FHWA Study of South African Pavement and Other Highway Technologies and Practices

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FHWA Study of

South African Pavement and Other Highway Technologies and Practices

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Particular acknowledgment is due to American Trade Initiatives, Inc., for coordinating and escorting the team, planning the travel, and producing the report.

EXECUTIVE SUMMARY

Introduction

With the new Republic of South Africa Government in power and the lifting of United Nations sanctions, the country is opening up to the outside world. South Africa is very advanced in many highway technologies, including concrete and asphalt materials, pavements, and low-volume roads. Many of these design and construction techniques are largely unknown in the United States, but are understood to be advanced and cost effective. The March 1995 signing of the Memorandum of Understanding between the Federal Highway Administration (FHWA) and the South African Department of Transport (SADOT) allows for joint activities between the two agencies and provides avenues for information exchange and the mutual sharing of ideas, practices, and experiences.

This summary highlights the findings of a U.S. scanning tour to study the Republic of South Africa's pavement and related technologies. This scanning tour was sponsored by the FHWA and conducted May 13–17, 1996. The scanning team was composed of representatives from Federal, State, and local governments; contractors; contractor associations; and a consulting engineer. As expressed in the team's mission statement, the purpose of this trip was "to observe what the South Africans are doing well with regard to their highways, learn from them, and inform the U.S. highway community." Effort was also made to "facilitate some linkage between the U.S. and South African private sectors as a means of facilitating future cooperation and exchange."

Organizations Visited

The scanning team met with one or two organizations each day. Personnel from the organizations were both thorough and generous with the information they presented within limited time restrictions. The organizations visited are as follows:

- SADOT
- Cement and Concrete Institute (CCI), formerly Portland Cement Institute
- South African Bitumen and Tar Association (Sabita)
- Council for Scientific and Industrial Research (CSIR)
- South African Federation for Civil Engineering Contractors (SAFCEC)
- National Black Contractors and Allied Trades (NABCAT)
- South African Association of Consulting Engineers (SAACE)
- South African Black Technical and Allied Careers Organization (SABTACO)

Road Funding in South Africa

Central fiscal allocations, special allocations from the Government, private sector loan funding, and toll income are the primary sources of funding for rural roads in South

Africa. Central government funds currently available cover only 60 percent of required maintenance for these roads. This fact has forced the South African Roads Board (SARB) to investigate alternatives for financing roads. As a result, the use of tolls has become a major source of funding for new construction and many other road projects in South Africa.

The South African Government promotes private sector involvement for both financing and developing infrastructure projects. Two of the most common private sector financing mechanisms are contractor-arranged financing and build, operate, and transfer (BOT) arrangements.

Contractor-arranged financing can include commercial loans, export credits, and occasionally, soft loans as "seed money." This type of financing is used to alleviate the need for public authorities to finance projects up front. Instead, debt serving begins after the Government and public realize the benefits from the facility.

In a BOT arrangement, the developer finances, builds, and operates the project and collects tariffs from users; although, in some cases, the collection is done by the state. At the end of the franchise period, the facility is transferred to the Government at no cost. There are prerequisites for initiating BOT projects, and once these are met, it is necessary to address certain key issues to successfully package the project to make it attractive to potential investors.

Research

The South Africans have done a superb job of conducting valuable and useful research. Their research projects are approached with an end use in mind, and they take care not to duplicate other international research efforts. Existing research is also used, where applicable.

Much of the research for SADOT is conducted by CSIR (a research agency under the South African Ministry of Trade and Industry). Many organizations with which the scanning team met also conduct various research projects on their own. These organizations have been quite effective in identifying, developing, and implementing research technology, often in cooperation and partnership with CSIR and SADOT.

The heavy vehicle simulator (HVS), which was developed by CSIR, has been used to conduct in situ accelerated pavement testing (APT) in South Africa on a range of research projects over many years. Such well-directed use of the HVS has played a very important part in helping to calibrate the field performance of old and new paving materials. Similar studies have been conducted to test technical design models to improve South Africa's states of the art and practice in paving technologies.

Recently, however, the South Africans have expressed some concern that research efforts may have lost some direction and long-term focus. CSIR's Division of Roads and Transport Technology (DRTT) has responded by examining other research programs and, more specifically, current concepts and models for technology management. As a result, an integrated, or holistic, framework has been proposed for managing the development of transportation technology in South Africa. This framework has clear application to transportation research in the United States, at both the State and Federal levels.

Finally, South African agencies have done an excellent job of recording their research findings. They are tireless in their efforts to document and share their findings by producing numerous manuals and reports.

Pavement Technology

South Africa has developed and implemented mechanistic design procedures for both flexible and rigid pavements. The procedure for flexible pavements was implemented in 1978, and subsequent updates were made in 1981 and 1994. Ongoing improvements to the procedure for flexible pavement design, particularly the transfer functions, can be attributed to extensive accelerated testing of in-service pavements using the HVS. A mechanistic procedure for the design of rigid pavements was recently introduced and is currently the subject of a draft SADOT manual. Rigid pavement procedures consider traffic loadings, temperature curling, and base erosion.

South African designers emphasize a good foundation support (subgrade) under their pavements. Granular subbases or stabilized subbases are placed under all pavement sections. Secondary road pavements typically include approximately 150 mm of subbase under untreated bases, although some older pavements do consist of lightly treated bases. The attention given to foundation design and construction is believed to contribute significantly to the high performance level of pavements in South Africa.

An unusual inverted pavement design is used on some routes that have heavy truck traffic. The design consists of a fairly thick (150 to 300 mm), cement-treated subbase, constructed under a 150-mm layer of very stiff crushed stone (G1) and compacted to a dense state using a final wet-slush rolling technique. This, in turn, is covered with a fairly thin asphalt surfacing (40 to 50 mm) or with designed surface seals. The unique inverted pavement design has provided very good long-term service in South Africa. The scanning team observed construction of this pavement design on the BOT project on the N1 highway, north of Pretoria. The contractor for this BOT project selected this pavement design over more conventional designs. This selection speaks well of the performance and economy of this design, because the N1 project contractor must build and maintain the pavement for 23 years, then restore it to an essentially "new" pavement before transferring it to SADOT.

Project Management and Contracting

The South Africans use a "schedule of quantities" in their contracts, which allows changes in the scope of work, if necessary. Contracts are typically awarded to the lowest bidder. What is notable about South Africa's bid requests is that bidders are required to include an explanation of how the contractor intends to address improvement of employment opportunities and living conditions for disadvantaged citizens. Some of the improvements proposed include providing training, employment, and subcontracting opportunities and building houses and community facilities. If a low bidder's plan is not approved, contracts are awarded to the next lowest satisfactory bidder.

Human Resource Development

Although the scanning team observed only limited formal training firsthand, the South Africans appear to offer a wide variety of formal construction training courses for both skilled and unskilled laborers. For example, the CCI provides courses through its School of Concrete Technology. In addition, SAFCEC offers a variety of formal training courses for both workers and "participating contractors" through its subsidiary training arm, the Civil Engineering Industry Training Scheme (CEITS).

Another interesting program in South Africa is the National Public Works Programme, which is part of the Reconstruction Development Plan (RDP). The objective of the program is to create "an enabling environment" through labor-intensive projects that focus on worker and supervisor training and through development of opportunities for small contractors.

Other Highway and Pavement-Related Technology

The scanning team visited a new interchange construction project in which a bridge was being "jacked" under the existing N1 freeway. The bridge, with full abutments, was constructed next to the existing embankments, then pulled through the embankment while the embankment was excavated at the contact face. Clearances were quite limited—less than a meter between the top of the bridge and the top of the existing pavement surface. This technique was used to minimize impact on traffic and eliminate use of temporary structures.

CSIR researchers have also developed a vehicle-road surface pressure transducer array (VRSPTA) to measure tire/road interface stresses under moving tires. The system simultaneously measures the vertical, transverse, and longitudinal vehicle tire/road interface stresses and strains. Results of the testing appear to be promising in evaluating tire/road interface stress patterns.

Findings and Transferability

The scanning tour of South Africa was conducted to observe, discuss, and document detailed information on South Africa's pavement and other related highway technologies. South Africa has a reputation in the international transportation community for high-quality engineering and research in pavement technology. The team encountered pavement technology during its tour that was clearly advanced; however, 1 week was adequate for only a general overview—much too short a time for an in-depth review of specific pavement technology.

Tour participants agreed that the following areas of pavement technology observed in South Africa were unique or uniquely advanced and had potential application in the United States:

- BOT concept
- Broad funding sources for research
- Technology management
- Use of HVS for APT

- Construction of stiff foundations for pavement support
- Development and *use* of mechanistic pavement design
- Establishment of a Superpave Center
- Construction of extremely stiff granular base courses
- Contract award negotiation for better labor use and training
- Organizational links to enhance training and assistance programs
- Labor optimization strategies and technologies
- Industry-driven, project-specific training
- Use of surface or "chip" seals.

To fully gather and document the detailed information involved in many of the highly technical areas will require a longer and more specific scanning tour visit. The scanning team recommends that FHWA conduct extended and specific technology-directed studies, if technology transfer to the United States is desired.

In some areas, it may be more efficient to invite individuals from South Africa to come to the United States for presentations to specific but larger technical groups. For example, the work CSIR has done to create a holistic framework for technology development should be of considerable interest to the FHWA Highway Research Center and the American Association of State Highway and Transportation Officials (AASHTO) Subcommittee on Research. However, a more specific and in-depth scanning tour to South Africa should take place, before this is undertaken.

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1.0 INTRODUCTION

1.1 Purpose

From May 13 to 17, 1996, FHWA sponsored a scanning tour to observe, discuss, and document information about South Africa's successful practices in concrete pavement, asphalt pavement, and other highway-related technologies. This information was to be disseminated to the U.S. transportation, engineering, and contracting communities. In simple terms, the purpose of the scanning tour was to observe what the South Africans are doing well with their highways, learn from them, and inform the U.S. highway community. In addition, efforts were made to introduce and facilitate some links between the U.S. and South African private sectors as a means of fostering future cooperation and exchange.

1.2 Background

FHWA is currently engaged in assisting SADOT with establishing technology transfer centers and is also providing information on conducting demonstration projects to achieve technology transfer at a faster pace. Over the last few years, a few FHWA engineers visited South Africa to conduct these activities. Informal discussions with SADOT personnel and industry representatives revealed that both sides have a strong desire for technical exchange in several areas. FHWA engineers involved in this effort had the opportunity to visit a few construction sites and meet with representatives from CCI and CSIR and a few consultants. These engineers believed that much could be gained from a scanning tour from the United States, with participation of FHWA, State Departments of Transportation, and private industry.

In the past, a few FHWA and other U.S. engineers have met with representatives of the South African highway community in South Africa, but in most cases, the South Africans have traveled to the United States. With this in mind, a scanning visit was proposed to learn the states of the practice and technology in South Africa and to link the contractors and industries of the two countries. The scanning visit could result in the sharing of information, show processes that could possibly improve the state of the practice in the United States, and provide a means of introduction and cooperation for industry associates as opportunities arise in South Africa, and other sub-Saharan countries.

1.3 Scope

The 1-week scanning tour focused on concrete and asphalt materials, concrete and asphalt pavement design, construction, and pavement maintenance practices, as well as low-volume road design, construction, and preventive maintenance practices. Information on South Africa's various contracting practices was also obtained. Contacts were established with technical leaders who could offer immediate detailed design, construction, and maintenance information and participate in a long-term network for future cooperation.

1.4 Team Members

The scanning tour team members included representatives of Federal, State, and local governments; contractors; and contractors' associations and a consulting engineer. The team members were as follows:

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1.5 Format of Report

The scanning tour was limited to visits to organizations in the Pretoria and Johannesburg areas. The organizations visited gave both formal and informal presentations, which were sometimes combined with field trips. A large amount of information was presented over the short 5-day period. The scanning team's 1-week program itinerary is shown in Table 1.

Table 1. Scanning Tour Itinerary

Date	Morning	Afternoon	Site Visit
May 13	SADOT		Toll Road Facility
May 14	CCI	Sabita	Portland Cement Concrete Pavement (PCCP) Labor-Intensive Rehab./Widening
May 15	CSIR		Operation of HVS
May 16	SAFCEC, NABCAT		Toll Road From Warmbaths to Pietersburg
May 17	SAACE, SABTACO	SADOT	Soweto Macadam Project, Bridge-Jacking Project

It is impossible for this limited report to adequately cover all the information presented during these meetings and field trips. For example, SADOT provided the team with over 40 bound publications containing information or recommendations for road building and design, published either by the Chief Directorate for Roads or the Committee of State Road Authorities. Sabita also provided close to 20 manuals. This report only highlights the technical material presented over the 5-day period.

The various organizations visited discussed the subjects of road funding, research, pavement technology, project management, and human resources from their individual points of view and involvement. To provide some reasonable order and continuity to this report, it has been organized into the following six subject areas, which were covered to varying degrees by each organization:

- Organizations Visited
- Road Funding
- Research
- Pavement Technology
- Project Management
- Human Resource Development.

In addition, a section titled "Other Technologies" is included to cover unique areas of interest that did not fall into any of the main subject categories. The final section in this report, "Findings and Transferability to the United States," emphasizes specific technical areas that could be transferred to the United States to improve the states of the art or practice of road design and building.

2.0 ORGANIZATIONS VISITED

2.1 South African Department of Transport

The scanning team met with personnel from SADOT on the first day of the tour. A list of those participating in the meeting from SADOT is in Appendix A.

SADOT is responsible for national transportation facilities for land, air, and maritime transport. Air and maritime transport responsibilities are managed by the Civil Aviation and Shipping Branch, which has separate chief directorates. Land transport responsibilities are managed by the Land Transport Branch, which is subdivided into separate chief directorates for urban transport, road traffic, and roads.

The team met primarily with Dr. Malcolm Mitchell, Deputy Director General for Land Transport, and Mr. Naxir Alli, Chief Director, Roads, and his staff, which manages the operational directorates listed below:

- Strategic Planning
- Geometric and Structural Design
- Financial Programming and Land Administration
- Construction and Maintenance
- Materials and Pavement Engineering
- Toll Roads.

The arrangements for all the scanning team's meetings and field trips were coordinated by Mr. Jaco Wiesner, Manager of the Technology Transfer Center, and Mr. Basie J.P. Nothnagel, Director for Materials and Pavement Engineering.

Responsibility for managing the entire road network in South Africa is shared by the SADOT Road Chief Directorate, the nine provincial governments, and the urban governments, which consist of cities and townships. The SADOT Road Chief Directorate is responsible for designing, constructing, and maintaining the national road system, which has a total length of 6,100 km. The nine provinces are responsible for designing, constructing, and maintaining their respective provincial road networks, as well as maintaining part of the national road system. The combined provincial road network totals close to 360,000 km, a large portion of which is classified as tertiary, unsurfaced roads. The urban road network totals close to 165,000 km and is managed by individual cities and townships. A large proportion of the urban road network is also classified as tertiary roads, which are predominantly unsurfaced.

SADOT is also responsible for developing and providing standards and guidelines for road design, construction, and maintenance.

The following subjects were covered in meetings with SADOT:

- History and overview of roads in the Republic of South Africa
- Overview of the road industry in the Republic of South Africa
- Road funding
- Toll roads in South Africa

- Management systems
- Maputo and other development corridors
- Types of contracts and small, medium, and micro enterprises
- Quality control for contracts
- Pavement engineering.

2.2 Cement and Concrete Institute

The scanning team met with members and staff from CCI in the morning of the second day. A list of participants is in Appendix A.

CCI was established in 1938 to provide technical services to all users of cement. It is funded by cement-producing companies, such as Anglo-Alpha, Ltd.; Blue Circle, Ltd.; PPC, Ltd.; and NPC, Pty., Ltd.

CCI's stated objectives are to:

- Act as a clearinghouse for information and technical data on the many uses of cement and concrete
- Extend the scope and use of these materials
- Promote the improvement of construction methods.

The Institute has a staff of professional engineers and technologists, as well as technicians, and a number of specialist consultants in such fields as geology, petrography, corrosion, and quality assurance. CCI provides the services listed in the following paragraphs, which are available to all Portland cement users.

2.2.1 Advisory Services

Engineers and technologists provide information and advice on the use of cement and concrete in projects of any size and type. Advice is given in response to inquiries by telephone, in writing, or by personal visit to one of CCI's offices. Problems are also investigated on site.

2.2.2 Laboratory Services

CCI's laboratories in the cities of Midrand, Durban, Cape Town, and Port Elizabeth are equipped to carry out a wide range of tests on materials for cement-based products and on the products themselves. All four laboratories have been accredited by the South African Bureau of Standards for compliance with SABS 0259.

2.2.3 Education and Training

The CCI School of Concrete Technology offers a range of courses in the production and use of concrete on both practical and technical levels. The courses range from basic construction practices to advanced concrete technology. Qualified civil engineers and technologists present the courses, which are designed to offer the ideal combination of theory, practical hands-on training, and laboratory sessions.

2.2.4 Library Services

The Institute's library in Midrand has the most extensive collection of literature on cement and concrete in Southern Africa.

The library is open to all members of the public for reference and research. Smaller libraries operate from the regional offices.

2.2.5 Urban and Rural Development

By training people to both make and build with cement, bricks, and concrete, CCI contributes to reducing the housing shortage and creating employment opportunities.

2.2.6 Publications

CCI publishes leaflets, booklets, and books and stocks items on concrete by other publishers.

The Portland Cement Institute, now CCI, developed the Portland cement concrete (PCC) pavement design procedure, previously used by SADOT, the provinces, and consultants. The Institute has followed, and is very familiar with, the design, construction, and performance of all PCC pavements in South Africa.

The following topics were covered in the meeting with CCI:

- Cement industry and the role of CCI
- Design of concrete roads
- Construction of concrete roads
- Repair of concrete roads.

2.3 South African Bitumen and Tar Association

The scanning team met with Sabita on the afternoon of the second day. For a list of participants, see Appendix A.

