F Data Requirements

F.1 Development and Implementation of IPFS

資料來源：

Hall, J. P., M. E. Dwiggins, M. I. Darter, C. L. Flowers, J. B. Dubose., "Development and Implementation Methodology for the Illinois Pavement Feedback System," Proceedings, Second North American Conference on Managing Pavements, Vol. I, Totonto, 1987, pp. 1.41-1.54.

F.2 IPFS Data Element Catagories

資料來源：

Dwiggins, M. E., J. P. Hall, and M. I. Darter, "Logical Design of the Illinois Pavement Feedback System," Executive Summary Report, Illinois Cooperative Highway Research Program Project IHR-517, February 1987..

F.3 路面評審系統

資料來源：

賴森榮、侯羿，「台灣區高速公路路面養護管理系統」，期終綜合報告，財團法人台灣營建研究中心，中華民國七十七年十二月，第61-73頁。

F.4 Road Roughness

資料來源：

Paterson, W. D. O., "Road Deterioration and Maintenance Effects : Models for Planning and Management," The Highway Design and Maintenance Standards Series, the World Bank, Washington, D.C., 1987, pp. 27-29, 34-37.

d N. American Conference
lanaging Pavements - Proceedings
)

DEVELOPMENT AND IMPLEMENTATION METHODOLOGY FOR THE ILLINOIS PAVEMENT FEEDBACK SYSTEM

HALL, James P.
Pavement Technology Engineer
Illinois Department of Transportation

DWIGGINS, Mark E.
Civil Engineer
University of Illinois

DARTER, Michael I.
Professor of Civil Engineering
University of Illinois

FLOWERS, Craig L.
Systems Analyst
University of Illinois

DUBOSE, James B.
Pavement Inventory Engineer
Illinois Department of Transportation

DEVELOPMENT AND IMPLEMENTATION METHODOLOGY FOR THE ILLINOIS PAVEMENT FEEDBACK SYSTEM

James P. Hall, Mark E. Dwiggins, Michael I. Darter,
Craig L. Flowers, James B. DuBose

Since 1985, the Illinois Department of Transportation (IDOT) has been actively involved in the implementation of an Illinois Pavement Feedback System (IPFS). The purpose of IPFS is to provide a formalized data processing structure and process which will collect, store, retrieve, and analyze design, materials, traffic, condition, and performance data for existing pavements.

This paper describes the process by which IDOT analyzed its pavement management requirements and implemented them across organizational lines. This process identified the needs of top, middle, and lower level management, documented end user requirements, outlined communication flows, investigated existing affected information processing systems, and identified and resolved major areas of concern in developing a realistic plan of implementation.

organizational analysis, information systems, pavement management, pavement management implementation, microcomputers

1.42

INTRODUCTION

A formalized process for pavement management within a state department of transportation involves many operational areas throughout the department. The key aspects in the development of such a system are the identification and acquisition of pertinent information on the pavement network and then providing a mechanism to share appropriate information in a useable and accurate form to all users.

Due to the complexities involved, pavement management implementation is a long-term effort which must address many organizational issues. Although the key information required for pavement management may appear simple, it is in fact located in many areas of the department in various computerized and manual information sources which have evolved over time for different purposes to meet the needs of specific operational areas.

Because of these facts, it is easier to implement a pavement management system for a smaller entity e.g. a city or county, than for a state. The parameters, organization flows, and processes for pavement management on a small network can be modified and controlled by an individual or a small group of engineers/administrators.

A state DOT operates in an dynamic environment, both external and internal. Environmental factors which affect pavement management implementation include changes in management (direction and/or personnel), funding, Department strategic direction, data processing capabilities, and hardware/software technology. Pavement management must also parallel and integrate with the development efforts of other Department management systems such as fiscal, personnel, project management, and roadway inventory.

This paper describes in detail the barriers involved in the implementation process and the methodology used by the Illinois Department of Transportation (IDOT) in developing the Illinois Pavement Feedback System (IPFS) to overcome these barriers and vastly improve the pavement management process.

IMPLEMENTATION BARRIERS

By necessity, pavement management requires communication of information across organizational lines; however, many barriers limit and prevent this sharing of information. These barriers are identified as data base configurations, organizational structure, changing management priorities, and modes of operation.

Data Base Configurations

Information systems within IDOT, as with many other agencies, have developed in a somewhat disjointed manner. This occurred because computerized data bases evolved relatively independently at different times to meet specific purposes. Early systems were developed to handle complex financial systems since there was an immediate payback in personnel savings and accuracy. These systems contained little supplementary information due to the high cost of data acquisition and storage at the time of their development. Newer data base systems have provided more specific detailed information.

Older systems have remained in place due to the cost and personnel commitments required for system redesign. Often, the system was developed to meet the specific needs of a single operational area. Other operational areas, which may have use for that data, are limited since it is often difficult to access the data and it may not contain the exact information required.

Manual systems are also still prevalent within IDOT. These are being gradually replaced by microcomputer systems. However, much of the information manually entered into a micro-based systems is already present in existing mainframe systems, but is not used because it is difficult to access in a timely manner.

An abundance of the historical pavement management information is not only contained in electronic and manual data systems, but also exists in plans, in microfilm records, and in an unwritten knowledge base of many Department experts. These different information systems require an extensive effort to determine what is available and how to integrate this data into the information flow.

IDOT is very similar to other states in that a road is a road ~~is a road~~ until you try to reference it in a traditional computer format. Different roadway referencing schemes have evolved based on their particular purpose. Major roadway information systems within IDOT are currently referenced by three independent numbering schemes: marked route, key route, and maintenance subsection.

These referencing differences inhibit the efficient transfer of data between data bases because direct link relationships are very difficult to establish. Also, interfaces are difficult to maintain since control of the key reference identifiers are located in different organizational areas.

All of this inhibits the preparation of summarized reports which would provide upper management a total picture of the condition and performance of the pavement network.

Organizational Structure

By definition, pavement management includes many organizational areas. Development of a PMS requires an extraordinary amount of inter-bureau communication and assistance. Often this communication must occur across major Department divisions. While one division may have a greater need for a formalized PMS, the implementation process may demand a more extensive effort in another division.

For example, the greatest need for the IPFS resides in IDOT's Division of Highways (Figure 1). However, responsibility for the electronic data processing development resides in the Bureau of Information Processing in the Office of Finance and Administration. The prioritization and integration of work activities is a difficult effort to implement and maintain.

Changing Management Direction

IDOT operates in an ever-changing environment. Changes in top management, Department priorities, budget restrictions and personnel limitations all affect IPFS development. Since IPFS implementation requires a long term effort and significant time, resources, and personnel committments, a continuous management emphasis is essential. The continual development and presentation of IPFS/PMS demonstrations is necessary to keep upper management informed.

Modes of Operation

IPFS implementation will change the way that IDOT operates. IPFS will provide information to user areas and top management; information which many times was previously available only from a single area or source. Some personnel may resent the perceived intrusion into their organizational area and being forced to change long-standing operating procedures. Also, data entry may be moved to more logical, decentralized areas as a formal system is developed. Data adequacy and control will become an issue. In addition, some new data must be collected which leads to budget and personnel problems.

IPFS DEVELOPMENT

To avoid the pitfalls in system development, it is essential that a formalized process be established. This process can be broken down into the logical steps of PMS Investigation, System Development Management Process, Organizational Analysis, Definition of Requirements, Logical Design, and Physical Design.

