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Data Collection Technologies for Road Management

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Different types of data are required for managing the road infrastructure. Inventory data describe the physical elements of a road system. Condition data describe the condition of elements that can be expected to change over time. There are a wide range of technologies available to the road manager for measuring attributes of the road network. The challenge is to select the appropriate equipment, given local conditions and the way in which the data are expected to be used.

The purpose of this note is to give a general view of the currently available survey technologies applied to pavements, bridges and traffic. This includes an assessment of the applicability of these technologies in developing countries. The goal is to assist managers in establishing an appropriate and sustainable e data collection program and procuring the appropriate equipment to collect the data. This note is a summary of the report 'Data Collection Technologies for Road Management'. The full report is available for download from www.road-management.info and from http://www.worldbank.org/highways.

The note opens with a discussion of data collection requirements. This is then followed by separate discussions on pavements, bridges and traffic survey technologies. A cost/performance analysis between available equipment is presented in each section. Finally, recommendations for data collection are presented as a guidance to managers in developing countries.

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1 Road Infrastructure Data Needs

Different types of data are used for road management. Data collection technologies and data needs vary depending on which infrastructure element is evaluated. In general terms, elements such as Road Inventory, Pavements, Structures and Traffic require two types of data:

- Inventory; and
- Condition.

Inventory data describe the physical elements of the road system. These do not change markedly over time. Condition data describe the condition of elements that can be expected to change over time.

There are a wide range of technologies available to the road manager for measuring attributes of the road network. The challenge is to select the appropriate equipment, given local conditions and the way in which the data are expected to be used.

1.1 What Data should be Collected?

Excessive data collection is probably one of the top five reasons road management systems (RMS) are abandoned. The systems are seen as too data intensive and too expensive to sustain. To avoid this situation, three guiding principles should always be considered when deciding which data to collect:

- Collect only the data you need;
- Collect data to the lowest level of detail sufficient to make appropriate decisions; and,
- Collect data only when they are needed.

1.2 Information Quality Levels (IQL)

Road management information can be classified into different quality levels. These correlate to the degree of sophistication required for decision making and methods for collecting and processing data. Bennett and Paterson (2000) identified five information quality levels (IQL) for general use:

- **IQL-1** represents fundamental, research, laboratory, theoretical, or electronic data types, where numerous attributes are measured.
- **IQL-2** represents a typical level of detail of engineering analyses for project-level decisions.
- **IQL-3** represents typically two or three attributes, used for network-level surveys or where simpler data collection methods are appropriate.
- **IQL-4** is a key attribute used in planning, senior management reports, or in low technology data collection.
- **IQL-5** represents top level data such as key performance indicators, which combine key attributes from several pieces of information.

2 Location Referencing Data

Location referencing is the singularly most important consideration in conducting a survey. Unless the data are properly referenced, they will be of limited use in making management decisions.

In road management there are two common location referencing methods:

- **Linear:** gives an address consisting of a distance and direction from a known point, for example: Kilometre point, Kilometre post, Reference point, Reference post.
- **Spatial:** gives an address consisting of a set of coordinates. This is commonly done using Global Positioning System (GPS) data.

Location referencing is achieved using digital Distance Measuring Instruments (DMI) for linear referencing, and Global Positioning (GPS) receivers for spatial referencing. Video logging is included in location referencing as it is commonly used to determine the position of objects, although it is recognized that it is used for more than just referencing.

Table 1 presents some examples of location referencing equipment.

Table 1. Location Referencing Equipment

CLASS	EQUIPMENT
Digital DMI	Conventional digital DMI
	Digital DMI integrated with other data
GPS	Portable GPS
	GPS integrated with inertial systems
Video Logging	Analog imaging
	Digital imaging

3 Pavement Condition and Structure

3.1 Types of Pavement Evaluations

Pavement evaluations record pavement characteristics that influence pavement performance. The key pavement characteristics considered in an evaluation are usually:

- Roughness;
- Texture;
- Skid resistance;
- Mechanical/structural properties;
- Surface distress; and,
- Geometry.

Depending on which characteristic is being surveyed, a pavement evaluation can be classified as functional or structural.

- **Functional Evaluation:** Provides information about surface characteristics that directly affect users' safety and comfort, or serviceability. Safety is evaluated in terms of skid resistance and surface texture, while serviceability is quantified through roughness measures.
- **Structural Evaluation:** Provides information on whether the pavement structure is performing satisfactorily under the traffic loading and environmental conditions. This includes surveys on pavement distresses and mechanical/structural properties of pavements.