Sabita is a nonprofit association funded by members of the bituminous product and construction industry to serve the membership and users of its products and services through engineering, research, service, and education. Its current membership totals about 35 companies.

Sabita's stated goal is:

> to develop asphalt technology, education, and training at the appropriate levels, and, through contact with decision makers in governments, the public and private sectors, the media, and organized industry and commerce, to promote the economic and social upliftment value of asphalt as a product critical to the transportation needs of Southern Africa.

The primary goals of the association are to:

- Promote excellence in the technology and all matters allied to the industry
- Provide a forum for discussion, the expression of views and opinions, and proposals for the technology associated with the industry.

To meet these goals, Sabita is heavily involved in education and training. It supports a university chair in asphalt pavements and conducts courses in the basics of bitumen and asphalt testing, participating in two to three implementation seminars each year. It produces an educational series that consists of 16 manuals and 17 videos. Sabita provides membership and financial support for the Society for Asphalt Technology (SAT) and participates in the Bituminous Materials

Liaison Committee. It also serves as the secretariat for both SAT and the Conference for Asphalt Pavements for South Africa.

In addition to participating in a wide range of activities in the technological arena, Sabita also directs significant resources to its communication program. Its communication activities include:

- Acting as speaker for the industry in the national media and on national and international committees and making presentations to elected and appointed officials in government at all levels

- Providing the road industry with a wide range of forums for technology exchange and development and offering accredited public contact forums to promote realistic and practical specifications and procedures

- Providing a better understanding of the value and functions of roads (i.e., their use in the efficient delivery of goods and services to better manage a growing economy) to newly elected and appointed officials at local government levels.

The following subjects were covered in the meeting with Sabita:

- Overview of Sabita and its operating environment

- BOT contracts

- Repair, operate, and maintain contracts

- Bitumen-rubber in Southern Africa

- Technology development achievements

- Surface seals in South Africa

- New technology development.

2.4 Council for Scientific and Industrial Research

The scanning team met with CSIR representatives on the morning of the third day. In the afternoon, the team visited a site where CSIR was conducting a test on a rural pavement using the HVS. A list of participants is in Appendix A.

CSIR has played an integral part in the development of South Africa as a nation and in its technological advancements for over 50 years. During the past 10 years, CSIR has become a market-driven research and development organization with 13 divisions that employ approximately 3,200 scientists, engineers, and support staff personnel.

CSIR's mission statement indicates that the Council's focus is:

> to perform research and development to gain technology, and thereafter insure its implementation in order to:
>
> - Be the technology partner of the transportation industry in both the

formal and informal sectors to promote economic growth;

- Provide technology solutions that improve the quality of life in urban and rural developing communities; and

- Provide scientific and technological support to enhance decision making in the public and private sectors.

The 13 principal divisions of CSIR are:

- Building Technology
- Earth, Marine, and Atmospheric Science and Technology
- Energy Technology
- Food Science Technology
- Forest Science Technology
- Information Services
- Manufacturing and Aeronautical Systems Technology
- Materials Science and Technology
- Microelectronics and Communication Technology
- Mining Technology
- Roads and Transport Technology
- Textile Technology
- Water Technology.

The team visited CSIR's Division of Roads and Transport Technology (DRTT); a chart showing the division's various program areas is included as Appendix B. Presentations were conducted by the Roads and Transport Division Director and by members of the Road Engineering and Maintenance and Infrastructure Management Programs. The research program conducted by DRTT, and the results of that program, have had significant impact on the states of the art and practice of road building in South Africa.

The following subjects were covered in the meeting with representatives of DRTT:

- Overview of CSIR

- Technology management in the road engineering program

- The HVS and its impact on South African pavement engineering technology

- Design and use of large aggregate mix and modified binders in South Africa

- Labor-enhanced construction of emulsion-treated bases

- Structural design of road pavements.

2.5 South African Federation for Civil Engineering Contractors

The team met with representatives of SAFCEC on the morning of the fourth day. In the afternoon, the team visited the contractor's office and training facility and observed active construction on the BOT project on the N1 route between Warmbaths and Pietersburg. A list of those participants is in Appendix A.

SAFCEC was founded in 1939, has over 250 members that are contracting companies, and has branches throughout South Africa. Its main functional areas are:

- Contractual Affairs
- Economic Affairs
- Manpower Affairs
- Public Relations
- Regional Training.

Contractual Affairs covers issues of contract interpretation by working with major clients on such issues as standardization of contract documents. Economic Affairs not only tracks general contract activity, but also provides an electronic bulletin board service to its members that tracks all tenders (bids) and awards. Current active tenders are available through the bulletin board for contractor review. If a contractor finds a tender of interest, it can be downloaded from the bulletin board. Manpower Affairs is involved in both regional and national collective bargaining with the various trade unions and is also responsible for following and taking action on labor-related legislation. Public Relations issues press statements for SAFCEC and organizes special functions, such as Race Day, Sports Day, photographic competitions, and annual conventions.

The following subjects were discussed with the staff of SAFCEC and the N1 BOT contractor:

- Introduction and overview of SAFCEC
- State of South African construction industry
- Introduction and description of the scope of work for the N1 BOT project
- Overview and discussion of on-site training in the BOT project.

2.6 South African Association of Consulting Engineers

The scanning team met with SAACE and SABTACO on the morning of the last day of the tour. In the afternoon, the team observed a labor-enhanced, water-bound macadam-surfacing project in Soweto and a bridge-jacking project under the N1 near Johannesburg. A list of participants in the meetings with SAACE and SABTACO is in Appendix A.

SAACE promotes the professional and business interests of its members and their clients and is committed to improving the quality of life for all South Africans. Its goals are accomplished through the promotion of superior engineering knowledge and skills and their application to projects with professionalism, integrity, independence of judgment, and sympathetic consideration of the environment.

Engineers who elect to practice in the private sector, rather than in industry or government, may join SAACE. About 1,000 consulting engineers, who are principals in 375 firms that employ over 8,000 engineers, are members. SAACE membership provides a wide range of benefits to its members and their clients, including those listed below.

- The quality assurance implicit in membership is underwritten by a program of internal peer reviews, adherence to quality management systems, and the basic tenet of commercial viability, on which SAACE members' businesses depend.

- SAACE member firms are committed to participating in continuing education and to uplifting their staff and the communities they serve. Many firms have affirmative action programs and assist in the growth of emerging professional and consulting engineering firms.

- Members carry a required level of professional indemnity insurance, which provides clients with financial recourse.

- SAACE and its members are committed to the concept of labor-based construction and design that facilitates the use of semiskilled labor in engineering products.

The following subjects were covered in the meetings with SAACE and SABTACO:

- Profile of SAACE
- Profile of SABTACO
- Capacitation of emerging firms
- South Africa's Rural Development Act (RDA)
- Overview of bridge design
- Labor-enhanced, water-bound macadam project in Soweto.

3.0 ROAD FUNDING IN SOUTH AFRICA

3.1 Background

Roads and streets in South Africa constitute a major population link. They provide support for economic growth and must satisfy the basic accessibility needs (i.e., the ability to be reached) and the basic mobility needs of the population.

Authorities involved in the management, maintenance, improvement, and expansion of the road system are as follows:

- The South African Roads Board (SARB) is responsible for all the toll and other roads declared national roads, which are financed by tolls and general tax funds.

- The nine provincial authorities are responsible for all other roads not considered national or urban roads. These roads are also financed by the general tax funds.

- The urban authorities are responsible for the roads and streets in urban areas. Urban roads are financed primarily by local taxes.

3.2 Road Network

Roads and streets are functionally classified in three types:

- Primary roads, which provide for needs at a national level

- Secondary roads, which provide mobility and accessibility at a regional level

- Tertiary roads, which provide for needs at a local level.

A similar functional system has also been developed for urban roads. Table 2 shows the approximate extent of roads and streets in South Africa.

Table 2. Approximate Extent of Roads and Streets in South Africa

Class of Roadway	Network Length (km)			
	Rural		Urban	Total
	National	Provincial		
Primary	6,100	13,900	25,000	45,000
Secondary	0	45,000	30,000	75,000
Tertiary	0	295,000	110,000	405,000
TOTAL	6,100	353,900	165,000	525,000

3.3 Funding Approaches

Rural roads are primarily financed with funding from the following three sources:

- Central fiscal allocations
- Special allocations from the Government
- Private sector loan funding and toll income.

3.3.1 Central Fiscal Allocations

From 1948 until 1987, South Africa's national roads were financed with a dedicated gas tax, used solely for road construction and maintenance of network roads. In early 1988, the dedicated fund was abolished, and the National Road Authority had to compete for monies from the general fund in the same manner as other government entities.

Beginning in 1991, the National Department of State Expenditures developed a multiyear planning system for public expenditures. The purpose of the system was to ensure that budget decisions for the current year were consistent with the expenditure plan for the 3 years following the current budget year.

"Function" committees for education, health, agriculture, and roads were established to provide input to the planning system. SADOT provided the input for the Roads Function Committee. In carrying out its duties, the Roads Function Committee created an allocation system that would provide a structured, interactive decision-making process that allowed all interested parties to participate in the allocation process.

South Africa recently ratified a new constitution that establishes a Finance and Fiscal Committee (FFC) to make funding recommendations. The FFC will be actively involved in allocating funds to the provinces. Technical and advisory committees are expected to replace the function committees.

3.3.2 Special Allocations

The RDP Fund Act of 1994 is administered by the Minister of Finance. The goal of the RDP fund is to leverage the budget for the new priorities of the South African Government. Those priorities are to use the country's resources to eradicate the results of apartheid and to build a democratic, nonracist, and nonsexist future for South Africa.

3.3.3 Private Sector Loan Funding and Toll Income

Tolls were first introduced in South Africa in the early 1980's and became a source of funds to construct a small portion of roads that were heavily used. With the approval of the Minister of Transport and Finance, SARB has the authority to raise money by way of loans from any source. Tolls are the only reliable means of repaying these loans; therefore, tolls have become the primary source of funding for the construction of new roads in South Africa.

From 1984 to 1994, SARB followed a conservative policy for toll roads and, as a result, the use of toll roads has established a sound reputation. The basic policy for tolls is to provide partial or total funding for necessary road projects. A practical aspect of this policy is that the toll must be an amount motorists are willing to pay to use a higher quality road, rather than an alternate, lower quality road. The basic premise followed by SARB is that a toll road must be economically viable, but not necessarily fully self-funding.

Proposed toll roads are evaluated based on the requirement that a high percentage of the project cost must be funded from loans to be repaid from forecasted revenue. This has resulted in the concept of loan-supportable revenue (LSR). LSR is the amount of loans that may be procured to assist in financing the initial capital cost of a project. In the past, the LSR was determined by discounting the forecasted net toll revenue of a project to the present worth at a predetermined interest rate for a 20-year period.

The mixed financing approach for toll roads came about by limiting the capital/money market funding to the predicted LSR of a particular project, i.e., what a project can afford to pay from its future revenue. The balance of the initial capital expenditure is being provided by means of a long-term loan from the National Road Fund (NRF).

3.4 Innovative Financing

The needs of South African roads have outstripped the traditional resources available for constructing and maintaining them. This situation is underscored by the fact that funds currently available from the central Government are sufficient to support only 60 percent of identified maintenance. Because of limited funds, SARB examined innovative financing to develop a funding concept to improve the road systems. At the same time, the Government was interested in promoting the involvement of the private sector to harness its expertise in financing and developing infrastructure projects. Additional funding sources would promote construction activities, create employment, and help establish the infrastructure network necessary for sustaining and expanding the economy.

Private sector participation in the construction, operation, and maintenance of large infrastructure projects was identified as the best current solution. Under this process, almost any project can be considered under private development, as long as public interests are not compromised.

A report authored by Dr. M.F. Mitchell of SADOT and Mr. P.M. Glass of Stewart Scott, Inc., states that the two most common forms of private sector participation are:

- Contractor-arranged financing, which can include commercial loans, export credits, and occasional soft loans as "seed money." Public authorities do not need to meet the expenses up front. Debt serving starts after the Government and the public start reaping benefits from the facility.
- BOT arrangements, which operate as concessions in which a developer finances, builds, and operates the project and collects tariffs from users. At the expiration of the franchise period, the facility (the entire asset) is transferred to the Government at no cost.

Prerequisites for BOT projects are as follows:

- There must be a genuine demand for the services provided by the project.
- The Government requires non-tax-based funds for financing.
- The revenue potential of the project must be sufficient to service at least a substantial portion of the debt established to construct the project.

After the prerequisites are satisfied, certain key issues must be addressed to successfully package the project and make it attractive to potential investors. These issues are:

- Commercial viability of the project
- Adequate assurances with respect to political risks
- Certainty of the revenue stream
- Equitable sharing of the completion risks
- Favorable financial climate
- The assured understanding and consideration of the public sector client.

The South African Government chose to use the BOT concept for a contract to provide a four-lane undivided roadway. The roadway extends from the northern end of the existing Kranskop Toll Road, near Middelfontein, to Pietersburg, the capital of the Northern Transvaal Province, a distance of 120 km (74.6 mi). Through the NRF, SARB guaranteed the bidder a specified monthly payment for a period not to exceed 30 years. Payments were to begin when the entire roadway was open to unrestricted and safe traffic. The BOT contractor was responsible for pavement design, road realignment and regrading, construction supervision, quality management, and construction environmental impact.

Some aspects of the design are obligatory, such as horizontal alignment and the location and layout of interchanges. Right-of-way was obtained by the Government, and basic levels of service standards were also specified for the new facility. The roadway was to be completed within 30 months. Revenues obtained from toll collection would be paid into the NRF and used for recovering expenditures incurred. The BOT contractor was asked to tender a bid indicating the build time (construction time) and operating time. Also outlined in the document were functional specifications for the maintenance of the road (e.g., pavement condition, routine maintenance) and specifications for the remaining structural life of the pavement to be provided at the end of the contract period.

The main contractor, Northern Toll Road Venture, in management agreement with Northern Toll Road Construction, was awarded the BOT contract. Northern Toll Road Venture bid the shortest period to provide an operating roadway, 23 years. After the 23-year operating period, the roadway will be returned to the South African Government as a public facility.

This same general concept could be used for contracts to maintain and operate; repair, operate, and maintain; and fund, rehabilitate, operate, and maintain, all of which are being considered. The contract to design, construct, fund, operate, and maintain discussed in Section 6.4 is similar to the BOT with regard to risk-sharing, capital requirements, and complexity. Figure 1 illustrates the relationships of the contract models.

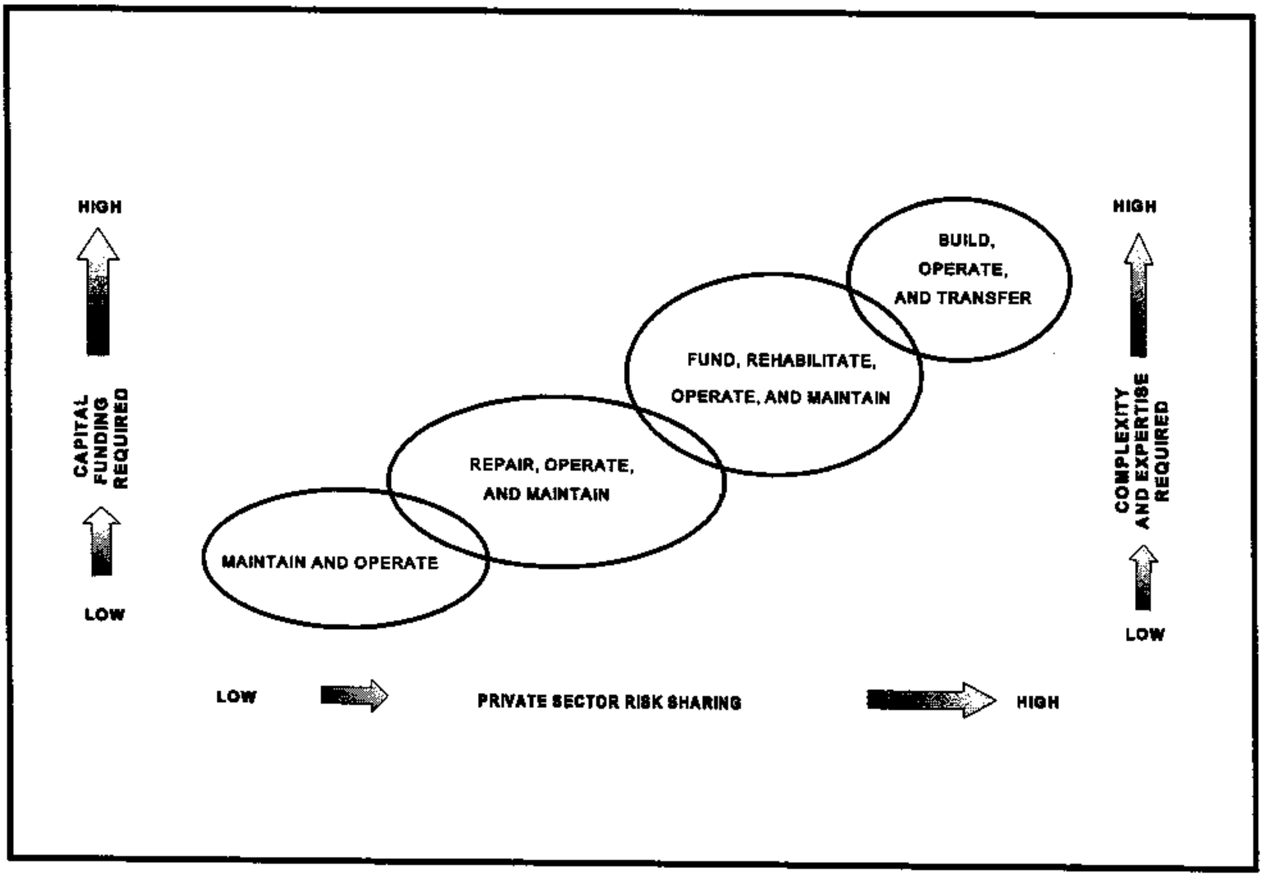

Figure 1. Diagram of Contract Models and Significant Parameters

4.0 RESEARCH

4.1 Background

One of the main reasons for the advanced states of the art and practice of road building in South Africa is that they have been directed and supported by very sound local research. The South Africans have compiled a fairly complete body of research that has not duplicated other international research efforts, but has been well focused and used existing research where applicable. Researchers have worked with local materials and processes to develop better design and analysis processes and to identify and develop improved material properties to produce enhanced pavement service.

