. Sometimes permeability is compromised when going to higher-type materials.

- A target has been set for 25 percent of all construction aggregates to come from secondary sources by 2006. This can include non-mineral materials.
- A tax of £1.60 per ton is charged for virgin aggregates. Legislation in the works would encourage use of secondary materials. The government pays for some materials to be used (e.g., glass).
- Tarmac is working with TRL to evaluate the use of steel slag under heavy traffic. The cost of transport limits its use, and the risks are higher because of the material's greater variability. Slag users will need a waste management license, since it is considered a waste product.
- Tarmac acquires secondary materials through its separate recycling business. It has established relationships with local authorities to get waste materials (e.g., concrete curbs), as well as with the steel industry. Blast furnace slag is ground to make a cement replacement, and steel slag is used as an aggregate.

#### *Cold Recycling (The SMART Project)*

- The Sustainable Maintenance of Roads Using Recycling Techniques (SMART) Project follows the Linear Quarry project, which has the objective of reusing all the materials along the project during reconstruction or resurfacing.
- Non-destructive testing devices are used in the field to identify in situ stiffness.

#### *Discussion*

- Freeze-thaw issues are not a major consideration because the climate is mild. A standard frost test exists, and a design consideration is made for no frost-susceptible materials within a certain depth from the surface.
- When a producer develops a new product, the first step for a contractor is to ask for literature and supporting data. The contractor may opt to test the product in-house, but will usually ask for BBA certification instead.
- New materials often are tested on a quarry haul road. Because it involves both heavy and slow loading, it is a good test of the durability of a material under accelerated conditions.
- Testing of a product in the contractor's lab is usually done as a result of an in-house committee. The board makes the final recommendations on what products deserve testing

## **DENMARK**

### **Summary**

The following is a summary of findings from Denmark, including commentary on the observations in italics.

**Process-Related Issues**

- Warranties
  - *Warranties in Denmark do not appear to be as strong an initiative as in the United Kingdom. Varying the lengths of warranties for different activities appears to be working, but there are few contractors (and no “mom-and-pop” contractors) to work with.*
  - A company with an innovative product is likely to have the most success by introducing it with the highway agency. No special testing and documentation is required in this case, but a special agreement is written that includes a warranty on the performance of the pavement.
  - Even with use of a warranty contract, the contractor still has to perform to a minimum specification, and quality assurance activities are still carried out.
  - A 5-year warranty is used on asphalt resurfacing. The specifications require extensive quality control by the contractor, with the test results sent to the agency. The agency occasionally performs random, unannounced testing. The contractor submits its job mix formula.
  - *In the United States, warranties may be misused. Denmark is still doing quality assurance testing on warranties. The focus should be on how warranties may introduce innovation.*
- Maintenance contracts
  - In long-term (15-year) maintenance contracts, performance standards are set by the local municipality, with assistance from a third-party engineering firm or institutions such as the DRI. Performance measurements are performed yearly, or as specified by a third party. This system encourages contractor innovation.
  - As a result of the bidding process, the municipality pays a fixed amount per year. Contractor costs must be greater than municipality payments after two-thirds of the warranty period. Unusual costs are renegotiated as needed.
- Life-cycle cost analysis bidding
  - Bid evaluation is based on the lowest life-cycle cost, with the life defined in the contract.
  - *Denmark is working on life-cycle cost analysis using HDM-4 software. The U.S. Department of Transportation is doing the same, and could possibly coordinate efforts.*
  - *The most economical bid has the lowest annual cost, but evaluation needs to consider the fact that competing contractors may bid different terms.*
- Reevaluation of existing technology

- *Denmark has been looking at older technology that has posed problems. An example is lean concrete bases, on which Sweden plans to conduct full-scale testing.*
- *Instead of dismissing a product with one or two failures, determine why it failed, and reuse it if it shows promise.*
- Importation of proven technology
  - *Denmark uses a new technology model similar to one used in some States in the United States. Technology developed by other countries is often tested before being used in Denmark, enabling the contractor to import highway technology rapidly.*



Figure 4. Replacing hot-mix asphalt in wheel paths in Denmark. (Photo source: Danish Road Institute, Denmark)

- Multi-stage product evaluation process
  - *A process has been developed for product evaluation and acceptance that includes testing on the roadway with risk sharing by the owner, improvements, lab testing, accelerated full-scale testing, field application, and development of a road standard.*
- Real-life test sections
  - *Test sections are used to monitor product performance. Test sections commonly are monitored at a minimum of yearly.*
  - *Follow-up on test sections is not done as well in the United States.*

#### **Evaluation Techniques**

- Microscopy
  - *Thin-section testing might be useful for problem analysis (e.g., adhesion, aggregate degradation, binder intrusion, mineralogy, special filler types, and location of microcracks).*

## CHAPTER TWO: GENERAL OBSERVATIONS

- *We might be doing more work in the United States using computed tomography (CT) scanning.*
- Block samples for accelerated rut testing
  - *The procedure used to get samples directly from the pavement for rut testing is a technology we could use.*
  - *The box used to take in-place samples from the pavement could have useful applications, such as collecting samples for other tests in the laboratory.*
- Calibration of PMS model
  - *A heavy vehicle simulator and test slabs in the field are used to calibrate the pavement management system (PMS) model.*
- Reflectance testing
  - *If reflectance becomes a property of greater interest in the United States, this test could be adopted.*

### **Innovative Materials**

- Resin-modified (semi-flexible) asphalt
  - *A semi-flexible surface such as Densifalt® is an example of a technology that could be more widely used, but construction skill is needed.*
- Long-life wearing courses
  - *Denmark appears to be struggling with a single definition of long-life pavements.*
  - *Highway officials are conducting an economic evaluation of long-life wearing courses, and are part of a working group consisting of representatives from the United States and other countries.*
- Perpetual bridge decks
  - *Perpetual bridge decks for orthotropic decks have overlays designed for 20 to 25 years of service.*
- Bituminous membrane
  - *Bituminous membrane may be able to solve environmental issues, especially in sensitive areas.*
- Porous asphalt for noise
  - *This product has superior noise control, but lacks durability. Recent efforts focus on documenting the noise and spray of existing surfaces.*

### **Other Issues and Considerations**

- Noise

- *Noise is a hot topic.*
- Creating quieter pavements is a cheaper way to mitigate noise than insulating buildings or building noise walls.

### **Danish Road Institute, LOTCON, Colas Danmark A/S, COWI (Copenhagen)**

#### ***Jointless High-Performance Pavements: Semi-Flexible Approach (LOTCON)***

- A semi-flexible jointless system includes a porous asphalt skeleton filled with a cement grout to resist permanent deformation and increase impermeability. It is rut and fuel resistant. A variety of surface treatments can be used to increase friction, such as spreading sand on the surface while it is still wet. The economics is driven largely by the price of concrete, which is high in Denmark.
- Traditionally, it has been difficult to get cement grout to penetrate through the asphalt layer. If voids remain in the HMA, they can create freeze-thaw problems. In the 1980s, an asphalt and concrete team improved the process, increasing permeability of the grout into the asphalt layer. When the team looked at the rheology of the material, it found that without proper viscosity, the grout could not penetrate the porous asphalt skeleton. Densiphalt has an optimized viscosity, which allows for full penetration.
- The Danish International Airport, which had problems with concrete joint maintenance, tried Densiphalt on an apron near a jetway in 1998. This was of interest because the electronic jetway system requires the aircraft and jetway to park in the same spot each time. Underlying the Densiphalt was a thick bituminous layer, however, which led to permanent deformation problems under wheel loading. A forensic evaluation found permanent deformation in both the bituminous base course and the reclaimed crushed concrete base.
- Further optimization of the semi-flexible system came through identification of a better gradation of the semi-flexible wearing course, as well as use of a polymer-modified binder in the underlying bituminous layers. Analysis and design of the semi-flexible system can be done with layers of elastic modeling. The semi-flexible layer needs to be thick enough to minimize high shearing forces that can occur in the underlying binder course. As loads increase, the thickness of the wearing and binder courses must increase, but the base course can decrease.
- Air voids typically are 27 to 28 percent. If the air voids drop below 22 percent, it can create problems in getting the grout to penetrate. If air voids are higher than 32 percent, the system will be too rigid and prone to shrinkage cracks. A continuous high shear mixer is used to mix the grout. Distribution of the grout can be by hand or by tractor. Workers need expertise with the material to avoid trapping air in the matrix.
- The grout is sensitive to drying, and care should be taken that the asphalt is not too hot during grouting. In some applications, the asphalt can be laid down in the morning, and the grouting in the afternoon. The viscosity of the grout is measured with a funnel to ensure consistency.



Figure 5. Demonstration of bituminous membrane application in Denmark. (Photo source: Colas Danmark A/S, Denmark)

- Typical applications include bus lanes and truck standing areas, although it has had limited use for intersections.
- Typical costs depend on the job size (bus lane versus mainline). A life-cycle cost was not done on the Danish airport job, but other issues included environmental considerations at the airfield (no penetration of fuel through the wearing course).
- DRI recently tested the material with an accelerated load facility. A specimen of 1.5 square meters was loaded back and forth with a wheel. The specimen was encased in a steel box, and underlaid with a two-layer rubber support.
- Reinforcement was used on a trial section (steel grid), placed between the first and second lifts within the 160-millimeter Densiphalt. A crack formed on the border of the steel grid, probably because of the difference in behavior between the steel grid reinforced section and the surrounding pavements.
- The contractor provides a 5-year warranty.

***Stabiflex: A Composite Pavement (Colas Danmark A/S)***

- Stabiflex® is a semi-flexible pavement system imported from France.
- The original application method involved vibrating cement grout into pavement. The newer method uses a vibratory roller.
- These surfaces commonly are used for heavy-duty application, including airports, harbors, and other heavy industrial applications (including flooring).
- High-shear mixers are used for grout production.
- When high smoothness is required (e.g., floors), the existing surface can be ground and an epoxy treatment applied.

- This process uses a more thixotropic grout, which requires vibration for penetration.

#### ***Danish Main Road Network Repair Methods***

- Numerous budget cuts in Denmark have led to fewer technical experts at DRI. Technical expertise now comes from consultants.
- Since January 2003, private companies have been allowed to challenge the government with a proposal to do things cheaper. If found to be valid, the contract is awarded to the private sector.
- Like many agencies, DRI has a budget for pavement repair that is too small to meet system demands.
- Eleven repair methods are considered acceptable on the Danish Main Road Network. Different contractors perform different repair methods. Some partnering occurs between the DRI and private maintenance contractors.
- Rutting has been a particular problem.
- One repair technique is HMA replacement in the wheel paths only. When public reaction was sought, it was found that people did not notice the repair.
- Specifications for maintenance activities are largely prescriptive, although some maintenance elements are performance based. Resurfacing contracts, for example, have 5-year warranties.
- Three districts now have maintenance contracts. The DRI selects which facilities will receive maintenance, and what activities will be performed. Contracts cover not only paving, but also other types of maintenance (mowing, etc.).
- Paving contracts have an extensive quality-control program. For quality assurance, the DRI visits select jobs to collect test samples quality control data. A quality control plan that includes a job mix formula is required. On some jobs, additional testing may be required, but rarely does a contractor conduct tests beyond quality control requirements.
- In Denmark, only 2 kilometers of concrete have an exposed concrete surface. An additional 10 to 15 kilometers of concrete pavement lies beneath asphalt, but it will be removed soon. It was constructed jointed without dowels, leading to ride and skid problems.

#### ***Ultra Thin Layer Asphalt Concrete: Novachip Combifalt (Colas Danmark A/S)***

- An ultra thin layer asphalt concrete known as Novachip® Combifalt was developed in France in late 1980s. Denmark began using it in the early 1990s, and since 1995 it has become common. It was introduced on DRI roads in 1998.
- The system consists of a thin asphalt layer placed on a thick binder layer. Different grades are designated by the top-size of the aggregate.

- The purpose of this surface is to seal cracks in the underlying pavement, as well as to improve smoothness and or skid performance. Light-colored, reflective aggregates can be imported from Norway for improved nighttime reflection.
- An integrated paver is used that includes the emulsion applicator. The HMA is placed on a thick layer of emulsion. It can also be placed directly on an old concrete pavement, but only with a prime coat to ensure a good bond. In most of these cases, joints have reflected through the underlying concrete pavement, but surface disintegration has been minimal.
- About 1.5 million square meters of the material is laid in Denmark a year, compared to 2.5 million ton of HMA a year.
- The CEN will not include a European standard for this material, but EOTA is a means to get non-standard products such as this used.
- It is not known if the CEN standards can be modified slightly for climate and other considerations in Denmark. The CEN asphalt standard is not expected to be completed until April 2005.
- The DRI often determines whether a new product is more cost effective than conventional methods. If it is, the DRI can decide that it can be used.
- Extrapolated data is often used to determine the life of a product.
- Risks are taken more often when using new materials.
- For performance warranties, distresses (e.g., rutting) are defined in advance of the contract. Warranties typically are 5 years for rutting and 1 year for smoothness. The DRI performs annual surveys on all roadway sections. The survey used for the pavement management system identifies distresses and other indicators, and contractors in charge of those sections are notified if their section is out of tolerance.
- When a roadway section is found to be out of tolerance, DRI and the contractor will negotiate how best to correct the problem. Roads are expected to last 15 years. If the problem is severe enough to require replacement within 5 years, the agency typically will pay one-third of the cost and the contractor will pay two-thirds.
- The low bid is not necessarily used for bid selection. Instead, life-cycle costing is used, based on prescribed discount rates and maintenance schedules (related to the design specifics).
- Quality and past performance are not considered formally in the bid, but may be considered in the negotiation. In some bids, a weighting factor that accounts for past performance is used.
- Since the agency and contractor share repair costs, they share the risk of trying innovative materials.
- Denmark has few contractors, but they are large.

- The contractor has a bond requirement for warranties, typically 2 percent of the contract amount. The bonding industry has said that 5 years is about as long as it will support.

### *Asphalt Laboratory*

- Asphalt samples are taken from paving projects using core rigs. Bulk samples of the asphalt material are also taken from the asphalt plant.
- An extraction is performed, and the asphalt binder content and gradation are determined. Penetration and softening point tests are run on the extracted binder, while Marshall testing is run on the bulk samples. Density tests are conducted on the cores and air voids are calculated.
- Reflection is also measured on the cores. This is a unique specification in Denmark to ensure that roadway lighting will work as designed. Officials are working on getting the specification designated as a CEN specification. The reflection measure is pass or fail. For a while, equipment was used to measure the reflection of the surface in the field. Lab equipment was later calibrated to replicate the results of the field-testing.
- A typical pavement testing sequence includes the following:
  - Day 1—tests on samples of asphalt material, including binder content, water content, density of aggregate, grading curve, Marshall test, reflection (lightness) of the wearing course, and recovery of binder.
  - Day 2—tests on drill core samples, including height, density, compaction, air voids, and reflection.
  - The agency's test sample results are compared to the road standards. The contractor must take daily bulk and core samples, and the agency's test samples are compared to the contractor's samples.
- Contract sizes are designed as A, B, or C, which dictates the level of testing. Category C requires the most testing, including initial and production control. Categories A and B require less testing and are primarily controls of the process, such as consumption records of tack coat.
- The initial and production control have a schedule of samples that are collected. Initial control typically involves two samples daily, and production control is per lot (typically 500 tons). If more than 1,000 tons are produced in a day, more than two samples are taken.
- Warranty jobs involve specified sanctions. Minimum guarantees are required of the contractor.
- In the United States, it is believed that if the agency tests during a warranty job, it implicitly assumes some of the risk. In Denmark, it has worked to date, but it may be a problem in the future

*OECD Research Project: Economic Evaluation of Long-Life Wearing Courses*

- The Organisation for Economic Cooperation and Development (OECD) is conducting a study of materials and processes that can be used to extend the life of roadway wearing courses to 20 to 40 years. The national road research laboratories of the various member countries are participating, including Denmark.
- Other projects, such as the European Study on Long-Life Pavements, are looking at the base and the pavement structure as a whole.
- Participants in a recent workshop concluded that although many materials are available, logistical challenges remain, including labor demands and equipment. The toxicity of many materials also creates environmental issues. Both the benefits and costs of alternatives need to be evaluated.
- Synthetic binders have been used on Danish bridge decks for some time, but for low-traffic facilities only. They are now being used on facilities carrying heavier traffic.
- Semi-flexible options also are being used on bridge decks.
- All of these options are labor intensive, and the initial cost generally is three to 10 times more expensive than an asphalt-wearing course.
- Whole-life costing on the OECD project is being conducted with U.K. model. In Denmark, the ministry determines the discount rate. For a while, it was set at 7 percent, while it is 3 to 5 percent in the United States.
- A big consideration is the recyclability of the material. Energy consumption from the various options also needs to be considered.
- Both the Forum of European Highway Research Laboratories and the Western European Road Directors are trying to define "long-life pavement." Current thinking is that the definition should include a range of years during which no maintenance is required.
- Common European definitions are difficult to develop because of language barriers and cultural differences.

*Surfacing of Steel Bridge Decks*

- A recent effort included the identification of a 20-to-25-year surfacing for steel bridge decks. It is known that rutting and sliding are key distress types, so a hard and stable surface was sought to minimize this. A friction course is also required to provide adequate friction.
- Since shear stresses can be high, a sound bond was needed between the steel deck and surfacing. The mastic is laid at 240° C, and consists of 18 percent bitumen (85 Pen) and 82 percent limestone (less than 2 millimeters). Any entrapped voids in the mastic would be repaired.

- The binder course must resist rutting and be able to release stresses between the wearing course and the steel deck. Bitumen in mastic asphalt is 7 percent (by weight) and 25 percent limestone filler.
- Samples are taken during construction for quality control tests, including the ring and ball indication, ultimate penetration strength, and density.
- In 1998, after 28 years of service, the surface of the Lillebaelt Bridge was removed and replaced. Before the surface was removed, the mastic layer was investigated to determine if it had enough remaining life to support the new surface course for at least 15 years. Conventional milling equipment was used. Where underlying layers were damaged, a full-depth reconstruction was performed.
- On other bridges, performance has been fair to good. Rutting (in some cases 10 to 20 millimeters) is one distress that has been observed. The agency considers 20 millimeters a safety hazard that warrants corrective action, and 10 millimeters a standard for contractors on warranty jobs.

#### *Use of Low-Strength Lean Concrete to Eliminate Reflective Cracking (COWI)*

- An investigation is underway on the use of low-strength lean concrete to eliminate reflective cracking.
- Lean concrete has been banned in Denmark for almost 20 years because of reflective cracks. PCCP is not used and is not likely to be used in the near future. Use of salt is one reason, but past performance is the primary consideration.
- On some sections of M3 (the circumferential road around Copenhagen), the existing lean concrete base (LCB) has resulted in an extended life of the wearing course.
- In future construction, competition is expected since asphalt and cement are both candidate materials for use in the base course. In preparation for an upcoming bid, modeling and testing of LCB materials will be conducted. An incremental recursive model is used to model deterioration of LCB for decrease of stiffness.
- A new Danish simulation-based design standard will incorporate these new models. An English version of the program may also be published.
- To validate the response of the new material, heavy vehicle simulator testing will be conducted in Sweden (Denmark does not have a testing apparatus).
- This is an example of how a material could be accepted for a project after sufficient data has been collected.

#### *Abatement of Traffic Noise with Special Porous Asphalt (LOTCON)*

- Noise is an increasingly important issue in Denmark. It has been found that the cheapest way to mitigate noise is to alter the pavement type. Porous asphalt concrete is one of the best solutions.

## CHAPTER TWO: GENERAL OBSERVATIONS

- A self-cleaning effect occurs at higher speeds, but at lower speeds (like center city streets), this does not happen.
- A set of test sections was constructed in Copenhagen to try different techniques. The alternatives include designs with binder contents ranging from 3.9 to 6.3 percent, and top sizes ranging from 2 to 5 millimeters to 16 to 22 millimeters.
- Two-layer porous asphalt includes a fine surface and a coarse base mix. A protective membrane is applied to minimize penetration into the underlying layers.
- One problem with most conventional porous asphalt is that fine material migrates into the underlying parts of the layer, clogging it. By having a finer gradation at the top, any trapped fines can be blown out occasionally with water.



Figure 6. Innovative hot-mix asphalt plant in Denmark.