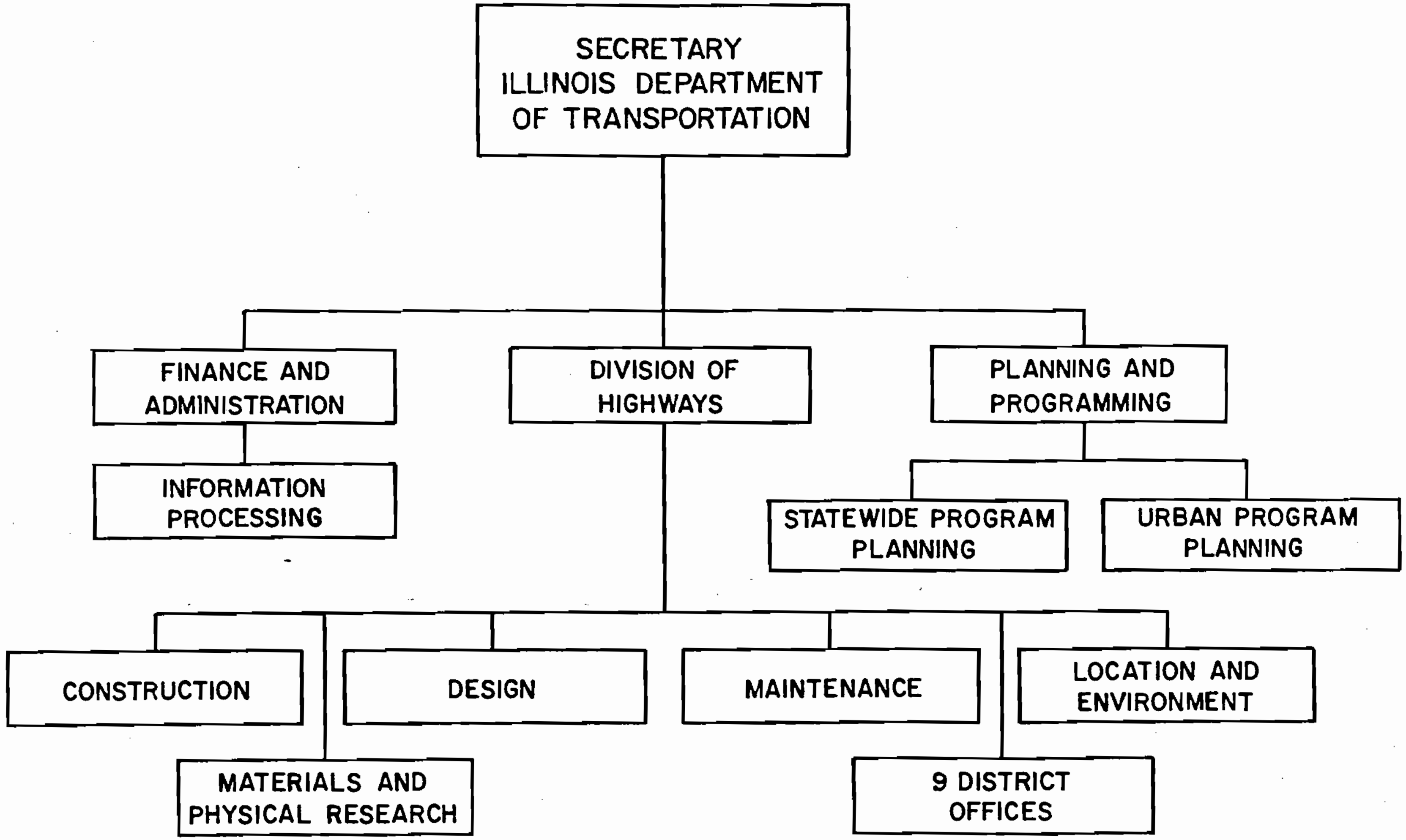


Figure 1. Primary Pavement Management Related Areas Within IDOT.

PMS Investigation

It was easy to get department personnel to agree that a PMS was needed. It was very difficult to reach agreement on how to implement it. The successful method involved the creation of a group of knowledgeable users of pavement management information within the department. Additionally, research on what is occurring in other states and in PM technology as a whole provided further helpful information to the group.

In 1982, IDOT formed a high level Standing Committee on Pavement Management (SCOPM) to oversee the IDOT pavement management process. This committee included representatives from all pavement related areas within the Department. The SCOPM undertook an investigative study with the Univeristy of Illinois in 1983 and 1984 to determine the feasibility and strategy for pavement management system development. From this study, a four year effort was initiated to develop the IPFS as a joint effort between the University and IDOT. IPFS development was scheduled in four phases I) Definition of System Requirements - FY85, II) Logical Design - FY86, III) Physical Design - FY87, and IV) Implementation - FY88.

System Development Management Process

An IPFS Steering Committee was established with a top level manager as chairman and middle management of affected areas as members. These areas include Design, Materials, Physical Research, Planning, Programming, Finance and Administration, Information Processing, two of the state's nine highway Districts and the Federal Highway Administration. The function of the committee was to set the overall direction of system development and maintain upper and lower management support and involvement.

A Pavement Feedback User Team (PFUT) was then developed composed of lower level management of affected areas. This group was formed to address the basic details and issues of IPFS development.

Personnel from the University of Illinois and the Bureau of Materials and Physical Research were selected to form a project team and spearhead the day to day development process with organizational responsibilities of keeping the IPFS development on schedule and maintaining communication flows. Close communication was required between these three groups to ensure compatibility of effort. How this was achieved will be discussed later.

Organizational Analysis (Know Your Department)

Although this may appear simple on the surface, analysis of all pavement management activities within a Department is a very dynamic and complex issue, but is essential for timely and useful PMS development.

The investigative study provided a basic outline on the areas within IDOT which were interested in pavement management. Organizational analysis requires a detailed identification of existing data bases, existing pavement management activities, information flows, and affected personnel within the Department.

This analysis goes much further than the simple, direct lines of an organizational chart. It involves human interactions and informal operating procedures which are not written down anywhere. Figure 2 portrays a simplified version of the actual pavement related information flow within IDOT.

The Pavement Feedback User Team provided an effective method to determine these interrelationships. Initial meetings concentrated on identifying all of the parameters involved in pavement management and what could realistically be included in the IPFS. Through group discussion, the major organizational issues were identified and recommendations were developed. These issues, including such items as project scope, budgeting, hardware acquisition, personnel required for the development effort, and restructuring of organizational resources, were brought to the attention of the IPFS Steering Committee for resolution.

The PFUT met every two to three months and the IPFS Steering Committee every six months. The University of Illinois and Materials and Physical Research project team met at least once every two weeks to maintain continuity in the development effort.

Requirements Definition

Following completion of the investigative study the project team began work on the Definition of System Requirements. Written questionnaires were distributed and follow-up interviews were conducted to aid the project team in determining what outputs should be developed or improved to aid IDOT's offices in performing the following pavement management-related activities as defined in the investigative study:

1. Development and evaluation of design procedures and standards,
2. Development and evaluation of policies and guidelines,

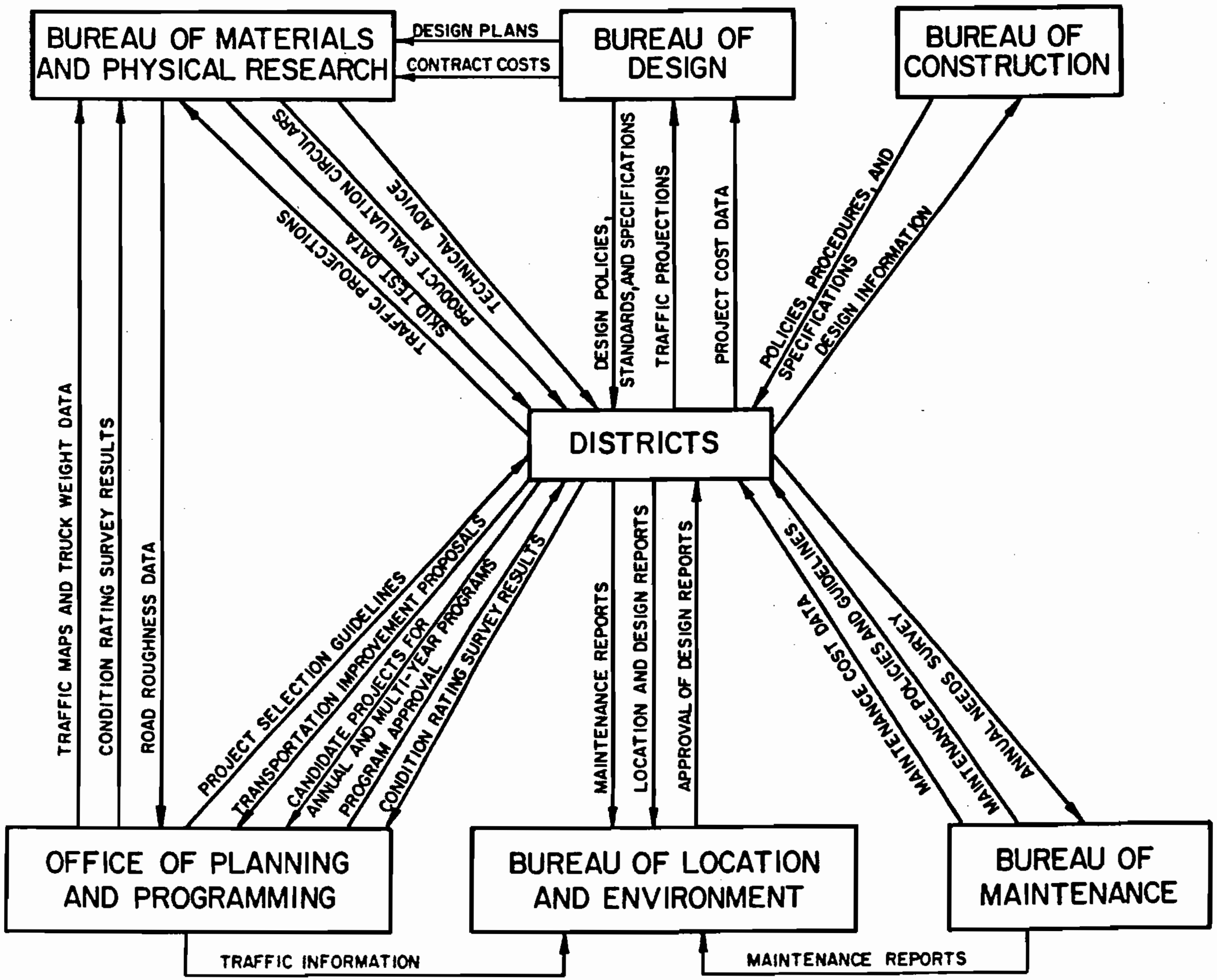


Figure 2. Flow of Major Pavement Related Information in IDOT.

3. Special studies and research.
4. Development of performance models.

The following bureaus or offices were identified as the primary users of the initial data feedback system and participated in the interviews:

1. Bureau of Materials and Physical Research
2. Bureau of Design
3. Bureau of Statewide Program Planning
4. Bureau of Urban Program Planning
5. Bureau of Maintenance
6. Bureau of Construction
7. Bureau of Location and Environment
8. Highway Districts

From the interviews the project team compiled the following general applications of the IPFS:

- Detailed information on a specific pavement section or network.
- Summary information on a specific section or network.
- Prediction of future performance.
- Evaluation of IDOT pavement policies, design and construction procedures.
- Evaluation of rehabilitation strategies.
- Special pavement studies and research.
- Life-cycle costs for various pavement types.
- Answers to "What if" questions to help improve management strategies.

The system must be able to generate reports quickly and in a user friendly fashion for a wide variety of users across the State. Some standardized reports should be available; however, a strong emphasis must be placed on flexible, user specified reports for the many one-time special studies. Business graphics such as graphs and histograms must be liberally used to enhance the outputs. Graphical mapping must also be used to easily identify section and network locations.

