AN INTERNATIONAL VIEW

OF PAVEMENT ENGINEERING

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ABSTRACT

The authors have attempted to show that local differences in pavement practices and climate are typically not all that different (with the exception of countries such as South Africa). Further, the transfer of technology is difficult given the current transfer venues. To address this issue, two major new approaches are proposed. The International Pavement Guide is not being developed and requires much discussion if such an effort is ever undertaken. An international technology workshop is currently being planned for 1998. Possibly, this joint South Africa/USA activity can serve as a model for this type of venue.

INTRODUCTION

Virtually all pavement design procedures (either new construction, reconstruction, or rehabilitation) are based on either empirical or mechanistic-empirical principles. Further, similar materials are used whether it be asphalt concrete, portland cement concrete, crushed stone, etc. Unfortunately, local differences in how such principles and materials are used make sharing and transfer of pavement-oriented knowledge far more difficult than it should be. Local differences in pavement design, construction, evaluation and rehabilitation are somewhat understandable due to variations in available materials, climate, traffic, and budget; however, improved technology transfer of known pavement practices is needed. Technology transfer is defined quite broadly and includes design procedures, specifications, test methods, and construction practices. This lack of knowledge sharing and the methods to enhance such sharing are further exacerbated by the fact that there appears to be no international organization currently addressing this need; however, there is evidence that organizations such as the World Road Association (formerly known as the Permanent International Association of Road Congresses) will be helpful.

This paper will be used to first overview general road and pavement statistics followed by more specific pavement practices for a selection of countries. Such information will be used to propose improved mechanisms for sharing pavement technology among countries. The issue of the potential benefit of such technology sharing will also be addressed. As the authors will show, there are generally broad similarities in pavement practices with a few countries having somewhat different practices (such as South Africa). Such information (including both the similarities and differences) supports the need for improved technology sharing.

GENERAL STATISTICS

In preparing this paper, road and pavement related data from a number of countries will be used. One group of countries are used to show broad world trends followed by more specific data from various countries (mostly Europe and the USA). First, a selection of countries were chosen to represent Africa, the Americas, Asia, and Europe. In Table 1, these countries are shown along with information on size, kilometers of motorways and total road network, percent paved, and road density. Most countries shown for Europe, Asia, and the USA have a substantial percentage of the road network paved (greater than 50 percent). Naturally, such numbers are always a bit uncertain depending on how national statistics are developed and published. Further, some countries such as Iceland have very low traffic levels on a substantial portion of their national route systems, hence the low percentage of paved roads. Of the world's 24 least developed countries with national route systems with more than 10,000 km of highways (United Nations[1]), the average percentage of roads paved was 13 percent. These countries had a Gross Domestic Product of only US$319 per capita in 1994. This compares to US$21,875 for developed market economies (a difference by a factor of about 70).

Table 2 overviews selected country density statistics which illustrate the wide range of population densities (South Korea with a high of 454 persons per square kilometer to a low of three persons per square kilometer for Iceland). It is interesting to note that a wide range of country densities can reflect a wide range of development.

Table 3 shows various traffic statistics (where available) in terms of annual vehicle-kilometers and ton-kilometers. It appears that several countries have ratios of truck-kilometers divided by tonne-kilometers of about 1.0. Exceptions (with higher ratios) are Sweden, Lithuania, Latvia, and South Korea. Possibly better measurements of road usage are shown in Table 4 which shows the same measures, but on a per capita basis.

Tables 5 and 6 provide a view of specific climate statistics. As one would expect, the countries near the equator have little variation between the coldest and warmest months. Some of the largest differences occur in the USA, South Korea, and Europe. The majority of the selected cities have substantial precipitation. With only one exception (Santiago, Chile), about one-third of the time (or greater) the cities shown have days with measurable precipitation in a typical year.

Table 7 shows the depth of freeze for several countries in Europe as well as Washington State in the USA. Pavement design and performance is strongly influenced by this specific climate feature - possibly more so than any other single climate measure.

The information shown in this section of the paper reveals that:

- Most "developed" countries have about 50 percent or more of their roads paved.
- Population density measures offer no substantial information about pavement usage.
- For countries such as Denmark, Estonia, Latvia, Lithuania, Japan, and Sweden, about 300 E80s are applied to each kilometer of road (on average) for each person in those countries. The USA has a value about double that figure.
- Yearly mean and highest mean monthly temperatures for selected cities in various countries shown exhibit only modest differences. The mean temperature for the coldest months reveal significant differences.
- Most cities studied have measurable precipitation days for at least 30 percent (or more) of a typical year.
- Numerous countries have very warm summers accompanied by significant freezing depths due to cold winters.

PAVEMENT TYPES AND PRACTICES

This section will be used to overview some of the available information about the pavement types used in various countries along with various pieces of design-oriented information.

Table 8 shows the relative percentages of pavement types shown for various European countries (the selection of countries was influenced by an earlier version of the paper presented in Estonia). Flexible pavements surfaced with asphalt concrete tend to dominate (as is true with most countries throughout the world). This view is supported by statistics from the USA (FHWA[2]) which reveals that 94 percent of the public road system is flexible pavement and the remaining six percent is rigid.