One example of a focused research effort is the development and application of mechanistic-based pavement design procedures. Some of the basic analysis procedures and material characteristics were originally developed at various universities in the United States in the late 1960's.[1] The first European-based mechanistic design was produced by the Shell Oil Company in 1977.[2] The first U.S.-developed mechanistic design procedure was produced by the Asphalt Institute in 1982.[3] In South Africa, the first simplified mechanistic design procedure was developed in 1974; a more comprehensive design procedure was in use by 1978,[4] with ongoing review and revision.

Though mechanistic design procedures have now been around for some time, most States in the United States still use the empirically based AASHTO design procedures developed in the early 1960's and still contained in the 1993 AASHTO *Guide for Design of Pavement Structures*. AASHTO is currently developing a mechanistic design procedure that will be used in its *2002 Guide*. At that time, most States may finally start using mechanistic-based pavement design procedures, 24 years or more after South Africa adopted them.

The scanning team was not able to find any written or prepared material that would provide a simple general reference for the history and development of road research in South Africa. Most of the following comments, therefore, are based on observations made during the tour.

Much of the road-related research in South Africa has been conducted by CSIR's DRTT. As mentioned earlier, CSIR is a research agency under the South African Ministry of Finance, Trade, and Industry that employs approximately 3,200 scientists, engineers, and support staff. The DRTT is one of 13 principal divisions.

Although much of the primary research is conducted by CSIR for SADOT, there has also been much interaction within the South African road-building industry to identify, develop, and implement research technology. Sabita has clearly been involved in the research effort. The association has funded research by CSIR and has worked with SADOT and CSIR to develop a better understanding and characterization of unique bituminous-bound materials. Of the 18 manuals published by Sabita, 6 were prepared by CSIR.

In addition, the private consulting-engineering industry has participated by conducting various research projects for

SADOT and by implementing much of the research in its own design practices. CCI has also participated in improving the state of the practice and the state of the art in South Africa. CCI conducted its own research and implementation effort that resulted in development of the PCC pavement design procedures used by SADOT. Ongoing interaction among the various agencies and associations in the research implementation process in South Africa has resulted in significant use of that work. Research and implementation efforts have resulted in improved road design and construction practices, and little energy has been wasted on research that cannot be fully used.

4.2 HVS

APT through the development and use of an HVS has played an important role in pavement technology in South Africa. CSIR developed several HVS units, starting with a fixed unit and progressing to mobile units. The first functional prototype mobile unit was put in operation during the early 1970's. By 1972, successful use of the prototype resulted in a commitment for three full-production HVS Mk IIIs. By 1978, the prototype and three production HVS Mk IIIs were in full operation on a variety of projects throughout the country.[5]

Appendix C is an outline of material provided by CSIR that describes the various technical areas and products that the HVS research program has provided South Africa. It offers a quick summary of the uses and accomplishments of the HVS program.

Three of the four HVS Mk IIIs are still in operation. One is currently being used in South Africa as part of an investigation into superlight pavement structures, a study that is funded by the Province of Gautrans. Two are in California operated by CSIR for Caltrans as part of the California APT project. Two new HVS Mk IVs are currently being built—one for the Cold Regions Research Engineering Laboratory of the U.S. Army Corps of Engineers in Hanover, NH, and one for Finland.

Figures 2 through 4 show the HVS testing a fairly thin pavement structure on a Gautang provincial road south of Pretoria.

4.3 Applications

Most of the research in South Africa has been focused on a well-defined end use. Development of the mechanistic pavement design procedure and collaborative work with HVS to confirm damage models and material characteristics improved pavement design practice and performance.

Much of the research that stands out in South Africa was not produced by a single research group, then simply expected to be implemented. It was developed with clearly defined needs and strongly committed sponsorship for the work through a process that brings together researchers, those who use the technology, and those who have to construct it.

In his paper "The Impact and Management of the Heavy Vehicle Simulator Fleet in South Africa" (referenced earlier), Dr. Emile Horak quoted three axioms with regard to the probability of successful research implementation:

Figure 2. Scanning Team With HVS

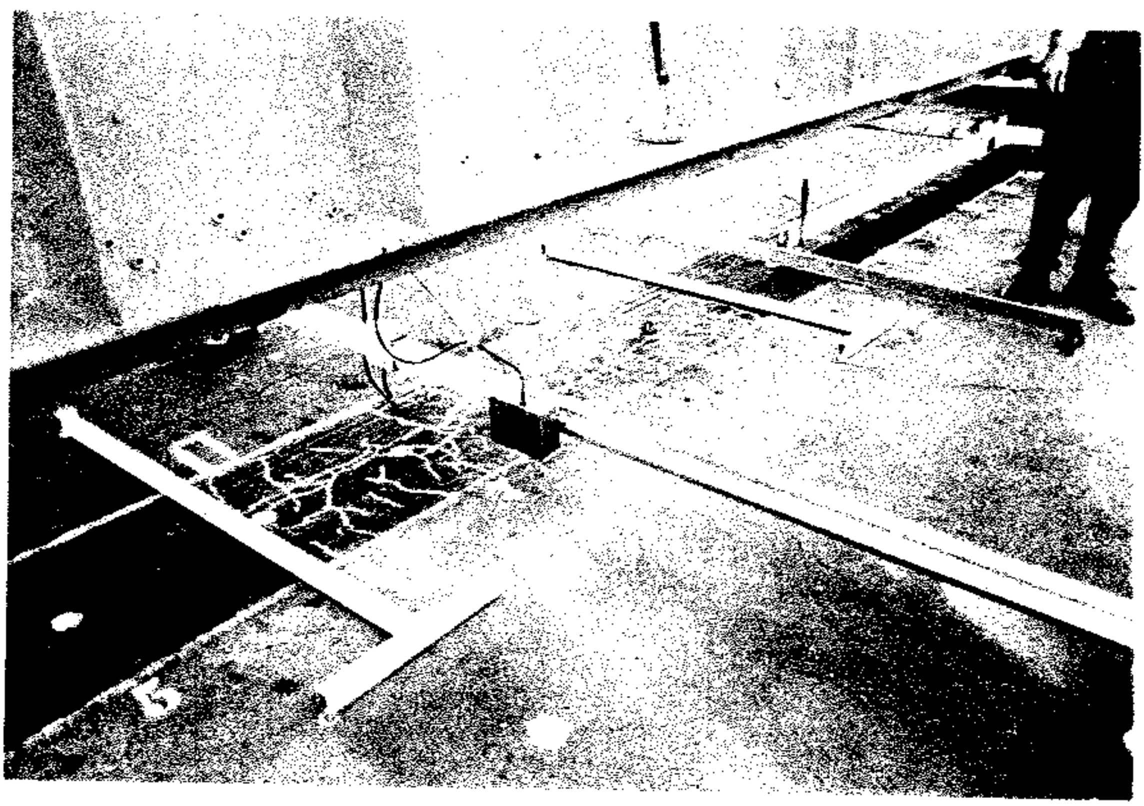

Figure 3. Traveling Wheel With Wheel Path Measurement Equipment

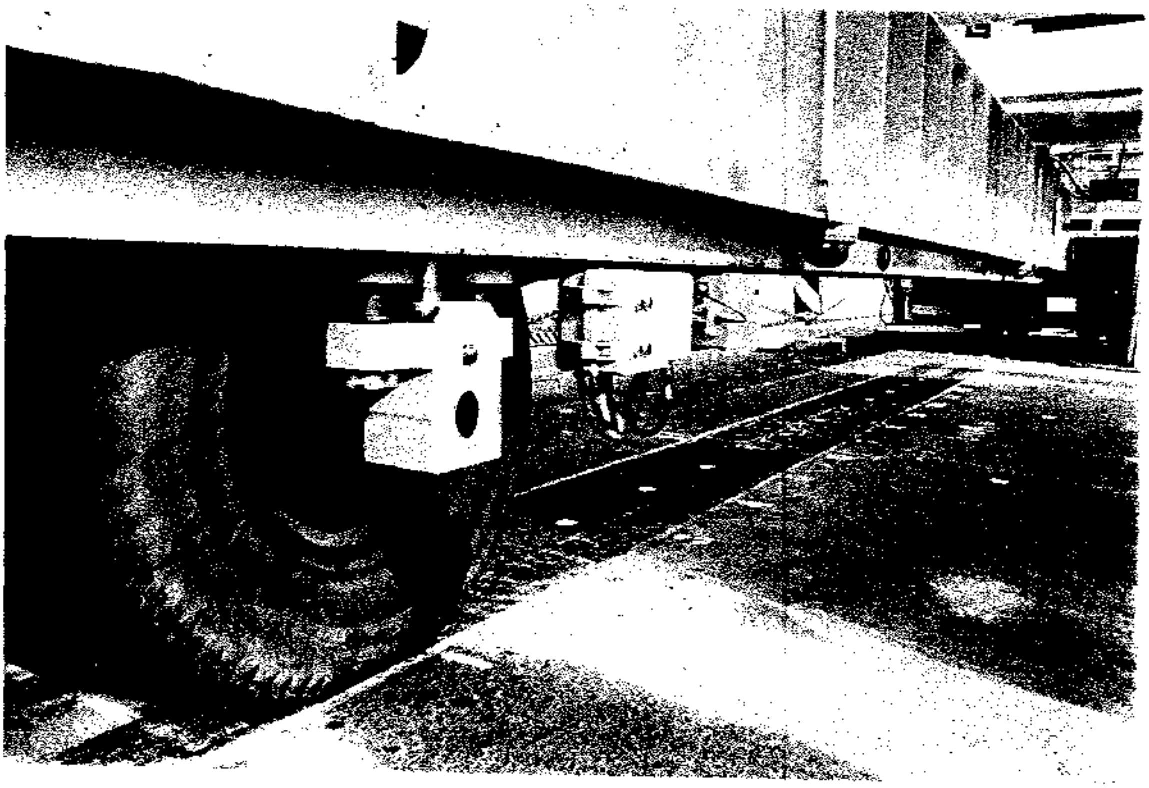

Figure 4. Traveling Heavy Wheel Load in Action

Axiom1. Utilization is inversely proportional to the distance between the researcher and the users of research.

Axiom 2. Utilization is inversely proportional to the degree of formality in the communication between the researcher and the user.

Axiom 3. Utilization of research increases with the degree of understanding that the researcher and the user have of each other's problems and motivations.

These axioms seem to speak directly to what has worked well in South Africa's pavement research and implementation efforts. An example of how this process works is the research and implementation that produced granular emulsion mixes (GEMS).

In Sabita's manual series, Manual No. 14 is *GEMS—The Design and Use of Granular Emulsion Mixes*. The manual was compiled by Mr. F.C. Rust and Mr. J.E. Grobler from CSIR and Mr. R.M. Vos from Sabita, with contributions from a group of experts, including consultants, researchers from the provinces, and representatives of SADOT. The manual was based on a 3-year project on emulsion-treated bases undertaken by CSIR and sponsored by Sabita, as well as in situ trials and HVS tests sponsored by the Province of the Orange Free State and SADOT.

The resulting manual includes the following subjects:

- Design considerations for GEMS
- Mix design of GEMS using the stabilization design approach

- Mix design of GEMS using the modification design approach
- Guidelines on the structural design of GEMS
- Guidelines on the construction of GEMS
- Quality control of GEMS
- Economic considerations.

SADOT publishes a series of technical recommendations for highways (TRHs), which are written for practicing engineers and describe current, recommended practice in selected aspects of highway engineering. The series is compiled under the guidance and support of the Committee of State Road Authorities. Draft TRH7, published in 1994, covers "The Use of Bitumen Emulsions in the Construction and Maintenance of Roads." TRH7 contains a very concise description and guidelines on the use of GEMS, referring to Sabita's Manual No. 14 for more detail on the design and construction procedures for GEMS.

Thus, work that started as a research project in 1988 and is reported in nine separate research reports through 1993, is now a well-defined package used in road construction with specific guidelines for thickness design, mix design, and construction quality control.

This focused research effort stands in contrast to the U.S. experience with GEMS over the last 25 years.[6] The use of these mixes started with a mix design procedure developed by FHWA's Federal Lands Highway Office to make use of lower quality aggregate on national forest roads. Over the last 25 years, such mixes have been used more frequently by various Western States in the United States and in several Scandinavian countries than by FHWA's Federal Lands Highway Program. Various papers have been written about the performance of these mixes, but nothing has been done in the United States to develop detailed design, construction, and use guidelines similar to those found in Sabita's manual on GEMS.

A similar story can be told about the research, development, and implementation work behind large aggregate bases covered in Sabita's Manual No. 13 *LAMBS—TheDesign and Use of Large Aggregate Mixes for Bases*, published in 1993.

4.4 Technology Management

Alhough SADOT and CSIR have been fairly successful over the years in making good use of research efforts, concern has been expressed that some of the structure and long-term focus that produced such marked achievements has been lost.

To address this concern CSIR's DRTT conducted an in-depth examination of the full range of issues surrounding technology management. The result is a proposed integrated, or holistic, framework for managing the development of transportation technology for South Africa.

The principles of managing technological advancements include:

- Coherence, not fragmentation (holistic approach)
- Short- and long-term objectives
- Focused strategy
- Consultative process
- Inclusive process
- Implementation and technology transfer

- Links to education and training
- Monitoring of the impact of advancements
- Enhanced intellectual capacity
- Stimulation of innovation.

The framework for a holistic process for managing technology development was designed to include the following features:

- Focused effort, including cooperation among client bodies, research organizations, educational institutions, and industry
- Participation by all stakeholder groups
- Significant focus on implementation and technology transfer
- Negation of fragmented technology development
- Management structures that reflect the current structures in SADOT and include major stakeholders
- A process based on strategic focus and direction.

A more detailed description of the CSIR proposal for managing technology development is included in its research report DPVT/236, "A Proposed Holistic Framework for Technology Development and Implementation in South Africa." The executive summary of the report appears as Appendix D.

4.5 Information Dissemination

Engineers in South Africa's public and private sectors have clearly made an ongoing effort to implement products or processes produced by their combined research work. Many implementation efforts follow a five-step pattern similar to the following:

1. Research development
2. Construction of trial sections
3. Accelerated testing with the HVS
4. Development (by committees representing both the public and private sectors) of guidelines for use
5. Active information dissemination.

To facilitate the information dissemination, SADOT, CSIR, and Sabita produce a large body of information in the form of research reports, manuals, and technical guides and recommendations. SADOT publishes the TRH series, as well as technical methods for highways (TMHs), urban transport guidelines (UTGs), and current research reports. The TRH series is intended as a guide for practicing engineers and leaves room for exercising engineering judgment. The TMH series is produced to complement the TRHs; TMHs are similar to manuals for engineers, prescribing methods to be used in various road design and construction procedures. UTG is a series of documents that describes current recommended practices in selected aspects of urban transportation. The scanning team found that these publications are kept up to date, and many include references to research conducted within the last 5 years.

As mentioned earlier, Sabita also produces a series of manuals that provides guidance in design and construction for a wide range of bitumen-bound materials. Many of the manuals were prepared by CSIR's DRTT, following several years of research and field testing of those materials. A review of Sabita manuals shows that they are well written, easy to understand, and quite up-to-date. Sabita also produces a series of video training aids that covers a large number of laboratory test procedures, as well as a series on "blacktop roads" and a series on the manufacture, paving, and compaction of hot-mix asphalt.

DRTT produces numerous reports covering ongoing research, as well as "Techno-Briefs," which are short (one- to two-page) synopses describing results or products of various research projects. DRTT has also been active in preparing papers that have been accepted for presentation and publication in various international conferences. A detailed listing of the various manuals, guides, and reports that were available to the team is included in Appendix E.

5.0 PAVEMENT TECHNOLOGY

5.1 Background

5.1.1 History

The following is an excerpt from a brief discussion of pavement design in "Materials and Pavement Engineering Overview," presented by Mr. J.P. (Basie) Nothnagel to the U.S. scanning team.[7]

> The procedure for the structural design of road pavements evolved from the CBR-thickness [California bearing ratio] curves, followed by a structural number method, based on the AASHTO-road test and local experience, to a locally developed mechanistic design procedure in which the HVS played a significant role in deter-mining the influence of traffic loading, material characterization type, and distress nodes. The current method is reflected in various research papers, funded by SADOT, which were reduced in Technical Recommendations for Highways (TRH4, 1985). This publication is presently under revision and will concentrate on flexible pavement only, with a provision for lower volume [loading] roads. Apart from the catalogues listed in TRH4, the design procedure is also available in a computerized form.
>
> In the case of rigid pavements, AASHTO and Portland Cement Association methods formed the basis for design in the past. Over the last few years, SARB funded a project to develop a local design method for concrete pavements. This work was recently finalized, and a design manual (M10) will soon be published for local use. This design procedure is based on elastic multilayer and finite element analysis for material properties of locally available materials and material standards. Materials' properties can either be directly determined or indirectly approximated from simple material tests. Composite slab theory is applied, and the thickness of continuously reinforced, plain-jointed, or plain-jointed with load transfer bars (dowels) can be determined from appro-priate curves. Previously, a flexural strength of 3.8 MPa was used but has now been increased to 4.5 MPa. This allows for a reduction in concrete slab thickness of approximately 10 percent.

5.1.2 Philosophy

The structural design philosophy in the Republic of South Africa is to protect the subgrade from "overloading" by providing pavement layers of sufficient thickness and strength. For purposes of pavement design, roads are placed into one of four categories that describe importance, service level, design reliability, and traffic volumes/ loadings (see Table 3).