- Care must be taken not to let material collect at the gutter line, or clogging will proceed from the edge of the road toward the centerline. A special edge drain system has been developed to channel water away from the edge into the drains.
- What initiated the need was a policy decision to reduce the noise in apartments along city streets.
- About a 5-decibel (dB) decrease in noise is observed with the new systems in place, but after one year the noise-reducing effect tends to decrease because of partial clogging.
- This technology has been imported from the Dutch. As long as the material is kept clean, it appears to work. It becomes increasingly difficult over time to clean it, however, and almost impossible to do so after 6 years. Maintenance people do not like this pavement type because it is difficult to maintain.

- The next step is to find a longer-life surface that will reduce noise. Easier-to-maintain alternatives may exist, even if they do not reduce noise as much as 5 dB.
- Officials expect that over time, the noise levels of the various methods will be validated. Most are now being modeled.

#### ***Bituminous Membranes in Road Construction (Colas Danmark A/S)***

- Bituminous membranes are being used in road construction for the protection of groundwater facilities.
- The product is manufactured by combining bitumen with various synthetic plastics (geotextiles).
- In the past, the membranes were manufactured in situ by hot-spraying bitumen on top of a plastic mat or grid. This led to a non-uniform product, making some areas susceptible to leakage.
- The membranes are welded in the field by applying heat. The quality of the weld is checked with non-destructive evaluation methods.
- At a site in Ireland, 200,000 square meters of membrane was used to develop a pond protecting the groundwater in case of a spill. It involved 90,000 meters of welding, all quality checked.
- A project is being planned in Denmark that includes fly ash. A membrane is being recommended on the embankment to protect the groundwater.
- In areas where impervious clays are not readily available, membranes are more cost effective.
- In the past 25 years, Europe has used more than 7 million square meters of this product.

#### ***NCC Roade A/S (Herlev)***

##### ***Introduction***

- The NCC Roade A/S asphalt plant started production in 1987 and has produced 2 million tons so far, 120,000 to 130,000 ton per year.
- To keep the dust down, the materials are kept in silos. The silos added DKK 7 million to the cost of the plant.
- Natural gas is used for fuel for the burner, which also is set up for oil. Once dried, the heated materials are screened and placed into 17 insulated silos containing heaters. Nine silos are set up for more complicated mixes.
- More than 200 different HMA recipes are available at the plant. The mix design is changed 50 to 60 times during the day. Many orders are small (less than 500-kilogram loads).
- In some cases, the mixer needs to be cleaned between batches.

- Most of the raw materials are located about an hour's drive away. Eighty percent of the materials are local and 20 percent are from Sweden.
- The hot mix typically is held in the silos for 24 hours. In some cases, it is held less than hour. Open-graded and/or polymer-modified mixtures can be stored only a few hours.
- The plant can serve about a 100-kilometer radius (about 1 hour of haul time).
- The ring and ball (R&B) temperature is in the specifications. The R&B temperature from the binder on the road and the virgin binder is 6° C.
- In addition to manufacturing HMA, NCC has 16 paving crews.
- Cores are used most commonly for thickness and density. The specifications establish how often testing is required, but they normally do more than the minimum.
- Ten to 15 municipalities use material from the facility. Between 300 and 400 kilometers of roads are common in some of these municipalities. The recipe for a job is selected by asking the client what the application is and how it will be applied.

#### *Financing and Building in Municipalities*

- Customers prefer to spend a fixed amount per year, which can be represented as a stair step on cost versus time from 0 to 15 years. The alternative is to spend a lot in year 1, and do maintenance after that. The delta investment from the stair step to the large initial outlay can be a problem.
- Financing roadways using warranties is difficult because bankers believe that if the company goes bankrupt, it will not be able to recover its investment by taking over the facility, as it can with real estate.
- Another risk is premature failure, which could require a major reconstruction or rehabilitation. Rutting, for example, has increased significantly in recent years because of a switch to super single tires. Heavier axle loads also are permitted.
- Understanding how materials perform in the field is critical to proper financing and investment. Innovative materials that demonstrate longer (and predictable) performance are beneficial.
- The DRI certifies the material, establishing a control program to check the performance of the material in place. NCC and the DRI do this in a cooperative manner.
- Other vendors compete against the NCC/DRI maintenance and control package, but the DRI is employed by the Ministry of Transport to help develop standards. If they come up with something new, it will be considered in the investment decision.

- The DRI proposes to come in and assist in evaluating the final product, demonstrating to the municipality that the quality promised is actually delivered.
- In some cases, one asphalt contractor is hired to evaluate the work of another asphalt contractor.

### **Danish Road Institute (Roksilde)**

#### ***Introduction***

- The DRI has been cut from 110 to 67 employees. One third of DRI income comes from consulting, which occasionally creates problems when DRI competes against private firms.
- If a material is developed with public money, the intellectual property is owned by the public. If it is developed for private industry under contract, the rights stay with the sponsoring firm.
- A specification is written on what a material should do, and vendors try to meet that. In many cases, the specification may be based on an existing pavement.

#### ***Microscopy Evaluation of Asphalt Mixtures***

- Thin section and plane section are two methods of microscopy for evaluating asphalt mixtures. This technology was first demonstrated in the United States under the Strategic Highway Research Program (SHRP).
- Samples are prepared under vacuum with an impregnated epoxy resin that contains a fluorescent dye. A plane section is cut from the impregnated material and polished before being examined in an automatic image analysis instrument. A thin section is a cut, ground, and polished section about 30 by 40 millimeters and 20 mm thick.
- Plane sections are used primarily for void content.
- Stripping can be found using thin sections.
- Adhesion between aggregate and binder is readily detectible.
- Also detectable is whether the polymer phase has separated from the binder/filler phase and whether the polymer has migrated to the aggregate boundary or remains disbursed.

#### ***Accelerated Load Testing***

- The Danish facility gave a presentation on rut testing of block samples during the International Society for Asphalt Pavements conference in Copenhagen (see "Selection of Pavement Maintenance by use of Accelerated Load Testing," by Carsten B. Nielsen, Jeanne Rosenberg, and Jørn Raaberg, International Society for Asphalt Pavements, Ninth International Conference on Asphalt Pavements. Volume II Proceedings: ISBN 87-91177-15-4, 2: 3-1).

## CHAPTER TWO: GENERAL OBSERVATIONS

- A linear extrapolation is made from the rut curve generated by the accelerated load testing facility. This allows for prediction of failure without having to load to that level. A typical failure criterion is 15 millimeters.



Figure 7. Block samples for accelerated loading facility testing in Denmark.

- A log-normal distribution is used in risk assessment (number of loads to failure).
- Typical costs for testing of three samples is EUR 10,000 to EUR 15,000.

## GERMANY

### Summary

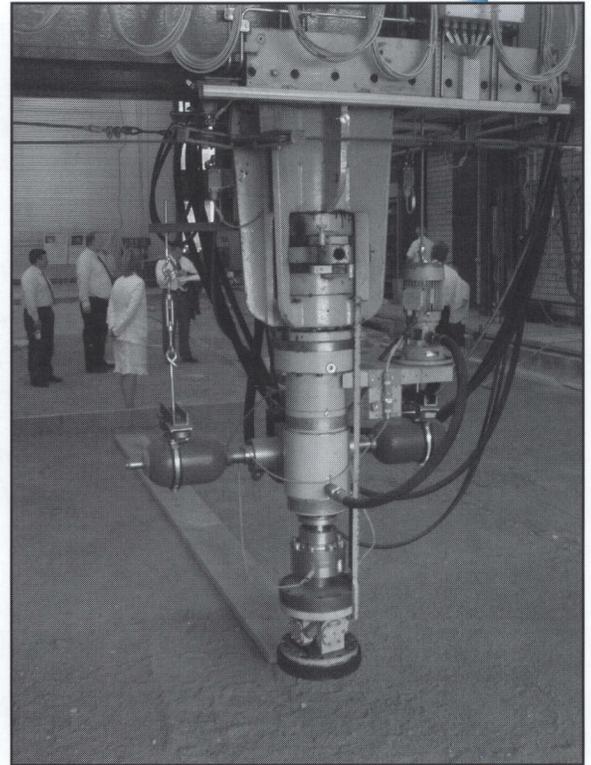
The following is a summary of findings from Germany with commentary on the observations in italics.

### Process-Related Issues

- European Union standardization
  - *EU standardization has had an adverse impact on innovation by complicating and delaying it.*
  - *Even though the EU has opened up the market for new products, Germany does not necessarily plan to use them.*
  - *The EU standards have various levels of specifications that can accept a wider range of materials, but no mechanism exists for member countries to add or subtract test procedures.*
  - *One way around the new standards is to use unique materials with no standards. A good example is reflective sheeting. With no European standard, Germany was able to develop its own standard.*

- *The impact of the EU should be studied in more detail, including how it works and how a similar system could affect business between the United States and bordering nations.*
- *A specification does not force a buyer to buy a product, but it can provide a more consistent product. Knowing that a product has received approval from an authoritative body has value.*

Figure 8. Accelerated loading facility in Germany.



- *NTPEP could be modified to accommodate this concept, perhaps by combining the systems of NTPEP, HITEC, and APEL. A central organization might be able to coordinate with the EOTA.*
- Warranties
  - *The use of 4-year performance warranties is in line with the United Kingdom and Denmark. The difference in Germany is the use of method specifications. The Germans also appear to have little confidence in the long-term performance of warranted work without considerable testing.*
  - *The warranty looked at only at the beginning and the end. Many believe that if a product lasts 4-to-5 years, it is sufficient.*
- FGSV research organization
  - *The Road Transport and Research Association (FGSV) serves as both a research and standard-setting organization, including industry, academia, and government.*
  - *Getting a product used requires going through either FGSV or BAST.*

## CHAPTER TWO: GENERAL OBSERVATIONS

- *FGSV can be considered a cross between ASTM and TRB. Another parallel is the Superpave expert task group system, which employs the expertise from several bodies.*
- User costs
  - *Driving forces for innovation include worker safety, environmental (noise) issues, and quality, but not user costs.*
- Federal-versus-local control
  - *Germany has more federal control than the United States, but locals can buy what they want. While the local entity does not have to follow federal direction, it generally does. Vendors that bypass the federal government probably will not do as well.*
- Equipment innovations
  - *Equipment manufacturers appear to be willing to take risks with new equipment, but it takes time to get a technology in place. Performance specifications should provide the incentive to use more innovative equipment.*
  - *Much innovative equipment comes from overseas. It is possible that innovation will come from a push for an agency need (e.g., ride quality leading to better profilers).*
- Field trials
  - *It is difficult for a vendor to get permission to use an unproven product.*
  - *Denmark appears to willing to try anything, while Germany appears more conservative.*

### Evaluation Techniques

- Stripe wear simulator
  - *The BAST wear simulator for paint and other traffic stripe testing is also known as RPA=Rundlaufprufanlage.*
  - *The way NTPEP does this testing is expensive, although there is a smaller and simpler device good for relative assessments.*
  - *If U.S. manufacturers were pooled, they could help fund a device. Canada also could be involved.*
- Accelerated load facility
  - *Accelerated pavement testing is used to determine relative damage by trucks and to set user fees (taxes) proportionally.*
  - *The use of pulse technology to simulate full-scale accelerated wheel loading should be evaluated for laboratory testing. It should be quicker and cheaper than loaded axles.*

- *Testing could be improved by adding a rolling wheel device.*
- Skid-resistance pendulum
  - *This is an older technology used for measuring skid-resistance values of road-marking materials.*
- Signage evaluation and specification
  - *It seems that private industry could accomplish this.*
- Asphalt design methods
  - *More information is needed on how tire pressure, loading, pavement thickness, etc., affect pavement performance, as well as how saturation of subgrade and temperature fluctuations affect performance.*
  - *This topic was identified in previous scanning studies.*

### **Innovative Materials**

- Geotextile separator
  - *A geotextile separator is used for PCCP over a cement-stabilized base.*
  - *It is used primarily for drainage, but also acts as a cushion. This is different from earlier work with notched portland cement concrete bases.*
  - *This technology might be used between layers of SMA mixtures to prevent closure of the open asphalt.*
- Two-course paving
  - *This two-course paving technology is laid during a single operation.*
  - *The concept is good, but it appears expensive. Also, it may involve logistics issues, especially since two contractors and two plants may need to be involved.*
- Porous asphalt (composites)
  - *This is CRCP with a porous asphalt surface.*
  - *It is becoming popular, in part because they are fighting the catalog.*
- Low-temperature asphalts
  - *The use of low-temperature mixes might be something to evaluate in the United States. Typically, the United States gets European technology many years after it is developed, so perhaps the process could be accelerated for this product.*
- PCCP rapid repairs
  - *Additional information is needed on the mix details for PCCP rapid repairs.*
- Bridge deck surfaces

## CHAPTER TWO: GENERAL OBSERVATIONS

- *Microsilica concrete is most often used as an overlay on concrete bridge decks, but some asphalt decks are used.*
- Sprinkle treatment
  - *For sprinkle treatments to be effective, innovative equipment needs to be available.*
  - *Used in the 1970s and '80s in the United States, the equipment was rented from England and never caught on. Perhaps it could be used for skid and noise applications, now that functional issues have become more important.*

### **Other Issues and Considerations**

- Noise
  - *Germany has a special program with the automotive and pavement industries.*
  - *The United States needs a process to treat noise as a tire/vehicle/type of pavement/bridge expansion device system.*

## **Bundesanstalt für Straßenwesen (Bergisch-Gladbach)**

### **Introduction**

- The organization of Bundesanstalt für Straßenwesen (BASt) includes six departments—administrative, behavior/safety, traffic, automotive, highways, and bridges.
- Presentations focused on road construction. The department has six sections—PMS, geotech/aggregates, PCCP, pavement testing, HMA, and chemistry/lab.
- BASt has 350 staff members, one third of them engineers.
- BASt serves as a scientific advisor to the federal ministry.

### **Overview of German Road Network, Regulations, and Innovation**

- Germany has 16 Laender (states), but they are less independent than in the United States. The network has 626,250 kilometers of roads. The autobahn is 1.8 percent of the network, and federal highways are 6.6 percent. These two categories constitute the federal trunk roads. Property and financial obligations for rural federal roads lie with the federal government. Cross-town links are under federal control if the population is less than 80,000, and under local control if greater.
- Seventy percent of the autobahn is constructed with asphalt and 30 percent with concrete.
- Germany spent EUR5 185 billion spent on federal trunk roads in 2002. The maintenance and resurfacing budget is about the same as the new construction and widening budget.
- Germany spent EUR 59 million on research and development and publications.

- The Road Transport and Research Association (FGSV) has 2,100 members from the administration, industry, and science. FGSV sets standards and guidelines, among other things. It has 10 research council coordinating commissions, nine group councils, 81 committees, and 145 task groups.
- Contract documents are modeled after the German Building Contract Code (VOB), which is used for all types of construction (not just roads). VOB/A is related to the award of contracts, VOB/B is for the execution of contracts, and VOB/C is related to technical conditions of contracts.
- In addition to the contract, there are guidelines, technical bulletins, information sheets, and recommendations. These regulations are mandatory for the federal trunk roads, and strongly recommended for other roads.
- Levels of investigations on public roads include three stages:
  - Trial—with a systematic variation of materials and a lot of testing. It involves one site and offers no guarantee of success.
  - Testing—further development of material successful at the trial stage. It is performed on other roads under a wider range of conditions.
  - Survey—long-term performance testing with fewer measurements. The road is built according to the technical regulations with normal risk
- An example of the process, which can be lengthy, is the development of porous asphalt. The material was introduced in 1975, and information was collected on drainage asphalt constructed on single sites. From 1986 to 1993, BAST conducted a testing program. In 1991, an information sheet was published. From 1994 to 1998, the asphalt was applied on new construction. In 1998, a revised information search was published. It is likely that in 2005, porous asphalt will be incorporated into the technical supply terms.

### *Discussion*

- If private industry wants to bypass the three levels of the investigation process when it introduces a product, it first must show test results, preferably on a situation with a lot of traffic (trucks). In general, it is permission to get permission to use products on the public roads.
- Use of a product must be widespread, not just in one or two countries, before a European standard can be adopted.
- When introducing a new product, sometimes the BAST is approached and sometimes the FGSV is asked.
- Sometimes the government will allow a contractor to use a newer product, but will assign the risk to the contractor. A normal contract has a 4-year warranty on items that will be maintained. After that, the risk is with the administration. The 4-year term can be lengthened to 6 years or shortened.
- EOTA provides special approval for a product that does not have a standard, while CEN provides standards. EOTA can categorize a group of products.

Germany has the authority to determine whether a product approved by EOTA can be used.

### *Innovations in Concrete Pavements*

- Meeting participants discussed the use of geotextiles, renewal of slabs using high-performance concrete (HPC), skid-resistant and low-noise surfaces, and CRCP with an HMA surface (composite pavements).
- Water often causes failures in concrete pavements. In the past, dense base courses acted as water dams. Water percolated up through the longitudinal shoulder joint, causing pumping. The resulting loss of support led to cracking.
- To counter this, longitudinal edge drains covered with a geotextile are now used. In some cases, geotextile is laid beneath the entire construction.
- Not only does geotextile minimize pumping, but it also creates a distinctive bond breaker. It creates a bedding function that evens support and provides a cushion for traffic forces.
- A textile is laid down by unrolling it in a longitudinal direction and fixing it with studs.
- After the textile is applied, construction traffic and slipform pavers can drive on it.
- After 11 years, the maximum deflection of slabs with the geotextile is much less than slabs without it (constructed on lean concrete).
- Concrete repair can be done with a quick-hardening HPC manufactured with a premixed sand and cement mixture. Water is added on site. Twenty MPa is achieved after 4 hours, and 50 MPa after one day. This strength gain allows for early trafficking. Most work is done at night.
- After saw cuts are made on the cracked panel, it is removed by crane. Tie bars and dowel bars are drilled and inserted. Mixing is done in a small portable mixer, where water is added to the dry materials. A small vibrating screed is used for finishing. The roadway can be opened to traffic in 5 or 6 hours.
- A 16-cubic-meter mixer has been developed that can be placed on the back of an 18-wheel flatbed rig.
- Because of the vibrating and finishing process, the upper zones of a concrete pavement include fines at the top (mostly paste) underlaid by fines and sand, and underlaid again by fines, sand, and coarse.
- Texturing is at the surface, but is eroded under traffic. The question is whether enough sand will be there to provide good skid resistance. Over time, the coarse aggregate will begin to play a part in the skid. Both microtexture and macrotexture are needed for good skid resistance at higher speeds.
- A favorable texture depth is 0.4 to 0.8 millimeters, or a porous layer should be used. For concrete, sharp and cubic aggregates should be used. If no

microtexture is used, surfaces will be slippery. Polish-resistant aggregates should also be used.

- Transverse structuring with a hard broom (steel broom) traditionally was used to introduce texture. Since 1987, longitudinal structuring with burlap has been used to reduce noise. The surface mortar (fines and sand) is not as stable as before, so longitudinal tining, hard brooming, or turf drag is used to compensate.
- Exposed aggregates also have been used in experiments, as well as open porous concrete, placed with an asphalt finisher.
- A current initiative calls for quiet traffic and reduced noise. Fifty partners formed a working group called Quiet Road Traffic to study reducing noise in all transportation modes. The group also is looking at the effects of noise on people. This effort is a result of an increase in traffic noise in the past 20 years of an average of 2.5 dB(A) (decibels using an A-weighted scale).
- Porous concrete was researched to reduce noise. The life was low until recently, with the introduction of newer admixtures. On B56 near Ansicht, a porous concrete overlay was used.
- If porous concrete is used on top of normal concrete with joints, the joints fail quickly (within 3 years).
- Open porous asphalt has a lower noise than other options, but it also has lower skid resistance. Additives used in making the porous concrete make it slippery.
- CRCP is good because it does not have joints and can be overlaid with nearly any material.
- CRCP with a mastic asphalt surface (wearing) course is an alternative. It provides the bearing capacity of CRCP with a renewable surface.
- It also may be possible to use porous concrete as the wearing course, providing longer life.
- On plain jointed concrete, dowel bars are coated with epoxy.
- SMA overlays of jointed concrete pavements have been a problem because of joint movement. In addition, water can migrate through the SMA into the joints.
- Polypropylene geotextile is the most common type. A European standard will be adopted for it. The specification calls for clean polypropylene, because if it contains polyethylene it is not alkali resistant.
- The geotextile is only used on lean concrete bases. It cannot be used on other bases, especially unbound, since it cannot be fixed to the base.

### ***Innovations in Asphalt Pavements***

- The stress distribution in the layered system should drive the properties of the layers.