Table 9 is a summary of work done by Nissoux et al.[3] for PIARC. It shows rigid pavement practices for 11 European countries and Japan. Basically, plain jointed concrete pavement tends to dominate. For heavily trafficked roads, the slab thicknesses range between 220 to 260 mm (a bit thinner for CRCP). Currently, the legal single axle loads average slightly over 11 tonnes (9.1 tonnes in the USA) and about 19 tonnes for tandem axles (15.4 tonnes in the USA). The average transverse joint spacings are 5.0 m although they range from 3.5 to 6.0 m. Dowel bars typically are 25 mm in diameter, 500 mm in length, and spaced 300 mm apart. The following observations are based on USA practices (FHWA[4]):

- Twenty-one states provide for the use of plain jointed PCC (no dowels) with an average transverse joint spacing of 4.6 m.
- Twenty-three states provide for the use of plain jointed PCC (with dowels) with an average transverse joint spacing of 5.5 m.
- The majority of states use dowel bars with the following characteristics:
  - Diameter: 32 mm
  - Length: 460 mm
  - Spacing: 305 mm

Currently, most states only construct doweled JPCP (NCHRP[5])
Though specific emphasis was not placed on traffic loadings in this paper (with the exception of the axle load limits shown in Table 8), recent data obtained from the Washington State Department of Transportation (WSDOT) shows the level of E80s experienced on the Interstate system. On average, about 800,000 E80s are applied to the "design lane" each year. The heaviest trafficked pavements received about 2,500,000 E80s per year. WSDOT Bituminous Surface Treatment (BST) pavements received the "lightest" amount of annual E80s, about 40,000 per year on average (these roads generally have less than 2000 ADT).

Tables 10 and 11 overview various pavement design practices in the USA (Table 10 for flexible and Table 11 for rigid). What such data reveals is that:

- Most thickness design procedures are empirically based.
- Pavements are mostly designed by use of manuals (as opposed to software).
- A 20-year design life is most commonly used.
- Life cycle costs are typically done for a 30- to 40-year analysis period.

Tables 12 and 13 summarize some of the mixture design processes and other required materials tests used in the USA. Clearly, the R-value and CBR tests are dominant for unstabilized materials.

One country which, in general, designs and constructs their flexible pavements quite differently than most countries is South Africa. About 70 percent of its pavements are constructed with thin asphalt bound surfaces (40 mm or less) placed on top of high quality crushed stone bases. These bases are placed on either unstabilized or cement-stabilized subbases. The design and construction requirements are unique and result in high performance pavements which can accommodate high E80 loadings. Further, South Africa has adopted advanced pavement design and test methods (such as a mechanistic-empirical pavement design procedure and in-situ material testing devices such as the Dynamic Cone Penetrometer (DCP)). The details associated with its pavement practices are important and, as such, not necessarily straightforward to transfer to another country. Evidence of this fact is that South African engineers have published technical papers widely in proceedings associated with international pavement conferences; however, there is little evidence, in the view of the authors, that South African practices have been adopted elsewhere.

The question may be asked whether it would be worth while to embark on significant activities to transfer South African technology to the USA. In order to demonstrate the possible effect such technology transfer may have, a pilot project to compare the relative cost of pavement structures from the two countries was conducted. The purpose of this work was to calculate the relative cost of three typical flexible pavement structures designed using the South African mechanistic pavement design method, the Californian Department of Transportation (Caltrans) pavement design method, and the Washington State DoT pavement design method. The following conditions were selected :

- pavement to be a flexible structure;
- three levels of traffic (1 million, 10 million and 30 million equivalent standard axles or E80s), and
- two subgrade types (weak with a CBR of 5 and strong with a CBR of 15).

One of the problems encountered was that the high quality aggregate bases often used in South Africa, had never been constructed in the USA and therefore it was difficult to estimate construction costs for these bases in the USA. For the purpose of a relative analysis, the construction costs of the various layers as currently prevalent in South Africa was therefore used. A more accurate answer could be obtained using USA costs once high quality granular bases have been constructed.

Table 14 shows the structures obtained from the various design processes as well as their relative costs. The data is shown graphically in Figures

1 and 2. It is obvious that the design philosophy to use high quality granular bases supported by a cemented subbase and covered with a relatively thin wearing course yield more cost effective designs than that utilising relatively thick asphalt layers on weaker granular layers. It is evident that, should one be able to construct these materials cost-effectively in the USA, a significant initial cost saving should be effected. The saving on initial cost could be somewhere between 50 and 80 per cent. This initial, somewhat superficial calculation shows that it may well be worth while to transfer the materials and design technologies from South Africa to the USA (or elsewhere) for use in areas with similar climatic conditions.

The information shown in this section of the paper shows that:

- Most countries tend to construct substantially more kilometers of flexible than rigid pavements (however, this varies depending on traffic levels and urban versus rural pavements).
- For rigid pavements, the dominant pavement type is doweled JPCP.
- The transverse joint details are about the same in Europe and the USA.
- The typical design periods are a bit longer in Europe than in the USA (though design periods are increasing in the USA).
- Most design procedures in use today are empirical.
- The CBR test appears to be widely used throughout the world.
- Some countries design and construct pavements quite differently (the example being South Africa), and
- a pilot study comparing relative costs of typical pavement structures from South Africa and the USA indicate that significant cost savings may be effected by transferring materials and design technologies from South Africa to parts of the USA.