Designers must select both an analysis period and a structural design period. The analysis period is usually related to the geometric life of the road—if the alignment is fixed, a period of 30 years is recommended. The analysis period includes the initial construction of the pavement and any resurfacing or structural rehabilitations. The structural design period is the period during which no structural maintenance is required; however, functional overlays may be included in this period. Recommended analysis and structural design periods are shown in Table 4.

Table 3. Descriptions of Road Categories

Characteristics	Road Category			
	A	B	C	D
Description	Major interurban freeways and roads	Interurban collectors and major roads	Lightly trafficked rural road, strategic roads	Light pavement structures, rural access roads
Importance	Very important	Important	Less important	Less important
Service Level	Very high	High	Moderate	Moderate to low
Approx. Design Reliability	95 %	90 %	80 %	50 %
Total Traffic Loading (E80/lane)	3–100 million (over 20 years)	300,000–10 million	<3 million	<1 million
Daily Traffic (evu*)	>4,000	600–10,000	<600	<500
IRI** Initial (m/km)	2.4–1.6	2.9–1.6	2.5–2.4	4.2–2.4
IRI Terminal (m/km)	3.5	4.2	4.5	5.1

*Equivalent Vehicle Unit **International Roughness Index

Table 4. Recommended Analysis and Design Periods

Road Category	Recommended Analysis Period (yr)		Structural Design Period (yr)
	High Certainty*	Low Certainty	
A	30	-	25
B	30	25	20
C	30	20	10–20
D	20	10–15	10

* Fixed geometric alignment

5.1.3 Climate[8 9]

When evaluating the pavement designs used in South Africa, it is important to remember that the climate is generally mild throughout the year. (Summer in South Africa is from October until March and winter is from April to September.) The average number of hours of sunshine each day is among the highest in the world. Winters are mild, and snowfall is limited to the highest mountain ranges. Over 40 percent of South Africa is more than 1,210 m above sea level, which has a major influence on the climate of the interior of the country. The Western Cape Province has dry summers and rainy winters. The rest of the country experiences afternoon thunderstorms in the summer. On the whole, South Africa is a dry country with a mean annual rainfall of 502 mm. The average minimum and maximum monthly temperatures of four of South Africa's major cities are shown in Table 5.

For purposes of pavement design, South Africa is divided into three macroclimate regions:

- Dry (large central portion)
- Moderate
- Wet (southern and eastern coastal strips).

In the wet regions, special attention is given to the quality and type of subgrade materials used. In some cases, the selected subgrade materials may be modified with lime or other materials that increase the strength and make the material less susceptible to water. In the dry region, the *unsoaked* CBR values are considered, which results in a cost savings. The soaked CBR value is usually used in the wet and moderate regions. The design input values for elastic modulus used in the wet areas are also slightly lower than the values used in the dry areas.

Table 5. Average January and June Temperatures (°C)

City	Summer (January)		Winter (June)	
	Avg. Max.	Avg. Min.	Avg. Max.	Avg. Min.
Cape Town	26	16	18	7
Durban	28	21	17	11
Johannesburg	26	15	15	6
Pretoria	28	17	19	4

5.2 Pavement Design

5.2.1 Traffic

Table 6 shows the maximum legal axle loads in 1996. Standard axle load for pavement design is 80 kN. The traffic load spectrum is converted to 80-kN-equivalent standard axle loads (E80). For flexible pavements, the traffic loadings are converted to design E80s using the following formula:

$$F=\left(\frac{P}{80}\right)^n$$

where n = relative damage exponent
F = load equivalency factor
P = axle load (in kN)

Traditionally, the relative damage exponent was taken as 4, but pavements that are sensitive to overloading, such as shallow pavements with thin cemented bases, may have n values of more than 4; less sensitive (i.e., "deep") pavements may have n values of less than 4.

For rigid pavements, the equivalency factors to relate axle loads to standard 80-kN loads were based on deflection of the slab under loading, and stress in the slab was taken as the reference variable. These were calculated using a finite element technique for a typical South African concrete pavement (235-mm slab on top of a stabilized subbase) and different axle and wheel loads.

5.2.2 Portland Cement Concrete[10]

Such factors as construction-related problems, environment, and slab support conditions were predominant in determining the structural capacity and performance of concrete pavements in South Africa. The thickness design procedure recently developed by the South Africans was based on the use of linear elastic layer theory to characterize the foundation and finite element analysis to calculate the stresses and deflections in the slab. The design procedure takes into account the findings of Poblete, et al.,[11] that slabs tend to curl upwards for the main part of the day. The design curves developed take into consideration erosion settlement, curling, and the subsequent loss of support up to a length of 600 mm from the joint or crack.

Table 6. Maximum Legal Axle Loads

Type of Axle	Number of Tires	Load (kN)
Single axle (steering)	2 or 3	76
Single axle (nonsteering)	2 or 3	78
Single axle	4 or more	88
Tandem axle	4 or more	176
Tridem axle	4 or more	235

Thickness is derived based on limiting the relative vertical movement at the joints or cracks in continuously reinforced concrete pavements.

Transverse joints are spaced at 4.5-m intervals. Load transfer at the joints may be provided either by aggregate interlock or dowels. Dowels are typically used on high-volume motorways and are generally spaced at 300-mm intervals. Diameters of the dowels range from 32 mm for a 175-mm slab to 37 mm for a 280-mm slab. Longitudinal joints have tie bars, which are designed based on the subgrade drag theory.

There is one 21-km section of continuously reinforced concrete pavement in South Africa. The pavement was completed in 1989 and has a variable thickness (trapezoidal slab) of 150 mm at the center to 170 mm at the outside edge of the truck lane. Longitudinal steel in the amount of 0.62 percent of the cross-sectional pavement area was used. The design was based on the requirement to achieve an average crack spacing of 600 mm.

5.2.3 Asphalt Concrete[12 13]

Procedures for the selection and structural design of flexible pavements are outlined in TRH4, "Structural Design of Flexible Pavements for Interurban and Rural Roads." TRH4 presents a pavement design catalog of possible flexible pavement types and structures. It was developed using mechanistic design procedures, coupled with experience and the results of HVS tests performed over the past 15 years. Development of a mechanistic design procedure for flexible pavements has been underway in South Africa since the early 1970's. Proceedings of the 1977 International Conference on the Structural Design of Asphalt Pavements contain a paper by Walker, et al., discussing the initial procedure used in the development of TRH4 in 1978. The mechanistic procedure was updated in 1981 and 1994 for use in the 1995 and Draft 1996 TRH4. Ongoing improvements to the mechanistic design analysis procedure, particularly the transfer functions, can be attributed to the extensive accelerated testing of pavements, performed using the fleet of HVSs.

Structural analysis of flexible pavements is usually performed using a static, linear, elastic multilayer analysis program. The maximum horizontal tensile strain at the bottom of asphalt layers and the maximum tensile strain at the bottom of cemented layers are used to determine the fatigue life.

The performance life of each pavement layer is predicted and the ultimate life of the overall pavement is evaluated. Granular materials are evaluated for shear failure using a "safety factor" concept developed by Dr. J. H. Maree using Mohr-Coulomb theory. Cemented material exhibits two failure modes, fatigue and crushing. The maximum tensile strain at the bottom of the layer predicts fatigue life, and vertical compressive stress on top of the cemented layer predicts crushing life. Transfer functions are provided for two crushing conditions: crush initiation with roughly 2-mm deformation on top of the layer and advanced crushing with 10-mm deformation and extensive breakdown of the cemented material. At the end of effective fatigue life, cemented materials are assumed to behave in the same way as granular material. Asphalt materials are predicted to fail from fatigue cracking as a result of tensile strain at the bottom or in the layer. A distinction is made between thin surfacing layers (<50 mm) and thick bases (>75 mm). Transfer functions are provided for continuously graded or gap-graded surfacing layers and asphalt base layers with stiffness from 1,000 to 8,000 MPa. Subgrades are evaluated for permanent deformation based on the vertical strain on the top of the layer. Recent work shows that the vertical stress on the top of the layer is more relevant and correlates with HVS data.

Typical pavement sections used in South Africa are shown in Figure 5.

5.3 Materials

5.3.1 Granular Bases[14]

One of the unique pavement features observed in South Africa was the G1 crushed-stone base. This base has a minimum density requirement of 88 percent of apparent relative density, which equates to approximately 105 to 108 percent of modified AASHTO density. The scanning team was shown a test pit that had been cut in a section of G1 base. The test pit was excavated several years ago during HVS testing on the section and was protected by a steel cover. The perimeters had been cut using a diamond saw; the faces of the cuts had the appearance of a cement-stabilized base. The surface remained intact when struck with a geologist's hammer and showed no signs of raveling.

The G1 base type has been used for more than 25 years in South Africa. It consists of 37.5 mm of densely graded, crushed, fresh (unweathered), and durable (hard) rock. Dolerite, granite, quartzite, norite, andesite, and felsite rock types are commonly used. All the material, including fines, must come from the same parent rock, without addition of soil binder from other sources.

The excellent performance of this base is achieved through a high level of densification. The high level of densification is enhanced by an additional "slushing" operation, usually performed 1 day after the initial compaction. Slushing consists of adding water to the surface and rolling with a three-point flat steel wheel and rollers with pneumatic tires. The slushing process removes excess fines used for lubrication during the initial compaction and compresses the coarser particles in contact with each other. The slush (fines and water) is broomed from the surface until a closely knit aggregate mosaic is clearly visible. The surface is primed after the layer has dried sufficiently. During the process, suction forces are developed that contribute to the strength of the material. Figures 6 through 10 illustrate the process.

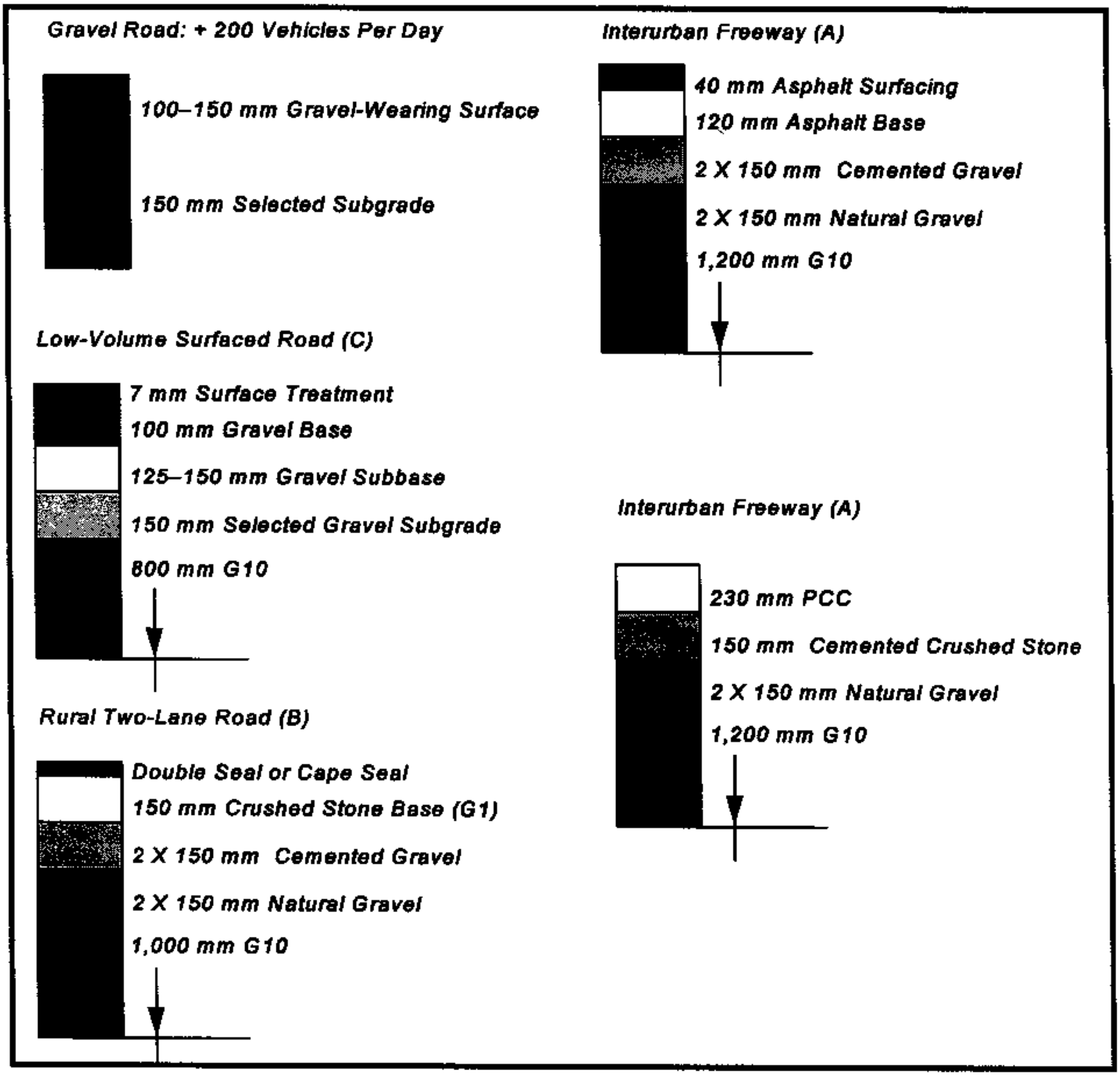

Figure 5. Typical Pavement Sections (A, B, and C refer to road categories.)

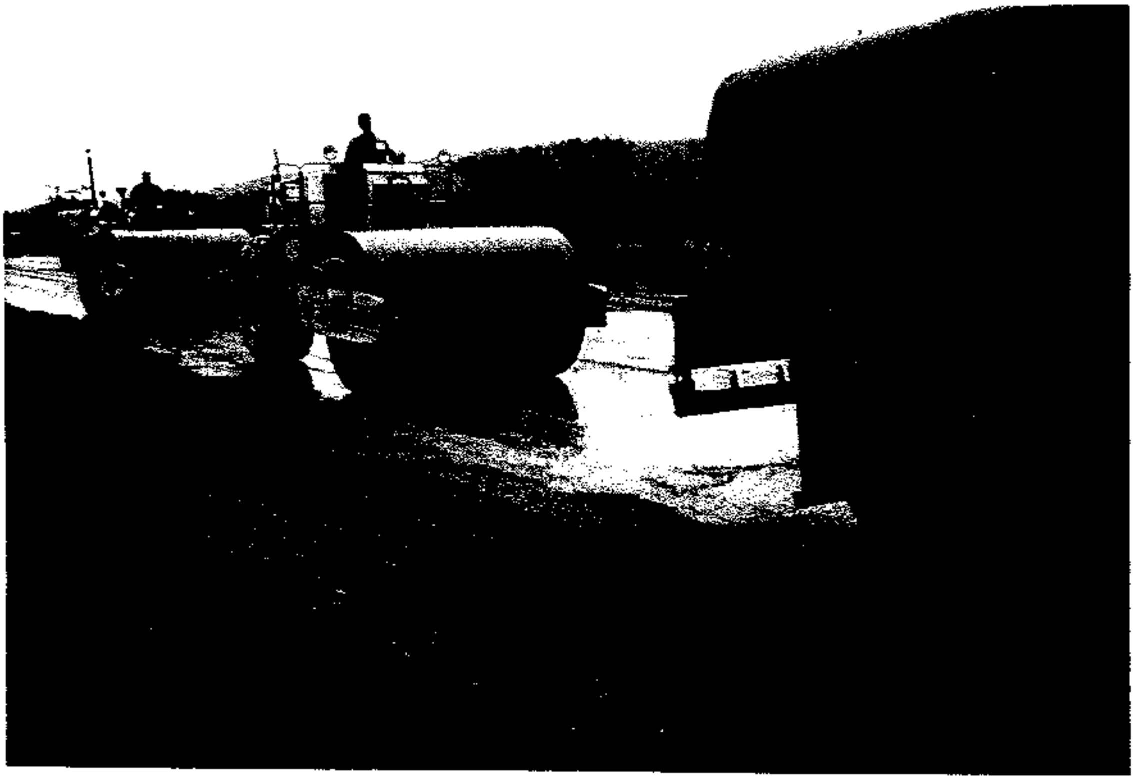

Figure 6. Gravel Slushing and Rolling Operation

Figure 7. Closeup of G1 Gravel After First Slushing

Figure 8. G1 Gravel After Third and Final Slushing Operation

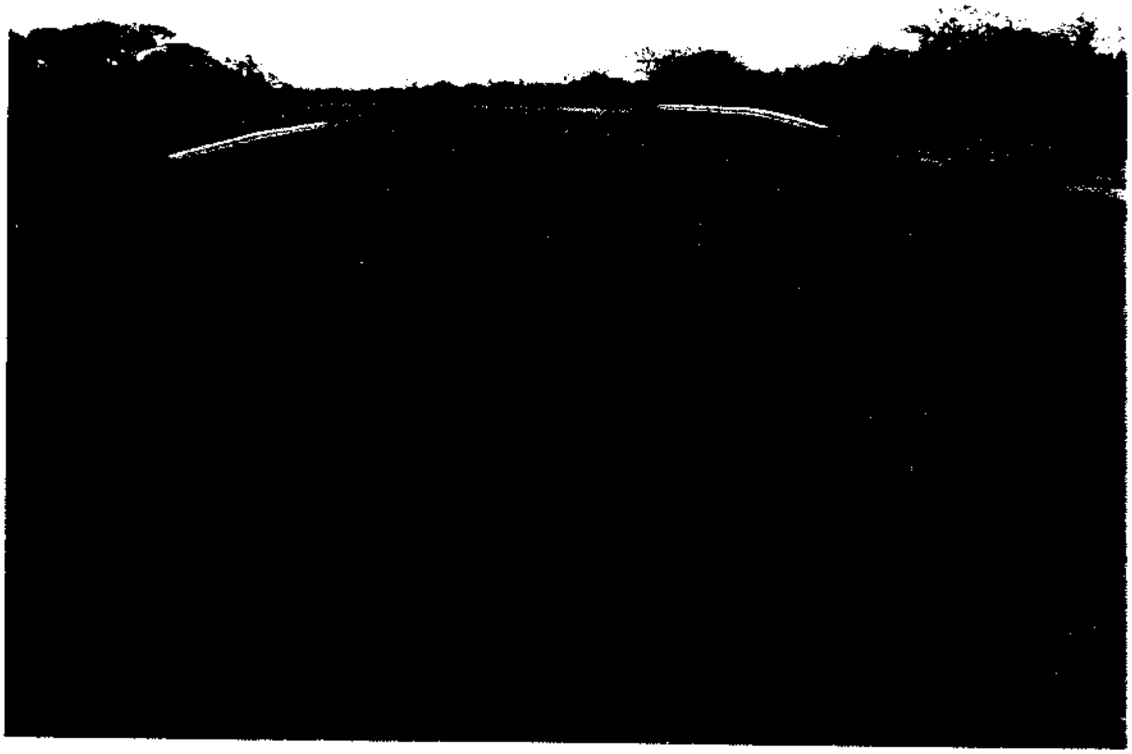

Figure 9. Final Grade After Construction of G1 Base

Figure 10. Paving Final 50-mm Layer on G1 Base

5.3.2 Bitumen

Asphalt cement is referred to as bitumen in South Africa. Produced at four refineries in the country, approximately half the bitumen is used in surface treatments and thin surfaces, while half is used in hot mix.