## CHAPTER TWO: GENERAL OBSERVATIONS

- Thin layers are difficult to place because of rapid cooling and lack of compaction.
- A compact asphalt system is being used in which two layers of asphalt are laid one right after the other. This allows the system to remain warm longer, improving compaction. It also ensures a better bond. This approach has other technical and economical benefits.
- A unique feeder system was developed with material transported by conveyors. Material for the second paver is moved over the first paver. At least two mixing plants are required for projects employing this process. Six-hundred tons of asphalt per hour must be produced to keep the operation running continuously. Many trucks are needed, further increasing the logistic issues.
- The upper and lower layers in the compact asphalt system have unique mix requirements. Rolling three or four passes without vibration is typical for breakdown. Evenness (smoothness) cannot be as easily compensated, since the system has one less layer to help correct ride issues.
- When one of the two pavers breaks down, it can cause problems. Layer thickness can be difficult to determine, since the boundary is not as clear. Also, dropping the material from a conveyor belt can cause segregation.
- The next step is to develop a single paver that can place the two materials at the same time. So far, no jobs have had permanent deformation issues.
- A second innovation is porous asphalt in two layers (twin-layer), which was developed in the Netherlands.
- It came about to solve a problem with clogging of open pores in the system, which caused a noise-reduction loss. The solution is to combine a filter and drainage system with two layers. To date, this concept is at the trial level, with only one section in place.
- The top of the system is a porous asphalt 5/8, and the bottom is porous asphalt 11/16. The top is 3 centimeters, and the bottom is 5 centimeters. This is placed on top of the old binder course. The binder layer is first coated with an emulsion to minimize water infiltration.
- On the trial application, chippings from the first porous asphalt layer stuck to the roller. Voids found when coring the porous asphalt system ranged from 21 to 27 percent.
- A noise reduction of 8 dB(A) was found when applying this technique.
- A similar reduction is found with a single layer of porous asphalt. The porous asphalt clogs at low speeds, however, reducing the benefit. On higher-speed roadways, traffic can self-clean these pavements.
- A new system has been developed for the asphalt hopper to protect it from cooling down.

- A technique recently implemented employs a collection system to divert the fumes from the hot HMA away from the paving operator.
- An electronic monitoring system is fixed to the paver that monitors thickness before and after placement. This allows for better construction joints.

Figure 9. Geofoam application in Germany.  
(Photo Source: BASt, Germany)



- In the past, skid resistance had a loose specification, but it is now specified quantitatively.
- One way this is achieved is by applying a loose set of chippings rolled into the hot-mix asphalt. These chips are selected for quality and pre-coated with asphalt before being dropped on the fresh mat.
- Prediction of skid resistance is tested during the design process with a machine using a triple-cone apparatus to simulate traffic.
- Most asphalt paving is done during the day. Nighttime paving results in lower quality because of visibility, and the labor force willing to work at night is limited. It is common to have two crews working on paving operations, one from early morning to noon, and another from noon to early evening.
- It may take 10 years to bring the two-lift and porous systems online.
- Normal SMA surfaces have been found to last about 14 years.

#### **Low-Temperature Asphalt Mixes**

- When considering a reduction in carbon dioxide, production of modifiers is an issue.
- The most important benefit is reduction of fumes and aerosols, improving occupational safety. This is regulated in Germany to 10 milligrams per 1,000 liters.

- Low-temperature asphalt mixes are one solution. They also have better compaction.
- Modifiers are used that should have a decreasing viscosity above 100° C. Fischer-Tropsch paraffins are most commonly used, but they produce a lot of carbon dioxide. Montan waxes are also used, as well as fatty acid amides and zeolites. Zeolites provide a smoothing effect on asphalt mixtures during mixing and construction. They have a slow release of stored water at higher temperatures.
- Three products were studied and compared to a 30/45 bitumen. Chemical characterization was performed using chromatography and infrared testing. Mechanical tests (e.g., bending beam rheometer, or BBR) were also run, along with wheel track behavioral tests.
- The temperature sensitivity of stiffness is increased using the modifier. The BBR test showed decreased bending with all of the binder modifiers. Ductility was significantly different, also. A correlation exists between the molecular weight of the modifier and the rutting susceptibility.
- These techniques may be useful in estimating the quality of new products.
- Not enough experience has been gained with these modifiers yet to test durability in the field.
- Conventional laydown does not violate the occupational safety standard for exposure to gases, but if gases can be reduced the standard may be tightened.

#### *Development of Geofam Construction Methods*

- Geofam is used as frost protection and is technically successful, but it is more expensive than granular materials.
- Geofam showed promise in 1972 as a lightweight fill material. Geofam was used on a full-scale model road at BAST.
- In 1995, an information sheet was published on the use of expanded poly-styrol (EPS) rigid foam for road embankments.
- Permanent deformations were measured periodically on the full-scale test facility at BAST. Sections at BAST included placement of concrete, gravel, and stabilized subbase directly on top of EPS. Class 3 and 5 construction was used (according to the German guidelines). Permanent deformations after 1 million passes were recorded. They included 1.74 millimeters (concrete), 3.2 millimeters (stabilized subbase), and 26.8 millimeters (gravel subbase after only 400,000 passes since cracking had developed). Reference pavement of 220-millimeter asphalt, class III, was used to compare the test sections.
- For the field project, location of the EPS was varied for different sections.
- When looking at the surcharge versus deformation curves, the design is established for a deformation of less than 1.5 percent.

- The first application of EPS was in 1995 on A31 near Emden. The native soil was 7.5-meter clay (with peat) with a bearing strength of 10 kilonewtons (kN) per square meter. The original design had a long structure, but because of economics, the structure was significantly shortened and a surcharge method for construction on the embankment was proposed.
- It was important to place the EPS blocks on top of the abutment foundation. Five-hundred cubic meters of EPS blocks were placed.
- A slight depression has formed above the EPS on one end, but the other end (with no EPS) has a significant depression (up to 11 centimeters).
- EPS has been used in the United States, but solvents are a concern. Germany had similar concerns in applying a plastic sheet over the EPS to protect against solvents. On the other hand, this does not fall into the general strategy of containment. Probabilities are used to determine if an additional protection method is necessary.

### *Discussion*

- A presentation described the relationships between the EU, CEN, and EOTA.
- EOTA has several subgroups, including one to consider single products and another for several products of the same classification.
- The German process is not rapid. Several steps must be accomplished before a product is used routinely. A manufacturer might be more successful going to local authorities, but a manufacturer wishing to introduce a product on the national system must approach either BAST or FGSV.
- The highway authority can specify a proprietary product on a test road, but it cannot routinely specify a product by name.
- When a process is desired, a number of alternative methods are defined. This allows for some competition to be established.
- Recommendations for a material are described broadly, so the specifics (trade secrets) of a material do not need to be revealed. It only must meet the specifications.
- The durability of a material must be established before it is adopted. Materials that appeared beneficial at first fell far short of anticipated durability. Industry is beginning to regulate itself to advance technologies with greater durability. To cut costs, however, some elements of processes are made cheaper, which results in lower durability.
- The warranty period is set at 4 years by default, but this can be negotiated.
- Contractor selection has changed over the past few years. In the past, a specific recommendation for a material was needed. More recently, performance specifications have been used. This appears to be the trend for the future, partly because of a decrease in staff overseeing projects.

## CHAPTER TWO: GENERAL OBSERVATIONS

- Recently, contracts have been developed for much longer durations, such as 20 years, with payments based on the actual pavement performance compared to a target.
- The thickness design is based on a catalog concept, but the catalog does not cover newer materials. In the future, Germany plans to move away from the design catalog concept and use analytical techniques instead.
- Germany has a restriction on using whole-life costing because of annual budget limitations. This is one reason innovative materials are not used more often.



Figure 10. Signs reflecting daytime lighting at reflectivity lab in Germany.

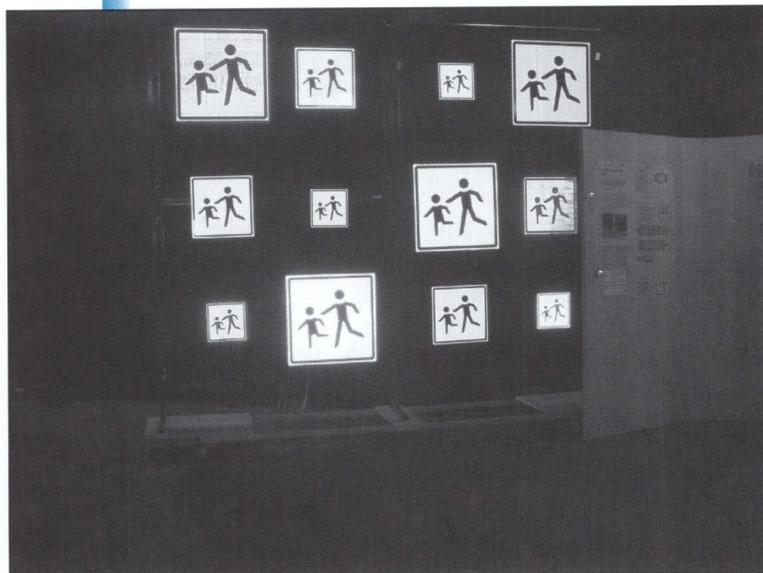


Figure 11. Signs reflecting nighttime lighting at reflectivity lab.

- Ninety-five percent of the technology used since reunification came from the west, and five percent from the east. The reason was the substandard quality of materials in the east, although some experience was gained in using these substandard materials.

- The western regulations were adopted throughout Germany after reunification.
- High-speed construction is a big initiative in the United States, but it does not appear to be a major concern in Germany.
- AASHTO standards are commonly used in the United States because they are developed by highway agency representatives. ASTM is used to a lesser extent, primarily because it is driven by industry. Selecting test methods from the European standardization will be difficult, since the number of tests to choose from likely will be fewer.
- Issues such as quality control plans for thin surfacing are fixed in the regulations, including the degree of control. For the production of HMA, frequencies are fixed and laboratories must be accredited.
- In recent years, the use of more rubber in HMA has been recommended, but it has been a difficult variable to control.
- Quality assurance systems are not required to be in accordance with the International Organization for Standardization (ISO), but tighter control may come soon as a result of the European standardization.
- There is not much participation in the International Union of Laboratories and Experts in Construction Materials, Systems, and Structures (RILEM). Part of it is the lack of road construction materials in the program.
- During the asphalt warranty period, measurements are done only at the beginning and at the end, but they can go out in the interim. After the warranty period, the road is evaluated very three years.
- The pavement management system is used only for prioritization requirements. One exception is skid resistance, which will trigger more immediate fixes.
- Germany uses its own smoothness metric, not the international roughness index (IRI).
- Materials such as rubber are used only under a mandate, although at one time there was a financial incentive.
- Roads are divided into seven classes. In the specifications, a wide range of standards exists depending on the classification. The specifications are cascading, so that a higher classification of road uses additional specifications.
- The road research organization provides some funding for universities, and BAST is the oversight for these monies.
- Each program is prioritized, based on the level of funding available versus the relative needs of each program.

### ***Innovations in Highway Equipment***

- The Road Equipment Section is located under the Traffic Engineering department.

- Anything installed in the road has material requiring approval before installation.

### *Innovations in Traffic Signs*

- Traffic signs are driven by the public's need, and not materials.
- The geometrics of the driver and the sign and the headlight range are known. Signs can be designed based on these known parameters.
- Retroreflection relates the incoming and outgoing light, which also depends on the direction.
- The luminance factor is a summation of this effect in all directions.
- DIN EN are European standards as well as German. RABT is a special national regulation for tunnels.
- When a new material is introduced, it must achieve the minimum standard.
- New performance requirements may result if newer materials are used.
- Light-emitting diode (LED) technologies will be demonstrated in the laboratory. Some problems have been associated with them, including "phantom" effects.

### *Innovations in Road Restraint Systems*

- The national guidelines include a catalog for selection of approved material for road restraint systems.
- The process of accepting a new material can be lengthy. The material must pass several expert panels. Requirements for design under development are clearly defined.
- National guidelines will continue to be used in the future, but they no longer will include a catalog. Instead, the restraint system will be rated on performance.
- To show that a material meets performance, it must be tested at an approved location (such as BAST). The new specification, EN 1317 (European), defines the process.
- In this case, the material must be subjected to an impact test to specify the material. Proof of conformity is also required during production.
- The standard is not yet complete, although parts have already been published and are in use. Because a performance test is being used, the possibility of using new materials is greater.

### *Discussion*

- Traditionally, Germany has used steel because it is cheaper, but maintenance causes problems. At this point, quick barrier is not used in Germany.

- EU member countries are not allowed to add testing to a standard. Once the European standard is set, a country may only specify the material using that standard. Exceptions are allowed only under special circumstances. If the country decides to add a test anyway, policy repercussions may be imposed.
- In some cases, restraint systems are license free, which means anyone can install, fix, or maintain them. For proprietary systems, only the vendor can install, fix, or maintain them.
- A typical sign is expected to last 8 to 15 years, but some last as few as 5 years.
- On construction projects, signs are installed sometimes by the general contractor and sometimes by a specialty firm.
- A guarantee in construction is commonly used, but the CEN standard does not require a specific time period.
- It took 2 to 3 years to come up with a standard for microprismatic signs. The manufacturer provided materials used in the final specification.
- An EU directive (via CEN) for construction materials includes a list that must be specified according to the European standards. For these materials, member countries cannot maintain their own specification in lieu of the CEN specification.
- Various classes of material have been established in the CEN specification. Normally, they involve the same test procedure with different limits (minimums and maximums).

### **Road Marking Tests**

- Minimum requirements for road marking have been identified through research.
- White stripes need to be visible in all weather, and illuminated by headlights.
- Marking systems include both marking materials and additives.
- The Ministry of Transport first defined road marking in Germany in 1957. In 1969, the first testing of road markings was performed using test vehicles. In the 1970s, more significant testing of marking was conducted. German highways have more than 500 test marks to date.
- It is becoming more difficult to find suitable test fields. In some cases, test fields have led to confusion, and in the worst case, crashes.
- BASt developed a wear simulator to replace the need for field testing, but it was not ready until 1988.
- The wear simulator allows results to be shown in 2 percent of the time field experiments require. The results are reproducible and traffic is not interrupted. Some test fields yield different results, however, because of differences in the test surfaces, environment, and traffic types.

- EN 13197 is the standard based on the experience of the wear simulator. The wear simulator at BAST is a turntable format. The diameter is 6.4 meters. It is located in an air-conditioned room and has room for 72 test specimens.
- The wheel slip angle was 1.5°, but is now 1.0°. The velocity is 60 kilometers per hour, and four wheels are used. Heating is generated during the test, and the wheel loads are 3 kN. The test temperature is 5 to 10° C.
- Periodically, the samples are taken off the disc for testing of reflectivity, etc.
- Over time, various components of the test system have been updated.
- Rollovers on a stripe were evaluated to determine the wheel slip angle that should be used in the testing (side force).
- Regulation for road markings is different for permanent and temporary striping. Some classes in the EN specification are not used.
- A fingerprint is identified for the various markers for the chemistry.
- The most important standards are the reflectivity of the materials, which are different for permanent and temporary markings, and under different roadway conditions. A special test apparatus evaluates the reflectivity of the markings under both daytime and nighttime conditions.
- Skid resistance is also evaluated using a skid resistance tester pendulum device.
- More automated measures will continue to be implemented. A second wear simulator is manufactured in Spain.
- In the future, considerations will be made for a wider range of climatic conditions, both temperature and moisture.
- No current marking systems resist snowplow damage, although some are better than others.
- Skid resistance of the marking is second only to nighttime reflectivity, limiting some options.
- Markings are of two types: Type I is normal, while Type II guarantees visibility under nighttime and wet conditions.
- The marking system is selected on the surface type (concrete or asphalt).
- White tapes are guaranteed to last 4 years. Only one company produces them, and they are expensive. Other stripes last two years, while paint lasts one year.

#### ***Waterproofing of Steel Bridge Decks***

- Orthotropic slabs on bridge decks are flexible structures. When a wheel passes over the slab, the asphalt will deflect 1.5 millimeters between the longitudinal supports. The surface treatment needs to be flexible enough to accommodate this.

- Longitudinal cracks will occur if the softness is not sufficient. If it is too soft, rutting will occur.
- Three types of pavements are used on steel bridges. The first is reactive resin, which consists of a resin primer, topped by a resin-sealing layer with chipping, covered by a bituminous buffer layer. A protective layer and wearing course are then applied for a total pavement structure of 80 millimeters. The second type has a waterproofing layer of bitumen. The third type has a resin primer with a bituminous sheet on top.
- The reactive resin primer offers good protection, but is sensitive to climate and is most expensive. The second type (with the bituminous sheet) is robust and is cheapest, but it does not offer as much corrosion protection. The third type number is also susceptible to weather, since it includes resin.
- Initially, when reactive resin was used, no sprinkle treatment was used. As a result, the shear resistance between the waterproofing layer and the protective layer was insufficient, leading to shoving (noted in the distortion of the markings). A gap at the edge of the pavement also opened up, since the hot mix slid sideways on top of the resin. On the other side, the gap was squeezed.
- To improve testing of the waterproof system, temperature testing is now performed. A specimen is stored at a 50-degree angle at 60° C for 100 hours. The pavement must not slip more than 0.5 millimeter. Resin will meet this demand only if it is sprinkle treated, but sometimes sprinkle treatment is not sufficient to achieve bond.
- Excess bitumen is sometimes needed, which causes the surface to become uneven and wavy. Creep in the waterproofing layer can occur in the asphalt. During the creep process, the aggregates grind grooves into the waterproofing layer. The remedy is the buffer layer. Cracks on the pavement also will occur on the surface between the longitudinal stiffeners at lower temperatures. Materials are needed that remain soft at cold temperatures and stiff at high temperatures.
- The result is a drive toward polymer-modified bitumen. Penetration is used at higher temperatures and the Fraass Brittle point is used for low temperatures. On steel bridges, polymer-modified mixtures (mastic asphalt) typically are used.
- SMA or concrete is also possible for surfaces, but investigations have showed that SMA and bitumen-concrete combinations are insufficient, especially near edges. Insufficient compaction in the SMA leads to percolation of water at various spots (seen by staining in the asphalt).
- Concrete bridge decks are the most commonly used in Germany. They are commonly covered with asphalt. Only rarely is a concrete riding surface provided.
- A vapor pressure relief system is provided under the deck. A glass fabric, for example, is used to allow the humidity of the concrete to be absorbed. This

avoids the formation of bumps. In 1985, this technique was specified. If a crack occurred and water infiltrated, it would end up in the membrane, reducing the damage. If the water contains chlorides from salts, it would be trapped and corrode the concrete (steel reinforcement). Corrosion could not be seen, and was only noted when a destructive failure occurred.

- The concrete is covered with bitumen as a welding layer, and a bitumen sheet is added. This is beneficial, but bubbles can form. As a remedy, epoxy resin is used as a primer with all permissible types of construction. The concrete surface must be prepared by shotblasting. High-pressure water can also be used, but the concrete must dry before the epoxy is applied.
- Epoxy resin is flooded onto the surface to fill cracks and gaps. After 5 to 10 minutes, excess material is removed. Fire-dried quartz sand is applied as a sprinkle treatment. It is possible to shorten the process by combining the quartz sand with the resin at a ratio of 1 to 3 or 1 to 4, producing mortar. A smooth trowel is used to even out the surface of the resin mortar. The temperature range for application is 8 to 45° C. The surface temperature must be 3° C above the dew point of the ambient air. Dew or rain cannot be present. Epoxy resin must be placed when temperatures are falling (e.g., late afternoon). If temperatures are rising, bubbles can form in the primer that may lead to bubbles in the pavement.
- For the third pavement type (bitumen sheet on top of resin primer), a burner must be used to warm the sheet for placement. The burner does not damage the epoxy, and the heat improves the bond strength between the sheet and the resin. The sheet must be pressed down to get a good bond. Otherwise, failure will occur.
- Some vendors have developed equipment to automate this process. Most is hand propelled. The mini-roller used for pressing the sheet has dense rubber wheels. Self-propelled units still require two people to shed the excess bitumen that forms along the edge of the process.
- The second pavement type uses two layers of bituminous sheets. During placement, the top layer is heavily loaded by the paver, which limits its application. It is used most commonly in southern Germany. It can be used on bridges with a steep incline. If the gradient exceeds 6 to 7 percent, this is the only option. A liquid resin (commonly polyurethane) is used. The material components are combined and delivered with a heated application hose. The combination occurs inside the spray nozzle. Since the materials are heated, reaction is rapid. Application results in a 2-to-6-millimeter thickness. This type of construction is not used often, since it is the most costly and error prone. For bridges, the asphalt mixture must meet additional requirements to provide the required protection.
- Much experience has been gained, and the standards used are based on that. Incidences of failure do not negate the fact that this type of application is sufficient to cover bridges in the long run. The durability of the epoxy resin

systems is probably a couple of decades. It is anticipated that the surface courses may require more frequent replacement.