Illinois has over 17,000 centerline miles of State maintained pavements. The interstate highway system includes 1700 of the 17,000 miles. In order to facilitate implementation of the IPFS, the scope of the initial data bank was limited to the Interstate highway system. The Interstate system includes a sufficient number of sections to compile a prototype database to perform evaluations of many of the specific designs that are used on the remaining primary and secondary routes.

Logical Design

The first step in the Logical Design of the IPFS was to mock up final versions of all of the reports that the primary users felt were needed to address the applications determined in the Requirements Definition. Initial drafts of reports were created by the project team and reviewed first by the Pavement Feedback User Team and then the Steering Committee. These reports were created without regard to existing IDOT data handling systems and without regard to the existing pavement data being collected. A total of 45 reports were created to demonstrate the required capability of the IPFS.

From these reports a list of required data elements was derived. A total of 451 data elements were identified. These were divided into three groups based on their primary purpose. The first group consisted of those elements necessary in the programming of improvements. These would be collected for each management unit and would be the first ones to be collected. By consensus, a management unit was defined as a section of roadway, at least 1/4 mile long, which has uniform characteristics along its length, including:

- Pavement structural design
- Truck traffic/total traffic
- Responsible District
- Structural condition

The second group consisted of data elements necessary for evaluation of design policies. They would also be collected for every management unit. The third group consisted of those data elements needed for special studies and research. These data elements would be collected on only enough management units to achieve a good statistical sample.

After reviewing the report mock-ups and the required data elements, the current and future pavement related computerized data processing systems were investigated. IDOT is currently undertaking an extensive Roadway Referencing effort which will develop a link/node roadway base from which existing location reference numbering schemes can be directly obtained. This will provide direct interfacing and communication of current IDOT roadway information systems in future years.

In analyzing IPFS hardware requirements, it was determined that much of the data is contained in various existing IDOT mainframe systems which would be accessible upon completion of the link/node base. Data which is currently not in a computerized system, e.g. plans, project records, microfilm, would be entered into a formalized data base using the fourth generation NOMAD2 data base management software. This project data base will include most of the data required by IPFS for section and network inventory reports and for condition prediction and network rehabilitation. Additional elements can easily be added to the data base. This data flexibility is one of the most important reasons for selecting the NOMAD2 software.

The NOMAD2 data base will be formally integrated into the IDOT Roadway Inventory File when it is redesigned as a part of IDOT's Roadway Referencing effort in several years. At that time, the NOMAD2 data base will have been operationally in place and data elements will be finalized. Data input operations will probably transfer to the operational area first to obtain the data e.g. design details by the Bureau of Design. All involved areas will have access to the data. Completion of the Roadway Referencing project will allow direct access to other important pavement related data bases including accident, maintenance, and materials files.

To facilitate the development of the graphic mapping applications, the project team obtained the use of the University of Illinois Department of Energy and Natural Resources' ARC/INFO Graphic Information System. The mapping applications are being developed on this system and will be transferred to the IDOT system as the capability becomes available in the future.

In 1985, a distress survey was conducted as part of the IPFS project to identify the distresses present along each interstate highway, excluding the Chicago expressways. The data collected is in the project database and is being used in developing pavement condition prediction models and network rehabilitation selection routines. This distress data and the other inventory and monitoring data is being made available to selected IDOT users as part of a gradual IPFS implementation process.

Much of the work in Phase III was devoted to producing demonstrations of the IPFS capabilities. One demonstration compared the performance of jointed reinforced concrete pavements and continuously reinforced concrete pavements in Illinois. Another demonstration worked on a sample network to select rehabilitation strategies and timing over a specified analysis period. Although preliminary in nature, the demonstrations were well worth the effort to illustrate to the Steering Committee the value of the proposed IPFS.

Physical Design

During the Logical Design Phase the output reports and required data elements were identified and the decision was made to build the data base on the existing IDOT computer system. The project team then began writing a scheme to organize the NOMAD2 data base. Procedures were written to convert the data collected from various sources into a uniform format. Data loading began with an emphasis on the level 1 and level 2 data elements.

Data was continually being collected and tested for accuracy. Some data came from existing IDOT computerized files and some were generated from previous University research projects. The 1985 pavement distress survey information was included. Much of this data was first stored temporarily on mainframe computer files at the University and used by the team in developing pavement condition prediction models and rehabilitation selection strategies before the NOMAD2 data base was operational. The project team submitted recommendations to IDOT for collecting pavement monitoring data including equipment needed and frequency of surveys. Another pavement distress survey is being conducted in 1987 incorporating some of these recommendations.

Work on the condition prediction models and the rehabilitation selection and optimization routines continued in the Physical Design Phase. Condition prediction models were developed for each type of pavement and for each type of pavement rehabilitation as data became available during the collection process.

Of the 45 report mock ups, five were chosen as best representing the capabilities of the IPFS and will be the first to be generated from the NOMAD2 database:

- o Detailed section information.
- o Selected information for each section of a user specified network.
- o Section condition prediction
- o Section rehabilitation strategy selection and optimization.
- o Network rehabilitation strategy selection and optimization.

Demonstrations were given to interested groups. More intense effort was put towards developing a presentation to the top level Directors of IDOT. In addition to the demonstrations, several IDOT groups requested specific information from the IPFS. This information was compiled and delivered by the project team. These activities served to increase Department wide interest in the IPFS.

Use of Personal Computers

Extensive use of personal computers by members of the project team greatly expedited development of the IPFS. During Logical Design, word processing and graphics packages were used to create the report mock ups. A sample network database was loaded into a spreadsheet package and a demonstration of network rehabilitation optimization was created and presented to the Steering Committee and other interested parties.

During Physical Design links were established between the project personal computers and the mainframe computers at the University and at IDOT. Most of the physical design of the NOMAD2 database was done from the comfort and convenience of the team offices by using a PC as a terminal which greatly reduced travelling expenses. The links also allowed the transferring of data subsets from the mainframes to the PC's for the development of the prediction models and optimization routines. The inventory and monitoring data was stored on the University mainframe computer which is better adapted to manipulating the full data files.

The acquisition and use of personal computers are becoming more prevalent throughout IDOT. Applications are being investigated which would allow manipulation of subset pavement data files on personal computers.

IMPLEMENTATION

Implementation is occurring in a series of phases which best fit the Department's organizational structure and strategic direction. The work done by the project team in building the NOMAD2 data base for the Interstate highway system and the accompanying prediction and optimization routines is a prototype of a full scale IPFS for all State routes.

The integration of the prototype system into the Roadway Inventory File through IDOT's Roadway Referencing Project will formalize the data base. Data control and system maintenance will then shift to appropriate areas as identified in the Logical Design of the Roadway Inventory File.

The Primary and Secondary routes involve many miles of roadway and a huge data collection effort. Also, much of the data may be unavailable due to the age and complexity of the systems. A sample of these systems could be included in the future based on specific criteria to limit the amount of data acquisition involved.

DATA ELEMENT CATEGORIES

I. Pavement Management Section Identification & Location

II. Construction/Rehabilitation

III. Project Design

IV. Structural Design

V. Materials & Soils Properties

VI. Construction History

VII. Joint Design

VIII. Subdrainage

IX. Reinforcing Steel

X. Detailed Condition Survey

XI. Friction Characteristics

XII. Deflection Data

XIII. Roughness Information

XIV. Maintenance

XV. Traffic Loading

XVI. Climatic History

XVII. Condition Rating Survey (CRS)

DATA ELEMENT LEVELS

Many different data elements have been identified as being requied for the IPFS data base. However, all identified data elements need not be included for every pavement management section due to the different uses of the various data elements. Three general levles showing this general "need" are identified as follows:

LEVEL 1 - PROGRAMMING NEEDS

Data required for Districts and the Office of Planning and Programming to identify projects for prioritization in the multi-year programming process. Also, data required for identification and lcoation of key design features and traffic conditions.

Data elements at this level are required for all Pavement Management Sections within the identified highway network.

LEVEL 2 - POLICY AND DESIGN EVALUATION NEEDS

Data required for evaluation and development of IDOT pavement policies, standards, and design procedures. Data would also be used in establishing rehabilitation decision making criteria.

A representative sample of Pavement Management Sections would be included to gather this level of data.

LEVEL 3 - RESEARCH AND SPECIAL STUDIES NEEDS

Very detailed data required for special/unusual pavement research needs and special studies. Experimental projects would be included in this level.

A small sample of Pavement Management Sections would be included dependent upon the scope of the study.

NOTES ON LEVELS

All data in Level 1 would be required for Level 2 sections, and all data in Levels 1 and 2 would be required for Level 3 sections.