TECHNOLOGY SHARING VENUES

INTRODUCTION

The preceding data suggests that many countries have broadly similar pavement practices with the exception of countries such as South Africa;

however, this is not to say that pavement performance is necessarily similar among countries. This suggests that potential exists in understanding both the similarities and differences in country pavement practices. Further, there exist numerous activities and processes through which exchanges of pavement practices are made (or enhanced). These include, but are not limited to:

- international conferences (such as the BCRA)
- study tours
- agency agreements
- technical reports
- books
- short courses

Each will be briefly discussed; however, first results from a recent survey in the USA will be described.

USA SURVEY

A survey conducted by Carter and Rochon [6] and [7] on USA State Highway Agencies (SHAs) addressed the ability of these agencies to have "a well-trained pavement engineering staff." The survey had the following objectives:

- "to determine the existing training in Pavement Engineering - topics, frequency, and participants
- to assess the [pavement] training needs over the next decade
- to ascertain what new training is being developed and/or anticipated
- to determine the training shortfall; the difference between the training needs and the training to be in place in the next decade, and
- to determine how the training needs can be met if there is a shortfall."

The results of this survey showed:

- that the Pavement Design group is most often located in the Materials group within a SHA (43 percent of the SHAs reporting)
- the Pavement Design staff are composed of 72 percent engineers and 28 percent technicians
- Pavement Management staff are composed of 43 percent engineers and 48 percent technicians

- generally, more than 50 percent of such personnel have less than five years experience (about 60 percent of the design engineers and technicians had less than five years of experience)
- the National Highway Institute (NHI)/FHWA is the source of 61 percent of SHA pavement oriented training
- only 13 out of 39 SHAs responding have a formal training program for new graduate engineers, and
- SHA Chief Engineers and Pavement Design Engineers typically emphasized the need for training in pavement design. Other areas of emphasis were pavement rehabilitation and pavement management.

Overall, the survey tended to emphasize the quantity of pavement oriented training that has been offered in the recent past as opposed to the current (or needed) quality or effectiveness of training. This is understandable in that defining training quality is a difficult task at best. The survey did not address the issue of follow-up after a SHA person received some type of pavement training. For example, how did people use their newfound knowledge (if at all). Further, both Chief and Pavement Engineers stated a preference for more training in pavement design. Interestingly, there appeared to be limited interest in training on pavement construction issues (an area where pavement performance is profoundly affected).

A final set of recommendations were made by Carter and Rochan. These included:

- that a regional level consortium of SHAs be established (five to ten states in each) to provide for "pooled" training at various levels and topics
- a typical SHA training program was proposed which included separate courses on
  - pavement materials
  - pavement construction
  - detailed pavement design
  - basic mix design methods
  - pavement maintenance
  - pavement management
  - pavement rehabilitation and reconstruction
  - workshop on new pavement technology

For each of the above courses, a specific duration and frequency of offering was made.

Carter and Rochon ([7]) also provided summaries of the number of attendees at all NHI pavement courses for 1992, 1993, 1994, and part of 1995. Of the 2,480 attendees in 11 courses with 98 offerings, 76 percent of the attendees were from SHAs, 9 percent from the FHWA, 4 percent from local agencies, and less than 1 percent from the private sector. Even though NHI classes are only a part of the USA's total pavement training picture, this points out the need for additional concentration on training opportunities for local agencies and the private sector. The above numbers result in an average course size of 25. This suggests that such training is rather expensive when the total cost per attendee is examined. It is not unusual to spend $100,000 to $800,000 to fully develop high quality traditional short course materials. If these development costs are amortized over say 250 to 1,000 attendees (a reasonable range given the information provided by Carter and Rochon[7], then the course materials alone (development costs only) can range from $100 to about $3,000 per person. Adding other course expenses (such as the instructors, travel, loss of job production time, per diem, etc.) can easily push the real cost to $500 to over $1,500 <u>per day per attendee</u>.

Based on the above information from the USA, the following can be concluded:

- a large percentage of SHA pavement oriented engineers and technicians have limited experience
- few SHAs have formal pavement training programs
- NHI/FHWA courses constitute a large percentage of SHA pavement oriented training
- "locally" held training courses are preferred by SHAs
- training for local agency and private sector personnel needs more attention
- existing short courses, when all costs are summed, can be costly on a per attendee basis, and
- no direct evidence was found which answers the question of training quality or effectiveness (as opposed to quantity).

INTERNATIONAL CONFERENCES

International pavement-oriented conferences have become quite common. Typically, proceedings are published which become widely available. Some of the pros and cons associated with such conferences include:

- Pros
    - Provides "packaged," recent technical information.

    - Provides a venue for meeting colleagues.
    - Provides a written record of proceedings.
- Cons
    - Expensive to attend when all expenses are totaled.
    - Information presented may not be applicable or appropriate for the attendee.

STUDY TOURS

Pavement study tours have been commonly done for the last 100 or so years (a study tour to Europe by Washington State engineers in 1900 had a profound impact on the Northwestern part of the USA and the "good roads" movement). Until recently, structured study tours by US personnel were rather rare; however, this changed in 1990 with the European Asphalt Study Tour (with representatives from AASHTO, FHWA, SHRP, TAI, and TRB) and the 1992 U.S. Tour of European Concrete Highways (with representatives from AASHTO, ACPA, FHWA, PCA, SHRP, and TRB). Organized tours from various countries have been commonly observed in the USA. Some of the pros and cons associated with such tours include:

- Pros
    - Substantial pavement-orientated information is exchanged in a short period of time.
    - A trip report (documentation) is often produced.
    - Face-to-face meetings/introductions take place.
- Cons
    - Benefits of such trips tend to accrue primarily to those who participate in the study tour.
    - Results are a bit slow for being placed in practice though notable exceptions have occurred in the USA (SMA wearing courses being one).