### **Discussion**

- Concrete surfacing is used only with smaller structures, or when the road is made of concrete as well.
- For concrete surfaces, a layer of bitumen sheet, two layers of bitumen sheet, or a liquid applied resin is used. In all three cases, an epoxy layer must be underneath.
- In the United States, a number of redundant corrosion protection systems are used, including epoxy-coated rebars, low-permeability concrete, and a waterproofing membrane. The Germans do not use epoxy-coated rebars, and no special measures are taken for low permeability of concrete. Waterproofing comes through the system described above, and it is believed to be sufficient.
- The Germans are experimenting with quickset materials that can work under a wide range of conditions. This is important because bridgework can be done only on weekends.
- The waterproofing systems have no performance specification. Construction contracts include a 5-year warranty, but that is probably too short for problems to occur.
- Non-destructive evaluation methods are not used to detect potential failures. The Germans believe that the durability of the systems is such that failures will not occur. Several evaluation methods have been offered, but none stands up to practical application.

## **THE NETHERLANDS**

### **Summary**

The following is a summary of relevant findings from the Netherlands, with commentary on the observations in italics.

#### ***Process-Related Issues***

- Roads to the Future
  - This is a two-year, high-risk, long-term research and development process.
  - Upon initial (concept) award, the contractor is paid a stipend to develop a more detailed design. Staff and goals for the effort are revised every three years. Construction costs are negotiated and split 50-50.
- Rapid product evaluation
  - A two-year evaluation period is used for new products, which speeds up the process.
- Product certification

- A system is used that researches and tests new products which ends in a judgment. A certificate is issued after long-term field trials.
- Probabilistic risk analysis
  - For prescriptions and specifications, detail is developed to match risk. Probabilistic analysis is performed based on available data. Certification of compliance is conducted by an independent lab.
- Maintenance contracting
  - The Dutch are beginning to incorporate this into design-build.

### *Evaluation Techniques*

- Winfrabase pavement maintenance system
  - Winfrabase is a software database that integrates pavement management with a construction and materials database. Combined data—including construction, materials, products, testing, and PMS pavement performance data—can result in epidemiological studies.
  - The whole road network becomes an experiment, and everyone has access to data. The system can answer such questions as what products perform well, and how the smoothest roads are designed and built.
  - *Indiana has a similar system, as do other States, but what is unique is how this information is being used.*
- Automatic road analyzer raveling assessment



Figure 12. Wooden guardrail in the Netherlands.

- The Automatic Road Analyzer (ARAN) laser is being used to detect raveling. The algorithm looks for data on missing aggregates with five rocks in a row missing.

- Polymer content testing
  - Using gas chromatography, testing for the presence and possible quantification of polymers in asphalt is possible.
  - *If the right kind of performance test is developed, the need for this is lessened.*
- Skid truck with large tank
  - The Road Analyser and Recorder (ROAR) was developed to measure skid resistance.
  - It consists of a large truck with a large water tank and no trailer, and allows testing for friction over extensive distances before stopping to refill the water tank.

### ***Innovative Materials***

- Porous asphalt
  - This material provides a quiet surface on mainline routes at test sites.
  - Also demonstrated was a two-layer porous asphalt pavement with a geotextile layer between the layers.
- Smart roads (lighted stripe)
  - Embedded lights allow an increase in the number of lanes from three to four during rush hours.
- Noise resonators
  - Helmholtz resonators used in precast concrete panels are overlaid with porous bituminous or polymer mixes.

### ***Other Issues and Considerations***

- Noise
  - New noise measurement techniques include the algorithm for the mitigation from the walls.
- WIM and surveillance
  - Weigh in motion (WIM) is used in conjunction with video surveillance for enforcement.
  - *This could possibly be used to identify anomalous WIM readings.*
- Sustainability
  - The emphasis is on environmental impacts (sustainability, noise, energy use reduction, recycling, attractiveness to users and adjacent residents, etc.)
  - Ninety-eight percent of waste materials are recycled.
  - It is against the law to dump anything that can be recycled.

## CHAPTER TWO: GENERAL OBSERVATIONS

- Pavement marking for tracking performance
  - A pavement marking system is used to track the performance of the systems in use.

### Dienst Weg-en Waterbouwkunde, Rijkswaterstaat, Heijmans (Delft)

#### *Introduction*

- Dienst Weg-en Waterbouwkunde (DWW), the Ministry of Transport, Public Works, and Water Management, is the top level. Rijkswaterstaat (RWS), the Ministry of Transport, is the next level. Under that are the regional directorates (which are like State DOTs, but also cover waterworks).
- Recently, emphasis has been on the environment (sustainability) and noise.
- The Netherlands is densely populated. Noise walls work, but are considered ugly, so engineering the road surface is preferred for mitigation.
- Sustainability is another major consideration. Wood, for example, is used more often because it is a renewable resource. Steel corrodes and is not.
- Transport along rivers and canals is the other major business. Most freight traffic comes through the Rotterdam Port.
- With two-thirds of the country below sea level, flooding is a major consideration. If the dykes broke, most of the country would flood. The RWS has a EUR 3.25 billion budget, with more than 10,000 full-time equivalent in staff. EUR 950 million is spent on construction and EUR 500 million on road maintenance (primary system only). A total of 7,155 kilometers of the network is carriageway, with 3,549 objects (e.g., bridges, crossings).
- Waterways consume EUR 570 million for construction, management, and maintenance.
- The Road and Hydraulic Engineering Institute oversees the hydraulic and road engineering divisions.
- Road engineering includes a realization and maintenance department, environmental affairs, road monitoring, road maintenance systems, and materials research.
- Dienst Weg-en Waterbouwkunde (DWW) has about 300 staff, 70 percent with college degrees.
- EUR 55 million is spent within the DWW annually, EUR 30 million of which is outsourced.

#### *Winfrabase: Road Infrastructure Database*

- It is important to have a database to track the performance of sites constructed with different materials. It also is useful for maintenance planning.

- The center of the database is road location data. Also included is the area of the road, condition data (measurements), noise-restraining construction, pavement loading, road weather information system (RWIS) data, and pavement information.
- The road location data includes the road number, lane number, and chainage. The area includes length, width, etc.
- The Netherlands has 3,250 (centerline) kilometers in its main road network. More than half of the roadways in the Netherlands are covered with porous asphalt.
- Roadway condition is measured with a variety of equipment. One is the ARAN, which has been used since 1988. The Netherlands has two units, which measure smoothness and rut depth. Raveling used to be measured by visual survey, but can now be evaluated by a laser technique with the ARAN. This algorithm is based on the texture data measured by the ARAN. The cracking algorithm used was developed by the ARAN manufacturer.
- Raveling is the only distress still present. Cracking and rutting are no longer a major issue. The climate is too mild for thermal cracking to be a problem.
- One major disadvantage of conventional skid measurement is the water tank capacity. The new system has a large water tank. It also has a variable slip resistance for the tire, while the old system was fixed. All measurements are at 80 to 90 kilometers per hour.
- Noise-restraining construction is also included. This includes the type of noise wall (height and material).
- Pavement loading is from the WIM systems installed nationwide. Six sites came online at the beginning of 2002. The Dutch believe that if overloaded traffic can be avoided, the system life can be extended significantly.
- If a heavy truck passes by, a photo is taken and the police are notified. The truck is pulled over, and the static weight is checked.
- The country cannot tax the transport of freight across the Netherlands.
- RWIS data will be collected soon. This includes 300 sites around the country that measure air temperature and humidity, as well as pavement temperature.
- Dutch officials are discussing whether this information should be available to the public on the Internet. One possibility is to make the information available with a disclaimer.
- Access to the data is critical. The data can be shown by geographical, static, and dynamic means.
- Materials management during construction is not yet connected to the database, but this is a goal, one that will be time consuming. Information is available on test sections, but not on the entire network.

- Only 2 percent of the road network is concrete. Most is porous asphalt, and the remainder is mostly dense graded asphalt.
- An in-service noise index will be added soon, but the consequences to the maintenance system need to be considered first. Noise is now calculated, not measured, because it is difficult to measure it at 80 kilometers per hour without shutting down the road.
- The database is accessed by drop-down lists, starting with the region, then pavement type, then data type.
- The data is updated once a year. It is input automatically from the ARAN, filtered by quality-control steps.
- Development costs are difficult to quantify, since the system has been developed over the years. EUR 3 million to 4 million has been spent to develop the database and software.
- Global positioning system (GPS) data is used for profile measurements.

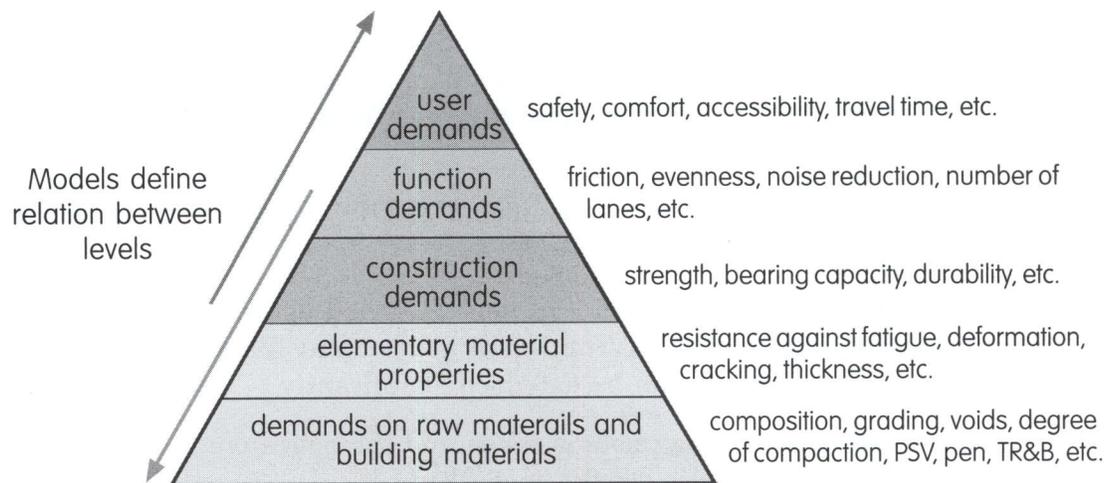


Figure 13. Pyramid of demands used in the Netherlands. (Photo Source: DWW, The Netherlands)

- The system is run once it is decided that a road needs maintenance or has a construction problem. On an annual basis, 1 to 3 percent of the road network is run. Software calculates the remaining life from the information.
- The raw data from the ARAN is stored, but not in the database. The data is stored in the database, but is not available to the user though the interface.

#### ***Innovation in Road Building***

- It is difficult to determine what a superior material is because the definition is likely to differ between the Netherlands and the United States. The objectives of a pavement type often is be driven by policy (e.g., noise reduction).

- Invention is finding new things, but innovation is implementation of technology. Innovation can involve just improving the state of the practice, but this requires knowledge of what has been done.
- Standardization is a hindrance to innovation. This is difficult enough on a national level, but even more difficult on the EU level.
- If the responsibility lies with the client, a more conservative approach generally is taken.
- Empiricism is also a hindrance, since it is difficult to prove that something will provide durability without a means to predict it on a more fundamental basis.
- Money is a key driver to innovation. This is likely a universal component of the definition, although it can be difficult to quantify at times.
- Solving problems is the second driver.
- The contractor makes money, which is provided by the agency. A market is generated between the client and private enterprise. The market has to be created. Demand must be generated for recycled materials, for example, or they will not be used. Price can influence demand.
- Skid resistance is a priority for the United Kingdom, which results in a different pavement (materials) design than noise mitigation, which is a key driver in the Netherlands.
- The client identifies the problem, which can be real or politically driven. Research is done to find solutions, which are then implemented.
- CROW is not a technical or research institute. It is a platform that organizes the work using working groups.
- A new railway is being built to transport goods from Rotterdam to Germany. Originally budgeted at EUR 1.5 billion, it is now more than EUR 8 billion. The cost increase is due to the value of space requiring more tunnels, for example.
- Recycling is another key problem driver. It is more difficult to mine virgin materials, but nobody wants these facilities near them.
- Porous asphalt was used at first to control splash and spray, but then for noise reduction. This department and the environment department have cooperated. They wanted to increase the speed, but were rejected because of the increase in noise. This was countered by advancing the porous asphalt alternative.
- Noise barriers, if constructed in full, would cost an additional EUR 4 billion.
- Reclaimed materials can no longer be dumped in the Netherlands, creating an incentive and competition to sell these materials.
- The Dutch believe that it can be difficult to spur innovation within an organization, so going outside of the organization is sometimes beneficial.

- The Dutch stated that giving more responsibility to contractors would increase innovation, although it will depend on the risks that contractors accept when using an innovative material. The higher the risk (for example, if they must maintain the road), the more conservative an approach they are likely to take.
- One disadvantage to the client for long-term responsibility is changing priorities of the agency.
- The Dutch use a “pyramid of demands.” On the left side of the pyramid are models that define the relationship between the levels. On the right side are examples of each layer in the pyramid. At the top are “safety, comfort, accessibility, travel time, etc.” and at the bottom are “composition, grading, voids, degree of compaction, PSV, pen, T(R&B), etc.” Several levels of relationships must be derived before the process can be fully realized.
- Implementation is difficult, especially if the horizon is 2030 technology. It is possible, however, for some technologies to be implemented today. This is especially true if a market is generated because of the technology.
- The innovation test center must be implementation driven.
- Monopolies are an obstacle that needs to be considered.
- The RWS pays half the research and development cost and provides test and demonstration sites.
- If the client wants innovation, it must accept risks.
- The RWS can show regional directorates that product performance has been demonstrated.
- Innovation requires broad support at all levels, especially the highest levels. If the market for the innovation is not there, it is not going to work.
- The details of the innovations are kept confidential. The Netherlands has open records laws like the United States, but a confidentiality clause can be added to a contract.
- France has a more innovative environment. It has a 4-year approval process, but that is changing to protect its market because the Netherlands and other countries have a shorter proofing period.
- The political pressures behind the markets generated for innovation include such things as traffic congestion and noise.
- Political pressures will continue to overwhelm the decisionmaking process. Life-cycle cost is a consideration, knowing that it is the best way to serve the public in the long term. More than 60 percent of the costs are related to traffic congestion.
- For test trials, regional directorates are contacted. This process is not formal.
- The tests at the center are a mix of small and large contractors.

- Sometimes, innovation provides a minimal delta value compared to the delta costs.

#### *Private Sector Research and Development (Heijmans)*

- Heijmans, a contractor, has been involved in several projects in the Roads to the Future initiative.
- It is important that research does not stop in the laboratory, and that innovations are tried on the roadway.
- Short-term research (optimization of existing technologies) and long-term research (new technology) need to be separated.
- Programs like Roads to the Future and the Innovation Test Center work for long-term research, but not for short-term research. Long-term research requires stimulation via government funding.
- Research needs to be looked at as not just as a product, but also as a learning process.
- Rolled asphalt was an interesting concept that would not have been tried (because of the cost) without a forward-thinking, supportive system in place, sponsored by the government.
- If submitted ideas are approved, a design is made and a test section constructed. The last step is follow-up.
- An acoustical engineer was employed to help develop the noise-absorbing capabilities of the layer.
- A synthetic binder is used in this system, which is dyed black.
- The layer can include recycled materials, such as rubber particles and aggregates.
- Many Roads to the Future projects are developed first as scale models.
- Flexible lane marking is a technology that allows the number of lanes to be adjusted during peak hours. Even though the lanes are narrower during peak hours, traffic does not travel as fast.
- Feedback from drivers was key. It was concluded that drivers do tend to follow the lines.
- A second generation of the system was developed to improve the strength of the units.
- Longer units pose difficulty with thermal changes, and using small modular elements helped mitigate this problem. They are half-round, so that a broad sawcut blade could be used to insert (retrofit) them into the surface easily.

- The Dutch have specifications for painted lines, but it is difficult to translate them to the new technology. Competitors will want to enter the market if the demand is there, but they cannot violate patents.

### *Discussion*

- The rollable pavement in the Roads to the Future program is not recyclable.
- It may be possible to pull the surface up and roll it down again at a different location.
- It is too soon for application of the rollable pavement because costs are high and the market is not there.
- It is possible to replace the synthetic layer with a hot-mix layer.
- The Roads to the Future staff is renewed every two years to keep innovation fresh.

### *Innovative Technologies*

- Users can have competing interests. Both drivers and those who live adjacent to the transportation system need to be considered. Two-thirds of the public has reported annoyance with transportation, including noise. Users of industrial areas are also a consideration, because a delay in the system can translate into a cost. These three users can have competing interests.
- Political considerations include safety, accessibility, environment, durability, and costs. Comfort and roadway appearance are secondary considerations. These elements are at the top of the pyramid.
- Without innovation, noise will be a costly fix.
- The political considerations translate into specific targets for research results.
- A 4 dB(A) reduction is targeted for 2005 construction, and a 6 dB(A) reduction in 2010 (compared to dense-graded asphalt).
- The target is to keep it SMART—simple, measurable, acceptable, realistic, timely. These targets should be repeated often (especially to decisionmakers), and translation between levels should be updated.
- The stages of innovation include idea, concept, pilot, implementation, and use. Each stage results in a higher probability of success. At the end of each stage, a “go or no go” decision needs to be made.
- Implementation is a difficult phase. The specifications should be developed as this process goes on.
- Dynamic marking is an example. The first generation required electrical sources on the side of the road at each point. The next generation required fewer power sources.

- The cost of trial implementation should be considered, since closing a road is expensive.
- Various characteristics (e.g., cost and risk) vary in importance at each stage.
- Laboratory tests (EUR 10,000 to EUR 50,000), full-scale tests (EUR 200,000 to EUR 500,000), and in situ tests (EUR 500,000 to EUR 3 million) are used.
- Industry should be involved in the process, including setting the goals and timetable.
- Problem development should come from higher levels. Over-specification in the early stages may kill a product that requires changes because of interim testing. The progress plan for each stage needs to be laid out in advance.
- The role of the RWS is not to be just an obligatory process. It should weed out substandard materials.
- Performance test standards are coming as a result of the EU open market process.
- The EU structure includes rules for innovation, but it is not clear yet how they will work. EN 13108-1 to 8 are product standards, 138107-20 and 21 cover quality systems, and EN 12697 1-40 are test methods.
- The product standards include various types of surfaces. In each, desired properties are and quality levels are defined.
- Either an empirical or fundamental approach can be used.
- The asphalt plant has to have a quality system in place.
- Different classes of material are specified for different layers in the road and different roads.
- The national annex contains the specified grades for each material, and can be changed. Changing standards takes a longer time.

### **Ministerie van Verkeer en Waterstaat, Vermeer Infrastructuur BV, CROW, (Apeldoorn)**

#### ***From Innovation to Specification (CROW)***

- The Information and Technology Centre for Transport and Infrastructure (CROW) brings together diverse parties to get a mix of opinions during the standardization process.
- Knowledge and responsibility from the owners and the contractors need to be balanced.
- For products and materials in use for a long time, the experience gained can easily be put into the specification.
- For new products, it is more difficult. Competition is affected when just one contractor is able to deliver the innovative product. A competing contractor

may propose a look-alike product, but the contractor must describe how the product will work. Without a product history, it is difficult to assess quality.

- CROW has described the innovation process and proposed a solution to achieve it.
- A certification system can be used. This involves defining properties, test methods, and quality levels. Once trial sections have demonstrated benefits, a certificate can be issued.
- A number of private bodies can issue certifications. For example, noise reduction can be certified. CROW does not do certifications now, but may be able to in the future.
- Another example is thin asphalt layers. CROW may be able to offer the certificates on a temporary basis. In the future, a more formal certification institute can be put in place independent of contractors.



Figure 14. Traffic on Roads to the Future demonstration site in the Netherlands.