5.3.3 Bitumen Rubber

Crumb rubber asphalt products were introduced to South Africa in 1982 by Arm-R-Shield, based on the Arizona refining process used in the United States. Over 200,000 tons of rubber asphalt have been used on roads in South Africa, mainly as chip seals and stress-absorbing interlayers. Rubber asphalt is also used in porous asphalt surface mixes (20- to 40-mm thick with 7 to 8 percent binder).

5.3.4 Porous Mixes[15]

In 1953, South Africa constructed an open-graded friction course similar to the open-graded plant mix seals being constructed in the United States. The open-graded pavement performed well over a period of 11 years. Since 1970, open-graded wearing courses have been constructed by all major road authorities and on major airports in South Africa. These mixes generally had void contents of 18 percent or less and were constructed in relatively thin layers. They tended to ravel at an early age and become clogged.

In the early 1990's, South Africa began investigations of porous asphalts similar to those used in France. The French porous asphalt mixes have interconnected voids, with void contents in excess of 20 percent. The introduction of polymer-modified binders, bitumen rubber binders, and cellulose fiber additives made it possible to construct mixes with higher void contents and thicknesses in excess of 40 mm. These additives provided binders with greater viscosity and reduced drain down, resulting in greater film thicknesses and improved durability. As part of the implementation process, Sabita commissioned CSIR to develop a mix design procedure for porous asphalt and to study the types of binders and aggregate that would provide the best performance. The findings and recommendations are summarized below.

- High-viscosity binders, such as bitumen rubber or binders with very high polymer contents, are recommended for medium- to high-traffic volumes, hot climates, and/or mixes with void contents in excess of 22 percent. For low- to medium-traffic volumes, mild climates, and/or mixes with void contents of 18 to 22 percent, polymer-modified or unmodified binders are recommended.

- Sound, durable, cubical, and nonpolishing aggregate is required. Nominal stone sizes of 9.5 to 13.2 mm are commonly used.

- One to two percent mineral filler (limestone powder, hydrated lime, or cement) is recommended.

- Fibers are often added to the mix to stiffen the binder to reduce drain down (0.3 to 0.5 percent of the total mass of the mix).

In 1993, approximately 260,000 m^2 of porous asphalt was placed on the Ben Schoeman Highway in Johannesburg. As part of the project, the selection of binder type and amount was studied and the mix was subjected to accelerated loading using the HVS. The aggregate grading is shown in Table 7.

Table 7. Porous Aggregate Grading for Ben Schoeman Highway

Sieve Size (mm)	Percent Passing	
	Design Grading	Grading Band
19.0	100	100
13.2	93	90–100
9.5	28	25–65
4.75	11	10–15
2.36	9	8–15
0.075	3	2–5

Bitumen-rubber, SBR-modified (styrene butadene rubber), EVA-modified (ethylene vinyl acetate), and unmodified bitumen were evaluated during mix design. Based on the test results, a bitumen-rubber binder was selected. The design binder content was 5.8 percent by mass of the total mix.

HVS testing was performed to determine the resistance of porous asphalt to raveling, fatigue, and permanent deformation at both 23 °C and 37 °C. Each section was trafficked with a 40-kN, dual-wheel load for up to 125,000 repetitions, after which the applied load was increased to 70 kN for a total of 175,000 repetitions. HVS testing showed that the 40-mm porous asphalt layer does not contribute to the structural capacity of the pavement. Despite high deflections of the pavement section, no raveling or other signs of surface deterioration occurred.

5.3.5 Large Aggregate Mixes for Bases (LAMBS)[16]

LAMBS are defined as mixes that obtain their strength and resistance to deformation primarily from aggregate interlock. This strength is achieved by using aggregates with large top sizes, about 37.5 to 53 mm. Because LAMBS are used in the base layer, such factors as skid resistance, raveling, noise generation, and bleeding are not considered in design. In the development of LAMBS, the dynamic creep test was used extensively to predict permanent deformation. (The static creep test was not satisfactory.) An improved method of measuring the resilient modulus was used to estimate stiffness, which corresponded very well with in situ values determined by back calculation from in-depth deflection measurements.

Aggregate gradations that do not have reversals of curvature and/or small abrupt deviations were selected, because these can lead to a decrease in structural strength, as well as segregation. Constructability is generally improved by the use of higher binder and filler contents and finer grading curves. Note that semigap graded mixes tend to segregate easily when the binder content drops below a certain level.

The Hugo method is used for the compaction of laboratory samples. The compaction hammer that makes the method unique is illustrated in Figure 11.

Problems related to constructability can be avoided by taking appropriate measures. Careful attention must be given during aggregate production to prevent segregation.

When the 53-mm aggregate is used, some modifications to the gates of the cold storage may be required. The flights in the dryer and drum mixers may have to be reinforced to minimize wear and tear. To reduce wear and tear, drum mixers are preferred to batch plants, and it is preferable that an aftermixer be used.

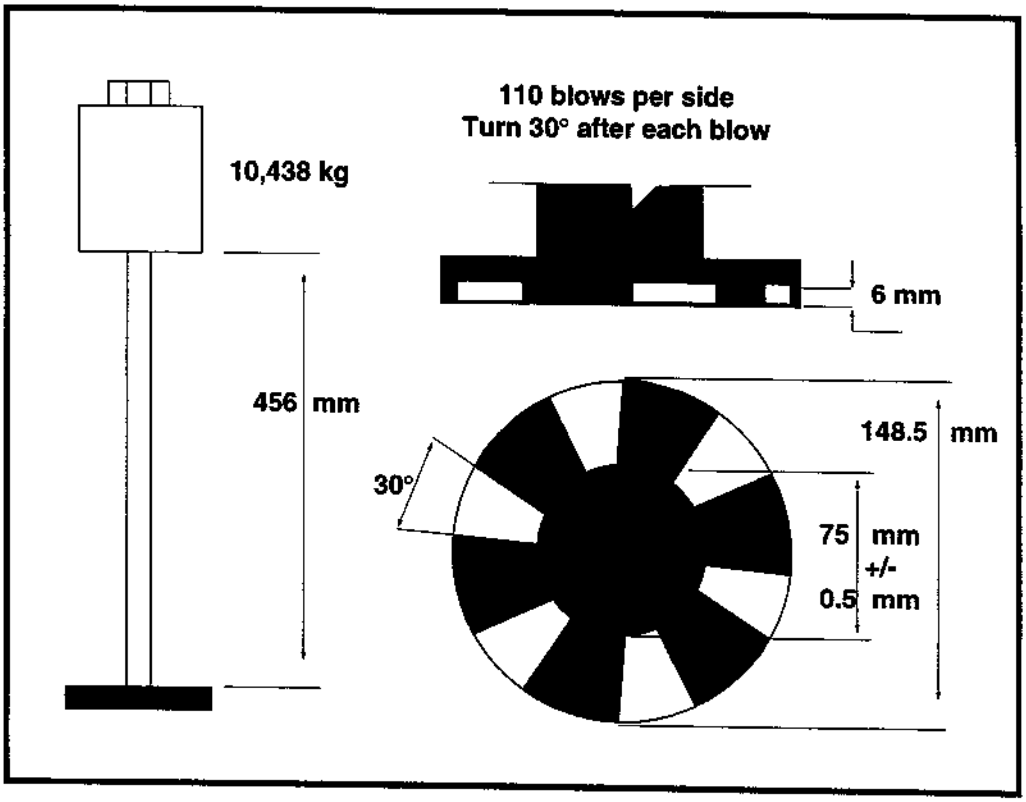

Figure 11. The Hugo Laboratory Compaction Hammer

5.4 Portland Cement Concrete (PCC)

5.4.1 Cement

Most cements have alkali contents between 0.15 and 0.55 percent. The exception is the Western Cape cement, which is below 0.6 percent.

5.4.2 Aggregates

All aggregates and sand used in concrete mixes are crushed, resulting in harsh mixes. Single-size aggregates are commonly used, resulting in a gap in grading between the stone and sand sizes.

5.4.3 Alkali/Aggregate

The first modern concrete road built near Cape Town in 1968 experienced alkali aggregate reaction. As a result, simplified test procedures were developed to identify reactive aggregates. Concrete mixes are tested and, if expansion is indicated, the total alkali per cubic meter is limited.

5.4.4 Fly Ash, Slag

Fly ash and granulated slag are not usually blended with Portland cement; however, when either material is used, a maximum of 15-percent replacement is allowed.

5.4.5 Joints

On early concrete pavement projects, plastic parting strips were used to form the longitudinal joints. Now, however, the South Africans use saw-cut joints, because they were not satisfied with the quality of the joints constructed with the parting strips.

In the past, preformed compression seals were used in the joints. Low-modulus silicone seal material is now used, and a unique specification has been developed. The specification contains the restrictive requirements of many specifications and is very difficult to meet. It was reported that the material commonly used in the United States will not meet the South African specifications. The South Africans are, however, considering the use of a self-leveling product from the United States.

A debate is occurring about whether dowels are needed in the joints. Many of the early pavements did not have dowels but performed well. Dowels are now included on projects for high-volume roadways.

5.5 Construction

A very small ready-mix concrete industry exists in South Africa—approximately 15 percent of the concrete is produced by ready-mix plants. The remainder of the concrete is mixed on site in relatively small and, in some cases, unsophisticated plants. Both slip-form and fixed-form pavers are used to construct concrete pavements.

Before 1971, construction of national roads was performed by the provincial road authorities using their own forces; beginning in 1971, construction of the national road system was performed by contractors. Early projects were generally constructed by numerous small contractors under the close supervision of the National Road Authority. With the exception of build, operate, and maintain projects, most projects are awarded on a low-bid system similar to that used in the United States. Contractors are required to maintain the road for 1 year after completion of the project. Repair costs for latent defects, discovered after the 1-year maintenance period, can also be recovered from the contractor. It is often difficult, however, to prove contractor responsibility as the pavement ages.

Quality control is based on a dual control system under which both the contractor and the supervisory consulting engineer are employed by the National Road Authority. Contractors are responsible for process control, and acceptance testing is conducted by the Road Authority's consultant. Contractors must furnish a laboratory building for material acceptance testing, and the consulting engineer is responsible for equipping and staffing the laboratory. Combined process-control and acceptance-testing laboratories are permitted.

Under this arrangement, process-control tests can serve as acceptance tests, reducing the amount of testing required. When the combined laboratory approach is used, the consultant is employed by the National Road Authority and the contractor contributes to a portion of the testing costs. A contractor's contribution to the total laboratory cost is generally set at the following percentages:

- Soil and chemical laboratory 25%
- Asphalt laboratory 35%
- Concrete laboratory 40%

Before a contractor is permitted to begin construction of any stabilized pavement layer, a test strip must be constructed to demonstrate that the equipment and processes planned for use can construct the layer within specifications. If the test strip complies with specifications, payment is made. Unsuccessful test strips are constructed at the contractor's expense.

In addition to material testing, the National Road Authority's consulting engineer also conducts detailed visual inspections. Signs of poor workmanship, such as material variability, soft spots, and cracking, are grounds for rejecting the work without further testing.

Current specifications require that the smoothness of granular bases and asphalt layers be checked using a 3-m rolling straight edge. SADOT has found that conformance to current specifications does not ensure acceptable smoothness and is investigating alternative methods. For the past 3 years, the smoothness of PCC pavements has been measured using the California-type profilograph. Acceptance is based on the profile index (PRI) per km, measured in 100-m lengths. Incentives are paid for PRIs of less than 100 mm/km, and disincentives are applied for PRIs of 151 to 250 mm/km. Any sections that have PRIs greater than 250 mm/km must be repaired at the contractor's expense, usually by means of grinding.

The National Road Authority is working with the asphalt industry to develop a product performance guarantee system for asphalt pavements. A 5-year warranty scheme is being considered under which contractors would be 100-percent responsible for the cost of correcting defects in the pavement during the first 3 years. During the remaining 2 years of the warranty, contractors would be responsible for 60 percent of the costs to correct defects. Contractors appeared enthusiastic about the concept.

6.0 PROJECT MANAGEMENT AND CONTRACTING

6.1 Highway Construction Contracts

SADOT advertises projects in several publications and generally awards schedule-of-quantity contracts for road construction. Under this type of contract, prospective contractors state a price for each specified quantity of work to be undertaken. The contract facilitates competitive bidding and allows for changes of work, although changes must always be tightly controlled. All construction projects include a 1-year maintenance period in the contract.

Award of highway construction projects is made by SARB, generally to the low bidder. All bidders must address social responsibility on every project. In other words, all proposals must explain how the contractors will address improvement of conditions for disadvantaged citizens. (Estimated unemployment rates in South Africa range from 20 to 46 percent,[17] and many individuals live in substandard conditions, such as homes that have no running water or electricity.) Contractors may propose training, employment, subcontracting opportunities, construction of houses or facilities, or other measures. Proposed plans are considered and discussed with the bidders before the award is made to ensure that the contractor can fulfill this social obligation. If the low bidder's plan is not satisfactory, award of the contract will be made to the next lowest satisfactory bidder.

6.2 BOT Contracts

The BOT method was introduced in South Africa in the mid-1980's. In 1984, privatization for toll roads was proposed by a consortium of civil engineering contractors. In 1985, the Minister of Transport invited expressions of interest in road privatization under BOT contracts. Eight construction companies came together to form two consortiums, and construction by these firms began in 1987. Final concession agreements between the state and private companies were conditioned on passage of "enabling legislation." The enabling legislation would have made it possible to award to a private sector company a concession to finance, build, own, and operate a national road for a specified period and then turn it back to the state. The legislation was rejected in 1988 and again in 1990, primarily because of concerns of communities affected by the tolling of existing roads.

As a result, the consortiums could not remain owners of the roads built under BOT contracts. On April 1, 1990, SARB assumed full financial responsibility for the projects and the loans taken out by the private sector companies. To settle the disputes that arose as a result of the termination, contract fees were negotiated to enable the consortiums to operate the routes for an additional 5 years. As a result, guarantees are provided to the contractor.

6.3 The N1 Project Model

N1 is the major north/south national road, located north of Pretoria and Johannesburg. The portion of N1 included in this discussion is the 123 km between Warmbaths and Pietersburg. The contract for this section includes the design (primary road and pavement), construction, funding, and maintenance of the road. The form is a lump-sum contract in which all risks are borne by the contractor (except for a few, which are stated in the contract). The contractor is responsible for the assessment and financial quantification and the cost and risk of all the work to be executed in the contract. The project should be self-financing through payments to the contractor derived from toll revenue generated by the project, with no external funding from SADOT's budget.

A schedule of monthly payments was derived from relatively conservative estimates of toll revenue over a 30-year period, measured from the completion of construction. Bidders were required to bid a contract period during which they would be paid the specified scheduled monthly payments, beginning when construction was completed. The successful bidder (the current contractor) projected a period of 23 years, which constituted the lowest bid. In other words, contractors bid on the time to com-plete the work, and the project was awarded to the contractor who indicated the shortest time period.

The scheduled monthly payments are specified in base-date terms and are subject to adjustment for inflation/deflation by a factor related to the consumer price index.

An important qualification among all the bidders (which was accepted by SADOT) was that the scheduled monthly payments would be guaranteed by the state. This meant that the payments would be made to the concessionaire, regardless of the actual toll revenue collected by the Government, for the period discussed above.

An overriding factor in the consideration of this model is the stipulation of the National Roads Act. At the time, it indicated that all monies generated on a toll route "must accrue to the NRF," and that "the Minister of Transport will determine the tariffs."

In retrospect, the concept of tendering on a predetermined schedule of payments, which was based on future toll income, can be regarded as an innovative method to circumvent legal constraints. This method, however, leaves little or no incentive for the concessionaire over the concession period, especially with regard to attracting traffic to the road.

6.4 Design, Construct, Finance, Operate, and Maintain

A contract to design, construct, finance, operate, and maintain is currently being undertaken on the N4 between Witbank, South Africa, and Maputo, Mozambique, and on a portion of the N3 between Heidelberg and Durban. These contracts are similar to those used in France, Hungary, Malaysia, and other parts of the world. For example, the N3 project includes the design, construction, financing, operation, and maintenance of a portion (up to 400 km) of N3 and associated facilities, under a concession contract. New construction will comprise approximately 120 km of four-lane undivided freeway. The estimated cost of the capital expenditure involved in the initial construction is about US$300 million.