3.2 Pavement Data Collection Equipment

Pavement evaluations are performed in the field through manual surveys or using specialized equipment. Evaluated characteristics of the pavement are quantified by means of indicators or condition indices.

Table 2 presents typical data collection equipment used to evaluate pavement characteristics in the field. Equipment are classified in terms of their precision and survey method. Laboratory testing equipment are not included.

Table 2. Pavement Data Collection Equipment

PAVEMENT CHARACTERISTIC	EQUIPMENT CLASS
Roughness	Class I: Precision Profiles - Laser - Manual
	Class II: Other Profilometer Methods
	Class III: IRI Estimates from Correlations
	Class IV: Subjective Ratings
Microtexture	Static
Macrotexture	Static
	Dynamic
Skid Resistance	Static
	Dynamic
Mechanical Properties	Falling Weight Deflectometer
	Deflection Beams
	Dynamic Cone Penetrometer
Surface Distress	Video Distress Analysis
	Visual Surveys
	Transverse Profilers
Geometry	GPS
	Inertial Navigation Units

Data collection equipment should be reliable, efficient and secure. To ensure cost effective surveys and data referencing consistency, it is recommended to collect multiple pavement characteristics during a single pass of the data collection vehicle. There are two broad approaches for achieving this:

- **Portable systems:** the systems can be installed in any vehicle and are designed to be modular and portable; and,
- **Dedicated vehicles:** vehicles with permanently installed instrumentation.

Examples of the different types of equipment available are given in Bennet et al. (2006). Company profiles and brochures are available at www.road-management.info.

3.3 Suitability Indices

A survey was conducted of the literature as well as of equipment manufacturers and users. The survey considered three components: general information on the equipment, cost evaluation, and operational evaluation.
From this, cost/performance suitability indices were developed for the different equipment, based on a linear relation between cost and operational performance evaluations for five road types (all roads, expressways, urban roads, rural roads and unsealed roads). Cost evaluations considered initial and operational/ maintenance costs per equipment class. Operational performance evaluations considered ease of assembly/installation, portability, ease of data collection/processing, interoperability, robustness, ease of operation, ease of calibration/maintenance, accuracy for IQL and data collection speed.

The Suitability Index values range from a potential minimum of 1 to a potential maximum of 5; 1 indicating high cost and low operational performance and 5 low cost and high operational performance.

3.4 Cost/Performance Analysis between Equipment

Suitability indices were ranked in descending order for the five road types. The higher the ranking, the better the equipment is in terms of its cost and operational performance for that road class. **Error! Reference source not found.** presents the suitability ranking obtained for **all** roads.

The results indicate that survey referencing and geometry systems are the most cost effective and operationally useful equipment for road management. However, it must be noted that referencing equipment does not measure pavement condition.

The best technologies for measuring pavement condition are those that balance cost and performance. They are relatively accurate, simpler and less expensive to operate and maintain. Often, they cost much less than more sophisticated technologies for measuring the same characteristic (e.g., Class III roughness vs. Class I roughness).

Comparatively low-performing equipment are expensive devices that use very specific technologies and usually perform measurements through static sampling or dynamic testing with low operational performance. This is the case of Falling Weight Deflectometer (FWD), deflection beams and dynamic skid resistance evaluation (SCRIM). Although accuracy and robustness of this equipment is high, maintenance and calibration is not trivial, since the equipment requires experienced people and significant expenses to operate them. Since sampling is so specific and in many cases static, the equipment cannot be operated simultaneously with other devices.

Table 3 Suitability Ranking for All Roads

EQUIPMENT CLASS	SUITABILITY RANKING
Referencing- Digital DMI	4.62
Referencing- GPS	4.29
Geometry GPS With INU	4.01
Macrotexture- Dynamic Low-Speed	3.88
Referencing- Video	3.82
Geometry Precision INU	3.76
Roughness- Class III	3.60
Macrotexture- Static	3.57
Macrotexture- Dynamic High Speed	3.51
Roughness- Class I Manual	3.50
Roughness- Class II	3.41
Rut Depth Profilers	3.41
Surface Distress Imaging	3.31
Roughness- Class IV	3.30
Skid Resistance- Dynamic (Trailer)	3.24
Skid Resistance- Static	3.12
Deflections- Beams	3.07
Roughness- Class I Laser	2.91
Deflections- Portable FWD	2.71
Ground Penetrating Radar- Dynamic	2.69
Ground Penetrating Radar- Static	2.61
Deflections- Trailer FWD	2.55
Skid Resistance- Dynamic (Vehicle)	2.23

Table 3 presents a subjective assessment of the relative cost to performance of different types of equipment. It should be noted that the performance considers more than just the ability to measure an attribute accurately, it also reflects practical considerations, such as ease of operation, flexibility, data processing requirements, etc. The matrix does not include these types of multi-function vehicles, since their ratings would vary depending upon cost and functionality.