DATA SOURCE TABLE

Data Source	Description	Primary Responsible Agency
BCA	Contractors Information System	Construction
Const.	Construction Job Records and Documentation	Districts
DPI	Roadway Inventory	Urban Program Planning
GAI	Accident Information System	Traffic Safety
MISTIC	Materials Test Records After 1/1/77 - Computerized Pre-1977 ----- Archives	Materials & Physical Research
MMI	Maintenance Management Information System	Maintenance
Plans	As-built Plans	Districts
PMF	Interstate Pavement Management File	Design
PR	Physical Research Test Data	Materials & Physical Research
U of I	Climatic Information	University of Illinois

I. PAVEMENT MANAGEMENT SECTION LOCATION AND IDENTIFICATION

Data Element	Level	Example	Units	Data Source
Marked Route	1	I-72		PMF
Management Section Begin MP	1	67.70		PMF
Management Section End MP	1	72.88		PMF
Direction	1	S		PMF
District	1	5		PMF
County	1	Piatt		PMF
Multi-Year Program Status	1			
Remarks	1			
High Accident Location	1	Yes		GAI
Annual Accident Rate/ Statewide Rate	1	1.1		GAI
Pavement Priority	1	3-5	Years	PMF

II. CONSTRUCTION/REHABILITATION

Data Element	Level	Example	Units	Data Source
Year of Improvement	1	1983		PMF
Improvement Cost	1	5,000	$000/Mile	BCA
Improvement Type	1	4.0" Class I		PMF
Improvement Contract No.	1	36923		
Improvement Section No.	1	53-4(1)		PMF
Beginning Milepost	1	67.70		PMF
Ending Milepost	1	74.35		PMF

III. PROJECT DESIGN

Data Element	Level	Example	Units	Data Source
Contract Number	1	32134		Plans
Letting Date	1	4/69		Plans
A) Original Design				
Number of Lanes	1	4		PMF
Lane Width	1	12	Ft.	Plans
Pavement Type	1	10" CRCP		PMF
Left Shoulder Surface Type	1	6" BAM		Plans
Left Shoulder Base Type	1			Plans
Left Shoulder Stabilized Width	1	6.0	Ft.	Plans
Left Shoulder Aggregate Width	1	2.0	Ft.	Plans
Left Shoulder Total Width	1	8.0		Plans

III. PROJECT DESIGN (Continued)

Original Design (Continued)

Data Element	Level	Example	Units	Data Source
Right Shoulder Surface Type	1	6" BAM		Plans
Right Shoulder Base Type	1			Plans
Right Shoulder Stabilized Width	1	10.0	Ft.	Plans
Right Shoulder Aggregate Width	1	0.0	Ft.	Plans
Right Shoulder Total Width	1	10.0	Ft.	Plans
Special Experimental Feature Flag	1			PR
Remarks	2			
1) Pavement Type Concrete				
Concrete Subbase Type	1	4" BAM		Plans
2) Pavement Type Asphalt				
Base Course Type	1	11" BAM		Plans
Asphalt Subbase Type	1	6" Gran		Plans
B) Rehabilitation Design				
Rehabilitation Type	1	3" Class I Mix D	AC Overlay	PMF
Shoulder Rehabilitation Type	1	Resurface 3"		PMF
Restored Shoulder Stabilized Width	1	10.0	Ft.	Plans
Underdrain Flag	1	Yes		PMF
Add Lanes	1	No		Plans
Widening	1	No		Plans
1) AC Rehab - Hot Mix Recycling				
Depth of Cold Milling of Existing Surface	2	1	Ins.	Plans
Percent Recycled Asphaltic Pavement in Overlay Mix	2	15	%	MISTIC
Type of Cold Mill Machine	3	Up Cut		Const.
Overlay Paving Equipment	3			
2) AC Rehab - AC Overlay				
Number of Binder Lifts	2	2	Each	Plans
Lift 1 Binder Thickness	3	1.50	In.	Plans
Date Lift 1 Binder Completed	3	7/82		Const.
Lift 2 Binder Thickness	3	1.25	In.	Plans
Date Lift 2 Binder Completed	3	7/82		Const.
Surface Thickness	3	1.25	In.	Plans
Date Surface Completed	3	8/82		Const.
3) AC Rehab - Cold, In-Place, Recycling				
Depth of Recycling	2	2	In.	Plans
Type of Cold Mill Machine	3	CMI		Const.
Type of Rejuvenator	3			Const.
Source of Rejuvenator	3			MISTIC
Type of Paving Machine	3			Const.

III. PROJECT DESIGN (Continued)

B) Rehabilitation Design (Continued)

Data Element	Level	Example	Units	Data Source
Direction of Cutting Drum	3	Down		Const.
Rejuvenator Application Rate	3	.85-1.0	% Residual By Weight	MISTIC
"Big D" of Mix	3	2.47		MISTIC
Sealed/Overlaid	3	No		Const.
4) AC Rehab - Heater Scarification & Overlay				
Depth of Scarification	2	.75	In.	Plans
Type of Equipment Used	2			Const.
Type of Asphalt Modifier	3			MISTIC
Asphalt Modifier Supplier	3			MISTIC
Virgin Asphalt Surface Mix Application Rate	3	70	Lbs/sy	Const.
Method of Applying Virgin Material	3	Mix with HST Material		Const.
5) AC Rehab - Cold Mill Only				
Depth of Cold Milling	2	.75	In.	Const.
Width of Cutting Drum	3	12	Ft.	Const.
Diameter of Cutting Drum	3	28	In.	Const.
Type of Cold Mill Machine	3	Up Cut		Const.
Speed of Cold Mill Machine	3	45	Ft/min	Const.
Type of Cutting Teeth	3	GTE AM 722		Const.
Ave. Number of Tooth Striations in Longitudinal Direction	3	18	Per 20 Ft.	Const.
Ave. Number of Tooth Striations	3	1.7	In.	Const.
Ave. Number of Rows of Tooth Striations in Transverse Direction	3	87	Per 5 Ft.	Const.
6) AC Rehab - Crack Sealing				
Type of Sealant	3	HFE 90		MISTIC
Type of Cover Chips	3	CA-16		Const.
Type of Reservoir	3	Sawed		Const.
7) PCC Rehab - Crack and Seat				
Pavement Breaker Type	3	Whip Hammer		Const.
Average PCC Breakage Size	3	3	Ft.	Const.
Reinforcement Cut or Broken	3	No Not Likely		Const.
Seating Roller Type	3	Pneumatic		Const.
Seating Roller Weight	3	35	Tons	Const.

一、地下水之不良影響

1.邊坡不穩定

邊坡不穩定現象之產生是由於外在施加之剪應力超過土壤或岩體之抗剪強度而沿著某一破壞面滑動。地下水之存在導致孔隙水壓上升，有效應力減少，降低抗剪強度；而水之流動所產生之滲流壓力亦會增加對土體之作用力，結果不是造成邊坡土壤之軟化，就是邊坡之滑動而破壞。

2.影響路面績效

在瀝青混凝土路面，若路基土壤之含水量過高，將導致孔隙水壓增高，承載力大為降低。當車輛經過時，容易造成垂直方向變形，終於破壞而造成裂縫。

3.經濟觀點

許多公路失敗之經驗顯示，地下排水措施不良是路面破壞之主要原因，不僅縮短公路使用年限，亦增添維修與養護費用。

二、地下水之來源與流動

路面下水之來源，可分為兩大類：(a) 地下水之流動，(b) 道路表面水之滲透。地下水主要來自降雨，雨水直接自土壤滲入或流至河流、湖泊與水塘後，再滲入地下，此等型式稱之為「重力流系統 (Gravity-Flow System)」另外一種常見之地下水為「湧泉流系統 (Artisian System)」。滲透入道路之水，其主要來源亦是降雨，水經由接縫處與裂縫進入路面底層。

三、公路地下排水設施之功能與型式

1.功能：(a) 攔截滲透水流，(b) 降低地下水位，(c) 收集其他排水系統之水量，並排除之。

2.型式：若以排水設施裝設之地點與本身幾何形狀可分為：(1).縱向排水系統 (Longitudinal Drains)，(2) 橫向與水平排水系統 (Transverse / Horizontal Drains)， (3) 排水帶 (Drainage Blanket)。

四、分析與設計所需要之資料

地下排水分析與設計所需之資料可分為四大類：(a) 流域之幾何條件，

(b) 材料本身之性質，(c) 氣候方面之資料與(d) 其他有關之事項。分析與設計階段所採用之資料，其精確度與完整性對設計成果有很大之影響，然而大地工程所涉及之問題與材料極爲複雜，所量測之數據變異性極大，雖然如此，吾人仍應力求得到接近眞實之資料。

五、排水設施分析設計

路面排水設施分析與設計相當繁瑣，涉及許多型式及各項方法，本報告附錄第四集第四册針對細節有許多說明，本處不重覆贅述。

2.5 路面評審系統

本報告對於路面評審共提出撓度、抗滑、糙度和路面紋理等四種作業項目，其中撓度作業是有關路面結構強度的評審，抗滑、糙度和路面紋理是涉及路面服務功能的評審。

2.5.1 撓度

撓度值可代表路面的承載能力，當路面結構完好，承載力強，撓度值會相當低，一旦撓度值增加，承載力降低，路面損壞隨即發生，失敗終將發生。一般路面撓度測量的方法，大致可分爲下列四大類：

- 靜力撓度 (Static Deflections)
- 穩態撓度 (Steady State Deflections)
- 衝擊荷重反應 (Impact Load Response)
- 波傳遞 (Wave Propagation)

以下介紹高速公路局的路面評審儀及撓度之溫度校正之發展。

一、路面評審儀

路面評審儀(Road Rater，Model 2000)是非破壞性動力撓度量測儀器，應用穩態撓度(Steady State Deflections)量測方法，測得路面結構彈性撓度。量測的結果可配合多層彈性模型，評估路面結構強度。

路面評審儀由一拖車及儀電控制箱組成，使用輕型卡車或小汽車牽引拖車，儀電控制箱置於小汽車上，主要的測試設備安裝在拖車上。測試前以三條電纜線連接拖車和儀電控制箱，操作人員在小汽車上由控制箱按鍵進行測試。操作程序簡單，停留在測站測試的時間短暫，測站間行進速率可達 88 KPH (55 MPH)沒有類似彭科曼樑測試緩慢推進的缺點，也減少對交通的干擾。

路面評審儀使用預先設定的動力荷重，加之於路面或路基結構之表面，以量測結構物表面之動力撓度。動力荷重是由震動體 (Vibrating Mass) 上下振動而產生，2000型路面評審儀之震動體約重817 kg (1800磅) 。震動體設置於評審儀之底部結構，如圖2.22所示。測試時，震動體下降與測點接觸，移動時震動體上升收起。測試時，震動體和底部結構首先作用於測點表面上。2000型路面評審儀之靜重約爲1590 kg (3500 磅) ，氣壓爲 40 psig。路面評審儀2000型之一般資料如下：