- Functional specifications can be provided for all stages of building. Depending on how the risks will be shared, an appropriate contracting vehicle can be selected.
- If responsibility is not clearly defined, misunderstandings are possible. In a conventional contract, for example, the design and construction elements are unique phases, leading to potential conflicts. In a turnkey operation, not only are the two roles combined, but also finger pointing is reduced because the contractor is also responsible for facility maintenance.
- The “Uniform Administrative Conditions for Contracts that are Integrated” outlines the risk shared between the contractor and the owner. Copies can be found at [www.uavgc.nl](http://www.uavgc.nl) and [www.crow.nl](http://www.crow.nl).

- The key challenge is develop test methods for functional requirements—such as evenness, skid resistance, noise—and materials properties—such as resistance to permanent deformation and fatigue. In the future, it will be possible for a contractor to use these specifications to demonstrate the quality of a proposed product.
- The specification for functional requirements is under development. For now, an informal interview process based on a statistical approach is used to quantify the risk of failure. Random tests are performed on the road during the field trial to assess performance.
- It is difficult to identify an exact definition for the required quality. The process is highly empirical.
- Minimum life expectancy for surface treatments is 7 years, although most last 10 to 15 years. The Dutch are trying to obtain technical information to determine which material properties are the most significant in predicting the life.
- When dividing the risk between the agency and the contractor, the contractor needs to have information on the methods to predict the behavior of the material.
- On some contracts, the contractor can choose a more durable initial construction, especially when the contract includes maintenance responsibility. Disincentives are built into the contract to limit maintenance activities. Examples include lane rental or a built-in period to do maintenance.

#### *Introduction to Rijkswaterstaat and Roads to the Future*

- A rest area near Apeldoorn was a suitable location to build the Roads to the Future trial sections without disrupting mainline traffic.
- Because of lane rental, the Dutch are looking for the least-disruptive methods to traffic.
- German contractors have tried to come in to work, but local contractors who know the area and the traffic have an advantage.
- Invitations for innovations were distributed throughout Europe, but the companies that responded were Dutch.
- Large contracts often bring in foreign contractors. Even then, awards are commonly made to the Netherlands.
- Sometimes, large foreign (commonly French) contractors will purchase local contractors.
- Large DBFO contracts are more common in other countries (United Kingdom, France, and Spain), so foreign companies that know how to execute them have an advantage.

- Sometimes contracts simply specify functional requirements. Some argue that this is dangerous because the agency may not get a good-quality product. These kinds of contract are considered an experiment.

### *Roads to the Future*

- The Roads to the Future program focused on improved functionality. It began with an inventory of user demands expected in 2030. The public and various specialists were consulted, and material, design, and construction needs were defined.
- The ministry recognized that this type of experiment was a benefit to the taxpayer, and agreed that this experiment was a good investment. A call for technology yielded 20 responses, and an independent jury selected four projects for trial. Originally, only two were to be selected, but the ideas were so good the ministry found money to do four.
- Innovations were sought for both the process and the product.
- In some cases, an existing product needs to be improved. In this case, it is a large leap in the process. Failures are expected, and it will take a number of iterations before the product can be used. This concept kick starts the innovation process.
- Roads to the Future includes sub-themes, including Road Architecture 2030, Flexible Infrastructure, and Virtual Mobility.
- Flexible infrastructure includes such innovations as floating roads that accommodate changes in water levels.
- Road Architecture 2030 defines user demands. In Rotterdam, an international congress is looking at the future of architecture.
- The Smart Road concept includes a means to identify lane changes to maximize road capacity.
- The Energy Road concept uses elements that can generate electricity from the temperature differences in the top and bottom of the road.
- For the modular road surface, various functional demands were considered first, including durability, safety, noise, ability to carry water away, etc. Modular construction was also a demand, since it had to be constructed and removed quickly.
- The LINTRACK facility at the Delft was used for assessing durability.
- Cost constraints were not a major consideration, although an upper limit was established. Sustainability also was not a major concern.
- While concrete could have been used, it was not selected because of the lack of time from original concept to pilot placement.
- The proposed solutions had various levels of functionality. Some, for example, were recommended as better on poor soils.

- The noise reduction on these systems has been measured, and results have been good.
- These systems could be built in a fully automated fashion. During the pilot project, however, the equipment used was less than automatic.
- The contractors have used techniques learned on these jobs on other projects. Other clients, such as airports, also are interested.
- The intellectual property of the concepts remained with the contractors for 4 years. Because of this limitation, the ministry could not combine elements of the four solutions. In the next step, they can negotiate with these companies to develop the second generation. The contractors have not approached the RWS yet with a next step, but have been using components of this on other RWS works.
- If another call for technology is issued, it will be for other types of projects. It is a risk for contractors, since they do not know if they will be able to proceed any further than concept placement.
- In theory, the cost was 50-50 between the contractor and the agency.

*Roads to the Future: Contractor Perspective (Vermeer Infrastructur BV)*

- Innovation is part of the company's mission statement.
- About 1 percent of the company's emphasis is on high-risk investments such as this.
- The development plan is the roadmap for the design and construction of the Roads to the Future concept.
- Two-layer porous asphalt by itself already meets the 5 dB(A) reduction functional requirement, but it is not prefabricated (a second requirement).
- The noise requirement was a minimum reduction, but greater reduction was sought.
- The company's decision to join this effort was not made lightly, since it would involve both design and construction costs (split 50-50 with the agency) and the cost of developing the concept proposal.
- Phasing took place in 2000 and 2001. The idea phase was a 30-to-40-page report. All costs were paid by the bidder (contractor).
- The design phase was 3-to-4 months, and included development of the specifics. The design had to include a list of equipment and costs in a form suitable for a construction contract. In this phase, the contractor was paid a fixed EUR 50,000.
- Designs had to be submitted with no company names in the proposals. The selection panel, which consisted of professors and other independent parties, had to sign a confidentiality agreement.

- After 4 years, the government will not publish the information, but there will be no restrictions.
- Construction occurred from June 2001 to September 2001. The government told the contractors what the road was, and were given a timeframe.
- The idea phase included a brainstorming session within Vermeer. Several good ideas had to be discarded because of the rapid schedule of the project.
- In the design phase, an animation film was required, along with scale and real-size models.
- Vermeer focused only on the wearing course. Other solutions added structural layers (precast concrete).
- Another division of Vermeer developed the construction equipment. This was difficult, because that part of the company was under a profit requirement.
- Vermeer tried several trial sections, and one of the later ones was an expensive failure.
- The asphalt mat was picked up after laydown with a spool carrier. The outside diameter of the spool was 3.5 meters and the diameter of the core was 2.5 meters.
- The company used a very highly polymer modified bitumen to get flexibility.
- They used an anti-sticking layer on top of the HMA surface to keep the roll from sticking together.
- The temperature cooled at night, which jeopardized the flexibility of the material on the spool. The material would be more flexible if placed in warm conditions.
- One idea to overcome this was to blow hot air on the roll as it was unrolled, but no heater was available. Instead, they unrolled it during the warmest part of the day.
- The mat was saturated when microwaving, which required a lot of energy to boil off before it could focus energy into the adhesive layer. The result, therefore, was less than satisfactory. Later, in an indoor facility, they were able to prove that the process works.
- A recent improvement is to use a giant induction device instead of a microwave. This is a safer solution, and does not interfere with communications. It also is not affected by water.
- A new contact layer was used as well. It included steel particles to absorb energy and heat.
- The company worked with a specialist who had demonstrated the basic technology before, but not for this specific application. When deciding which idea to submit, the company had to consider the short time it had to work with. It selected this idea because some research had been performed already.

## CHAPTER THREE

### KEY FINDINGS

Presentations by the various hosts to the U.S. delegation included discussion on the process of innovation, commonly used evaluation techniques, specific innovative materials, and other findings. The following sections describe the scanning team's key findings during the study.

#### PROCESS-RELATED ISSUES

Over the past several years, a migration in process and specification has occurred in most of Europe. Many countries are transitioning from using methods-based specifications to developing and adopting more functional requirements for their construction materials. Functional specifications are similar to end-result specifications used in the United States, but they also incorporate elements of performance specifications. The objective of a functional specification is to ensure that the end product is constructed to meet the function for which it is intended (e.g., the noise level, smoothness, and safety that the public expects or demands). The use of these specifications and contracting methods has resulted in the introduction of more innovative materials, since as long as a material meets the specified function, it is deemed acceptable.

In fact, the definition of "superior materials" appears to be based more on functional requirements rather than cost. Demonstrated innovations commonly resulted in more functional but more costly solutions. In some cases, the higher costs could be offset by incentives from policy or legislative requirements. In other cases, additional initial costs could be justified when life-cycle (whole-life) costing was considered.

The future trend appears to be a requirement of functionality over time (performance specifications). A wearing course, for example, will be required not only to meet a maximum noise level, but also to maintain a specified level over a specified number of years.

In short, the process of materials selection is commonly driven by a risk-versus-reward assessment. While this assessment is not always formal, it includes a rational means to weigh the costs and benefits of using conventional-versus-innovative materials.

#### European Union Standardization

The formation of the EU has had a profound impact on most facets of government. By working to eliminate barriers to free trade, the EU is creating opportunities for vendors and owners to move together toward standardized functional specifications rather than conventional prescriptive specifications. To assist in this effort, the European Committee for Standardization (Comité Européen de Normalisation, or CEN) was established to coordinate and manage the specification standards.

While the CEN standardization process is moving forward, it is not without difficulty. As part of the harmonization process, each member country must debate

the various details of its previously independent specifications. A further consideration is the differences that arise in definitions and language (the official language for the specifications is English, although French and German versions also will be approved for use). When asked if the EU standardization process leads to a more innovative environment, some countries responded that the process benefits industry (by encouraging cross-border competition, for example). Some individuals, however, believe that the CEN specifications may make them vulnerable to delivery of substandard materials.

In addition to the CEN, a second organization, the European Organisation for Technical Approvals (EOTA), provides a common testing and evaluation forum for products that do not have a standard specification. Additional information on the EOTA process will be researched during the implementation phase of this scan.

In summary, the development of the CEN specifications can be contrasted with AASHTO specifications. While AASHTO has produced guide specifications that States have the option to adopt or modify, the EU is in the process of combining current specifications into a common binding specification for use across Europe. It should be noted that within the CEN, quality classifications allow for varying thresholds and tolerances on the material test results.

### **Contract Mechanisms**

All of the organizations the scanning team met with discussed the use of warranties and performance contracts as part of their everyday practice. The specific elements of these contracts varied, ranging from short-term (1-to-3-year) materials and workmanship warranties to long-term (more than 30-year) design-build-finance-operate (DBFO) contracts. While these types of contracts are common, highway agencies appeared to have varying levels of comfort with them. Some agencies appear more willing to relinquish control because they have seen an obvious increase in quality, while others appeared to be more cautious in their adoption.

While an increase in quality often resulted, innovation through the use of superior materials was not always realized merely because of a warranty mechanism. Their use was more common on longer-term warranties in which the contractor had more latitude in the materials and processes it could use. Where superior materials were used, the specifications were much more performance based. Some difficulty remains, however, in how to define the performance standard, including what to measure, how to measure it, and when it should be measured.

In addition to warranty contracts, maintenance contracts were also commonly used. These contracts resulted in privatization of the maintenance activities for a highway facility, and were normally accompanied by functional requirements. In fact, the momentum gained from the use of functional requirements for maintenance contracts has led to their use on conventional construction projects. Contractors were encouraged indirectly to develop their own management systems to track resources. More innovative companies typically had lower life-cycle costs, and thus could submit lower bids covering a longer time period.

Finally, the scanning team learned that contractor quality (and/or past performance) was sometimes considered in the award process, as was life-cycle costing and sustainability (environmental impacts). In some countries, contractor quality overshadowed cost and the low-bid process. These considerations led to innovative solutions for some contracts, including the use of superior materials.

### Independent Product Evaluation and Certification

The scanning team observed a variety of models for product evaluation and certification during its study. While most countries had well-established systems in place, officials stressed that European standardization was changing this, with EOTA serving as the coordinated organization for considering materials for which a standard does not exist.

In the United Kingdom, the Highways Agency (HA) uses an innovative process termed the Highway Authorities Product Approval Scheme (HAPAS). Administered under an independent certification agency, the British Board of Agrément (BBA), the HAPAS process involves working with the private sector to establish functional specifications to replace conventional method specifications. Existing performance and quality data for a product classification is gathered from the private sector to assist in the functional specification development.

For certification, a vendor presents its existing product data to the BBA. A formal evaluation process is initiated that, if successful, results in a BBA certification that the product meets the quality and performance intent of the specification. In British terms, the product is deemed “fit for purpose.” Trade secrets, such as constituents and manufacturing details, are not released, but instead are sealed by the BBA to be used during subsequent quality audits. The HAPAS process appears to be successful, eliminating the need for routine on-site testing and continual surveillance for these material categories. It also provides the vendor with confidentiality. Certifications are available to the agency or owner on the Internet.

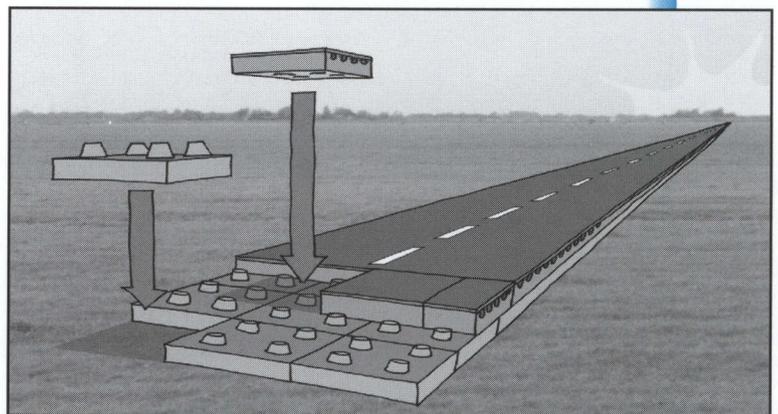


Figure 15. Very Silent Sounds Module from the Netherlands' Roads to the Future competition.

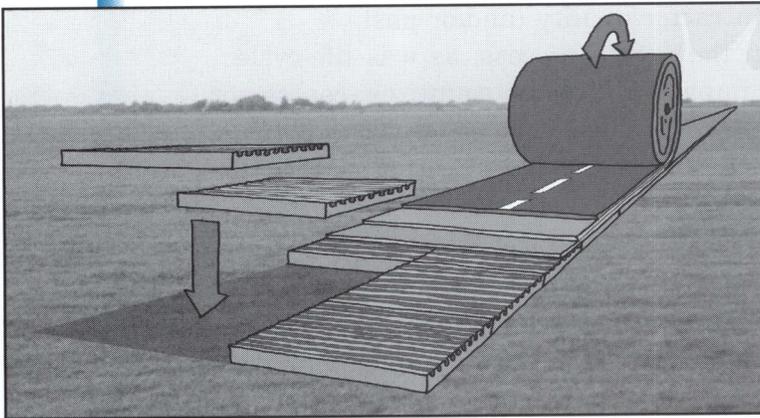


Figure 16. Roads to the Future rollable road.

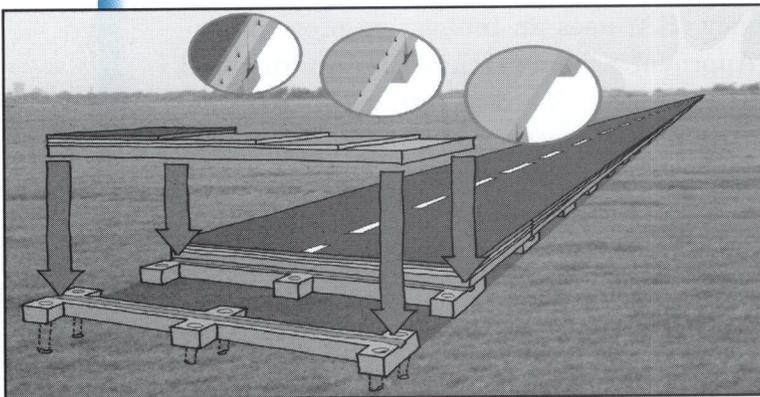


Figure 17. Roads to the Future ModieSlab pavement.

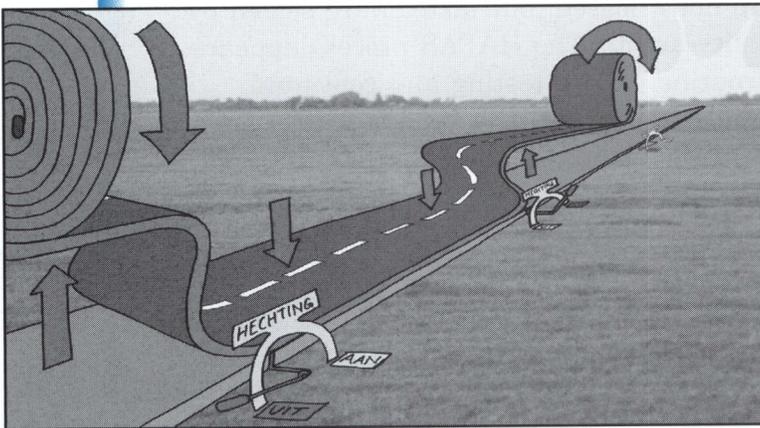


Figure 18. Roads to the Future adhesive road.

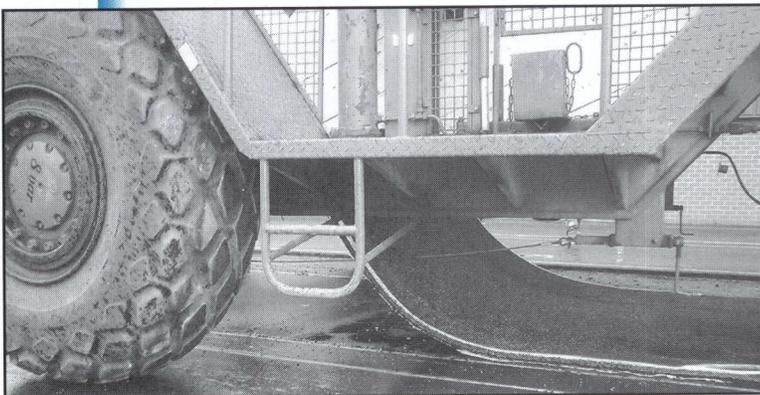


Figure 19. Roads to the Future adhesive road.

Other testing and evaluation organizations include the Building Research Establishment (BRE) and Transport Research Laboratory (TRL) of the United Kingdom, Danish Road Institute (DRI), Bundesanstalt für Straßenwesen (BASt) of Germany, and Dienst Weg-en Waterbouwkunde (DWW) and the Information and Technology Centre for Transport and Infrastructure (CROW) of the Netherlands. These organizations are prominent, well respected, and trusted within the highway community. Many times, a vendor desiring consideration of a material by an agency or contractor (e.g., on a warranty job) will seek the approval of one of these organizations.

Overall, the scanning team observed a number of common steps in most of the evaluation and certification processes it identified during the scan:

1. The process commonly begins with the vendor collecting and documenting data on material properties, behavior, and performance. The vendor has no incentive to take shortcuts on this step. Since the remaining steps require additional investment, the vendor wants to prove to itself that the material will not fail.
2. The vendor then approaches the evaluating organization, presenting the existing data and entering into a contract.
3. If the material falls into a new category, it may require a preliminary assessment of functional requirements for that category, including what properties should be tested to ensure the stated performance. This sometimes involves formation of a committee of experts in the field.
4. The material is then tested according to the specifications. If it passes, it is certified.
5. At this point, the vendor can approach the EOTA to gain additional certification of the material for more widespread use. The EOTA may accept the material based on the existing certification, or it may impose additional functional requirements, requiring further testing before certification.