As a general rule, if an agency has budgetary restrictions, equipment selected for pavement data collection should be located in the right bottom boxes shaded in the matrix (cost ranging between 3 to 5 and operational performance from 3 to 5). Specialized needs that require specialized equipment may necessitate going out of that area. Agencies with limited budgets or technical skills should focus on the 4 – 5 areas of the matrix.

Table 3 Cost/Performance Trade-off Matrix for All Roads

Equipment Global Cost	Operational Performance					
	Scale	**1 (Low performance)**	**2**	**3**	**4**	**5 (High performance)**
	1 (High cost)			• Skid Resistance Dynamic - Vehicle	• Imaging for Surface Distress	
	2			• Ground Penetrating Radar – Dynamic • FWD - Trailer	• Macrotexture – Dynamic High Speed • Precision INU for Geometry • Roughness – Class I (Laser)	
	3			• Deflection Beams • FWD - Portable • Ground Penetrating Radar – Static • Skid Resistance – Dynamic Trailer	• GPS with INU • Macrotexture – Dynamic Low Speed • Rut Depth Profilers • Roughness – Class II	
	4		• Roughness- Class IV	• Roughness – Class I (Manual) • Skid Resistance – Static	• Video Logging • Roughness – Class III	• GPS
	5 (Low cost)			• Macrotexture – Static		• Digital DMI

4 Bridge Data Collection

4.1 Types of Bridge Evaluations

Bridges suffer structural and functional deterioration as a result of structural damage or material degradation. For this reason, bridge structures should be inspected periodically, at time intervals dependent on the scope of the particular type of inspection. According to the practices in the U.S. and European countries, bridge inspections can be divided into two basic groups:

- **Routine Inspections**: Regularly scheduled, intermediate-level inspections consisting of sufficient observations and measurements to determine the general structural and functional condition of the bridge. Developing problems or changes from a previously recorded condition can be detected with these inspections. They can be carried out by skilled maintenance personnel or technicians, unless the bridge structure is very complex. Inspections are normally performed every one to two years, according to local specifications.

- **In-Depth Inspections:** Scheduled or unscheduled close-up inspections of bridges to assess the structural damage resulting from external causes. This includes deficiencies not readily visible in routine inspections. They are usually carried out by bridge engineers or experts. All parts of the bridge should be checked by close inspection of each bridge element. The frequency of the major inspection depends on both local specifications and bridge conditions, but usually should be less than 5 years. Examples of these tests include: deck permeability; concrete cover depth; internal cracking; and position of bearings, deflections, settlements, and joint openings.

4.2 Bridge Component Inspections and Data Collection Equipment

Bridge data collection varies depending on the bridge component being surveyed. Visual inspections are normally used for all bridge components, but other applicable physical inspection techniques vary with the material of bridge components. Typical inspections performed to timber, concrete and steel components are:

- **Timber:** Inspected by both visual and physical examination. Hammer-sounding is the most simple non-destructive method applied. Ultrasonic testing is the main non-destructive test available to measure crack and flaw size. Boring or drilling and probing are the two most commonly used destructive tests.

- **Concrete:** Inspected by both visual and physical examination. Two of the primary deteriorations noted by visual inspections are cracks and rust strains. Core sampling is a commonly used destructive technique for concrete inspection. Hammer sounding and chain dragging are two common non-destructive methods to detect unsound concrete areas and delaminations.

- **Steel:** Visual inspection is the major method used in steel members, particularly for surface defects. There are also several destructive and non-destructive techniques, such as: Acoustic emissions testing, Computer tomography, Dye penetrant and ultrasonic testing.

Typical data collection equipment used in Bridge inspections are listed in Table 4.