AGENCY AGREEMENTS

Agency agreements enable a continuing collaboration between two or more agencies. Such agreements often include provisions for exchanging information such as research data and reports, personnel visits, round-robin laboratory testing, etc. Two such agreements the authors are aware of exist between the State of California and South Africa and between the State of Minnesota and Finland. Pros and cons include:

- Pros
  - Detailed exchanges of information over an extended period of time.
- Cons
  - Information exchange can be slow and primarily resides with the parties to the agreement.

TECHNICAL REPORTS

Technical reports are widely available today which document various studies and/or pavement practices. This has been a common venue for sharing technical information for over the last 100 years or so. Some of the pros and cons includes:

- Pros
  - Careful documentation of results
  - Most major studies receive such documentation.
- Cons
  - Distribution of technical reports is limited; however, this may improve with extensive use of Internet "publishing."
  - A mixture of languages, terminology, and units between countries slows and impedes technology sharing.
  - Technical reports generally are used to document specific studies - the scope of which may be of limited use to the reader.

BOOKS

Books on pavement practices are actually not all that common. Some of the associated pros and cons includes:

- Pros
  - Books can provide a careful, complete explanation of the practices being described.
  - Books can be used in a variety of instructional venues.
- Cons
  - Book development can lag behind pavement practice development, i.e., the information can be "dated" by the time the book is published.
  - Updates are not timely and typically require the purchase of a new, revised book.

SHORT COURSES

Short courses have been used for some years as a way of packaging current pavement practices and presenting such practices to a small group (generally 25 to 30 attendees per course). Pros and cons include:

- Pros
  - Provide recent, relevant information by competent instructors.
  - Question and answer format generally a plus in learning new information.
- Cons
  - Expensive on a cost per attendee basis (typically US$500 to over $1,500 per day if all costs considered).
  - Details associated with implementation often lacking.
  - National courses may not address local practices and needs.

Lastly, given the worldwide push towards metrication, this barrier to information exchange is at last falling. The highway community in the USA is well on its way toward this goal.

Clearly, of the areas which are commonly used for exchange of evolving pavement practices, all have positive and negative aspects (as noted via the listed "pros" and "cons"). Are there other venues which might improve the pavement technology transfer process and, specifically, the "effectiveness" of such transfers?

NEW DIRECTIONS

Thus far, this paper has been a mixture of very general statistics for a selection of countries followed by a "snapshot" of selected pavement practices, followed by a brief discussion of some commonly used technology sharing practices. All of the technology sharing practices have pros and cons. Possibly one of the single largest deficiencies is in the area of material specifications and construction practices (for which very limited international information exists). It seems, in the opinion of the authors, that these areas are rarely adequately addressed and are crucial to the proper performance of any pavement project. Recent work in technology management (Rust and Vos, 1998) has indicated that technology transfer is more effective if it is managed as part of a holistic, systems approach to technology management. This implies that planning for technology development should include the essential elements of technology transfer and training upfront rather than "post planning" after technology has already been developed. This approach often calls for "reverse thinking", forcing researchers to think of the implementation of solutions first before developing them, thus facilitating the eventual transfer of such technology to practice. It also calls for using the appropriate "delivery systems" in order to ensure ease of technology transfer. In the case of transferring technology from one country to another after it had been developed and implemented in the former, one has to take into consideration that the technology package may have to be modified to suit the conditions, practices, material availability and material cost in the "target country". The most appropriate delivery system will also depend on the specific technology package and the circumstances in the target country.

The following "picture" emerges from the preceding information:

- Local (country) differences are apparent in usage of pavements; however, broad similarities are evident with respect to use of pavement types, materials, traffic, and importantly, climate. This runs a bit counter to the general view which seems to be that local conditions are somewhat unique requiring unique practices. Further, even modest differences in pavement practices make technology sharing more difficult. It is apparent that some countries, such as South Africa, build rather unique pavement structures. The authors have not attempted to address the issue of pavement performance.
- Those countries which experience substantial freezing weather do have a special set of design and performance issues to deal with; however, these are common among all countries north or south of 40° latitude (or high elevations). Designs for these climate regions appear to have a common solution as well, i.e., thicker pavement structures and specification of layer materials.
- The common venues for sharing knowledge about pavement practices all have pros and cons.
- In the complex case of transferring technology from one country to another, care must be taken to adjust technology packages and to select delivery systems to suit the conditions in the target country.

Given the above "observations," what are potential, improved pavement technology "delivery systems"? Two concepts will be briefly described which may have merit. The first is an International Pavement Guide, and the second is the concept of international technology workshops.

INTERNATIONAL PAVEMENT GUIDE

To bring together the substantial and relevant information that most "pavement people" would like to have, a document which reflects the "best" pavement design, rehabilitation, maintenance, and construction practices is desirable. A much more modest attempt at this was completed two years ago by the Washington State Department of Transportation (WSDOT) which resulted in the three-volume WSDOT Pavement Guide (Volume 1 (Pavement Policy), Volume 2 (Pavement Notes), and Volume 3 (Case Studies and Software Users' Guides)). This WSDOT document is over 800 pages in length and combines the important policy issues along with general to very specific pavement design, evaluation, and construction issues. One of the difficulties with this document is its length and the difficulty associated with locating specific information. Further, a document of this size is difficult to update and the addition of photographs (particularly, color) and other descriptive information is expensive. To address this issue, a CD-ROM containing this information, along with easy "links" to definitions, articles, photographs, design equations, etc. was recently completed for WSDOT. The CD-ROM format has an additional benefit; each copy costs only about US$10 (as opposed to US$40 for each copy of the paper Guide).