Figure 20. Use of the torque bond test in the United Kingdom. (Photo Source: TRL Limited, UK)

### Roads to the Future

The Netherlands is using a novel approach to exploring long-range solutions to meet future highway demands. A Roads to the Future contest was held in which the highway agency defined a number of highway functional requirements (e.g., noise reduction and paving windows). Contractors were invited to offer solutions,

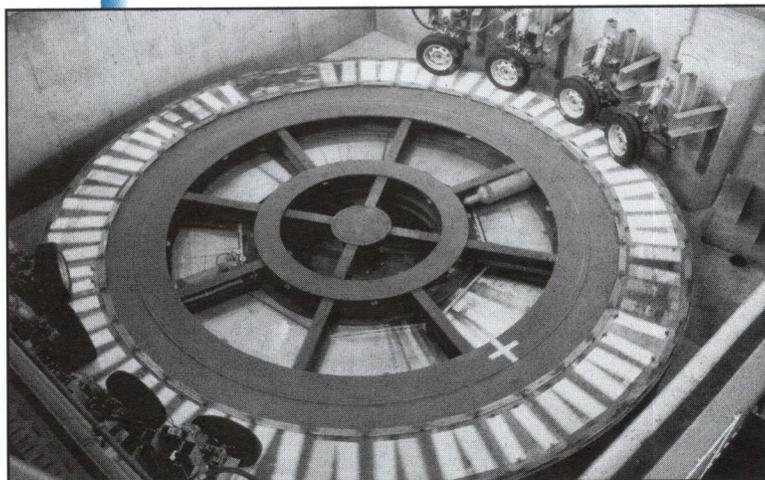


Figure 21. Accelerated pavement striping wheel test in Germany. (Photo Source: BAST, German)

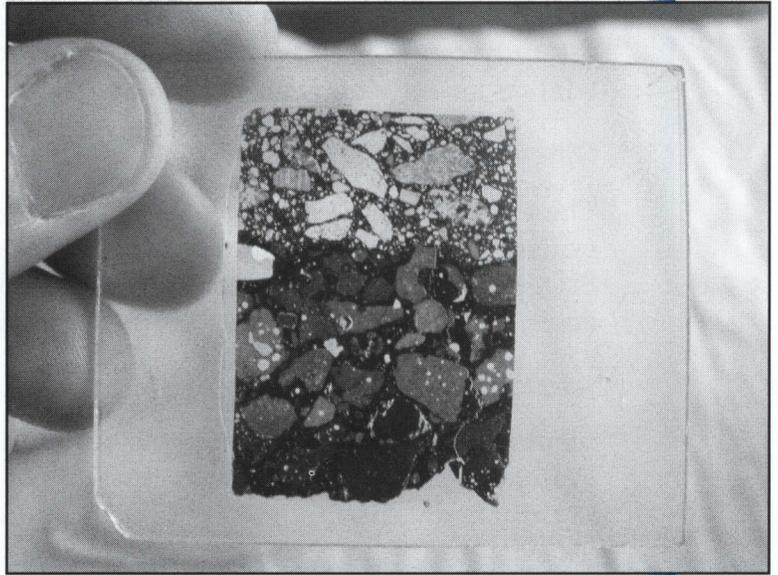
no matter how unconventional. The agency was surprised by the tremendous response. It selected four techniques for further evaluation on a predefined test section, including options with precast polymer surfaces that were laid down from rolls (like carpeting). This somewhat radical experiment resulted in a paradigm shift from the traditionally conservative thinking of the Dutch highway industry. Funding for this effort was divided equally between the agency and the contractors,



Figure 22. Surveying with the ARAN test vehicle in the Netherlands. (Photo Source: DWW, The Netherlands)

resulting in both shared risk and reward. A notable aspect of this experiment was the timeframe. The idea went from concept to final placement in two years.

Figure 23. Hot-mix asphalt microscopy in Denmark.



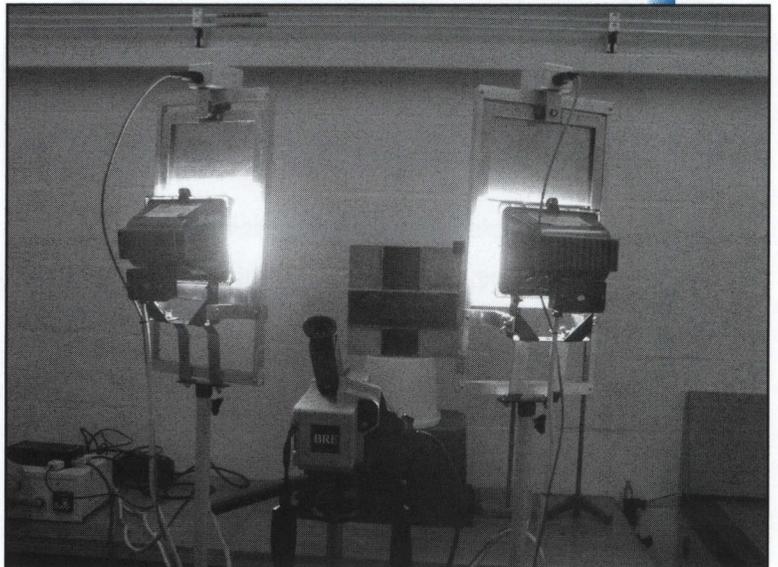
### EVALUATION TECHNIQUES

In addition to exploring evaluation and approval processes, the team observed a number of innovative evaluation techniques. The following sections describe some of these techniques.

#### Performance Data

Through the use of both accelerated load testing and various forms of field testing, superior materials were evaluated for not just their properties, but also their performance. The national testing laboratories with the requisite equipment and facilities, especially for accelerated testing, commonly used these procedures. Vendors that wished to evaluate the performance of a product before seeking certification or specification sometimes initiated the demand for performance testing (note Item 2 under the section “Independent Product Evaluation and/or Certification” above). By testing under accelerated loading, long-term performance

Figure 24. Pulse (active) thermography in the United Kingdom.



could be assessed in a limited timeframe. In addition, because the conditions were carefully controlled, this eliminated much of the inherent uncertainty of a field trial on an active highway.

### Other Test Methods

The countries the scanning team visited used a number of unique test methods to evaluate materials. While many have been used to some degree in the United States, the team believes that a renewed evaluation should be considered. A description of some of these methods follows.

#### *Torque Bond Test*

Identified by the Highways Agency in the United Kingdom, this test is used to evaluate the in-place bond effectiveness of thin wearing course systems. According to the agency, the first step is to take a core through the pavement. A stud is then attached to the core surface and force applied with a torque wrench. The force required for failure is noted, as well as the location of the failure. For a well-bonded material, the failure occurs in the underlying material, and not at the bonded interface.

#### *Stripe Wear*

Because of the expense and logistics associated with field testing of lane markings (stripes), Germany has developed a laboratory facility for accelerated lane marking evaluation. This facility is capable of evaluating tape, temporary paint, and permanent paint markings. Since the facility began testing in 1989, nearly 2,000 materials have been tested. This specification can be found in CEN 13197.

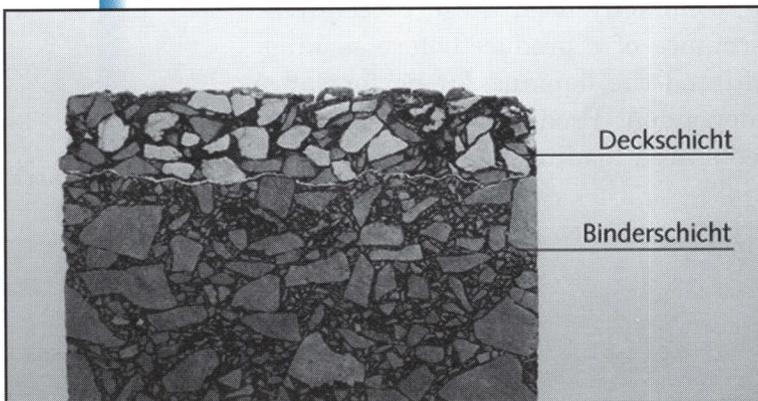
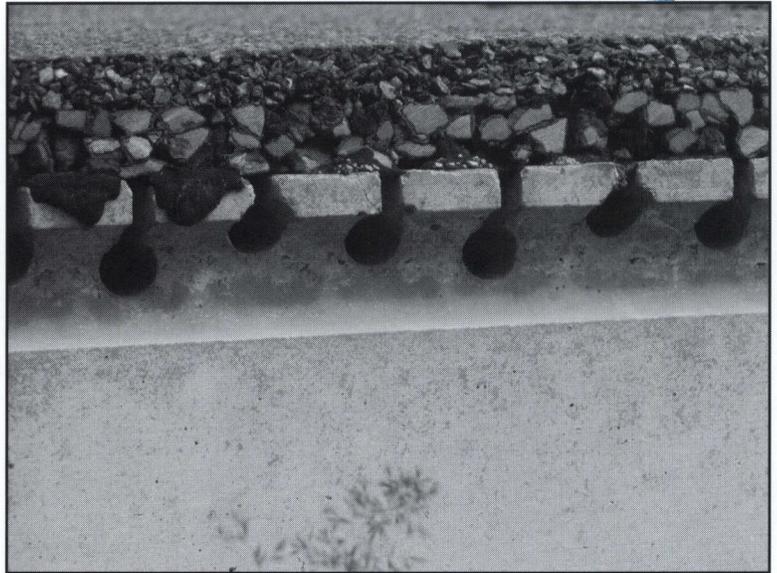


Figure 25. Twin-layer asphalt in Germany.  
(Photo Source: BAST, Germany)

#### *Automated Raveling Assessment*

In the Netherlands, raveling of hot-mix asphalt wearing courses was identified as a critical distress type. During a demonstration of the national pavement management system, it was revealed that an automated technique has been developed that can assess the degree of raveling from the laser data collected by the automatic road analyzer (ARAN) test vehicle.

Figure 26. Helmholtz resonators on Roads to the Future test section in the Netherlands.



### ***Hot-Mix Asphalt Microscopy***

The Danish Road Institute demonstrated a technique for evaluating hot-mix asphalt samples that originally was developed as part of the SHRP research program in the United States, but has been improved on since then. The purpose of the test is to better identify a variety of behaviors, including stripping and microstructural damage. It includes two methods of preparing samples: one that results in a sample with a polished surface, and another termed “thin microscopy” that results in translucent wafers. These preparation techniques are commonly combined with dye impregnation to assist in imaging and interpretation.

### ***Polymer Content Evaluation***

It was observed that infrared testing for the presence of polymer within a binder sample was being used in the Netherlands. It was reported that an effort is underway to further this process by quantifying the polymer content using the same basic techniques.

### ***Pulse (Active) Thermography***

The Building Research Establishment in the United Kingdom demonstrated an evaluation technique being deployed in the field to determine the bond effectiveness of composite laminate repairs for structures. While all thermography techniques record the thermal signature of a surface, this technique also employs an active heat source that, when pulsed, allows the evaluator to monitor the differential heat signature. The result is the ability to view delaminated areas beneath a composite laminate reliably.

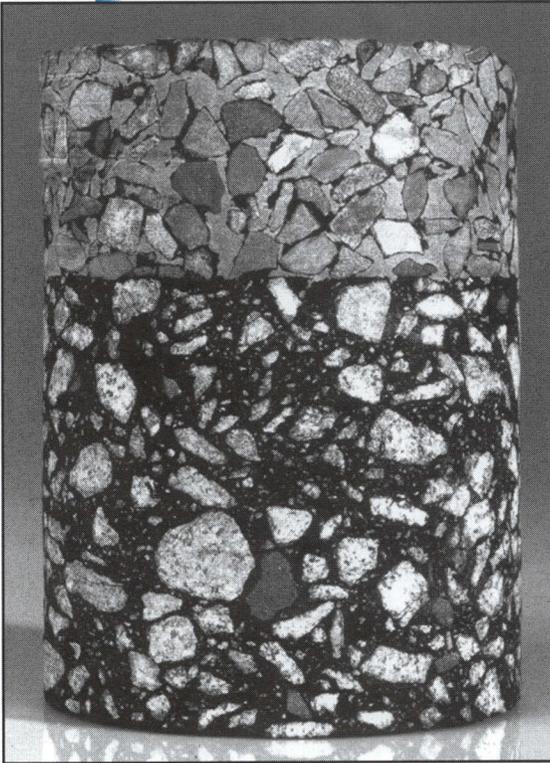


Figure 27. Semi-flexible pavement section in Denmark. (Photo Source: LOTCON ApS, Denmark)

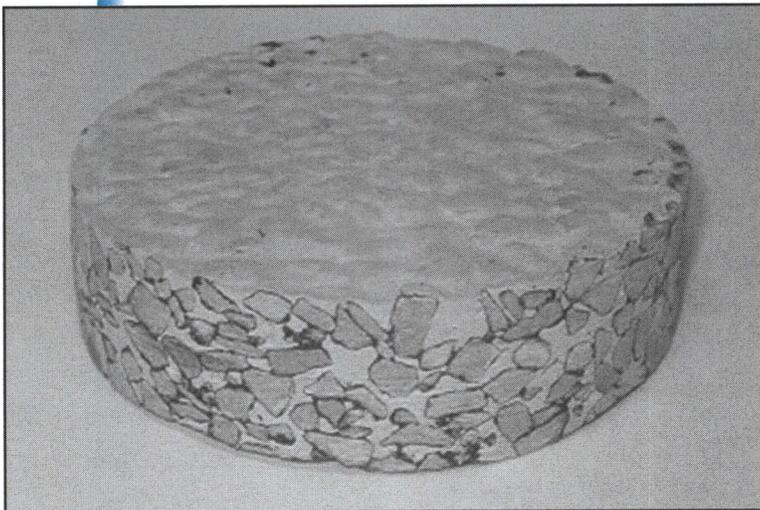


Figure 28. Stabiflex pavement section in Denmark. (Photo Source: Colas Danmark A/S, Denmark)

### INNOVATIVE MATERIALS

The scanning team learned about a variety of materials that meet the hosts' definition of superior materials. Like the test methods, a number of these materials have been introduced already in the United States, but are reported here to highlight their more widespread use (in some cases) in Europe. The team believes that some of these materials show promise for use in the United States as the pressures to better meet the needs and desires of the traveling public begin to dominate the decisionmaking process.

## Noise-Attenuating Pavements

- **Porous asphalt pavements**—Originally introduced to help with splash and spray issues, this pavement type has noise-attenuating properties that have made it popular in all of the countries visited. Some frictional issues that have been reported are believed to be due to the additives required to improve handling during the construction process.
- **Twin-layer asphalt**—While porous asphalts have become increasingly popular, difficulties have been reported with using them on lower-speed facilities. At high speeds, the traffic draws sand and other deleterious materials out of the pores, resulting in a self-cleaning surface. This does not occur, however, at the lower speeds typical of many city streets. A twin-layer paving system has been advanced that includes a larger stone porous matrix in a lower lift, covered by a porous mix with a smaller top size for the wearing course. The National Asphalt Pavement Association recently published an article on the use of twin-layer asphalts.
- **Helmholtz resonators**—Since about 1990, European researchers have been evaluating techniques to reduce noise caused by tire-pavement interaction using carefully engineered voids cast into the pavement termed Helmholtz

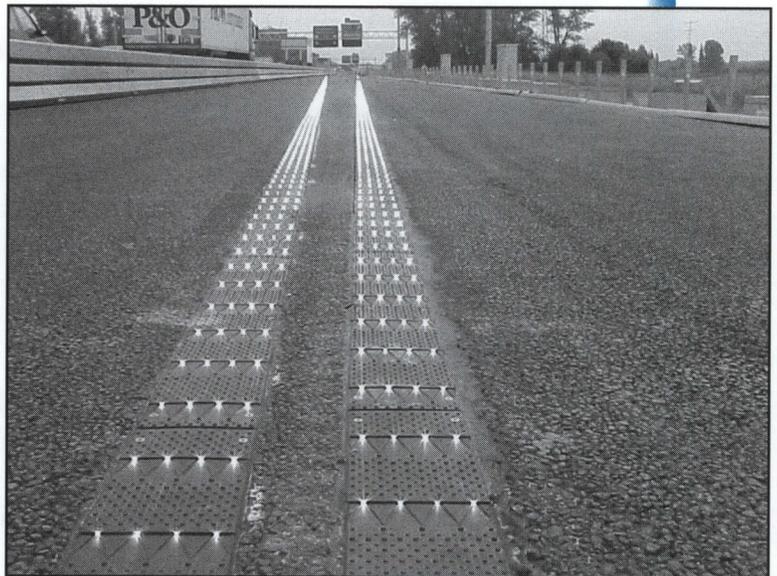


Figure 29. Dynamic road markings in the Netherlands. (Photo Source: Heijmans, The Netherlands)

resonators. These voids serve to dampen sound induced by excessive air pressure created as a tire rolls over the pavement. The scanning team observed these resonators firsthand on the Roads to the Future project. In this case, they were precast into a concrete layer used on some test sections.

## High-Friction Surfaces

In the United Kingdom, the team observed a number of superior materials introduced to meet high-friction requirements. These materials must not only meet frictional requirements, but also tests for adhesion, freeze-thaw degradation, and wear.

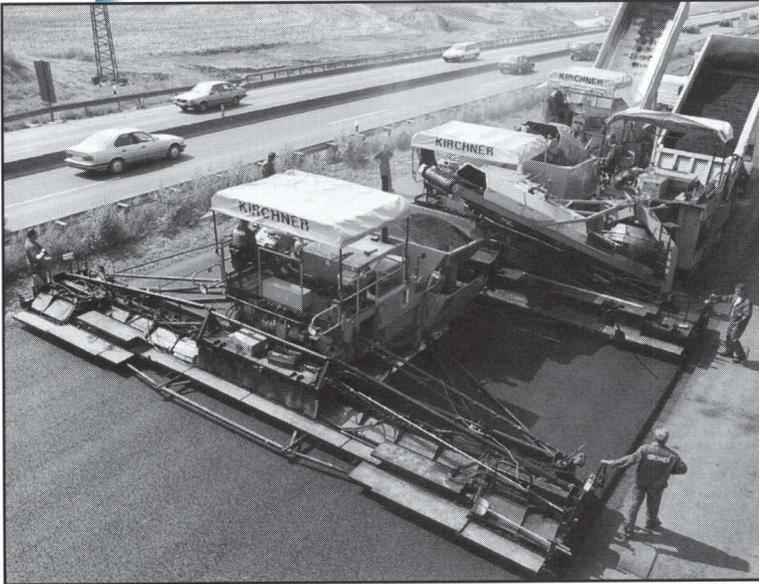


Figure 30. Two-course paving in Germany. (Photo Source: BAST, Germany)

### Waterproofing Orthotropic Decks

Because of the large deflections that commonly occur, orthotropic bridge decks are difficult to surface. The steel deck must be protected by a waterproofing system, but balancing minimal permeability with the need for a long-life wearing course flexible enough to tolerate high deflections is a challenge. A multilayered system of various polymer-modified materials has been advanced to meet this challenge.

### Low-Temperature Asphalt Mixes

Using a variety of organic and/or mineral admixtures, the Germans developed a process to manufacture and pave hot-mix asphalt at lower temperatures. Drivers for this technique included demands for lower emissions and reduced energy requirements.

### Semi-Flexible Asphalt

The team observed a variety of semi-flexible pavement systems that combine an open-graded hot mix skeleton with a polymer-modified grout. While some States in the United States have experimented with this type of pavement, some technology improvements observed in Europe may warrant further evaluation.

### Composite Pavements

While the Europeans construct few new concrete pavements, exceptions exist. On some projects, especially those being constructed under DBFO contracts, composite pavements are used. This pavement type consists of a new continuously reinforced concrete pavement (CRCP) overlaid with a durable hot-mix wearing course. Because the wearing course can be removed and replaced with relative ease, the functionality (smoothness, friction, and noise) of the facility can be maintained more easily.

### Fiber-Reinforced Concrete Inlays

Termed “NEWPAVE” by the United Kingdom’s TRL, this surfacing type is typically constructed as a 2-inch-thick concrete inlay for existing hot-mix asphalt pavements. Reinforced with both fibers and conventional mesh, the layer is rolled after placement to develop distributed microcracking rather than large working cracks.

### Rapid Concrete Repairs

In Germany, the scanning team observed a process for rapid panel repair of existing concrete pavements. Using a 16-cubic-meter mixer situated on a flatbed truck, the work is usually conducted at night. First, saw cuts are made on the cracked panel and the pieces are removed with a crane. Tie bars and dowel bars are then drilled and inserted, the concrete is placed, and a small vibrating screed is used for finishing. The roadway can be opened to traffic in 5 to 6 hours, since the process produces 4-hour strengths of 20 megapascals (Mpa) and 1-day strengths of 50 MPa.

Figure 31. External enclosure of bridges in the United Kingdom. (Photo Source: Highways Agency, UK)



### Dynamic Road Marking

An innovative approach to increasing traffic capacity was introduced to the team in the Netherlands. Working with industry, the Rijkswaterstaat sponsored the development of embedded pavement lights that can be used in lieu of paving stripe. Positioned at strategic locations, the lights can be illuminated in two different patterns to add a lane during peak hours.