靜重	1590 kg (3500磅)
頻率範圍	6 至60 Hertz
動力荷重範圍	91至2500 kg (200至5500磅)
系統總重	2000 kg (4400磅)
總長度	371 公分 (146 吋)
總寬度	208 公分 (82 吋)
總高度	150 公分 (59 吋)
動力	16匹馬力發動機
車輛總重	2724 kg (6000磅)
煞車	水壓反應式
荷重平版	圓直徑45.7公分 (18吋)

不同頻率之動力荷重，有既定的極限，如圖2.23所示。

二、柔性路面撓度之溫度校正之發展

一般而言，影響路面撓度值之因子很多，主要有：(1) 路面型態 (柔性或剛性) ，(2) 路面結構強度和厚度，(3) 路基土壤強度，(4) 荷重，(5) 環境 (季節、溫度、日照、氣候等) ，(6) 材料疲乏特性。

爲建立柔性路面撓度之溫度校正關係式，高速公路局選定中山高速公路

230 K＋103之特定點，也就是西螺交流道附近之北上外車道靠近匝道的主線上，自民國73年至民國77年，在不同的季節，隨機選取數日，做定點式全日的撓度量測，同時亦量測路表面以下4 公分深度之溫度作爲路面溫度，也記錄量測時的氣候狀況，共取得93組數據。如表2.2 所示。

由於撓度量測的定點未變動，因此假設路面結構強度、厚度以及路基土壤強度爲定值。因爲車輛極少可能通過此地點，因此不考慮超載或軸次累積數的影響。由於測試之定點位於主線上，且量測的荷重及頻率皆與主線相同，因此測試、分析的結果能適用於高速公路主線。

對於路面撓度的季節效應，依據路面溫度變化的趨勢，將全年概分爲四季，分別是春季（4、5、6 月）、夏季（7、8、9 月）、秋季（10、11、12月）和冬季（1、2、3 月）等四季。對於其他環境因子，主要考慮溫度和日照兩因子。溫度是以路表面以下4 公分之溫度表示之；日照因子是以量測的時間表示之，以上午九時作爲基準。校正溫度爲70 ℉（21.1℃）。

路面評審儀量測時，有五個撓度值D1、D2、D3、D4和D5，經過溫度和日照校正後之撓度值，分別爲（D1)a、(D2)a、(D3)a、(D4)a 和（D5)a。假設校正值和量測值之間存在線性關係，其校正因數分別爲F1、F2、F3、F4和F5。對於不同季節的線性關係，以撓度值D1爲例，其關係式如下：

$$(D1)a = F1 * D1 \tag{2.55}$$

$$F1 = F1(T,t) = G1(T) + H1(t) \tag{2.56}$$

式中：(D1)a ：撓度校正值。

D1 ：撓度量測值。

F1 ：校正因數。

T ：路面溫度（℃）。

t ：量測時間。

G1(T) ：路面溫度之函數。

H1(t) ：量測時間之函數。

式中G1(T)與H1(t)分別由統計分析之逐步分析（Stepwise）測試而得。

由於（D1)a校正值無法準確得知，因此選定最靠近校正溫度21.1℃之撓度值，或是定點量測時的最小撓度值，作爲（D1)a校正值。

由於缺乏春季（4、5、6 月）的量測數據，因此全年的迴歸方程式不具代表性。一般而言，夏、秋兩季的路面溫度較高，撓度測值較大，較常接近臨界狀況，因此夏、秋兩季的五個校正因數方程式如下：

(1) 夏季：

$$F1 = 1.5040 - 0.9108\ \exp(-\frac{T}{10}) + 0.0075\ (\frac{1}{t})^2 + 1.1112\ \sqrt{t} - 4.1070\ \log(t+2) - 0.1935\ \exp(-t) \quad (2.57)$$

$$F2 = 0.6624 - 1.5832\ \exp(-\frac{T}{10}) + 0.0056\ (\frac{1}{t})^2 - 0.0980\ \log(t+2) \quad (2.58)$$

$$F3 = 0.2401 + 0.0685\ \sqrt{T} + 0.0045\ (\frac{1}{t})^2 \quad (2.59)$$

$$F4 = 0.9863 - 10.2630\ \frac{1}{T} + 0.0050\ (\frac{1}{t})^2 \quad (2.60)$$

$$F5 = 0.7876 - 3.8831\ \exp(-\frac{T}{10}) + 0.0068\ (\frac{1}{t})^2 \quad (2.61)$$

(2) 秋季：

$$F1 = -0.2175 + 0.0226\ T + 355.902\ (\frac{1}{T})^2 - 0.1139\ \log(t+2) \quad (2.62)$$

$$F2 = 0.6909 + 90.3837\ (\frac{1}{T})^2 + 0.0107\ \frac{1}{t} \quad (2.63)$$

$$F3 = 0.5831 + 0.0042\,T + 109.911\left(\frac{1}{T}\right)^2 + 0.0008\left(\frac{1}{t}\right)^2 \qquad (2.64)$$

$$F4 = -0.3253 + 0.2887\ln T + 152.524\left(\frac{1}{T}\right)^2 + 0.0010\left(\frac{1}{t}\right)^2 \qquad (2.65)$$

$$F5 = 0.7627 + 0.6588\exp\left(-\frac{T}{10}\right) + 0.0151\,\frac{1}{t} \qquad (2.66)$$

式中：T ：路面溫度（℃）。

t ：量測時間（上午九時爲1 ，九時30分爲1.5 ，十時爲2 ，依此類推）。

上述校正因數迴歸方程式之適用範圍，溫度自21℃至56℃，時間自上午九時至下午四時。路面撓度值D4、D5與路面溫度、量測時間的關係較少，尤其是D5的變化量更少，一般D5的變化範圍爲0.24至0.32之間，通常D5在一日內的變化量很小。

三、撓度之分析

路面評審儀有#1至#5五枚探測器，第一號探測值爲最大撓度（DMD)，第一及第二號探測器測值差，爲表面曲率指標（Surface Curvature Index. SCI)，代表面層強度狀況。第四及第五號探測器測值差，爲底層曲率指標（Base Curvature Index, BCI)，代表面層以下各層強度狀況。

由路面評審儀量測資料，需經過溫度或濕度的修正以得到撓度數值；其中五個值之最大值DMD 若不超過 7×10^{-4} 吋，則路面結構系統尚佳；若不超過 6×10^{-4} 吋，則路面結構強度在可容許範圍內。若同時考慮SCI ，BCI 及 DMD 等三種數值，則可得到下表：

DMD	SCI	BCI	路 面 結 構 狀 況
> 1.6	>0.35	> 0.2	面層及下層結構弱。
		< 0.2	結構弱，面層是主因。
	<0.35	> 0.2	結構弱，下層是主因。
		< 0.2	不會存在。
< 1.6	>0.35	> 0.2	不會存在。
		< 0.2	面層結構弱，不甚嚴重。
	<0.35	> 0.2	下層結構弱，需研究。
		< 0.2	面層及下層結構強。

2.5.2 抗滑

一. 抗滑儀器

1.1270型路面抗滑儀

此儀器是由美國K. J. Law 工程公司依照ASTM E274 標準試驗方法設計而成，儀器主要部分有拖曳車 (Towing Truck) 及兩輪拖車 (Two -Wheeled Trail)。 拖曳車是由一噸級之雪佛蘭小貨車改裝而成，車中主要裝置有：(1) 能連續控制及自動顯示結果的電子測定儀器，(2) 列表記錄器，(3) 供水給兩輪拖車測試使用之自動控壓水泵，(4) 水箱，(5) 空氣壓縮機。兩輪拖車主裝置包括：(1) 空氣壓縮盤式刹車制動系統，(2) 電橋電功率轉換器 (Transducers)所組成之力量測定系統，用以量度垂直力、水平力及轉動力距。(3) 噴水系統 (Water-Laying System)， 藉以敷佈0.5 mm均勻水膜於車輪行進前方之路面，(4) 合乎ASTM E501 標準規範之測試輪胎。

試驗時拖曳車在路面上以規定之速度行駛，並在刹車前噴水使路面潮溼，模擬在雨中行車狀況，以測定路面與輪胎間之摩擦力。1270型路面抗滑儀，具備了以上裝置，除了可提高測試效率外，可得更準確之測試結果。

2.英國擺式摩擦測試儀

英國擺式摩擦測試儀（British Pendulum Friction Tester），是實驗室中量測路面摩擦性質應用較早的儀器，爲英國道路研究試驗室(Transport and Road Research Laboratory)所發明，由於此儀器可應用於試驗室及現場鑑定路面摩擦性質，爲一種極普遍的路面抗滑測量儀器。此儀器係利用運動能量不滅定律，以測定路面之相對摩擦性質。測試時，利用擺臂上之橡皮滑板與路面發生摩擦，以測定路面面層之抗滑性質，試驗結果以BPN（British Pendulum Number）數値表示，BPN 値愈高表示測試路面之抗滑性質較佳。