The N4 Maputo Corridor project includes the design, construction, financing, operation, and maintenance of 350 km of existing road in South Africa, and about 80 km in Mozambique. The initial capital outlay may be as high as about US$200 million.

6.5 Empowerment of Disadvantaged Citizens

Recognizing the problems a bidder has complying with strict requirements for including affirmative actions (i.e., difficulty pricing competitively, organizing, controlling), SARB has elected, as a condition of contracts, to demand some level of commitment in this direction from bidders. The fact that the extent of commitment will be considered in the adjudication for bidders acts as an incentive, and SARB monitors the results during implementation.

6.6 Use of Consultants

SADOT employs consultants to design road projects. Frequently, the same consultants who designed the project are also hired to provide construction engineering services. Today, most design is done by consultants and subsequent construction is performed by contractors. SADOT does some design in its own offices to maintain the knowledge and ability to design projects within the agency. Design consultants are selected by SARB based on experience, technical ability, and the extent to which they are willing to train the disadvantaged.

7.0 HUMAN RESOURCE DEVELOPMENT

7.1 Background

Although the scanning team was not able to determine the extent to which its observations about human resource development in highway construction applied to building construction, the activities of the South Africans in this area are worthy of mention, even in a report focused on pavement technologies. Most human resource development activities in South Africa that were observed on highway construction projects during the tour involved either skill training or what was referred to as "small contractor development."

7.2 Formal Training Courses

Numerous formal construction skill training courses are offered in South Africa for unskilled and semiskilled workers. CCI offers one such group of courses through its School of Concrete Technology. Course modules include: Introduction to Concrete, Concrete Practice, Concrete Technology, Concrete Technology and Construction, and Advanced Concrete Technology. CCI also offers specially developed skill training courses, such as Site Testing of Concrete, Repairing Honeycombed Concrete, and Testing Concrete Aggregates.

SAFCEC, through its subsidiary training arm, the Civil Engineering Industry Training Scheme (CEITS), also offers a variety of formal training courses for both workers and "participating contractors." The formal skill training that was described by CEITS might be comparable to that for a helper or laborer in the U.S. apprenticeship hierarchy, but the team was told that the career path included section leader and foreman modules. The Participating Contractors Development Program, on the other hand, appears quite extensive, consisting of several modules, including Basic Business Appreciation and Estimating and Tendering.

7.3 Skill Training and Small Contractor Development

At each of the construction sites visited, some aspect of skill training was incorporated in the project (see Figure 12). In addition, the scanning team observed examples of efforts to encourage previously trained workers to progress to hiring a few other workers and contracting for small pieces of labor-intensive work themselves. Less evident was significant development of a black contractor base beyond the micro-enterprise level.

The need for more vertically integrated inclusion of skilled black construction workers and black construction firms was apparent. This observation is especially relevant, given the South African RDP, which clearly mandates that both the chronic unemployment of blacks in South Africa and the need for capacitation of emerging firms must be addressed. For example, Mr. James Ngobeni, President of SABTACO, in his comments to the scanning team, addressed the issue of capacitation by indicating that not enough technical assistance and management support is supplied to black firms in South Africa, especially the architectural/engineering and construction companies. He suggested that increased effort is needed to provide meaningful opportunities for such firms (and individuals) to participate in contracting opportunities.

In a separate meeting with a small group of tour participants, representatives of the

South African Ministry of Public Works presented an overview of the National Public Works Programme, which is a part of the RDP. The objective of this program is to create "an enabling environment," through labor-intensive projects that focus on worker and supervisor training and development of small contracting firms. The Ministry is currently exploring several pilot projects of this type and was greatly interested in learning of the U.S. experience with these types of training delivery systems.

7.4 Examples of Human Resource Development and Use

Although the U.S. team did not observe the project firsthand, a notable example of both skill training and small contractor development was discussed by Mr. Phil Hendricks, Programme Manager for Maintenance and Infrastructure Management Systems at CSIR. This effort is taking place in Phuthaditjhaba, in the North-Eastern Free State, and involves using local citizens to maintain the roads in their communities. Maintenance strategies include community involvement and the use of cost-effective, labor-enhanced technologies that, it is hoped, will lead to economic empowerment of maintenance workers. The road maintenance techniques in this project involve using emulsion-treated bases and are found to be very applicable for labor-intensive construction methods. The program is proving to be effective, both in providing and maintaining low-cost roads in this area and in developing a cadre of workers and microbusiness entrepreneurs. These workers and fledgling companies are expected to form the initial core of workers and small subcontractors on larger scale road construction projects in the area. The project is also viewed as a pilot for establishing similar projects on a national level. CSIR officials believe that road maintenance is an ideal vehicle for encouraging the use of appropriate technology, providing employment and transfer of skills, and promoting small business development.

Perhaps the most sophisticated example of small contractor training and development that the scanning tour observed occurred under the LMG Joint Venture effort of the N1 project (toll road from Warmbaths to Pietersburg). The joint venture partners have contracted with SAFCEC, particularly CEITS, to provide formal training to small and emerging black contractors who are currently providing, or are anticipated to provide, subcontracting services on the project. The classroom sessions are held in a specially designated training center at the project headquarters, shown in Figure 13. As of April 1996, this effort had resulted in over R20 million (US$4.5 million) in subcontracts over a surprisingly comprehensive range of activity categories. Appendix F is a table of the contracts that have already been awarded to emerging contractors and suppliers on this project. The training center also includes skill training and enhancement areas for those workers currently employed or about to be employed on the project. Appendix G outlines the more than 1,000 training certificates that have been awarded to workers on the project, as of May 15, 1996.

The team also visited the Soweto Macadam Project, which provides labor-enhanced training and work opportunities through the use of water-bound macadam to pave and repair streets in the township (see Figure 14).

In the examples cited, with the exception of the N1 project, there did not appear to be as obvious a delineation of skilled labor categories in highway construction as is the case in the United States. Cursory observations and discussions suggest that the vast majority of black workers on these projects would fall into our "laborer" category. The team noted, however, that practically all labor was performed by these black workers, including such skilled activities as heavy equipment operation. This practice of using a laborer category for a wide variety of semiskilled and skilled activities has important implications for wage scales and "portability" of work experiences. It could be argued that it is the contractors who benefit from this practice, but the actual objectives are to create a "win-win" environment in which both parties stand to gain and to focus on labor enhancement and skill development.

Figure 12. Construction Skill Training

Figure 13. Subcontractor Classroom Training

Figure 14. Construction of Water-Bound Macadam Pavement

8.0 OTHER TECHNOLOGY

8.1 Bridge Jacking

Between Johannesburg and Pretoria, the scanning team observed a concrete bridge structure being "jacked" through an existing embankment on the N1, as part of the construction of a new interchange (see Figures 15 and 16).

The concrete structure (top and side walls) was constructed alongside the embankment on top of sills. The sills were extended beneath the embankment by auguring a concrete pipe through the embankment, then constructing the sills in the pipe. A second bridge, which will carry traffic entering the N1 from an adjacent rest area, was also built on the same continuous set of sills. This bridge will be moved into place along the same sills, after the primary bridge structure is jacked under the N1.

Jacks slowly pull the structure along the sills and into the embankment. The jacking cables are also positioned inside the concrete pipes above the sills. The top of the pipe is broken off as the side walls advance on the sills within the pipe. This requires workers to be at the leading edges of the side walls of the structure to remove the embankment material and broken pieces of pipe as the walls advance. Scanning team members expressed concern about this aspect of the work, which could be somewhat dangerous.

The top two-thirds of the leading edge of the side walls are tapered toward the embankment. This facilitates the movement of the structure through the embankment and enhances the degree of protection available to the workers during the movement of the structure. A graphite lubrication system assists the movement of the structure as it rides on the sills. A slurry grout is pumped behind the side walls and between the top and bottom of the N1 pavement as the structure advances. The top of the structure is less than 1 m beneath the concrete pavement of the N1. A steel structure is anchored adjacent to the N1 embankment to guide the concrete structure and contain any vertical and side movement as the jacking progresses. The embankment material in the concrete structure is removed by a front-end loader as the jacking progresses.

When complete, the project will result in an underpass for a new local road that will interchange with the N1 and serve a new development. This project was designed by consultants, and the procedure has been used to create underpasses at several locations around the country.

8.2 Toll Collection

As described in Section 6.0, South Africa has a number of toll roads. In general, the toll plazas look very similar to those in the United States, and the tolls are collected in a number of ways. The primary toll collection process is the standard use of a toll attendant, but automatic toll collection baskets are also in use. There have been some problems with automated coin collection, because South Africa has eight different coins of different sizes in circulation, with both older and newer series. Such coins as the 20-cent coin he 2-rand coin the new and old series have very similar sizes, weights, and shapes.

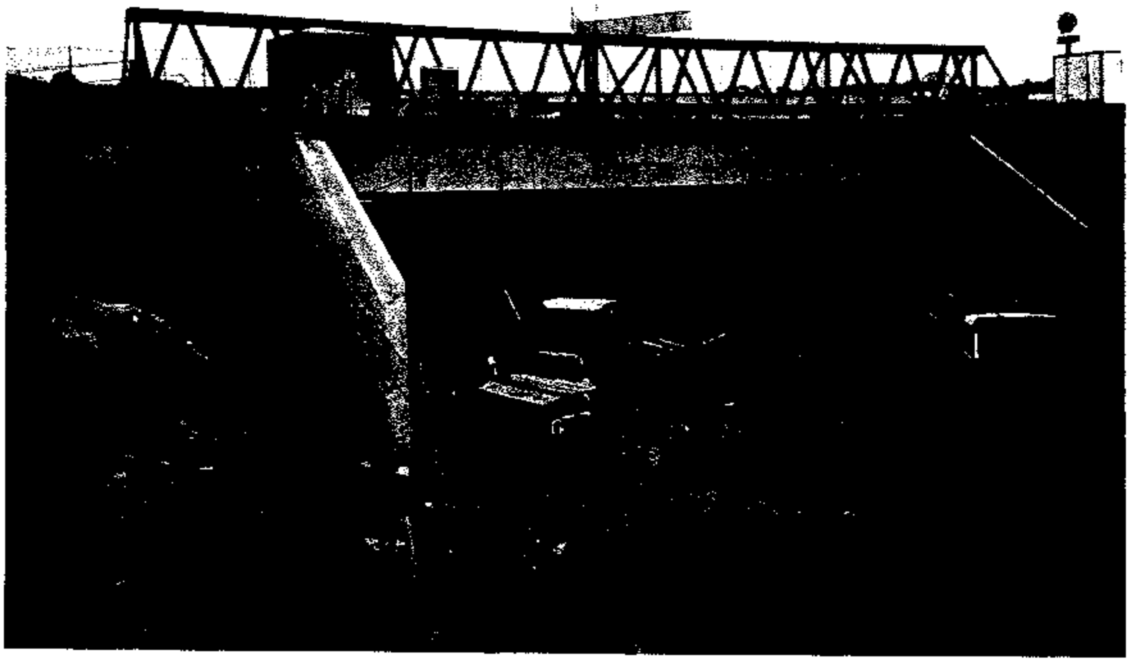

Figure 15. Bridge-Jacking Project

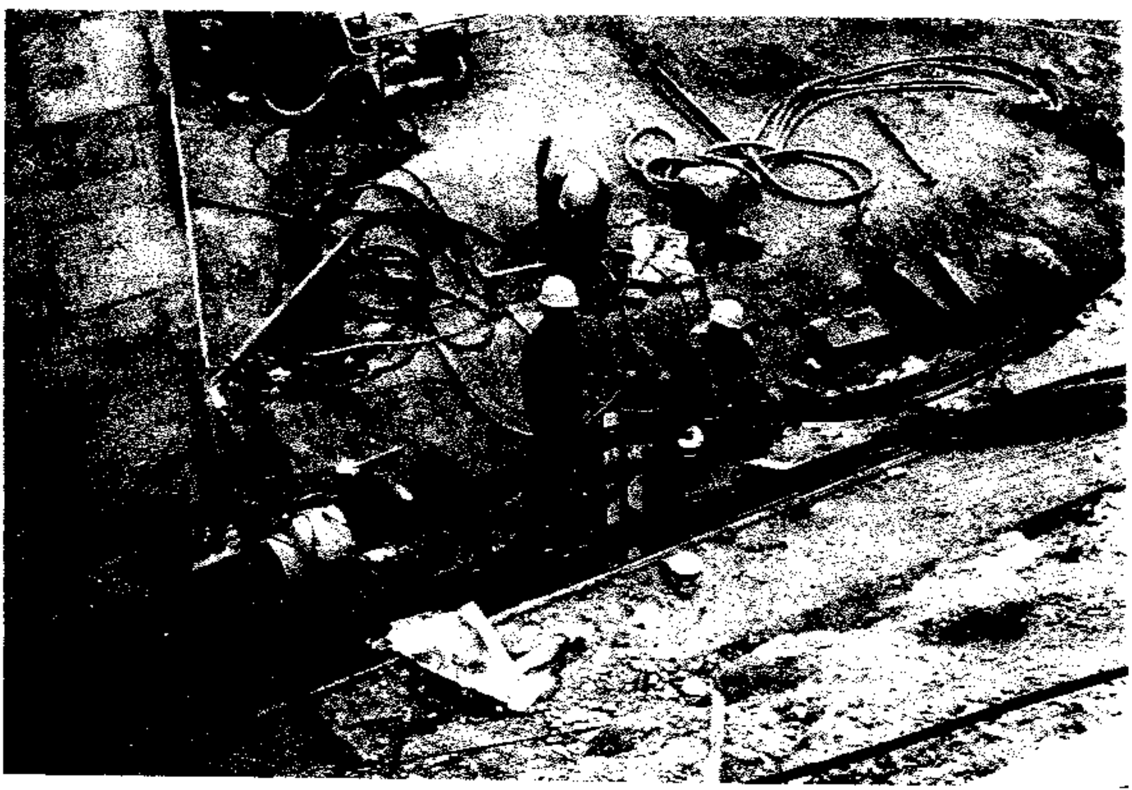

Figure 16. Bridge Abutment and Cables To Jack Bridge

Toll authorities also use automated credit card machines that accept all major cards, including those from gasoline/fuel companies. Credit card systems are preferred, because they are easier to manage and present fewer problems.

8.3 Speed/Distance Warning

To enhance road safety and to attempt to minimize accidents resulting from tailgating, SADOT has implemented a program in which white pavement warning markings are placed on the roadway. Referred to as "following-distance markings," these are a series of "V's" painted in each lane, pointing in the direction traffic is moving (see Figure 17).

The markings are placed as guides to warn drivers when they are traveling too close to the vehicles in front of them. A sign accompanies the pavement markings, indicating the number of "V's" that should be visible between the driver and the vehicle ahead for safe stopping distances. The scanning team was not given any information demonstrating the effectiveness of the warning markers.

8.4 Vehicle-Road Surface Pressure Transducer Array (VRSPTA)

Researchers at CSIR have developed a VRSPTA to measure tire/road interface stresses under a moving tire. The

Figure 17. Speed/Distance Warning Markers

system simultaneously measures the vertical, transverse, and longitudinal vehicle tire/road interface stresses. It consists of an array of calibrated, strain-gauged steel pins fixed to a steel base plate buried in the surface of the road; load-cell pins are installed at right angles to the direction of travel. Strain outputs from these pins are scanned at a high rate while the wheel traverses the pins, indicating the vertical, transverse, and longitudinal loads acting on each pin. The system is approximately 750 mm long by 360 mm wide and 108 mm high. Loads and load distributions are measured over the complete tire contact area.

Initial results from the VRSPTA system indicate that, in extreme cases, the tire side wall vertical stresses can be twice as high as the tire inflation pressure, and that the maximum transverse stresses can exceed the inflation pressure by as much as 27 percent. The maximum longitudinal stresses appear to be the lowest of the three, at a maximum of only 30 percent of the tire inflation pressure. Results appear to be promising in the evaluation of tire/road interface stress patterns.

Both structural performance (fatigue cracking) and functional performance (rutting) of asphalt pavements are directly related to the magnitude and distribution of the tire loads those pavements experience. A better understanding and quantification of the exact nature and distribution of the stresses imposed on pavement surfaces is needed to design more load-resistant paving mixes and layers.

9.0 FINDINGS AND TRANSFERABILITY TO THE UNITED STATES

The primary objective of the scanning tour was to observe, discuss, and document information on South Africa's pavement and other highway-related technologies. South Africa has a reputation in the international transportation engineering community for a very high state of the practice and art in pavement technology. The scanning team did encounter clearly advanced pavement technology in its 1-week tour of pavement research, design, and construction in and around the Johannesburg and Pretoria areas. It was clear from the first day that this scanning tour would be limited in its ability to fully capture the extensive and complex pavement technology observed. This last section of the report lists technical areas that the scanning team members believe have application in the United States, which could improve either practice or technology.

The team recommends consideration of the areas mentioned below, which are unique or represent uniquely advanced technology that has application and the potential to improve the state of the practice or the state of the art of road building in the United States. There was not enough detailed information gathered in this tour to fully describe and transfer the technology in the more complex areas. To fully gather and document the detailed information involved in most of these areas would require a more extended scanning tour visit. If a followup scanning tour is conducted to examine the more complex technical areas highlighted in this report, the team recommends that the tour members have strong technical backgrounds in the specialty areas under review.

9.1 Funding

The ability to obtain adequate funding to expand, replace, rehabilitate, and maintain highways throughout the United States is marginal. The continued rapid growth of truck traffic making just-in-time deliveries to our industries requires the national highway network to be properly maintained and, in some areas, expanded. Obtaining additional public funding is often difficult in this era of "no new taxes."

The BOT concept used by SARB is an innovative means of funding highway projects. South Africa's N1 Route, currently under construction, uses private funding to build and operate the facility, minimizing the need for up-front public funding and the addition of public employees for management. Traffic tolls, depending on location of the facilities, could pay all costs to build and operate roadways.

The condensed schedule of the scanning tour did not allow sufficient time for a detailed review of the BOT process. The team recommends that a followup review be scheduled to provide a more detailed report.