The International Pavement Guide would be far more ambitious. Unfortunately, there are several potential impediments to its development and use. These include:

- Development costs
- Lack of an international organization to sponsor and support the effort
- Implementation difficulties

INTERNATIONAL TECHNOLOGY WORKSHOPS

The second concept is to use international technology workshops as a means to enhance and accelerate the sharing of relevant technology between countries. An example of this type of workshop is currently being planned for the USA during 1999. The planned workshop, sponsored largely by the FHWA, will feature South African technology which has potential applications in the USA. The workshop will include sessions on materials, structural design, pavement maintenance, accelerated pavement testing, and practical field demonstrations. Documentation of development history and how these procedures or equipment were used will be fully included in a set of notes. As appropriate, equipment will be demonstrated in “field” applications (such as the semi-automatic DCP). All of this information will be presented by those South Africans most familiar with the specific technology being presented. Naturally, information on how to obtain specific reports, software, or equipment will be fully described at the workshop. How additional information or service can be obtained for any of the covered technologies will also be provided. It is expected that this type of activity can put detailed information into the hands of practitioners quickly and in a cost effective manner.

CONCLUDING REMARKS

Although environmental and institutional conditions vary greatly between countries, the authors are of the opinion that much benefit can be obtained from the transfer of technology packages with proven track records from one country to another. However, the magnitude and cost of such activities should not be underestimated. In addition, such activities require advanced planning using a holisitc approach rather then fragmented singular efforts.

An earlier version of this paper was presented at the 23 rd International Road Conference - Baltic Road Council during August 1997 in Parnu, Estonia. This version contains updated and improved information and is presented in the spirit of continuing the dialogue on international pavement practices.

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Table 1 : Country Areas and Road Kilometers

Country/State	Area (sq. km)	Motorways (km)	Total Road Network ** (km)	% Paved	Total Roads/ Area (km/sq. km)
Africa					
Kenya	582,646	-	62,573	13	0.1
South Africa	1,123,226	1,953	182,329	30	0.2
Americas					
Chile	756,945	-	79,593	14	0.1
Costa Rica	51,100	-	35,541	17	0.7
USA	9,809,418	86,818	6,277,859	59	0.6
Washington State	115,509	*1,229	97,090	68	0.8
Asia					
Japan	337,801	5,410	1,130,892	72	3.3
South Korea	99,392	1,602	61,296	85	0.6
Europe					
Denmark	43,094	747	71,111	100	1.7
Estonia	45,100	62	14,771	55	0.3
Hungary	93,030	441	158,711	44	1.7
Iceland	104,000	-	11,279	24	0.1
Latvia	64,589	-	58,600	55	0.9
Lithuania	65,200	394	55,603	76	0.9

Sweden	411,114	1,044	135,920	71	0.3

- 1993 statistics (mostly)
- Source: IRF [8] and Library of Congress (1992)

* Interstate highways only
** Public roads only

Table 2 : Country Density Statistics

Country/State	Population (thousands)	Population Density (per sq. km)	Percent Urban	Population Per Kilometer (Paved)	Population Per Kilometer (Total)
Africa					
Kenya	28,241	48	25	3,469	451
South Africa	43,931	39	57	803	241
Americas					
Chile	13,951	18	85	1,250	175
Costa Rica	3,342	65	44	553	94
USA	260,714	27	75	71	42
* Washington State	5,255	45	-	79	54
Asia					
Japan	125,107	370	77	154	111
South Korea	45,083	454	74	865	735
Europe					
Denmark	5,188	120	85	73	73
Estonia	1,617	36	71	198	109
Hungary	10,319	111	63	148	65
Iceland	264	3	91	96	23
Latvia	2,749	43	70	233	42
Lithuania	3,848	59	69	91	69
Sweden	8,778	21	83	92	65

Table 3 : Country Traffic Statistics

	Millions of Vehicle-Kilometers			Millions of Ton-Kilometers		
Country/State	**Cars**	**Buses**	**Trucks**	**Road**	**Water**	**Rail**
Africa						
Kenya	1,082	259	3,829	-	-	-
South Africa	58,495	1,717	34,734	40,000*	-	-
Americas						
Chile	-	-	-	-	-	-
Costa Rica	3,465	-	-	2,243	-	-
USA	2,567,060	9,234	1,012,262	1,189,900	662,840	1,616,220
Washington State	70,041	-	6,318	-	-	-
Asia						
Japan	405,729	7,068	265,414	281,599	248,002	26,668
South Korea	27,714	4,083	22,215	48,873	38,765	14,658
Europe						
Denmark	31,582	470	6,552	10,809	1,600	1,100
Estonia	-	-	-	4,218	8,698	5,919
Hungary	17,155	867	4,876	5,939	14,456	16,781
Iceland	-	-	-	-	-	-
Latvia	1,638	389	1,601	5,800	1	9,852
Lithuania	-	207	2,532	7,336	15,293	19,258
Sweden	52,800	748	3,191	25,200	-	19,156

- Sources: IRF[8], ECMT[9] (mostly 1990s' data), World Bank[10], World Bank[11], World Bank[12], SADOT[13]