二．基本原理

路面抗滑能力係路表面提供車輪胎被制動而不轉動，滑行於路面時，路面所提供的摩擦阻力。抗滑除爲路表面特性外，亦爲雨天路面潮溼時行車安全之重要因素。

摩擦力之構成，係兩物體間之表面附著力（Surface Adhesion Force）與表面遲滯力（Surface Hysteresis Force）之總體表現。兩種表面力發生於路面與輪胎間之情形如圖2.24所示。圖中右上圓中爲附著力作用之情形，左下方的放大圓是遲滯力作用之情形。表面附著力之發生主要是因由介面間剪力強度（Shear Strength）之傳送，其係數大小決定公式如下：

$$fa=\frac{A}{An}\cdot\frac{S}{P} \qquad (2.67)$$

式中：fa ：表面附著係數。

A ：實際接觸面積（in^2）。

An ：外在目視所得之接觸面積 (in^2)。

S ：路面與車輪胎間之剪力強度 (psi)。

P ：車輪胎橡膠承受之平均壓應力 (psi)。

由(2.67)式知，若表面平整則實際接觸面積較緊密，介面間有較強的剪力握裹 (Bond) 能力，均將增加表面附著力；然而，接觸面積潮溼時，剪力握裹能力因水膜存在而降低甚多，此時改善的方法可增加接觸表面之紋理 (Surface Texture)，使水膜得以由紋理組織形成之槽孔 (Channel)排除，而增加路面與輪胎間半乾燥接觸區 (Semi-Dry Contact Zone)之面積。

表面遲滯力產生之原因，主要是車輪胎橡膠接觸面變形導致能量的損失，其係數大小決定公式如下：

$$f_h = \frac{QD}{A_n P b} \tag{2.68}$$

式中：fh ：表面遲滯力係數。

Q ：車輪胎橡膠變形之體積 (in^3)。

D ：單位體積變形之能量損失 ($in - lb/in^3$)。

b ：車輪胎滑行之距離 (in) 。

An ，P：如(2.67)式。

由(2.68)式知，若表面其他條件固定，則具有凹凸不平的表面能產生較大的橡膠變形，產生較大的遲滯阻力；此外，胎壓、滑行速度及荷重亦會影響車輪胎變形狀態，故亦爲表面遲滯力之影響因素。

基於上述分析，路面抗滑能力之研究對象，爲路面與車輪胎，而在路面方面有路面材料性質與路面紋理；車輛與輪胎方面有輪胎材料、輪胎紋路 (Pattern)及深度、胎壓以及荷重等，此外滑行速度與水膜排除亦爲重要因素。

三、路面抗滑量測方法

量測路面抗滑能力方法，依其使用儀器不同有下列三種方法：

1.英國擺式摩擦測試儀法

此法是由英國運輸道路研究試驗室發展所得，除可應用於試驗室中量測試體抗滑特性外，亦可於現場進行路面抗滑調查，下表是早期使用這種方法評審路面時之建議BPN 最小值表，目前若採用此種方法量測路面抗滑能力時，表中資料可做爲評定路面抗滑能力之參考。

路面分類	道　　路　　狀　　況	BPN 最小建議值
A	操作困難路段： 1.圓環。 2.曲率半徑小於500 ft無管制路段。 3.縱坡大於1/ 20 且長度大於100 碼之路段。 4.無管制接近號誌之路段。	* 65
B	平均每日交通量大於2000輛之路段，如：高速公路、幹道等。	* 55
C	其他路段。	45

* 路段中行車速率超過90 KPH (60 MPH) 時需另加紋理深度 (Texture Depth)大於0.025 in之規定。

2.停車距離法

這種測定方法是利用汽車行車到某一速度後，剎車制動車輛以至停止，以此制動停車所需之距離，利用下列公示計算路面之摩擦係數。

$$f = \frac{V^2}{254\ S} - i \tag{2.69}$$

式中： f ：路面摩擦係數。

V：剎車前之車輛行駛速度（KPH）。

S：車輛於剎車期間行駛之距離（公尺）。

i：路面縱坡度，上坡爲正，下坡爲負。

3.拖車法

此法是根據ASTM E274 規範，以路面抗滑儀量測路面抗滑能力，量測時用兩輪拖車，由一部裝有水箱的小型卡車以預定的速度行經擬測路段。量測進行以自動控制，剎車制動拖車之車輪（左輪或右輪），使之以預定速度滑行於路面。此時並以電子儀器自動量測測試輪承受之垂直力與水平力，利用下列公式求得該測試路段之抗滑值(Skid Number，SN)

$$SN=\frac{F}{L}\times 100 \qquad (2.70)$$

式中SN爲路面抗滑值，F 爲摩擦阻力，L 爲車輪荷重。路面抗滑值即爲以ASTM E274 規範用車測試路面摩擦係數乘以一百之結果。

以上三種量測路面抗滑能力的方法，皆可應用於養護管理系統中，英國擺式摩擦測試儀較便宜，目前國內公路管理機構都有此種儀器設備，由於其儀器本身限制，此儀器常被用以鑑定低速時之路面抗滑特性，例如路面細質紋理（Microtexture），另兩種儀器可測試任何速度時之路面抗滑能力。一般停止距離法所得之結果較拖車法所得之結果爲大，因停止距離法測試過程中其汽車速度逐漸降低之故。在高速測試時，停車距離法具有危險性，至於拖車法因其裝備採自動電子儀器設備，測試效率較高，是目前較理想之路面抗滑量測儀器。

2.5.3 路面紋理和糙度

路面因施工或受車輛荷重作用，往往發生縱斷面起伏不平的粗糙現象，斷面起伏較大者，路面工程上稱爲糙度（Roughness），路面起伏較小者，則

稱爲路面紋理 (Pavement Texture) 。糙度之大小是造成行車震動之主要原因，與行車舒適與否有密切的關係。路面紋理之凹凸不平現象，係指路面與車輪胎接觸部份之小範圍內之不平整，如圖2.25所示。路面紋理依其功能及尺寸之大小，又可分爲粗質紋理(Macrotexture)與細質紋理(Microtexture)如圖2.25中，粗質紋理可爲骨材石塊 (Stone Chip) 形成起伏不平整之狀態，而細質紋理則指骨材石塊凸出部分，表面更微小的紋理。

一、紋理和糙度量測儀器

1.TRRL小型紋理測量儀

TRRL小型紋理測量儀是由英國運輸道路研究實驗室所設計，而由英國WDM 公司製造。儀器主要部分由兩輪台車 (Trolley)及可分離之手把(Handle)組成，把手長920 公厘，台車之長寬高則各爲305，640及300公厘，總重量爲19.5kg，是一可由單人手推進行量測之輕便儀器。

配備於儀器中之雷射變位轉換器(Laser Displacement Transducer)，可連續發射雷射光線照射路面，以量測路表面紋理深度，其原理如圖2.26所示。圖中光線由雷射光源發出，照射路面，其產生之反射角度，係由路表面高低變位狀態決定，因此，經由右邊接收鏡收集反射光，再以排列之檢波半導體 (Diode Array)檢視，可得路面反射點之起伏變位。檢視結果可記錄於電子記憶器中，直到一定路段長之資料收集完畢，即計算該路段之路面紋理深度指標，並輸出結果。

2.SDP 糙度儀

表面動力剖面儀 (Surface Dynamics Profilo) ，亦名SDP 糙度儀。高公局SDP 糙度儀爲K. J. LAW 公司所出品，型號爲M8300 。SDP 糙度儀爲一個獨立的儀器系統，可適合工程車或小汽車之牽引。它可提供路面養護管理系統所需之糙度指標(Roughness Index；RI) ，亦即路面現況的評審 (Pavement Condition Ratings) 。

路面現況評審記錄所得之糙度指標，對養護管理提供極爲重要之輸入資料。SDP 糙度儀提供公路工程師量測主次要道路糙度的一個快速方

法，SDP 糙度儀與牽引車輛種類、行車速率和溫度無關，且量測時不會產生時間不穩定現象（Time Instabilities）。SDP 糙度儀可計算均方加速指標（Root-Mean Square Acceleration Index；RMSA)和梅斯指標(Mays Meter Index)。兩指標可在任意選定之距離，列印一次。因而可使用各型車輛在時速超過32 KPH而測得梅斯糙度指標，結果與梅斯車輛或拖車在時速80 KPH之測值相同。

儀器系統使用電腦以記錄和列印路面現況評審觀測值，亦可自動計算加權情形。選用數值記錄器（Digital Cassette Recorder)以儲存資料，另外記錄器亦可將資料儲存於與RS 232相容之電腦上。

SDP 糙度儀之操作系統如圖2.27所示。

二、基本原理

路面工程與紋理有關的課題，有下列各項：

- 抗滑（Skid Resistance）。
- 路面抗滑速度梯度（Skid Resistance-Speed Gradient）。
- 雨天行車肇事率。
- 路面磨損（Pavement Wear）。
- 車輪胎磨損（Tire Wear）。
- 行車能源消耗。
- 行車產生之噪音。
- 雨天行車水沫飛濺影響行車視距。
- 雨天行車水面滑行（Hydroplaning）現象。

本文僅將紋理觀念應用於路面抗滑安全系統中，至於其他方面之研究課題可視管理系統中之需要，斟酌增加。路面紋理於抗滑研究中，粗質紋理的功能是在路面與車輪胎接觸面間保持槽孔，使路面與輪胎間之水分得於排開。此種功能在雨天高速行車時，更顯出粗質紋理在路面抗滑行車之重要性。細質紋理在路面潮溼時，路面與車輪胎接觸若有粗糙的（Harsh)的細質紋理，可增強接觸面間之附著力。

細質紋理因其尺吋 (Scale)小，量測不容易，一般以英國擺式摩擦測量儀來衡量。本文將這一部分，稱之爲路面材料摩擦性質。粗質紋理量測方法很多，較具代表性的有：

- 細砂鋪填法 (Sand Patch Method)。
- 縱斷面測量法 (Profile Measurement Method) 。
- 立體照片分析法 (Stereo-Photo Interpretation Method) 。
- 反射光法 (Light Reflection Method)。
- 排水測量法 (Drainage Measurement Method)。