9.2 Research

9.2.1 Broad Funding Sources

Pavement-related research in South Africa is conducted somewhat differently than in the United States. In the United States, most pavement-related research is conducted by universities, consultants, FHWA, and some

State DOTs. That is, many State DOTs, the Transportation Research Board, and FHWA fund pavement-related research, but the actual research work is performed primarily by universities and consultants. In South Africa, pavement-related research is conducted primarily by CSIR's DRTT. Research is also conducted by various universities and consultants, but much of that work seems to support the main body of research conducted by CSIR. Most of the superior pavement technology that the scanning tour observed in South Africa was produced from focused areas of research, primarily conducted by CSIR. This focused research had financial support from national and provincial road agencies and the road industry. It also had continuing support in the form of construction of test sections, cooperative meetings, action from private and public sectors, and organized implementation of the technology.

This pattern of broad participation throughout the research process, from the initial idea to implementation of the technology, is also reflected in the broad base of funding for the research work. In the past, up to 85 percent of CSIR's funding came from government grants. Funding for DRTT for fiscal year 1995-96 came from the following sectors:

- 22.1% International Sources
- 19.8% Provincial Governments
- 26.8% Government Grants
- 8.5% Private Sector
- 22.8% SADOT

A broad base of financial support provides a more consistent and predictable revenue stream, as well as a broad base of support for improved technology. South Africa's constant improvement of its road technology, stemming from broad-based research funding and general support from all sectors of the industry, could serve as a model for other countries. The United States, which spends considerably more on road research, but has not progressed nearly as far, could learn from the South African example.

9.2.2 Technology Management

Participants in the scanning tour were impressed by the successful implementation of road-related research in South Africa. Those working in CSIR, however, have been concerned for several years that South Africa's research program has lost some of its long-term focus and is not as effective as it has been in the past. For this reason, CSIR has been looking very pragmatically at the issue of technology and research management. Through this work, CSIR developed a proposed holistic framework for technology development for South Africa that could be put to use in the United States.

The proposed holistic framework for technology development is particularly applicable to FHWA and the State DOTs. The scanning team recommends that the work CSIR has done to develop a framework for technology management be presented to the AASHTO Subcommittee on Research and the FHWA Highway Research Center. Both groups should note how well research from CSIR is implemented in South Africa's road-building technology. Considering how much is spent in the United States on road-related research, this specific area alone would be well worth a special in-depth tour by those responsible for funding and managing research.

9.2.3 HVS

The HVS program has made a significant contribution to the advanced pavement technology found in South Africa. It was used to help calibrate the damage functions used in the South African mechanistic-based pavement design procedure. The HVS has also been used extensively for accelerated field testing of unique paving materials and layer configurations. Over the years, significant amounts of money have been expended by many States in the United States to prevent reflection crack of new overlays. In this effort, money has been spent on a range of materials, but very little *true* research was conducted on these projects. To date, the best information on pavement crack movement under load and reflection cracking comes from the South African HVS program. Had similar tests been conducted in the United States, the time and money expended on unsuccessful testing of materials could have been saved.

The California DOT is currently conducting APT using two of South Africa's Mk III HVS units, and the Texas DOT is also developing its own technology for APT. For several years, FHWA has been conducting APT at the Turner-Fairbank Highway Research Center, using the accelerated-loading facility. Emerging Superpave binder and mix technology and possible proliferation of modified asphalt binders demonstrate a clear need for more APT in the United States to help quantify the performance and value of such materials. Without a well-organized, national APT program similar to that used in South Africa, it is possible that the United States could repeat the same process it went through trying to find material that would stop reflection cracking.

The HVS program in South Africa should be examined in much greater detail, because it is particularly applicable to early quantification of actual performance improvements, the new Superpave mix procedures, and binder specifications.

South Africa has conducted over 400 accelerated pavement tests in its extensive HVS testing program, but most of the test results have not received wide circulation outside South Africa. The scanning team recommends that an effort be made to catalog the tests to determine which tests can be applied in the United States. APT does not necessarily have to be conducted in the United States to improve our understanding of material performance here. The body of tests that South Africa used to help calibrate the damage relationships used in the mechanistic-based pavement design procedure may also be useful in the United States, as the AASHTO Task Force on Pavements begins developing a mechanistic-based pavement design.

9.3 Pavement Technology

9.3.1 Foundation Support

In South Africa, heavy emphasis is placed on providing good foundations under pavements, typified by strong subgrades. The few subgrades that are weak are sometimes treated with lime or cement, and granular subbases are placed under all pavement sections. Freeway pavements typically include approximately 150 to 300 mm of granular or stabilized granular subbase under untreated bases. The attention given to the foundation design is believed to be an important contributor to the high performance of pavements in South Africa. This supports similar findings made during scanning tours of European pavement practices.

9.3.2 Mechanistic Pavement Design Procedures

South Africa has developed and implemented mechanistic design procedures for both flexible and rigid pavements. Ongoing improvements to the flexible procedure, particularly the transfer functions, can be attributed to extensive accelerated testing of in-service pavements using the HVS. The mechanistic procedure for rigid pavements was recently introduced, which takes into account traffic loading, temperature curling, and base erosion. South Africa may be a good source of information as the United States embarks on the development of the *2002 AASHTO Pavement Design Guide.*

9.3.3 Superpave Center

CSIR has acquired a complete set of laboratory equipment to perform the Superpave tests for both the binder and mixes. This equipment will give the South Africans the same capabilities as the U.S. Superpave centers. As a result of the extensive HVS testing of in-service pavement, CSIR should be in an excellent position to evaluate the relationship between the Superpave mixture analysis procedures and pavement performance. Close cooperation between South Africa and the United States would be beneficial in the implementation of the Superpave procedures.

9.3.4 G1 Base (U.S. Pilot Project)

Using a strong aggregate base with a thin bituminous surface is an appealing pavement approach for roads that carry lower total traffic volumes but have a significant number of heavy vehicles. In the past, the United States has successfully used bituminous surface treatments on aggregate bases for these applications. The ultimate mode of failure is often rutting or displacement in the aggregate base layer. The G1 base used in South Africa provides a very stiff foundation, which should be resistant to load deformations. Because of the moderate climate in South Africa, there is no experience with this type of base under freeze/thaw conditions. Concern has been expressed that this base may decompact under freeze/thaw conditions.

The team recommends that a G1-base pilot project be constructed in the United States at a location that does not experience significant freezing and thawing. The purpose of the project would be to gain experience with the technology and evaluate the economics and performance of the base under U.S. conditions. Because of the unique construction procedures used for compaction, on-site technical assistance from personnel experienced in G1-base construction would be required for the initial project. If the pilot project indicates that the base is a cost-effective alternative, research to evaluate performance under freeze/thaw conditions is recommended.

9.4 Social Factors in Project Management and Construction

SADOT's practice of using social responsibility factors in evaluating and awarding contracts is a process that warrants further study for applicability in the United States. Given the current climate of reductions in formal, obligatory affirmative action requirements in procurement, alternative approaches (such as the social responsibility approach in South Africa) might be used in construction contracting. These approaches would allow continued consideration of the capacity, capability, and contracting opportunity issues that minority and women contractors face in this country.

9.5 Human Resource Development

9.5.1 Organizational Links as Delivery Systems

The role of CSIR as the engine for highway construction research has already been discussed. CSIR, SAFCEC, SABTACO, and others are also working together to deliver training and assistance through their organizations. CSIR is the driving force behind the Phuthaditjhaba Training Program, and SAFCEC provides ongoing support for training through CEITS. In the United States, the CSIR counterpart organizations are not directly involved in training, and the comparable trade associations are not as extensively involved as they are in South Africa. Further investigation into the methods used by various South African organizations to identify training needs, reach out to potential trainees and workers, aggregate and deploy training resources, and measure the impact of training would be warranted for their applicability in the U.S. context.

9.5.2 Adapting Labor-Optimization Strategies and Technologies

The unemployment situation in the United States is not nearly as acute as it is in South Africa, but there are still major pockets of chronic unemployment in both urban and rural areas, on Native American reservations and among at-risk youth, particularly those f African-American and Hispanic origins. In South Africa, a conscious effort is made to use labor-optimization strategies and technologies to directly and effectively address the chronic unemployment in that country. Further study of such strategies and technologies, especially in road construction, maintenance, and repair, might suggest some approaches that could be used to address the U.S. unemployment situation, particularly among those groups mentioned above.

9.5.3 Industry-Driven, Project-Specific Training

One of the reasons that the South African training efforts seem effective is that they are developed by industry participants, particularly the contractors, through their trade associations and training schemes. Training is designed and implemented, for the most part, around specific, large-scale construction projects. A significant segment of craft training in the United States is provided through the vocational components of secondary education and through special programs, such as Job Corps and YouthBuild. Although these programs are worthwhile, they often do not have the extensive involvement of the construction industry, especially in the critical areas of curriculum development and job placement. The team recommends more active exploration of project-specific training efforts in South Africa. The United States should also study precisely how the South African highway construction industry (including CSIR) has become the impetus for conceptualizing and implementing much of the training that occurs in that sector.

APPENDIX A. List of Meeting Participants

Date	Name	Association	Position	Phone No.
May 13 SADOT	Malcolm Mitchell	SADOT	Deputy Director General	(012) 309-3173
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	Albert Du Plooy	SADOT	Dir., Financial Programs	(012) 309-3331
	Koos Smith	SADOT	Director, Operations	(012) 309-3419
	Neil Tolmie	SADOT	Director, Toll Roads	(012) 309-3432
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	Louw Lannermeyer	SADOT	PMS Engineer	(012) 309-3359
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May 14 CCI am	Graham Grieve	CCI	Executive Director	(011) 315-0300
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	Bryan Perri	CCI	Manager, Gauteng Office	(011) 315-0300
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	Piet Myburgh	Sabita	Executive Director	(021) 212-577
	Andrew Mhembu			
	Steve Emery	COLAS	Director	(011) 974-9760
	Ronnie Renshaw	TOSAS	Retired	
	Chris Potgieter	Consultant		
	Emile Horak	Murray & Roberts	Director	(011) 974-2622
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Date	Name	Association	Position	Phone No.
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	Phil Hendricks	DRTT CSIR	PM Maint. & Info. Mgmt.	(012) 841-2717
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	Dave Temple	SNA, Inc.	Director	(012) 347-1147
	David M. Gertzen	VNK	Project Engineer	(011) 886-4589
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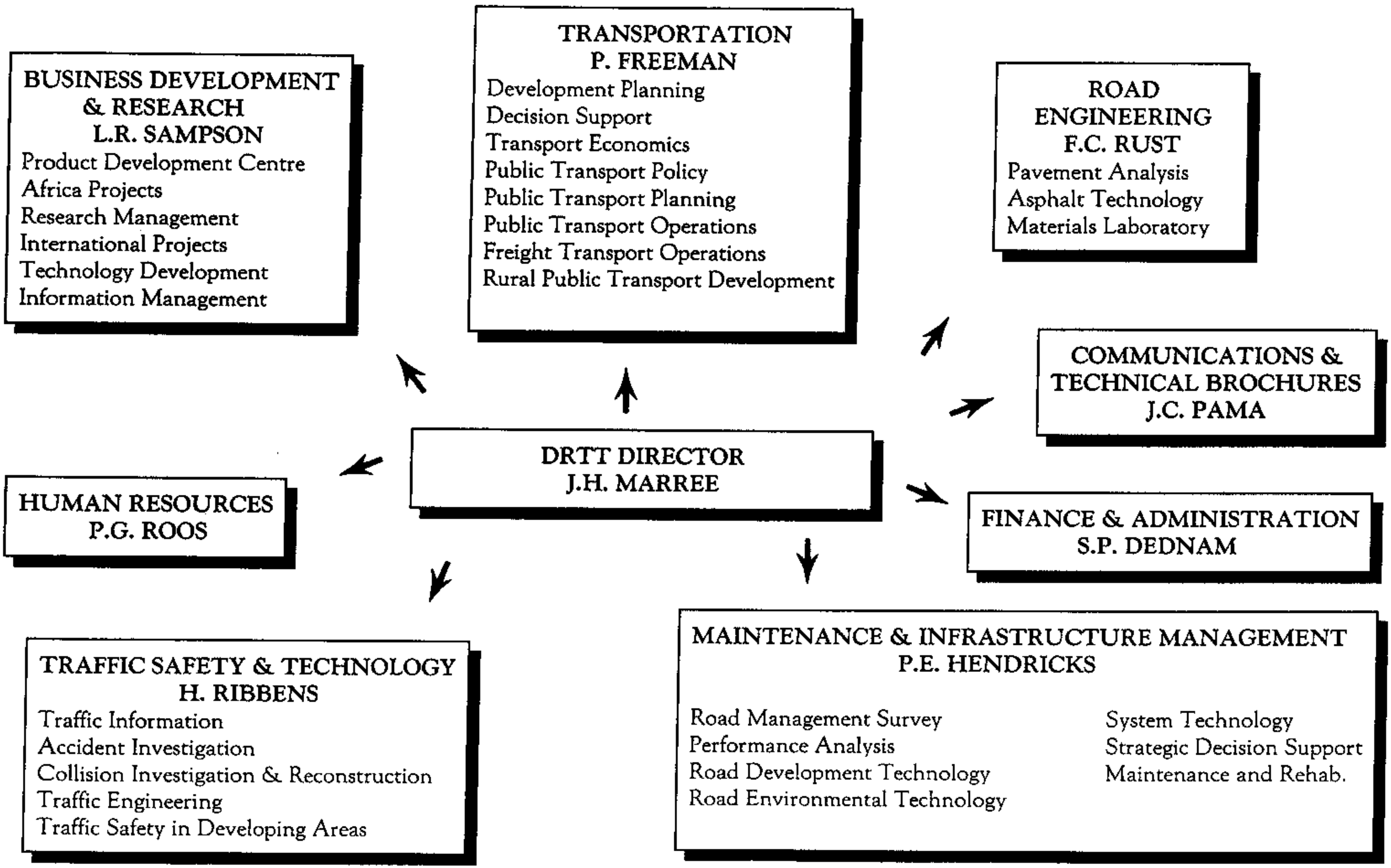
APPENDIX B. Organization Chart: CSIR Division of Roads and Transport Technology



APPENDIX C. Outline of HVS Program

HVS: Research Implementation, Associated Technologies, and Data Base

Structural Behavior

Structural pavement design improvements resulting from HVS testing include:

- Design manuals, such as the South African TRH series and material specifications used by the South African road authorities
- Structurally well balanced and inverted pavements
- Field verification of mechanistic approaches
- Field-verified fatigue and rutting performance prediction
- Verification that the exponent "n" (in the simplified AASHTO damage equivalency formula) depends on the pavement composition and that the behavior state (of the pavement) does not necessarily conform to the well-known 4th-power law
- Field verification of laboratory-determined parameters, such as fatigue curves.

The HVS APT program:

- Has been used to predict the structural behavior of a 70:30 mixture of reclaimed and new asphalt
- Has improved:
  - Durability models (erodibility) and fatigue models for cement-treated bases and subbases
  - The unique crushing failure mode and model of thinly surfaced, lightly cemented pavements.

The HVS APT program has also proven the value of the crack-and-seat method before the rehabilitation of unbalanced pavements and that the pre-crack life of cemented materials (stabilized) is less than 20 percent of total life.

Material Technology

Using enhanced material testing methods, the HVS APT program has:

- Evaluated new and "substandard" materials to enable their cost-effective use

- Evaluated such new developments as:

    - Large-stone mixes
    - Use of modified binders in asphalt mixes
    - Roller-compacted concrete
    - Block pavements
    - Emulsion-treated bases
    - Water-bound macadam bases
    - Porous asphalt with modified binders
    - Recycled asphalt base materials
    - Use of waste materials, such as slag and ash.

- Validated the development of new design methodology for large-stone mixes and evaluated their performance under very heavy traffic

- Verified material design methodologies for large-stone mixes and emulsion-treated bases.

Material test methods developed from, and verified by, HVS technology include:

- Dynamic creep test for asphalt
- Erosion test for cemented materials
- Crack activity meter
- K-mold (for triaxial tests)
- 3-D loadcell (for tire pressure distribution measurements)
- Semiautomatic dynamic cone penetrometer.

Laboratory and Field Work

The development of road deterioration models and transfer functions links laboratory investigations and field performance, thus reducing or even eliminating the use of shift factors (from laboratory-measured failure to predicted field failure) during the design phase.

Associated Technologies

Associated technologies used to measure the structural response caused by trafficking include:

- Multidepth deflectometer to measure elastic deflection bowls, as well as permanent deformation at preset depths, usually at interfaces between structural layers
- Road surface deflectometer (or modified Benkelman beam) used to measure surface deflection basins
- Electronic profilometer used to measure transverse and longitudinal rut profile

- Crack activity meter used to measure the movement of cracks with the passage of the wheel load
- 3-D loadcell to measure tire-contact pressure in three dimensions
- Various other test methods, including those to monitor temperature and determine material properties (e.g., the K-mould).

Data are gathered at various times during each HVS test. The information can be used to calculate changes in engineering parameters, such as layer stiffness over time, and the progression of functional parameters, such as rutting, as the road deteriorates.

Data Base

Over two decades, a significant data base, including data on more than 500 test sections, has been compiled. These data are readily available for enhancing the design of road materials and structural design of roads and to avoid the duplication of future work at significant cost savings.

APPENDIX D. Outline of Proposed Holistic Framework for Technology Development

Excerpted from "A Proposed Holisitic Framework for Managing the Development of Transportation Technology in South Africa," by F.C. Rust and J.H. Maree. Reprinted with permission from the authors.