## OTHER ISSUES AND CONSIDERATIONS

Additional observations include the following:

### Two-Course Paving

A unique hot-mix process was demonstrated in Germany that includes the laydown of two different lifts in a near-simultaneous fashion. The process made use of two pavers designed to work in tandem, with separate feeds for each paver. The result

is the ability to place a thicker section, which could take advantage of a hot bond. Furthermore, because of the increased mass, the paving season could be extended into colder weather than in the past.

### Noise

In all of the countries visited, the noise generated from vehicle-pavement interaction was found to have a profound effect on the decisions being made about pavement type selection. With many agencies requiring noise-reducing surfaces, industries were forced to respond quickly with viable and cost-effective solutions or face virtual elimination from the market. When the issue was first raised, the automotive, tire, and highways industries began to work together to identify common solutions.

### Damage-Based Taxation

As part of the accelerated load testing being performed in Germany, an assessment of pavement damage from truck (axle) loads is being made. The government believes that, based on the results of this testing, it can impose more rational taxation for trucks.

### Video Monitoring of WIM Stations

In the Netherlands, video units are being used at select weigh-in-motion (WIM) stations to identify overloaded vehicles in real time. The team believes that the same configuration could be used in the United States to identify unusual WIM data traditionally discarded during the data reduction process.

### Thaumasite

While visiting BRE in the United Kingdom, the scanning team learned about the results of a forensic investigation of concrete bridge piers. Severe deterioration of some concrete piers that were in contact with the native soils was observed. This deterioration was progressive and resulted in a complete loss of strength of the concrete. Thaumasite is believed to occur from a reaction between some types of concrete and aggressive sulfates under saturated and cool (less than 60° F) conditions. By better understanding the symptoms of this unique distress, guidelines for geotechnical investigations in the United States could be updated to increase the probability of identifying it in the field.

### Bridge Enclosure

In the United Kingdom, a technique was demonstrated that includes enclosing the bottom and sides of bridge structures with a permanent shell. The enclosure does not provide additional structural capacity, but instead facilitates bridge construction, inspection, maintenance, upgrading, and operation with minimum traffic disruption. It also provides corrosion protection, environmental protection, improved safety, and clear boundaries among responsible authorities.

## CHAPTER FOUR

# RECOMMENDATIONS

### ROADS TO THE FUTURE

The scanning team was impressed by a novel approach to exploring long-range solutions for meeting future highway demands in the Netherlands. The government integrated long-term perspectives with short-term test projects and demonstrations through a cooperative, split-funded program with industry called "Roads to the Future." The intent of this program was to examine road surfaces of the future and to develop demonstrable concepts for tomorrow's road surface. The agency's softer goals were to stimulate out-of-the-box thinking in both the agency and Dutch companies.

The government established three formal areas of interest: modular road surfaces, smart road surfaces, and energetic road surfaces. The criteria for the Modular Road Surface Program called for a surface that was prefabricated, noise reducing, easy to apply, and easy to remove. Private contractors were invited to offer solutions, no matter how unconventional. The tremendous response surprised the agency. Four techniques resulted in demonstrable projects in which the surfaces were placed on a freeway ramp. The scanning team proposes that one of these products be demonstrated in the United States.

### ACCELERATED PAVEMENT STRIPING WHEEL TESTING

Because of the expense and logistics associated with field-testing of lane markings (stripes), Germany has developed a laboratory facility for accelerated lane marking evaluation. This facility is capable of evaluating tape, temporary paint, and permanent paint markings. Since the facility began testing in 1989, nearly 2,000 materials have been tested. This specification can be found in CEN 13197.

The accelerated procedure consists of a wheel (8 meters in diameter) with spokes affixed with a rectangular test plate at the end. Each test plate is coated or painted as appropriate with pavement stripe material. As the test wheel rotates, the plates come in contact with up to six tires that apply pressure to each plate. The protocol describes the number of cycles and the environmental condition that the striping material is exposed to during the test. At predetermined cycles, the plate is removed and evaluated using various functional tests.

The scanning team recommends consideration of establishing a central test facility in the United States with an accelerated test apparatus for assessing the durability of pavement markings. With a basis in the proven German procedure, the new facility could include environmental controls to simulate various climates.

### INNOVATIVE PRODUCT DEVELOPMENT AND MATERIAL SPECIFICATION PROCESSES

The scanning team has identified several key processes worthy of additional examination. They include the EU, the British HAPAS program, and the French Charter for Innovation. Each has potential merit for implementation in the United States. The team was not able to clearly comprehend the full nature of the effort, the agreements, or the potential impact this may have on selling and procuring

products. While the United States is moving toward performance specifications, no formal national program or process is in place to coordinate and manage such a movement.

### **FUNCTIONAL MAINTENANCE CONTRACTING**

European public road agencies have faced many of the staff and funding cutbacks experienced by State DOTs. Also, they seek both innovation and cost-effective execution of their maintenance operations. All four countries the scanning team visited have experience with functional (performance-based) maintenance contracts. The United Kingdom is planning to award these contracts solely on quality. The Netherlands is working almost exclusively with these types of contracts and has moved to the second generation of specification. In Denmark, municipalities are beginning to use 10-to-15-year functional contracts for pavement surface renewal and restoration.

The transfer of work items associated with functional maintenance contracts includes the transfer of roles and responsibilities to the private contractor. This has an impact on the application of standards, material selection, mix designs, pavement design, quality control and assurance techniques, warranties, and independent government assessment of product value and safety.

### **RATIONAL APPROACH TO PAVEMENT SURFACE DESIGN FOR NOISE ABATEMENT**

The scanning team recommends that guidance be provided to help materials and pavement engineers supply State DOTs with rational approaches to addressing noise in pavement design, mix design, construction, and maintenance. This and other scans have identified noise generated in the highway environment as a problem of significant concern in Europe requiring innovative and sometimes expensive solutions. While U.S. DOTs have established procedures for designing and installing noise walls, only a few have addressed noise attributed to pavement type selection, material selection, and construction and maintenance techniques. Several DOTs are now addressing this problem by using modified pavement surface texturing such as diamond grinding or longitudinal tine texturing, or modified mixes such as crumb rubber, SMA, or open-graded asphalt friction courses as noise-attenuating surfaces.

Drivers' expectations and those of abutters to the highways are different in Europe than they are in the United States. As increasing numbers of State DOT material and pavement engineers consider noise issues, however, a more rational approach to pavement and mix design is needed to address the issue.

### **INNOVATIVE PRODUCTS, SPECIFICATIONS, AND TEST METHODS**

The scanning team identified numerous products, specifications, and tests that the European countries are using or developing that may be of interest to State DOT engineers in the United States. For a select number of these, the team believes that the logical step is to collect additional European background information. After the information is reviewed, potential benefits should be identified and compared to U.S. practice. Finally, a plan should be developed for possible introduction and

evaluation in the United States of select items. Items the team believes have the most potential for U.S. use include the following:

- Concrete pavement advancements
- U.K. thin surface friction treatments (HAPAS approved)
- External enclosures of bridges
- U.S. demonstration of pre-fabricated, rolled-out, noise-reducing pavement
- Torque bond test
- Automated raveling assessment
- Microscopy
- Wet pressure aging vessel
- Polymer content testing
- Pulse thermography
- Cold-in-place recycling functional specifications
- Danish and German orthotropic bridge deck waterproofing
- Low-temperature asphalt

## CHAPTER FIVE

# IMPLEMENTATION

### BACKGROUND

In June 2003, nine engineers from the FHWA, State DOTs, and private industry participated in a superior materials scan of four European countries. The team visited the United Kingdom, Denmark, Germany, and the Netherlands. Scan objectives included the following:

- Identify processes or procedures that bring superior products to market efficiently and quickly.
- Identify new technologies, test methods, or procedures that may improve State DOT material specification and testing programs.
- Implement the most promising and beneficial processes or technologies.

The team identified 18 items worthy of follow-up and possible implementation in the United States.

#### Group 1. Innovative Programs and Processes

1. The Netherlands' Roads to the Future program
2. Accelerated pavement striping wheel testing
3. Innovative European product development and material specification processes
  - European Union (EU) standardization process
  - New product certification program (British HAPAS)
  - French Charter of Innovation program
4. Functional (performance-based) maintenance contracting
5. Rational approach to pavement surface design for noise abatement

#### Group 2. Innovative Products, Specifications, and Test Methods

6. Concrete pavement advancements
7. U.K. thin surface friction treatments (HAPAS approved)
8. External enclosures of bridges
9. U.S. demonstration of pre-fabricated, rolled-out, noise-reducing pavement
10. Torque bond test
11. Automated raveling assessment
12. Microscopy
13. Wet pressure aging vessel

14. Polymer content testing
15. Pulse thermography
16. Cold-in-place recycling functional specifications
17. Danish and German orthotropic bridge deck waterproofing
18. Low-temperature asphalt

## **INNOVATIVE PROGRAMS AND PROCESSES**

### **1. Roads to the Future**

#### ***Background***

The scanning team was impressed with a novel approach to exploring long-range solutions for meeting future highway demands in the Netherlands. The government integrated long-term perspectives with short-term test projects and demonstrations through a cooperative, split-funded program with industry called "Roads to the Future." The intent of this program was to examine road surfaces of the future and to develop demonstrable concepts for tomorrow's road surface. The agency's softer goals were to stimulate out-of-the-box thinking in both the agency and Dutch companies.

The government established three formal areas of interest: modular road surfaces, smart road surfaces, and energetic road surfaces. Modular Road Surface Program criteria called for a surface that was prefabricated, noise reducing, easy to apply, and easy to remove. Private contractors were invited to offer solutions, no matter how unconventional. The tremendous response surprised the agency. Four techniques resulted in demonstrable projects in which the surfaces were placed on a freeway ramp. The team recommends one product for possible demonstration in the United States (see Item 9.)

#### ***Objectives***

- Develop a comprehensive paper on the Netherlands' Roads to the Future program.
- Raise awareness of the Roads to the Future program, targeting senior State DOT and FHWA research and policy officials.
- Develop a similar strategy appropriate for the United States.

#### ***Deliverables***

- White paper and slide presentation
- Action plan for further implementing the concept

#### ***Implementation Lead***

Scan implementation specialist

## 2. Accelerated Pavement Striping Wheel Test

### *Background*

Because of the expense and logistics associated with field-testing of lane markings (stripes), Germany has developed a laboratory facility for accelerated lane marking evaluation. This facility is capable of evaluating tape, temporary paint, and permanent paint markings. Since the facility began testing in 1989, nearly 2,000 materials have been tested. This specification can be found in CEN 13197.

The accelerated procedure consists of a wheel (8 meters in diameter) with spokes affixed with a rectangular test plate at the end. Each test plate is coated or painted as appropriate with pavement stripe material. As the wheel rotates, the plates come in contact with up to six tires that apply pressure to each plate. The protocol describes the number of cycles and the environmental condition that the striping material will be exposed to during the test. At predetermined cycles, the plate is removed and evaluated using various functional tests.

### *Objectives*

- Examine the German process in detail.
- Compare AASHTO's NTPEP pavement striping program to the German process and determine the potential benefits of switching to a wheel-testing program in the United States.
- If deemed beneficial and appropriate, develop various implementation strategies, including capital costs, operating strategies, partnerships with industry, etc.

### *Deliverables*

- A strategic paper that investigates possible application in the United States.

### *Implementation Lead*

AASHTO, FHWA, and scan implementation specialist

## 3. Innovative Product Development and Material Specification Processes

### *Background*

Under the AASHTO/FHWA International Technology Scanning Program, the superior materials scanning team has identified several key processes worthy of additional examination. They include the European Union (EU), the British HAPAS program, and the French Charter for Innovation. Each has potential merit for implementation in the United States. The team was not able to clearly comprehend the full nature of the effort, the agreements, or the potential impact this may have on selling and procuring products. While the United States is moving toward performance specifications, no formal national program or process is in place to coordinate and manage such a movement.

### **A. European Union Standardization Process**

Through its various commissions, boards, and associations, the EU has structured ways that individual countries cooperate in promoting trade and commerce in the transportation and highway construction fields. The EU standard-setting bodies addressing roadway and bridge construction are well into developing standards for many items, including asphalt concrete pavements and portland cement concrete pavements. The scanning team consistently heard new terms such as CEN, EOTA, and other programs involving individual countries.

Officials in each country discussed the major impact that this effort is having on their individual specifications, suppliers, laboratory programs, contractor pool, etc. The team was impressed with the way the highway agencies are cooperating in this complicated initiative. The process includes the development of functional specifications (commonly called end-result or performance specifications in the United States), laboratory certification programs, and classes of service for various products. It should be noted that the European process is geared to promoting free trade across country borders by agreeing on common specifications. The intent is to allow the countries and vendors who develop the products to discuss product data and performance within a unified framework, not to require road agencies to buy materials that do not meet their specific needs, budget, and conditions.

The scanning team believes that the European standardization effort eventually will have an impact on U.S. highway construction operations. European-based companies are expected to present new product data developed and approved in the European framework to potential U.S. customers. State DOTs could benefit from knowledge of the system and structure in place, the government partnerships, the new tests methods and techniques, the validity of performance data, and the independent vendor certification process. This undoubtedly would help DOTs understand the new products and expedite determination of their potential value on State projects.

### **B. British HAPAS Program**

The scanning team was impressed with the United Kingdom's HAPAS program. The program identifies key specification areas in which the Highways Authority and industry jointly develop a functional specification to replace a preexisting method specification. Once the HA approves the new specification, product vendors are free to develop products that meet these new functional requirements.

Before a new product is used, however, the HA requires an independent third party to thoroughly evaluate and certify it. In the United Kingdom, the British Board of Agrément (BBA) manages the certification program. It evaluates vendor-supplied performance data and inspects the vendor's facility and quality program. After the BBA issues the certificate, the vendor's product may be used on HA-funded contracts. The BBA also conducts periodic audits to reestablish compliance. The BBA maintains secret files on any proprietary material details that are fundamental to the product certification but are not required under the functional specification.

The HA (through the BBA certification) also requires that the product supplier certify the installation contractor. The vendor must certify that the contractor has been fully trained, is experienced, and has been formally certified to install the product.

The BBA is a government established, non-profit corporation with more than 30 years' experience in certifying products for the U.K. building trades. It is now the official certification agent for the HA under the HAPAS program and is well respected by industry.

The scanning team was extremely impressed with the results of the HAPAS program on thin friction surface treatments. Before the HAPAS effort, the HA had to select one of two proprietary products from one vendor. After 10 years, it now has 32 products from multiple vendors with a comprehensive certification program in place, an outstanding accomplishment.

### *C. French Charter of Innovation*

Each country visited mentioned that France had policies and programs that would be of interest to the scanning team. Officials also identified technologies developed in France years ago that are just now being evaluated in their countries. The French have instituted a public-private partnership to identify and develop new products and processes that by all indications is successful.

### *Objectives*

- Understand more fully European innovative material programs and processes, participating groups, missions, objectives, etc.
- Determine their impact on material specifications vis-à-vis method and functional specifications, new test procedures, certification, and compliance.
- Help State DOTs understand product information that references the EU tests and specifications.
- Determine if elements of the EU, HAPAS, and French processes could, if implemented, improve U.S. practices.

### *Tasks*

- Collect detailed information on the three processes, including site visits to U.S. and European EU offices, and interviews with key countries.
- Develop a comprehensive paper on how these systems work in practice.
- Compare the processes with U.S. practices and identify possible improvements to the U.S. system.
- In cooperation with the AASHTO Subcommittee on Materials, conduct a workshop to present the findings and to develop an implementation strategy, if appropriate.
- Working with the subcommittee, forward a final report with recommendations to the AASHTO Standing Committee on Highways.

**Implementation Lead**

Scan implementation specialist and AASHTO

**4. Functional Maintenance Contracting****Background**

The European public roads agencies have faced many of the same staff and funding cutbacks experienced by State DOTs. Also, they seek both innovative and cost-effective execution of their maintenance operations. All four countries the scanning team visited have experience with functional maintenance contracts. The United Kingdom is planning to award these contracts solely on quality. The Netherlands is working almost exclusively with these types of contracts and has moved to the second generation of specification. In Denmark, municipalities are beginning to use 10-to-15-year functional contracts for pavement surface renewal and restoration.

The transfer of many work items associated with functional maintenance contracts includes the transfer of roles and responsibilities to the private contractor. This has an impact on the application of standards, material selection, mix designs, pavement design, quality control and assurance techniques, warranties, and independent government assessment of product value and safety.

**Objectives**

- Obtain copies of the specific tender language from each country for sharing in the highway community.
- Participate in a national workshop focused on this concept with a select group of European public and private officials.
- Assist the FHWA Eastern Federal Lands Highway Division in developing and implementing a functional maintenance contract based in part on the European experience, with specific attention to pavement, bridges, signs, striping, etc. Study and apply as many principles as possible, linking them to the workshop.

**Tasks**

- Collect and synthesize European functional contracts. The team will collect as many of the detailed specifications as possible from the countries visited. This may require translation of specific documents.
- Conduct a performance-based maintenance contract workshop in partnership with TRB Task Force A5T60 on Accelerating the Adoption of Innovation. The task force is developing the program for the workshop, which is designed for senior State DOT officials. The goal is to invite select European officials to share their experiences and provide insights on materials-related issues.
- Once the first two tasks are complete, work with FHWA's Eastern Federal Lands Highway Division to implement appropriate European concepts, especially those associated with materials issues.

### *Implementation Lead*

Scan implementation specialist and FHWA

## **5. Rational Approach to Pavement Surface Design for Noise Abatement**

### *Background*

Many AASHTO/FHWA scans have identified noise generated in the highway environment as a problem of significant concern in Europe requiring innovative and sometimes expensive solutions. While U.S. DOTs have established procedures for designing and installing noise walls, only a few have addressed noise attributed to pavement type selection, material selection, and construction and maintenance techniques. Several DOTs are now looking at this problem, using modified pavement surface texturing such as diamond grinding or longitudinal tine texturing, or modified mixes such as crumb rubber, SMA, or open-graded asphalt friction courses as noise-attenuating surfaces.

European countries have had more than 20 years of experience in dealing with this issue and have evaluated many products and procedures. Currently, asphalt-based porous pavement that provides noise reduction, spray and splash reduction, and high-skid resistance appears to be an acceptable innovation. Other solutions include SMA. Porous pavements, however, may have an adverse impact on snow and ice control with the formation of black ice. They also have reduced life if sand clogs the pores.

For concrete pavements, the two-lift, wet-on-wet construction technique has been used with the Robucco process from Belgium. This technique was evaluated in 1993 in the European Concrete Pavement Demonstration Project in Michigan. The Robucco process has undergone changes since 1993, but has not taken hold in the United States or Europe. No other long-term concrete-surfaced pavement solutions are available in Europe.

Drivers' expectations and those of abutters to the highways are different in Europe than they are in the United States. As increasing numbers of State DOT material and pavement engineers consider noise, however, a more rational approach to pavement and mix design is needed to address the issue.

### *Objective*

- Provide materials and pavement engineers with rational approaches to addressing noise in pavement design, mix design, construction, and maintenance.

### *Tasks*

- Identify European and U.S. pavement surface products and processes, mix practices, and construction techniques as they relate to noise with consideration to spray, splash, skid, and product durability.
- Identify European and U.S. noise measurement techniques that quantify the noise level attributed to the pavement as a result of tire interaction and engine noise reflection.

- Identify European and U.S. noise standards, models, or procedures that attribute noise to the pavement and address mitigation with pavement surface solutions.
- Recommend a rational pavement surface design approach for noise that could be used in the United States.
- Recommend a rational noise measurement technique that could be used in the field. Prepare a guide procedure in AASHTO format.
- Recommend changes to the FHWA noise model to incorporate pavement type, mix design, and construction techniques
- Evaluate recommended test procedures through DOT and industry laboratory testing (optional if new equipment is not needed or is minimal to the effort).
- Prepare a plan for field demonstration and evaluation of proposed techniques.
- Prepare a final report.

### **Implementation Lead**

AASHTO and FHWA

## **INNOVATIVE PRODUCTS, SPECIFICATIONS, AND TEST METHODS**

### **6. German Concrete Pavement Advancements**

#### **Background**

The scan team identified four items of potential interest to the broader concrete pavement community:

- German geotextile drainage layer between the pavement slab and lean concrete base.
- German slow-setting unbound and slow-setting slag base under concrete pavements.
- German high-speed concrete pavement repair details.
- Role of composite pavements in European pavement technology. Composite pavement is defined as a continuously reinforced concrete pavement with a thin hot-mix asphalt surface wearing course designed and built as an integrated system.