各式方法詳細內容可參照FHWA RD-80-505之報告，本文除建議以TRRL小型紋理測量儀來測路面紋理，亦不排除使用多種方法來量測路面紋理。因爲使用多種方法量測，可建立各方法間輸出之相關性；並更廣泛地應用已有的研究成果。例如，法國以細砂鋪填法對各型路面之紋理所做之建議(如表2.3所示) ，可做爲將來高速公路釐定路面紋理等級之參考。

2.6 路面養護實施系統

在路面養護實施系統裡，養護工作管理系統，也是一個工作控制系統。

本節養護係指針對某段路面，經調查分析等養護先期步驟後，所擬定之路面養護改善辦法。在本節系統裡，這些改善辦法常爲一些不同的替代方案，供成本效益分析後，決定取捨。又本方案系統也是一套小型檔案系統，可查詢過去養護方案之檔案資料，以爲擬定本次養護改善方法之參考。本研究計畫擬定之路面養護方案系統如圖2.28所示。

2.6.1 養護方法

本系統乃根據路面調查資料，加上事先設定的決定樹形圖 (Decision Tree)，經過合理的評估過程，而決定出相容性養護方法 (Compatible results typically depend on the dynamic characteristics of the vehicle and speed, as shown by the response in Figure 2.6. Detailed information on the location, amplitude and frequency of movements usually is not obtained, so the result represents the average rectified slope of the axle-body motion (rectified because both upward and downward movements are counted) over the segment between successive outputs. The length of the tire contact naturally filters out very short wavelength effects.

Dynamic profile instruments

Dynamic profilers measure the profile from a moving vehicle or trailer. They differ in the reference used to represent the horizontal datum (Table 2.2) and in the method of sensing the profile. The early GMR profilometer and French APL profiler use direct contact through a following wheel on the pavement, while recent versions use indirect or noncontact methods such as visible light lasers, infrared light sensors and ultrasonic sensors. As these sensors can measure very short wavelengths, including surface texture and down into cracks (which are bridged by a vehicle tire and do not affect vehicle motion), high frequency filters or averaging needs to be applied to the data to suppress these effects. Figure 2.11(b) shows that the profilometers do not return the absolute profile exactly because of a lack of the lowest frequencies and slight distortions in the instruments, but the recorded profiles have been shown to contain all the information needed to calculate most roughness indices with adequate accuracy.

2.3 STANDARD AND COMMON MEASURES

The wide differences between the outputs of different devices used throughout the world, and the often poor reproducibility of results by the same type of equipment, have severely hindered the use of roughness data in decision-making, and particularly in research attempting to compare results from different studies. Awareness had grown that equipment hardware was generally unsuitable as a roughness "standard" because the characteristics change over time. Hudson (1979), with the proposal that roadmeters be calibrated over a series of road sections for which a standard roughness had been measured (successfully demonstrated in the Brazil-UNDP study (GEIPOT 1982)), and Gillespie and others (1981), with extensive study of the vehicle and road characteristics, laid the basic groundwork for standard calibration procedures.

2.3.1 International Road Roughness Experiment

In order to establish correlation between the different roughness measures and to select a standard for calibration, the World Bank convened the International Road Roughness Experiment (IRRE) in 1982 in Brazil, with sponsorship and participation by several international organizations (Sayers, Gillespie and Queiroz 1986). The experiment (see Table 2.3) was conducted on forty nine test sites of flexible pavements and unpaved roads covering a very wide range of roughness. Four profile measures, five types of roadmeter, and two types of subjective panel rating were run on all sections. The major conclusions were:

1. The average rectified slope (ARS) outputs of all roadmeters differ numerically but correlate highly when run at similar speeds (the correlations degraded when the speeds differed);

Table 2.3: Scope of the 1982 International Road Roughness Experiment

1. Road Test Sites

Road surface	Number of Sections	Range of roughness (IRI)			Length
		Mean	Minimum	Maximum	(m)
Asphalt concrete	13	4.22	1.9	7.3	320
Surface treatment	12	4.05	2.5	5.7	320
Gravel	12	7.63	3.7	14.1	320
Earth	12	8.35	4.1	16.6	320
All	49	6.03	1.9	16.6	320

2. Measurements and Methods

Method	Number	Description and test speeds
Roadmeters, car-mounted	5	Maysmeter (3), NAASRA (1), Bump Integrator (1): 5 runs at each speed 20, 32, 50, 80 km/h.
Roadmeters, trailer	2	Bump Integrator, BPR roughmeter: 6 runs at each speed 20, 32, 50 km/h.
Static profilers	2	Rod and level survey, TRRL beam.
Dynamic profilers	2	APL trailer (speeds 21.6, 72 km/h); GMR profilometer.
Panel rating	2	18-person PSR-panel, 4-person IRI-panel.

3. Participants

Transport Planning Agency (GEIPOT), Road Research Institute (IPR), Brazil; Central Bridges and Pavements laboratory (LCPC), France; Road Research Center (CRR), Belgium; Transport and Road Research Laboratory, Overseas Unit (TRRL), United Kingdom; University of Michigan Transportation Research Institute (UMTRI), USA; The World Bank; and contributions from Australian Road Research Board (ARRB); and Federal University of Rio de Janeiro, Brazil.

Source: Based on Sayers, Gillespie and Queiroz (1986).

2. Roadmeters generally performed satisfactorily over the full range of roughness (except the BPR roughometer was not robust enough for the rough roads, and the Maysmeter lost counts on very smooth sections), but dynamic profilometers were limited to paved roads (GMR) and all but the roughest unpaved roads (APL);

3. After calibration to a road profile statistic, there is a high equivalence and correlation amongst roadmeters and profilometers;

4. Of six profile statistics evaluated, most were satisfactory for calibration purposes, and the best correlations were given by the ARS of a quarter-car simulation (the reference simulation, RQCS, derived by Gillespie and others 1981);

5. The international roughness index (IRI) was selected to be the slope output (ARS) of the RQCS, with a simulation speed of 80 km/h, derived from the absolute profile of the road surface.

Further discussion on the experiment can be found in Sayers, Gillespie and Queiroz 1986b, 1987).

2.3.2 International Roughness Index

The international roughness index (IRI) is a mathematically-defined summary statistic of the longitudinal profile in the wheelpath of a travelled road surface. The index is an average rectified slope statistic computed from the absolute profile elevations. It is representative of the vertical motions induced in moving vehicles for the frequency bandwidth which affects both the response of the vehicle and the comfort perceived by occupants.

The IRI is defined by a mathematical simulation of a quarter-car (that is, one wheel with the associated dynamic characteristics of the suspension and sprung mass of a typical passenger car), as shown in Figure 2.12 and defined in Sayers, Gillespie and Paterson (1986). The simulated travelling speed is 80 km/h, which determines the bandwidth of the responses shown in (b) and (c) of the figure. These can be seen to cover the range of frequencies most affecting the users' perception of comfort and the impact on moving vehicles.

The IRI describes a scale of roughness which is zero for a true planar surface, increasing to about 6 for moderately rough paved roads, 12 for extremely rough paved roads with potholing and patching, and up to about 20 for extremely rough unpaved roads, as shown in Figure 2.13. The units of IRI are actually dimensionless, because it is a slope statistic, but it has been scaled by a factor of 1,000 so that it represents m/km, mm/m or inches/1,000 inches. The standard presentation is thus 2.1 m/km IRI, generally reported to one decimal place.

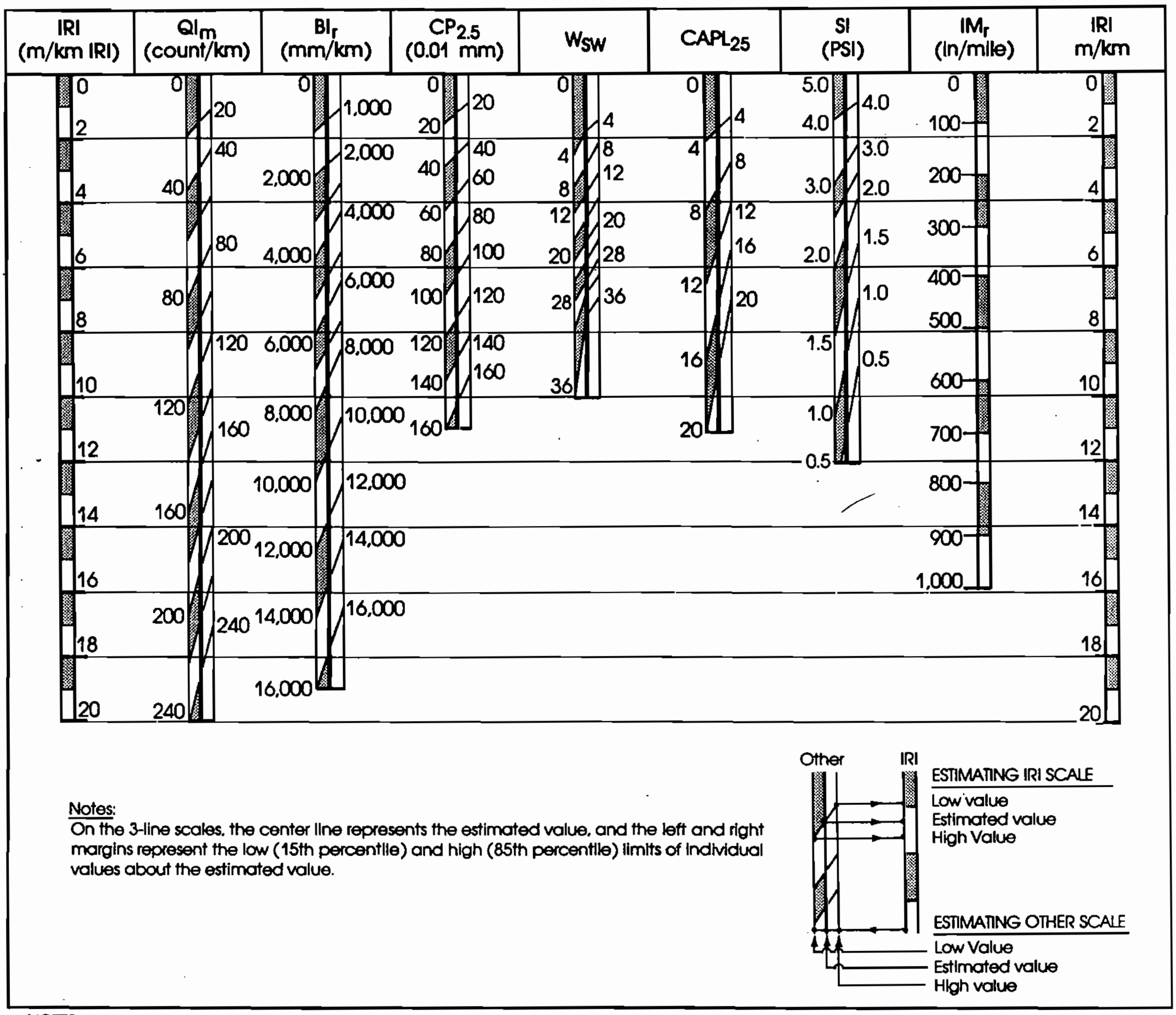
Details of the computation of the IRI, and guidelines for applying it to the calibration of equipment and the conduct of roughness measurements are given by Sayers, Gillespie and Paterson (1986). The calibration method refines the ones adopted in the Brazil-UNDP study (GEIPOT 1982) and proposed by Hudson (1979).