* Approximate estimate

Table 4 : Calculated Country Traffic Statistics

Country/State	Roads Only		Total**
	Vehicle*-km / Capita	Tonne-km / Capita	Tonne-km / Capita
Africa			
Kenya	183		
South Africa	2,161	910	
Americas			
Chile			
Costa Rica		671	
USA	13,764	4,564	13,306
Washington State	14,531		
Asia			
Japan	5,421	2,251	4,446
South Korea	1,198	1,084	2,269
Europe			
Denmark	7,441	2,083	2,604
Estonia		2,608	11,648
Hungary	2,219	576	3,603
Iceland			
Latvia	1,320	2,110	5,694
Lithuania		1,906	10,885
Sweden	6,464	2,871	5,053

* Includes cars, buses, trucks

** Includes road, water, rail modes combined

Table 5 : Climate Statistics

Location	Latitude	Temperatures (°C) January Mean	July Mean	Yearly Mean	Yearly Std. Dev.	Precipitation (mm)	No. of Days with Measurable Precipitation
Africa							
Nairobi, Kenya	1° S	18	16	18	1	959	117
Johannesburg, S. Africa	26° S	20	11	16	4	711	70
Americas							
Santiago, Chile	33° S	20	9	15	4	363	31
San Jose, Costa Rica	10° N	19	22	21	1	1,799	170
Washington, D.C., USA	39° N	1	26	13	9	1,067	124
Seattle, WA, USA	47° N	4	18	11	5	990	150
Spokane, WA, USA	47° N	-2	21	9	8	381	113
Asia							
Tokyo, Japan	36° N	3	24	14	8	1,575	107
Seoul, South Korea	38° N	-4	26	11	11	1,250	112
Europe							
Copenhagen, Denmark	56° N	0	18	9	7	610	171
Tallinn, Estonia	59° N	-5	17	5	8	568	179
Budapest, Hungary	47° N	-2	22	11	9	615	136
Reykjavik, Iceland	64° N	0	11	5	4	787	213
Riga, Latvia	57° N	-7	16	5	9	567	194
Vilnius, Lithuania	54° N	-6	18	6	9	640	
Stockholm, Sweden	59° N	-3	18	7	8	559	164

- Data mostly obtained from Pearce et al.[14] and other weather databases.

Table 6 : Calculated Climate Statistics

Location	Temperatures: Hottest Month Minus Coldest Month	Temperatures: Coefficient of Variation (%)	Annual Days with Precipitation (%)
Africa			
Nairobi, Kenya	2ºC	6	32
Johannesburg, S. Africa	9ºC	25	19
Americas			
Santiago, Chile	11ºC	27	8
San Jose, Costa Rica	3ºC	5	47
Washington, D.C., USA	25ºC	69	34
Seattle, WA, USA	14ºC	45	41
Spokane, WA, USA	23ºC	89	31
Asia			
Tokyo, Japan	21ºC	57	29
Seoul, South Korea	30ºC	100	31
Europe			
Copenhagen, Denmark	18ºC	78	47
Tallinn, Estonia	22ºC		49
Budapest, Hungary	24ºC	82	37
Reykjavik, Iceland	11ºC	80	58
Riga, Latvia	23ºC	180	53
Vilnius, Lithuania	24ºC		
Stockholm, Sweden	21ºC	114	45

Table 7 : Winter Climate Data (after OECD[15] and WSDOT[16])

Country/State	Frost Depth Range (mm)	Freezing Index Range (ºC days)	Average Seasonal Temperature (ºC)	
			Summer	Winter
Bulgaria	600 - 700	300 - 600	24	-2
Czech Republic	800 - 1,000	400 - 900	17	-2
Hungary	400 - 600	100 - 400	21	0
Lithuania	400 - 700	400 - 850	17	-5
Poland	800 - 1,200	150 - 700	16	-5
Romania	700 - 1,000	390 - 725	20	-8
Ukraine	600 - 1,400	100 - 950	24	-2
Washington State				
Seattle	0 - 200	10 - 50	17	5
Spokane	700 - 900	370 - 600	18	-3

Table 8 : Pavement Types for Various Central, Eastern European, and Baltic Countries (after OECD[15] and World Bank[10])

Country	Pavement Types (%)						
	Asphalt Concrete	Portland Cement Concrete	Asphalt Macadam	Sett Paving	Bitumen	Gravel	Other
Bulgaria	96.6	0.0	1.0	0.6			1.8
Czech Republic	95.9	2.6	0.0	1.5			0.0
Hungary	96.1	1.9	2.0	0.0			0.0
Lithuania	55.0	1.0	44.0	0.0			0.0
Poland	100.0	0.0	0.0	0.0			0.0
Romania	90.0	10.0	0.0	0.0			0.0
Russia	87.0	8.0	0.0	0.0			5.0
Ukraine	55.0	1.5	13.0	9.5			21.0
Estonia	17.4	0.0	?	?	27.9	46.7	8.0

Table 9 : Rigid Pavement and Design Practice - Twelve Countries*
(after Nissoux et al. [3])

Rigid Pavement Types	**Percentage**
• JPCP	75%
• JRCP	25%
• CRCP	50%
Slab Thickness (typical)	**mm**
• JPCP	220-260
• JRCP	unknown
• CRCP	200-230
Maximum Allowable Axle Loads	**tonnes**
• Single	
• Mean	11.25
• Range	10-13
• Tandem	
• Mean	19
• Range	18-20
Transverse Joint Spacing (typically with dowel bars)	**m**
• Mean	5.0
• Range	3.5-6
Dowel Bars	**mm**
• Diameter (range)	16-30
• Length (range)	250-700
• Spacing (range)	300-500