#### **Objectives**

- Describe each product with specificity.
- Identify the possible benefits for U.S. implementation of each product.
- If deemed necessary, prepare research statements for inclusion in the FHWA Long-Range Concrete Pavement Research and Technology Plan being developed by Iowa State University.

### ***Deliverables***

If deemed appropriate, this technology will be included in the Long-Range Concrete Pavement Research and Technology Plan as either research or technology evaluation.

### ***Implementation Lead***

Scan implementation specialist

## **7. U.K. Thin Surface Friction Treatments (HAPAS approved)**

### ***Background***

Thirty-two thin surface friction courses have been approved under the United Kingdom's HAPAS functional specification and certification process. The test techniques are not common in the United States. Many DOTs may be interested in this surface type, but may not be familiar the functional test requirements or the approved U.K. products.

### ***Objectives***

- Determine if the functional specification developed in the United Kingdom is applicable to U.S. practices.
- Identify new products that may be of interest to U.S. engineers.

### ***Tasks***

- Collect the standards and product sheets.
- Evaluate the functional specification and any specific test methods included.
- Evaluate the specific products to determine if they are already available in the United States and if they are appropriate for U.S. use and application.
- Prepare a summary paper with recommendations to the highway community.

### ***Deliverables***

- Functional specification
- Test methods
- Product sheets
- Report with recommendations

### ***Implementation Lead***

AASHTO

## 8. EXTERNAL ENCLOSURES OF BRIDGES

### Objective

- Collect information and determine if there is further interest in the bridge community to pursue the topic.

### Tasks

- Collect and summarize European information.
- Solicit comments and recommendations from bridge engineers.
- Prepare final report with action plan, if warranted.

### Implementation Lead

FHWA

## 9. Prefabricated, Rolled-Out, Noise-Reducing Pavement Demonstration

### Background

Under the Roads to the Future Program in the Netherlands, an innovative pre-fabricated, rolled-out, noise-reducing pavement was developed in a partnership between the government and Vermeer Corporation. The scanning team witnessed the product in service and was impressed with the speed at which the product went from concept to demonstration in less than 2 years.

### Objectives

- Work with the Netherlands and Vermeer to see if pavement sections could be placed and evaluated in the United States.
- Raise awareness of the Roads to the Future Program and its ability to bring research products to the demonstration phase.

### Tasks

- Contact Dutch officials and determine the appropriateness of a demonstration project.
- If appropriate, set up demonstration site in the United States.

### Implementation Lead

Scan implementation specialist

## Items 10-18

### Background

The scanning team identified various tests that the European countries are using or developing that may be of interest to DOT engineers in the United States.

## CHAPTER FIVE: IMPLEMENTATION

### *Objectives*

- Collect additional European background information on each test.
- Identify potential benefits of the tests and compare to U.S. practice.
- Develop a plan for introducing and evaluating appropriate tests in the United States.

### *Implementation Lead*

AASHTO, FHWA, and scan implementation specialist

## CHAPTER SIX

# CONCLUSION

As a result of the scan, the team made numerous observations on the evaluation and adoption of superior materials. The team observed process differences between European and American practice, along with a number of unique technologies that may be worth considering in the United States. This section summarizes conclusions the team drew from the various observations it made.

### DRIVERS FOR INNOVATION

Overall, the team found numerous instances of the use of superior materials throughout the countries it visited. While the drivers behind their use varied, governmental policy was a major factor in most cases. Issues such as noise, safety, and sustainability (environmental stewardship) were identified at the highest levels of government as policy requirements. These policy mandates resulted in functional requirements for highway construction, which ultimately drove the selection of specific materials. Superior materials were identified as a way to meet the newer challenges countries faced.

The types of standards employed on a given job were also found to be a key driver behind innovation. In general, the less prescriptive and more functional the specifications are, the more likely it is that the contractor will consider the use of superior materials. The use of functional requirements for materials was commonly observed. In these cases, a set of requirements is established for a material that either directly or indirectly ties to the functional desires for that material (e.g., noise, friction, or smoothness limits). Finally, since quality was commonly included as a bid-selection criterion, contractors that opted to use more innovative materials to improve quality (lower life-cycle costs) had an advantage over those that did not.

### WARRANTIES AND INNOVATION

While shorter-term (materials and workmanship) warranties did not typically result in an increased use of innovative materials, they were reported to result in a higher quality of construction. On warranties in general, it was found that most parties are willing to warrant products with a sufficient track record.

In general, first cost was not found to be a significant driver behind the use of superior materials. Contracts that employ long-term warranty periods (DBFO contracts) are an exception. On these projects, life-cycle cost considerations become almost mandatory. As a result, more innovative materials are sought that are more likely to meet rigorous durability requirements in addition to a reasonable initial cost.

### PUBLIC-VERSUS-PRIVATE ROLES IN INNOVATION

The source of funding for identifying or developing superior materials is commonly a function of the length of return on the investment. Long-term innovations—more durable structural members, for example—typically require government support because it takes a long time to determine the outcome with certainty. Innovations

whose benefits can be realized in a shorter time—new construction techniques, for example—often are financed and developed by the private sector.

The nature of highway specification also has an impact on investment decisions for new technologies and superior materials. With a transition from prescriptive to functional requirements, vendors are offering the private sector additional solutions. This includes new opportunities to demonstrate products that may not have met traditional specifications, but are known to provide superior performance. Some public agency representatives believe that before functional requirements were in place, little incentive existed to approve the use of innovative materials. They mentioned that since additional risk was taken if a failure occurred and little incentive was offered if the product performed well, innovative materials normally were not approved.

The team also noted the adoption of performance-based maintenance contracting in the European countries. Privatization of maintenance is not new to the United States, but while most U.S. maintenance contracts prescribe the activities that must be conducted, functional requirements are increasingly sought in some of the countries visited.

Finally, the Roads to the Future concept is an example of how the public and private sectors can successfully partner to develop solutions to issues that will continue to be more relevant in the years to come, namely expedited construction, and improvements in smoothness, noise, and safety. In this project, the two parties split costs evenly. The private sector retained confidentiality on the details of processes for a specified time period.

### NATIONAL LABORATORIES

Most of the professionals the team members met with during the study were representatives of national highway laboratories. From these visits, the team concluded that national highway agencies have more centralized control in the material evaluation and approval process than U.S. agencies have.

Also worth noting is the fact that many of the national lab functions are in various stages of privatization. Some organizations, such as TRL and BRE in the United Kingdom, have been privatized. As a result, and for reasons mentioned in the last section, long-range research may suffer in the future.

While the team observed a number of benefits from the materials approval systems of the countries visited, it concluded that these systems are rather involved. Simply adopting parts of a materials evaluation and approval process may lead to unpredictable results.

In observing the national highway laboratories in Europe, the team reflected on the various roles of the national labs in the United States, including the FHWA Turner-Fairbank Highway Research Center, U.S. Corps of Engineers facilities, and U.S. Department of Energy labs. The team concluded from this comparison that the U.S. labs should continue to focus on long-range research and take an active role in encouraging private-sector innovation, especially technologies that address short-term issues. A good example is the Roads to the Future concept. National

leadership would be required to coordinate and fund a similar initiative in the United States.

### **OTHER CONCLUSIONS**

The team drew a number of additional conclusions from its observations. For example, a technique was demonstrated in which the manufacturer (vendor) for a given product certified the contractor (installer). This may prove beneficial in the U.S. market for those products whose quality is particularly sensitive to the installation process.

The team also noted that the majority of the innovations presented appeared to be incremental improvements to existing materials and processes. With minimal but targeted research and development, superior materials may be more quickly realized by building on the products and systems already in place.

Finally, while the team observed a number of interesting evaluation techniques and innovative materials, few were completely new to the team. With globalization of the construction market and a significant increase in technical communication over the past 10 to 20 years, innovation has migrated quickly from Europe to the United States and vice versa.

## APPENDIX A

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## APPENDIX C

### AMPLIFYING QUESTIONS

For decades, transportation professionals in the United States have recognized that it can be difficult to approve and specify new materials and manufactured products within the standard highway construction practices of State departments of transportation. At the same time, significant advancements have occurred in the invention and innovation of superior materials, including metals, concrete, asphalt, coatings, composites, and high technology add-ons.

While the American highway industry is slow to respond, numerous other industries—including national defense, energy, and to some degree, commercial construction—quickly adopt these superior materials. In addition, the highway industry in many European nations enjoys more widespread adoption of superior materials, with seemingly fewer obstacles, than in the United States.

Recognition of the failure of the American highway industry to quickly adopt superior materials is one of the drivers behind the need for this study. We believe it is important to explore the use of more superior materials in the construction of our highway infrastructure. As a result, the Federal Highway Administration (FHWA) International Technology Scanning Program initiated this scanning study of European materials and practices.

For purposes of our study, “superior materials” are defined as those materials and manufactured products that do the following:

- Improve performance of the constructed facility significantly.
- Are cost effective, both initially and throughout the facility’s life.
- Improve safety for the traveling public and/or the construction worker.
- Reduce construction time.

Furthermore, projects on which the superior materials can be employed include the following:

- New construction.
- Reconstruction of existing facilities.
- Rehabilitation, repair, and preservation of existing facilities.

As part of the overall study, the scanning team will seek answers to the following general questions:

- What is the process to approve superior materials for use?
- If proof of long-term performance does not exist for the material, what testing is used in its place?
- How are standard tests developed or adapted for a new material?
- If accepted for use, how is the material routinely tested to assure the required degree of quality?

In each the countries we will visit, we wish to meet with individuals in the following three categories:

1. Representatives of the national highway laboratories, including a visit to the testing facilities and/or ongoing field experiments.
2. Highway contractors, preferably on ongoing projects employing innovative superior materials.
3. Technical leaders (e.g. chief engineers or senior materials engineers) in the various transport ministries (or equivalent), providing an opportunity to exchange ideas on introducing superior materials in highway projects.

In preparation for the visit, the scanning team developed the following questions. They are intended to assist the dialogue and convey the specific issues on which we seek the wisdom of our European counterparts. While the intent of our visit is to get answers to these questions, we do not intend to limit the information that our hosts wish to provide.

### **MATERIAL INTRODUCTION**

1. What is a vendor's standard procedure for approaching an owner with a new material that the vendor believes can provide superior performance?
2. Who are the first people to review a potential new material? For example, is a panel formed of in-house specialists who can determine if further evaluation is warranted?
3. When a need for a more superior material is identified, how is the industry queried for potential solutions to fill that need?
4. Is a formal risk assessment made to determine if superior materials may prove beneficial to meet a given challenge?
5. If the owner develops a product in-house, how does its acceptance into standard practice differ than if a vendor introduced it?

### **MATERIAL EVALUATION**

6. How do you define "superior performance?" Does this mean that the material lasts longer, costs less, has a lower whole-life cost, and/or is more reliable (has a lower risk of premature failure)?
7. When and how are the claims of superiority of the material offered by the vendor (seller) verified by the owner (purchaser)?
8. Is there a standard process in place to determine when and how to evaluate new materials?
9. Has it been necessary to develop new test methods and/or equipment to evaluate new materials?

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10. If new test methods are developed, is consideration given toward using them for material quality verification during construction? If so, what skill level (training) is often necessary?
11. Is a particular emphasis made on developing rapid test procedures that, if used in construction for verification, can expedite the feedback loop during quality control?
12. To prove “superior” performance, what methods are used: accelerated test methods, simulation, or long-term, full-scale field trials? What are typical periods (durations) of evaluation of a material before a decision is made?
13. Who conducts the testing/evaluation of the material? A national laboratory? Private consultant?
14. Who pays for the testing/evaluation of the material?

### MATERIAL SPECIFICATION

15. How does the owner typically buy materials for ongoing routine applications?
16. How can a specification be developed to ensure that the contractor (builder) provides superior materials?
17. In the United States, most materials specifications are modeled after AASHTO or ASTM International (formerly American Society for Testing and Materials) standards. The process of developing a specification can take many years. Is there a faster method of creating and agreeing on standardized test methods for materials?
18. In the United States, a new material is often specified under a “special provision” to the contract for a specific project. As the use of the material becomes more common, a “standard specification” is developed, but this process can take years. Is this process similar in your country? If so, how quickly are your superior materials moved from “special” to “standard” specification? How does this process work?
19. When a material is evaluated and deemed superior in performance, how often does it become a standard of practice? How long after the evaluation is over is the product typically used?
20. Does the vendor of a material contribute to the development of the material specification? How often does this occur? In what capacity do they contribute (e.g. panel membership, providing a “guide” specification)?
21. Are specifications for new materials typically prescriptive based (in which the process of constructing the material is specified) or end-result based (in which the final product as built is evaluated for quality)?

### MATERIAL CONSTRUCTION, QUALITY CONTROL, AND QUALITY ASSURANCE

22. Are statistical acceptance methods used during construction to assess quality? How are lot sizes and variabilities established for a new material?

23. For fabricators of some materials (e.g., vendors for prestressed concrete girders), is an owner-approved quality plan required before production proceeds? What does this plan typically include? For example, quality-control procedures, personnel qualifications, and test equipment standards?
24. Is specialized equipment sometimes required when using new materials? Is there a formal approval process for this equipment in addition to the material?

### **MATERIAL PERFORMANCE VERIFICATION**

25. What performance standards are typically used (e.g., pavement distress)? What process is used to define these standards? Are users of the highways (the public) involved in this process?
26. Is the performance of field trials of new and superior materials formally tracked? If so, by whom and how?
27. Can your pavement or bridge management systems be used to track the performance of projects employing superior materials? Is construction or materials data included or linked to the performance database? Are “lesser” materials (e.g., guardrail or retaining walls) tracked in a management system as well?
28. Are assessments made of the value provided by the superior materials compared to the additional cost? Is whole-life costing used in this assessment?

### **SPECIFIC MATERIALS AND PRODUCTS OF INTEREST**

29. Please list five to 10 specific materials that have been identified as providing superior performance when evaluated by your agency. On what basis was your decision made (e.g., initial cost, whole-life cost, longer performance period, reliability)? Examples of particular materials or techniques of interest to the scanning team include the following:
  - Drainage products
  - Geotechnical modular wall systems
  - Soil improvement products
  - Signing materials
  - Striping materials
  - Structural composites and steels
  - Performance-enhancing admixtures/additives for concrete or asphalt
  - Materials for rapid reconstruction of concrete pavement (are specifications used for in-place strength to expedite opening to traffic?)
  - Materials for rutting resistance from studded tire wear (e.g., thin bonded overlays of polyester concrete)

- Dowel bars for concrete pavements of ultra-long life (more than 80 years)
- Traffic controllers (signal controllers)
- Materials that address thermal differentials and associated density differentials in asphalt pavements
- Retaining walls (e.g., tieback anchors, soil nails, or other soil reinforcement materials)
- Materials to minimize moisture sensitivity of asphalt binder in asphalt pavements
- Stabilization materials for pavement bases
- Polymer modifiers for asphalt cement that provide ultra-long life or other superior performance
- Materials for mitigation of problems with roadways built on expansive (high volume change) soils such as heavy clays
- Process additions in cement (What are typical percentages? Does the use of these process additions result in different percentages of supplemental cementitious materials—fly ash, ground granulated blast furnace slag, silica fume—being used at the batch plant?)
- Materials for asphalt pavement maintenance
- Fiber-reinforced composite materials
- Processes used to expedite the acceptance of concrete, soil, and asphalt (e.g., density)

### POLICY AND COST ISSUES

30. Do governments and/or agencies have any legislation, regulations, or policies that endorse, encourage, expedite, or financially support the adoption of new technology? What pressures or lobbying led to the adoption of this legislation, regulation, or policy?
31. What procedures have been implemented to shorten the time needed to develop and implement superior materials?
32. Are any superior materials beneficial to the environment, compared to conventional alternatives?
33. What are your standard implementation practices for new ideas, technologies, and materials?
34. When demand for a new material is identified, is it publicized (advertised) to allow competitive forces to offer various alternatives?
35. Do you allow specification of proprietary products? Is special justification required? If so, what justification is often used?

36. Are there additional obstacles to using materials not invented in your country (i.e., importing technological advancements)?

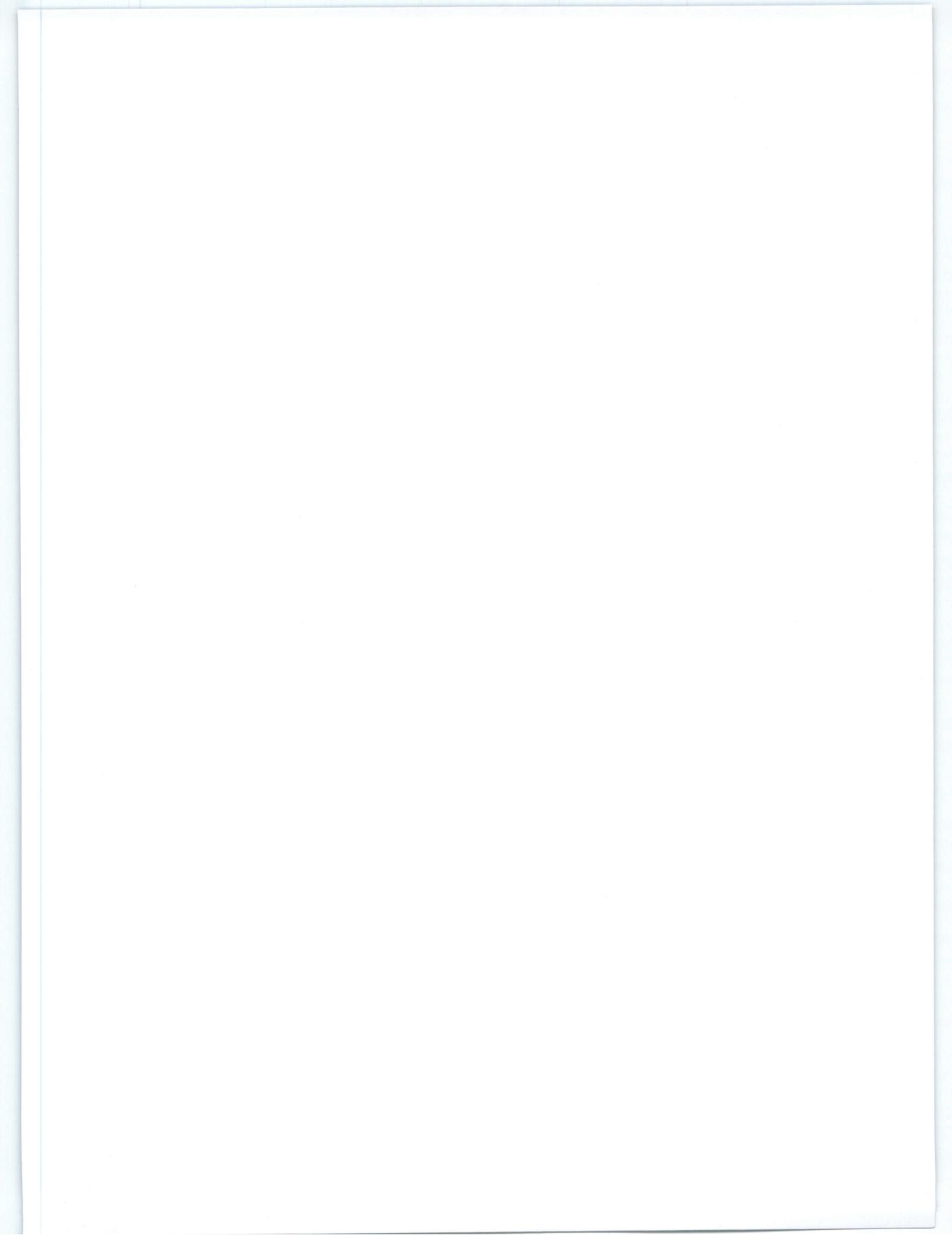
### **ROLES OF STAKEHOLDERS**

37. Do you collaborate with other countries, agencies, universities, vendors, contractors, etc., to identify, evaluate, and specify new materials?
38. Do you share your results of identifying, evaluating, and specifying new materials with other countries, agencies, authorities, etc.?
39. What role does the product manufacturer have in verifying the performance claims? What role do the product manufacturer's competitors have in the verification process?
40. Are practices for using superior materials different for concessionaires than for government agencies? Of the two, which tends to be more conservative in adopting new materials? Do they share results, or are independent evaluations common? Do multi-country private industries tend to bring things across borders?









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