EXECUTIVE SUMMARY

Technological development impacts significantly on society, both in everyday life as well as in enhancing a country's competitiveness. In South Africa technological development is of particular importance, especially with regard to its role in supporting initiatives such as the RDP and the NPWP [National Public Works Programme]. This impacts also on the transportation industry, especially in light of the fact that the transportation sector has the potential to support the objectives of the RDP through providing in basic needs, job creation as well as the stimulation of economic growth. In this scenario technology will play a significant role as enabler—be it "high-tech" or "appropriate technology." The success of programmes such as the RDP and the NPWP will depend on, amongst other things, the efficacy with which transportation technology will be developed, implemented, and managed.

Recently, concerns have been expressed that the national transportation research programme has not delivered up to expectations. A new, focused effort is needed to address real needs, to ensure sustainable technology development and implementation, and to enhance the development of human capacity for South Africa.

The process for managing technological development in the transportation sector should be designed to yield maximum benefit to the transportation industry, the economy of the country, as well as to transportation users and communities. The process should therefore include the following aspects:

- it should be a holistic approach
- the process should address both short-term and long-term objectives
- the process should be focused at the strategic level
- the process should be consultative
- the process should be inclusive
- implementation and technology transfer activities should form an essential part of the process
- technology development should be linked to education and training
- the impact of investment into technology development should be monitored
- the process should enhance intellectual capacity
- the process should stimulate innovation

In order to ensure maximum benefit from a technology development process, both short-term needs as well as longer-term objectives should be addressed. This implies that techniques such as technology tree development should be used to ensure that thrust and project portfolios are well balanced and address the spectrum of technology development from basic research requirements through applied work to technology transfer and implementation. Concepts such as the development of technology platforms can assist in ensuring that key solutions are delivered to the industry in a cost-effective manner.

Technology development (TD) is a powerful means of enhancing human capacity. The proposed model for the management of technology development is centred around an intellectual-capacity pool which consists of the knowledgeable people in the industry, including road authorities, consultants, universities, and the CSIR. The proposed TD process is designed to continuously develop the pool of intellectual capacity.

The approach is holistic, which implies that it does not address only research projects, but rather the complete environment of technology development including, strategy development, needs determination, research and development, technology transfer and implementation, education and training, as well as the measurement of the impact of the process. The elements of the process are interdependent and should not be separated but rather seen as elements of a system which impact on each other. The planning and management processes should be adjusted accordingly. Management structures that will ensure quality strategies and efficient monitoring and control are also suggested.

The proposed process will have the following advantages:

- it will ensure proper strategy and needs determination with participation from various stakeholder groupings;
- it will ensure efficient management and control at the relevant levels;
- it will ensure a focused effort with effective cooperation between technology development organisations to eliminate duplication, overlap, and fragmentation;
- it will ensure a holistic approach that recognises the interaction between the elements of the process;
- it will ensure effective technology transfer and implementation through well-structured delivery systems;
- it will enhance human capacity through technology transfer, education and training at all levels and will thus enhance the quality of the total intellectual-capacity pool;
- it is a very effective way to provide an opportunity for people from the technical to the academic level to enhance their capabilities; and
- it will measure the impact of the process in economic terms, technological terms as well as in the development of people.

APPENDIX E. Technical Manuals, Reports, and Papers Received

A. SADOT

Published Manuals

Technical Recommendations for Highways

Draft TRH 3: 1986, Surfacing Seals for Rural and Urban Roads, Committee of State Road Authorities, Department of Transport, Pretoria, South Africa, 1986. (Currently being revised.)

Draft TRH 7: 1994, The Use of Bitumen Emulsions in the Construction and Maintenance of Roads, Committee of State Road Authorities, Department of Transport, Pretoria, South Africa, 1994.

Draft TRH 8: 1987, Design and Use of Hot-Mix Asphalt in Pavements, Committee of State Road Authorities, Department of Transport, Pretoria, South Africa, 1987.

TRH 10: 1994, The Design of Road Embankments, Committee of State Road Authorities, Department of Transport, Pretoria, South Africa, 1994.

Draft TRH 13: 1986, Cementitious Stabilizers in Road Construction, Department of Transport, Pretoria, South Africa, 1986.

TRH 14: 1985, Guidelines for Road Construction Materials, Committee of State Road Authorities, Department of Transport, Pretoria, South Africa, 1986.

Draft TRH 15: 1994, Subsurface Drainage for Roads, Committee of State Road Authorities, Department of Transport, Pretoria, South Africa, 1994.

TRH 18: 1993, The Investigation, Design, Construction, and Maintenance of Road Cuttings, Committee of State Road Authorities, Department of Transport, Pretoria, South Africa, 1993.

Draft TRH 20: 1990, The Structural Design, Construction, and Maintenance of Unpaved Roads, Committee of State Road Authorities, Department of Transport, Pretoria, South Africa, 1990.

Draft TRH 22: 1994, Pavement Management Systems, Committee of State Road Authorities, Department of Transport, Pretoria, South Africa, 1994.

Technical Methods for Highways

Draft TMH 3: Traffic Axle Load Surveys for Pavement Design, Committee of State Road Authorities, Pretoria, South Africa, 1988.

TMH 1: Standard Methods for Road Construction Materials, Second Edition, Pretoria, South Africa, 1986.

TMH 5: Sampling Methods for Road Construction Materials, Committee of State Road Authorities, Pretoria, South Africa, 1981.

TMH 9: Pavement Management Systems: Standard Visual Assessment Manual for Flexible Pavements, Committee of State Road Authorities, Pretoria, South Africa, 1992.

Urban Transport Guidelines

UTG 2: Structural Design of Segmental Block Pavements for Southern Africa, Committee of State Road Authorities, Pretoria, South Africa, 1987.

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de Beer, E.J.H., and Schutte, I.C., *Transport Statistics*, Research Report RR 88/044, Department of Transport, Pretoria, South Africa, 1992.

Bofinger, H., et al., *The Design, Construction and Maintenance of Low-Volume Rural Roads and Bridges in Developing Areas*, S89/2 1989, Department of Transport, Pretoria, South Africa, 1990.

Floor, Bernal C., *The History of National Roads in South Africa*, 1985.

Jones, D., and Paige-Green, P., *The Determination of Acceptability Criteria for Dust From Unpaved Roads*, Research Report RR 90/217, Department of Transport, Pretoria, South Africa, 1991.

Jordaan, G.J., *The Applicability and Determination of the Shear Modules of Road Construction Materials for Pavement Design and Performance*, Research Report RR 91/225, Department of Transport, Pretoria, South Africa, 1994.

Jordaan, G. J., *Synthesis of Test and Estimation Procedures for Mechanistic Pavement Design Materials Properties*, Research Report RR 93/367, Department of Transport, Pretoria, South Africa, 1996.

Lourens, J. P., *Nonlinear Dynamic Analysis and Design of the Road Pavements*, Research Report RR 90/030, Department of Transport, Pretoria, South Africa, 1992.

Sandersa P.J., de Beer, M., and du Plessis, H.W., *Characterization of the Elastic Properties of Existing Pavements: State of the Art*, Research Report RR 91/012, Department of Transport, Pretoria, South Africa, 1993.

Strauss, P.J., and Jordaan, G.J., *Mechanistic Design To Prevent Reflection Cracks in Overlays*, Research Report RR 88/214/1, Department of Transport, Pretoria, South Africa, 1994.

van Niekerk, P.E., and Visser, A.T., *Dynamic Loading Effects of Heavy Vehicles on Road Pavements*, Research Report RR 91/280, Department of Transport, Pretoria, South Africa, 1992.

Policy Issues

A Future for Roads in South Africa, Department of Transport, Pretoria, South Africa, May 1996.

Green Paper on National Transport Policy, Department of Transport, Pretoria, South Africa, March 1996.

Contracts

"Basis of Contract and Financial Aspects," Contract No. SAPR N0124602/1, Part 1, Volume 1, Book 2, South African Roads Board, Department of Transport, Pretoria, South Africa, January 1994.

"Project Document," Contract No. SAPR N0124601/1, Part 3, Volume 3, Book 1, South Africa Roads Board, Department of Transport, Pretoria, South Africa, January 1994.

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"Quality Control on Road Construction Projects," South African Department of Transport Approach.

"State of the Industry: First Quarter, 1996," SAFCEC, March 1996.

"An Innovative Approach to Road Financing in South Africa—The N1 BOT Project," March 1995.

"Toll Roads in South Africa," January 1994.

"Concrete Pavement Design and Construction," *Manual M10*, Department of Transport, Chief Directorate, Roads, Pretoria, South Africa.

B. SABITA

Published Manuals

Technical Guidelines: Construction of Bitumen Rubber Seals, Manual 1, May 1990.

Bituminous Products for Road Construction and Maintenance, Manual 2, 1995.

Test Methods for Bitumen-Rubber, Manual 3, March 1992.

Specification for Rubber in Binders, Manual 4, 1988.

Guidelines for the Manufacture and Construction of Hot-Mix Asphalt, Manual 5, June 1992.

Interim Specification for Bitumen-Rubber, Manual 6, April 1989.

Economic Warrants for Surfacing Roads, Manual 7, October 1993.

Bitumen Safety Handbook, Manual 8, August 1993.

Bituminous Surfacings for Temporary Deviations, Manual 9, May 1992.

Appropriate Standards for Bituminous Surfacings for Low-Volume Roads, Manual 10, May 1992.

Labour-Enhanced Construction for Bituminous Surfacings, Manual 11, March 1993.

LAMBS—The Design and Use of Large Aggregate Mixes for Bases, Manual 13, October 1993.

GEMS—The Design and Use of Granular Emulsion Mixes, Manual 14, October 1993.

Technical Guidelines for Seals Using Homogeneous Modified Binders, Manual 15, May 1994.

REACT—Economic Analysis of Short-Term Rehabilitation Actions, Manual 16, October 1994.

Porous Asphalt Mixes—Design and Use, Manual 17, October 1994.

Appropriate Standards for the Use of Sand Asphalt, Manual 18, 1996.

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Potgeiter, C.J., and Hattingh, J., "Bitumen-Bound Macadams for Labour-Intensive Construction."

Asphalt News, First Quarter 1996.

C. CSIR

Published Material

CSIR Technology Impact, Pretoria, South Africa, 1995.

de Beer, M., *Measurement of Tyre/Pavement Interface Stresses Under Moving Loads*, Research Report DPVT 224 (Revised), Division of Roads and Transport Technology, December 1995.

Theyse, H.L., de Beer, M., and Rust, F.C., *Overview of the South African Mechanistic Pavement Design Analysis Method*, Divisional Publication DP-96/005, March 1996.

Rust, F.C., and Marree, J.H., *A Proposed Holistic Framework for Technology Development and Implementation in South Africa*, Research Report DPVT/236, Division of Roads and Transport Technology, June 1995.

Unpublished Material

Heavy Vehicle Simulator (HVS), May 1996.

Phuthaditjhaba Training Project, compilation of training project articles.

D. SAFCEC

Published Material

Annual Report, 1994-1995.

E. SAACE

Temple, D.S., *An Overview of Bridge Design and Construction in South Africa*, SNA Civil and Development Engineers, Inc., May 1996.

APPENDIX F. LMG Joint Venture Subcontracts Awarded to Emerging Contractors and Suppliers for the N1 Warmbaths-Pietersburg Toll Road (as of April 1996)

	Subcontractor/Supplier	Age of Firm (yr)	Number of Workers	Main Activity
1	Peternis Transport cc	1	16	Tipper Truck Hire
2	Springbok Construction	3	8	Fencing
3	K. Net Fencing	6	8	Fencing
4	NMS Consortium	1	0	Fencing
5	LOM Consortium	1	0	Fencing
6	LMM Consortium	1	0	Fencing
7	ND Steelfixers	4	0	Steel Fixing
8	Sam's Fixing Service	3	18	Steel Fixing
9	Thermane Projects	2	1	Supply Pitch Fiber Pipes
10	Future Construction and Earthworks	1	0	Construct Cross Roads
11	Libgem Plant Hire	1	2	Hire of TLB
12	Sebezile Plant Hire	1	1	Hire of TLB
13	E. Ngerma Steelfixers	2	18	Steel Fixing
14	Joe's Fixing Service	2	12	Steel Fixing
15	Kgaphola LH Co.	3	0	Gabions and Stone Pitching
16	A. Maja Steelfixers	2	13	Steel Fixing
17	L.J. Mnisi Construction	1	18	Fencing
18	A. Bubpape Steelfixers	1	12	Steel Fixing
19	Joseph Kgwahla	2	0	Steel Fixing
20	G. Mohlaba Building and Fencing	2	0	Gabions
21	Jascon Construction	3	18	Subsoil Drains
22	LGM & Partners Transport	1	3	Water Tank Hire
23	Polokwane Plant Hire	1	2	Pedestrian Roller Hire
24	Kgwaino Homes	2	16	Nyf Plaza Olvits and Building
25	Thescony Construction	6	15	Culvert and Head Walls
26	Monyamane Construction	3	21	Gabions
27	Mukwevko Civil Engineering	1	18	Kerbing and Guardrails
28	MGN Transport	1	12	Aggregate Transport
29	David Homes	1	30	Mookghopong Noise Barrier
30	Polokwane Civils	1	6	Zeb Plaza Water Supply
31	E.R.O.C.	1	10	Guardrails
32	Charlie's Paving	2	0	Block Paving
33	Mushungu Paving	2	0	Block Paving
34	R.S.A. Blasting	1	18	Drill and Blast
35	M.D. Nzimands	1	2	Transport Rebar
36	L. Mvusi	1	2	Transport Rebar
37	A. Mapenas Transport	1	2	Transport Rebar
38	Mafokeng Transport	1	2	Transport Rebar
39	I. Legodi	1	2	Transport Rebar
40	Phalaborweni Transport	2	2	Transport Rebar
41	D. Lebepe Transport	1	2	Transport Rebar
42	Phakishi Carriers	2	2	Transport Rebar
43	I. Legodi	1	8	Cut and Bend Rebar
44	A.K. Welders Transport	1	2	Transport Mesh
45	Phalaborweni Transport	2	4	Supply and Fix Rebar
46	RMP Insurance Brokers	3	6	Olalma Handling
47	J & R Transport	1	2	Transport
48	Phakiso Carriers	2	2	Transport
49	Transport Trucking	4	2	Transport Gabions
50	Isitebe Transport	6	2	Transport Gabions
51	Phalaborweni Enterprises	2	3	Supply and Deliver Rebar
52	Lebepe National Carriers	1	2	Plant Hire
53	A.C.M. Construction	1	0	Transport Hire
54	BKS MEL	1	16	Materials Testing
55	Sundry Plant Hire		17	Plant and Transport Hire
56	Sundry Suppliers			Camp Fencing, Toilet Hire, etc.

APPENDIX G. LMG Joint Venture Certificates Issued at Project Training Center for N1 Warmbaths-Pietersburg Toll Road (as of 15 May 1996)

Training Course	Certificates Awarded
Banksman	19
Basic Construction Hand	111
Bridge Backfilling	29
Business Appreciation	253
Construct "V" Drains	10
Fencing	37
First Aid	63
Gabions	30
Gabions and Stone Pitching	6
Guardrails	34
Kerbing	10
Measuring Skills	40
Operators and Drivers	224
Safety Representatives (Part 1)	38
Scaffold Support Work	79
Soilcrete and Measuring Skills	8
Soilcrete	7
Storm Water	4
Subsoil Drains	27
Survey Assistants (Part 1)	4
Team Leader	24
Wing Walls	27
Total	1,084

ACRONYMS

AASHTO	American Association of State Highway and Highway Officials
APT	Accelerated Pavement Testing
BOT	Build, Operate, and Transfer
CBR	California Bearing Ratio
CCI	Cement and Concrete Institute
CEITS	Civil Engineering Industry Training Scheme
CSIR	Council of Scientific and Industrial Research
DOT	Department of Transportation
DRTT	Division of Roads and Transport Technology (CSIR)
E80	80-kN-Equivalent Standard Axle Load
EVA	Ethylene Vinyl Acetate
EVU	Equivalent Vehicle Unit
FFC	Finance and Fiscal Committee
FHWA	Federal Highway Administration
GEMS	Granular Emulsion Mixes
HVS	Heavy Vehicle Simulator
IRI	International Roughness Index
km	kilometer
kN	kilonewton
LAMBS	Large Aggregate Mixes for Bases
LSR	Loan-Supportable Revenue
m	meter
mm	millimeter
MPa	Megapascal
NABCAT	National Black Contractors and Allied Trades
NRF	National Road Fund
PCC	Portland Cement Concrete
PCCP	Portland Cement Concrete Pavement
PRI	Profile Index
R	Rand
RDA	Rural Development Act
RDP	Reconstruction Development Plan
SAACE	South African Association of Consulting Engineers
Sabita	South African Bitumen and Tar Association
SABTACO	South African Black Technical and Allied Careers Organization
SADOT	South African Department of Transport
SAFCEC	South African Federation for Civil Engineering Contractors
SARB	South African Roads Board
SAT	Society for Asphalt Technology
SBR	Styrene Butadiene Rubber
TMH	Technical Method for Highways
TRH	Technical Recommendation for Highways
UTG	Urban Transport Guideline
VRSPTA	Vehicle-Road Surface Pressure Transducer Array

ENDNOTES

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17. The International Development Research Centre (Ottawa, Ontario) report of 1996 indicates an unemployment rate of 46 percent (refer to Internet address <http://www.idrc.ca/corp/emandela.html>). An International Labour Organization (Geneva, Switzerland) report of 14 October 1996 suggests that previous figures were exaggerated and an unemployment rate of 20 percent is "closer to reality" (refer to Internet address <http://www.ilo.org/english/235press/pr/96-31.htm>). Regardless of actual figures, unemployment is a serious problem in South Africa. In his budget speech of 6 March 1996, the Minister of Finance, Mr. C.F. Liebenberg, stated, "The economy has performed poorly with respect to employment creation: indeed this is a structural problem that cannot be addressed through conventional economic growth alone ... Consequently, we need to get a better understanding of the informal sector. One of the problems of unrecorded economic activity is that we do not know its income effects and it is difficult to monitor changes in the position of those involved in it." (See Internet address <http://www.anc.org.za/govdocs/speeches/ budget96.html>.)