* Includes Austria, Belgium, France, Germany, Great Britain, Italy, Japan, Netherlands, Norway, Spain, Sweden, Switzerland

Table 10 : Flexible Pavement Design Practices in the U.S. (after NCRHP[5])

	Percentage
Thickness Design Procedure	
• Empirical	77%
• Mechanistic-Empirical	2%
• Locally Developed	21%
Design Process	
• Computer Program	37%
• Manual	63%
Structural Design Period (years)	
• 15	3%
• 20	52%
• 30	28%
• 35	12%
• 40	5%
LCC Analysis Period (years)	
• <30	11%
• 30-40	75%
• >40	14%

Table 11 : Rigid Pavement and Design Practice in U.S. (after NCHRP[5])

	Percentage
Rigid Pavement Types*	
• JPCP	92%
• JRCP	23%
• CRCP	18%
Thickness Design Procedure	
• Empirical	
• AASHTO	81%
• PCA	5%
• Mechanistic	5%
• Locally Developed	9%
Design Process	
• Computer Program	37%
• Manual	63%
Structural Design Period (years)	
15	3%
20	51%
30	28%
35	13%
40	5%
LCC Analysis Period (years)	
<30	7%
30-40	79%
>40	14%

* multiple PCC pavement types used in some states

Table 12 : Flexible Pavement Materials in U.S. (after NCHRP[5])

	Percentage
Asphalt Concrete	
• Mix Design Procedures	
• Marshall	79%
• Hveem	21%
• Marshall Only	
• 75 blow	67%
• 50 blow	33%
Untreated Aggregate Base	
• Minimum Strength Value (only 11 SHAs specify a minimum strength value)	
• R-value	45%
• CBR	28%
• Other	27%
• **Minimum Compaction**	
• AASHTO T180	35%
• AASHTO T99	16%
• Other	49%

Table 13 : Subgrade Tests in the U.S. (after NCHRP[5])

	Percentage
Subgrade Strength/Stiffness Design Parameters	
• R-value	33%
• CBR	23%
• Resilient Modulus	23%
• Gradation Based	8%
• Soil Support Value	5%
• Miscellaneous	8%
Determination of Parameter	
• Lab Test	59%
• Correlation	19%
• Field Test	22%

Table 14 : Cost of comparable South African and US pavement designs

South African Designs									
Million ESALS	**1 to 3**			**3 to 10**			**30**		
Subgrade type	**Layer type**	**Thick-ness**	**Cost**	**Layer type**	**Thick-ness**	**Cost**	**Layer type**	**Thick-ness**	**Cost**
Weak, CBR = 5	AC	40	$3.18	AC	40	$3.18	AC	50	$3.98
	G2	150	$0.52	G2	150	$0.52	G1	150	$3.17
	G5	150	$0.89	C3	250	$3.19	C3	300	$3.83
	G5	300	$1.78	G5	300	$1.78	G5	300	$1.78
		Total :	**$6.37**			**$8.67**			**$12.75**
Strong, CBR = 15	AC	40	$3.18	AC	40	$3.18	AC	50	$3.98
	G2	150	$0.52	G2	150	$0.52	G1	150	$3.17
	G5	150	$0.89	C3	250	$3.19	C3	300	$3.83
		Total :	**$4.60**			**$6.90**			**$10.97**
Caltrans Designs									
TI Class	**9**			**12**			**13.5**		
Million ESALS	**0.8 to 1.27**			**9.5 to 13.5**			**26.1 to 35.6**		
Subgrade type	**Layer type**	**Thick-ness**	**Cost**	**Layer type**	**Thick-ness**	**Cost**	**Layer type**	**Thick-ness**	**Cost**
Weak, CBR = 5	AC	152	$12.13	AC	183	$14.56	AC	213	$16.98
	G5	107	$0.63	G5	198	$1.17	G5	213	$1.26
	G6	259	$1.53	G6	351	$2.07	G6	396	$2.35
		Total :	**$14.29**			**$17.80**			**$20.59**
Strong, CBR = 15	AC	137	$10.92	AC	183	$14.56	AC	183	$14.56
	G5	137	$0.81	G5	198	$1.17	G5	107	$0.63
	G6	107	$0.63	G6	107	$0.63	C3	168	$2.14
		Total :	**$12.36**			**$16.36**			**$17.33**
WSDoT Designs									
Million ESALS	**1**			**10**			**30**		
Subgrade type	**Layer type**	**Thick-ness**	**Cost**	**Layer type**	**Thick-ness**	**Cost**	**Layer type**	**Thick-ness**	**Cost**
Weak, CBR = 5	AC	105	$8.36	AC	105	$8.36	AC	105	$8.36
	G3	280	$3.69	BC	135	$8.82	BC	230	$15.02
				G3	170	$2.24	G3	135	$1.78
		Total :	**$12.04**			**$19.41**			**$25.15**
Strong, CBR = 15	AC	105	$8.36	AC	105	$8.36	AC	105	$8.36
	G3	75	$0.99	BC	60	$3.92	BC	115	$7.51
				G3	105	$1.38	G3	135	$1.78
		Total :	**$9.34**			**$13.66**			**$17.64**