Table 2.4: Description of various road profile statistics by category

Acronym	Source	Description
1. Mathematical simulation of vehicle response		
RQCS	NCHRP Report 228	Reference Quarter Car Simulation with parameters representing passenger car (Gillespie and others 1981); ARS output in "inches/mile."
QCS	GMR Profilometers	Quarter Car Simulation with vehicle constants derived by K.J. Law (Inc.); ARS output in "inches/mile."
IRI	World Bank	RQCS as above with scaled dimensionless ARS output (nominally in "m/km," where 1 m/km = 63.36 inches/mile). (Sayers, Gillespie and Queiroz 1986).
2. Estimation of vehicle response by correlation to wavelength statistics		
MO	Texas	Estimate of "Maysmeter Output" ARS (inches/mile) from root mean squared vertical acceleration (RMSVA) of profile in 1.2 m and 4.9 m baselengths (McKenzie and Hudson 1982): $MO = 20 + 23\ RMSVA_{1.2} + 58\ RMSVA_{4.9}$
QI_r	Brazil-UNDP study	Estimate of QCS output (ARS) of GMR profilometer from RMSVA statistics of profile on 1.0 and 2.5 m baselengths (Queiroz 1979): $QI_r = -8.54 + 6.17\ RMSVA_1 + 19.38\ RMSVA_{2.5}$.
BI_r	TRRL (Overseas Unit)	Estimate of Bump Integrator trailer by root mean square deviations (RMSD) from best-fit line through elevations at 300 mm intervals on 1.8 m baselength: $BI_r = 472 + 1{,}437\ RMSD + 225\ RMSD^2$ (Abaynayaka in Sayers, Gillespie and Queiroz 1986).
3. Statistics of Discrete Wavebands		
PI	NCHRP Report 275	Root mean square elevation statistic from the 0.5 to 2.4 m wavelength band (Janoff and others 1985).
$PU_{3.0}$	TRRL	Variance of elevation from 3 m moving average (Jordan 1985).
$CP_{2.5}$	CRR Belgium	Average rectified elevation on 2.5 m moving average baselength (Appendix G in Sayers, Gillespie and Queiroz 1986). Also for 10 and 40 m baselengths.
W_{SW}, W_{MW},	LCPC France	Mean square energy of profile signal in wavebands sw (1 - 3.3 m), mw (3.3 - 13 m) and lw (13 - 40 m) (Appendix G in Sayers, Gillespie and Queiroz 1986).

Source: Author.

Figure 2.15: Chart for approximate conversions between major roughness scales and the International Roughness Index (IRI)



NOTES:
Conversions estimated on data from the International Road Roughness Experiment, (Sayers, Gillespie and Queiroz, 1986) as follows:

1. IRI — International Roughness Index (Sayers, Gillespie and Paterson, World Bank Technical Paper 46, 1986)
2. QI_m — Quarter-car Index of calibrated Maysmeter, Brazil-UNDP Road Costs Study
   $\hat{IRI} = QI_m/13 \pm 0.37\sqrt{IRI}$ $IRI<17$
3. BI_r — Bump Integrator trailer at 32 km/h, Transport and Road Research Laboratory, UK:
   $\hat{IRI} = 0.0032\, BI_r^{0.89} \pm 0.31\sqrt{IRI}$; $IRI<17$
4. $CP_{2.5}$ — Coefficient of planarity over 2.5m baselength for APL72 Profilometer, Centre de Recherches Routiers, Belgium:
   $\hat{IRI} = CP_{2.5}/16 \pm 0.27\sqrt{IRI}$; $IRI<11$
5. W_{sw} — Short Wavelength Energy for APL72 Profilometer, Laboratoire Central des Ponts et Chaussées, France
   $\hat{IRI} = 0.78\, W_{sw}^{0.63} \pm 0.69$ IRI; $IRI<9$
6. $CAPL_{25}$ — Coefficient of APL25 Profilometer, Laboratoire Central des Ponts et Chaussées, France:
   $\hat{IRI} = 0.45\, k\, CAPL_{25} \pm 16\%$; $IRI<11$
   where k = 1 for general use, k = 0.74 for asphalt concrete surfaces, k = 1.11 for surface treatment, earth or gravel
7. SI — Serviceability Index, American Association of State Highway and Transportation Officials:
   $\hat{IRI} = 5.5 \ln(5.0/SI) \pm 25\%$; $IRI<12$
8. IM_r — Inches/mile equivalent of IRI from Reference Quarter-Car Simulation at 50 mile/hr (see 'HSRI-reference' in Gillespie, Sayers and Segel NCHRP report 228, 1980; and '$RARS_{80}$' in Sayers, Gillespie and Queiroz, World Bank Technical Paper 45, 1986):
   $IRI = IM_r/63.36$

Table 2.5: Relationships and statistics for conversions between roughness scales

Conversion relationship		Standard error	C. V.%	Bias slope	Units
IRI	= $QI_m/13$	0.919	15.4	0.989	m/km
	= $(QI_r + 10)/14$	0.442	7.3	0.975	"
	= $0.0032\ BI^{0.89}$	0.764	12.7	1.008	"
	= $CP_{2.5}/16$	0.654	12.4	0.993	"
	≃ $5.5 \log_e(5.0/PSI)$	-	-	-	"
	= $0.80\ RARS_{50}$	0.478	7.9	1.002	"
	= $0.78\ W_{sw}^{0.63}$	0.693	11.5	0.994	"
	= $CAPL_{25}/(2.2 + 0.8A)$	1.050	17.4	1.030	"
QI_m	= 13 IRI	12.0	15.3	0.993	counts/km
	= $9.5 + 0.90\ QI_r$	14.5	18.7	0.985	"
	= $BI/(55 + 18\ E)$	11.7	15.0	1.002	"
	= $0.81\ CP_{2.5}$	11.7	17.2	0.986	"
	≃ $72 \log_e(5.0/PSI)$	-	-	-	"
	= $7.9\ W_{sw}^{0.70}$	8.78	11.2	0.996	"
	= $6.2\ CAPL_{25}$	18.29	23.3	1.13	"
QI_r	= -10 + 14 IRI	6.32	8.3	1.024	"
BI	= $630\ IRI^{1.12}$	694	14.7	0.998	mm/km
	= $36\ QI_m^{1.12}$	1100	22.8	0.985	"
	= $(55 + 18\ E)\ QI_m$	673	14.2	0.976	"
	= $62\ QI_r$	850	18.1	0.971	"
$CP_{2.5}$	= 16 IRI	10.5	12.4	0.994	0.01 mm
	= $11 + 1.12\ QI_r$	14.8	17.6	0.995	"
	= $1.23\ QI_m$	14.4	17.2	0.986	"
	= $11.7\ W_{sw}^{0.65}$	8.87	10.5	1.018	"
MO_m	= IRI/1.5	0.25	0.9	1.04	m/km
MO_i	= 42 IRI	16.0	0.9	1.04	in/mile

<u>Note</u>:
E = 1 if earth surface, = 0 otherwise.
A = 1 if asphalt surface, = 0 otherwise.
BI = TRRL Bump Integrator trailer at 32 km/h (mm/km).
$CP_{2.5}$ = APL Profilometer coefficient of evenness (.01 mm)
IRI = International Roughness Index (m/km).
QI_m = Roadmeter-estimate of QI roughness (counts/km).
QI_r = Profile RMSVA-function of QI roughness (counts/km).
$RARS_{50}$ = ARS response of reference roughness simulation at 50 km/h (Sayers, Gillespie and Queiroz, 1986).
W_{sw} = Short wavelength (1-3.3 m) energy index of APL72
$MO_{m,i}$ = Maysmeter Output function of RMSVA (Table 2.4) (m/km; inch/mile)

<u>Source</u>: Computer analysis of data from Sayers, Gillespie and Queiroz (1986) and Sayers and Gillespie (1986).