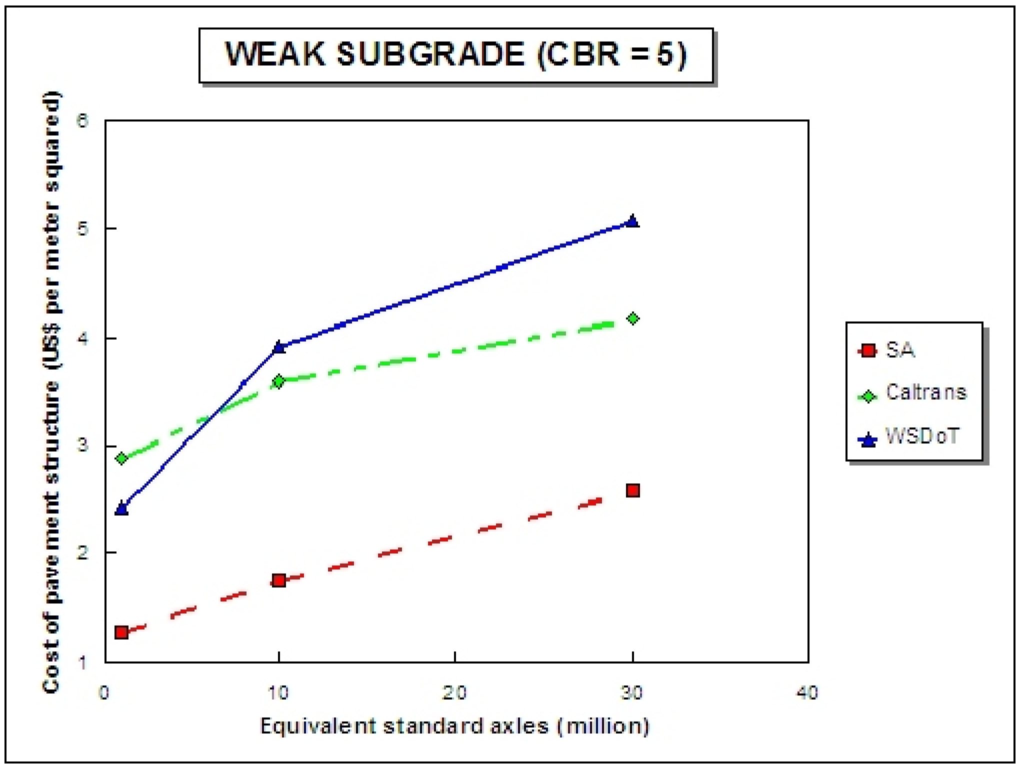

FIGURE 1 : COST OF COMPARATIVE DESIGNS ON A WEAK SUBGRADE (CBR = 5)

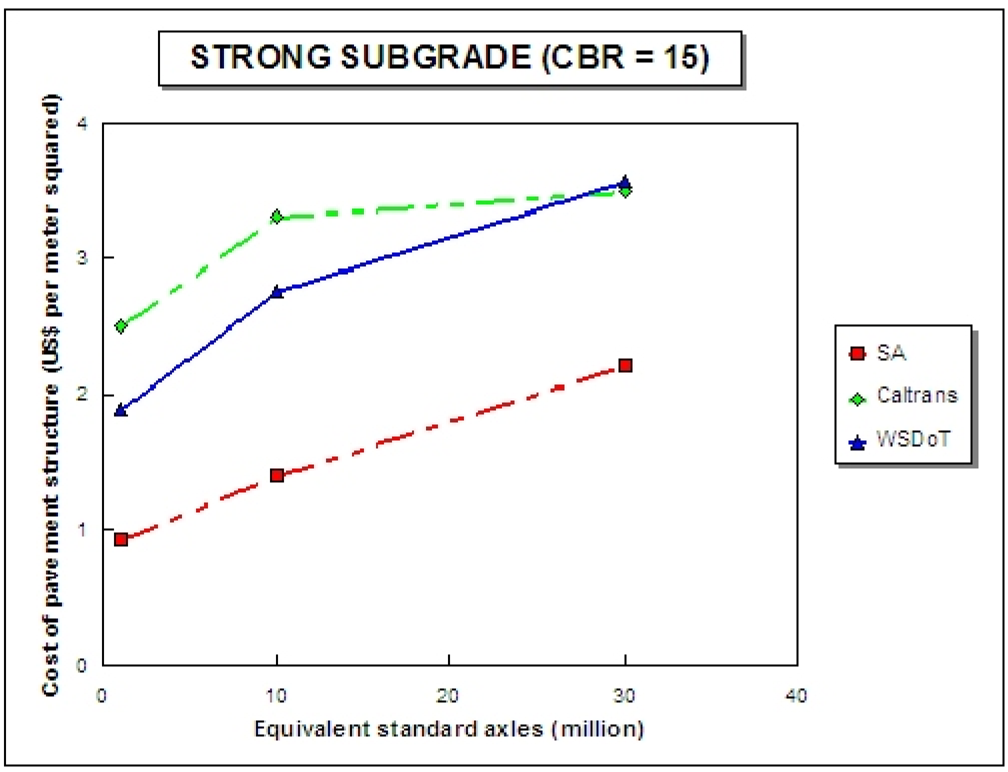

FIGURE 2 : COST OF COMPARATIVE DESIGNS ON A STRONG SUBGRADE (CBR = 15)