Table 4. Bridge Data Collection Equipment

TECHNOLOGY	EQUIPMENT TYPE
Bridge Access Technologies	Hydraulic lifts
	Snooper-type trucks
	boat or barge
	Scaffolds
	Diving equipment
Concrete Non-destructive Testing	Strength
	Sonic
	Ultrasonic
	Magnetic
	Electrical
	Nuclear
	Thermography
	Ground Penetrating Radar
	Radiography
	Visual Surveys (Manual or Digital)
	Transverse Profilers
	GPS
	Inertial Navigation Units
Steel Non-destructive Testing	Radiography
	Magnetic particle
	A.C. Wet
	A.C. Dry
	Eddy Current
	Dye Penetrants
	Ultrasonic5
	Visual Surveys (Manual or Digital)

4.3 Cost/Performance Analysis between Equipment

Suitability Indices were estimated using the same methodology applied with pavements. Results ranked in descending order are presented in Table 5.

Table 5 Suitability Ranking for Bridge Inspection

EQUIPMENT CLASS	SUITABILITY RANKING
Ultrasonic	4.0
Electrical	3.9
Digital Imaging	3.3
GPR	2.7
Infrared Thermography	1.7

The results show that ultrasonic and electrical testing equipment offer the greatest advantages, and infrared thermography the lowest. These two former technologies have low initial and operational costs, typically in the range of US $2,000 – US $6,500 and US $500, respectively.Traffic Data Collection

4.4 Types of Traffic Data

Traffic data are collected to monitor the use and performance of the roadway system. These data are applied in a variety of management and research areas, such as: economic analysis, finance, legislation, maintenance and planning.

The project considered data collection technologies for three categories of traffic data: volume, vehicle classification, and truck weights. Besides these three data types, a variety of other traffic characteristics, such as vehicle speeds and vehicle occupancies, can also be monitored. For the three categories considered, the traffic data collection system is composed of one or more sensors and a data collection unit.

4.5 Vehicle Classification Technologies

A key element of most traffic data collection systems is the ability to classify traffic. The counting strategy can be simple, discriminating between short and long vehicles, or may be complex, based on the number of axles and the distances between axles. The latter is the most common and is used with any system that records individual axles. For this, two detectors are required to classify traffic accurately.

Traffic classifiers count each individual axle, apply a classification system and may also record the speed. Traffic counters count the total number of axles. This is divided by a factor representing the average number of axles per vehicle to convert the measurement to the number of vehicles. Classifiers are generally preferable to counters as they provide more information for relatively little extra cost.

Vehicle classification technologies can be grouped between portable and permanent devices. Those using axle based classifications will usually give the most reliable classifications.

Portable devices, such as inductive loops, magnetometers and side-fired radar are length based data collection technologies. Piezo sensors and road tubes are axle based portable devices.

In addition to technologies used with portable devices, permanent devices also use fiber-optic cables for axle data, overhead radar, ultrasonic, acoustic and video as length based data collection technologies.

4.6 Traffic Sensor Technologies

Sensor technologies are the core of traffic data collection. There are two main categories of sensors used in traffic data collection equipment: intrusive and non-intrusive. The former consist of placing the sensors on top of or in the lane to be monitored, while the latter do not interfere with traffic flow either during installation or operation. Intrusive technologies represent the most common devices used today, including inductive loops, piezo-electric sensors, and pneumatic rubber road tubes. Non-intrusive devices include passive acoustic sensors and video image detection devices. Besides these two major categories, probe vehicles are beginning to be used to obtain traffic information.

Sensors can also be classified as permanent or portable. Table 6 provides an overview of the data collected by the various technologies available.

Table 6 Traffic Sensor Technologies

EQUIPMENT TYPE	TECHNOLOGY
Intrusive Devices	Inductive Loop
	Passive magnetic
	Pneumatic Road Tubes
	Piezoelectric Sensor
	WIM - Bending Plate
	WIM - Capacitive Weigh Mat
	WIM - Hydraulic Load Cells
	WIM – Piezoelectric Sensor
Non-Intrusive Devices	Active infrared
	Passive infrared
	Microwave Radar
	Ultrasonic
	Passive Acoustic
	Video Image Detection

4.7 Truck Weighing Technologies

Vehicle weighing systems are used to obtain the distribution of axle loads for each truck type. Trucks are weighed either at static weight stations, or using Weigh-in-Motion (WIM).

- **Static Scales:** Static systems use either portable scales or permanent platform scales. Portable scales are wheel pads that weigh one or more wheels at a time. Permanent scales come in a variety of sizes. Some are half, and some are full-vehicle-width, allowing either half the axle or a whole axle to be weighed at once. In length, they range from 0.5 m up to 15 m in length. Some use strain-gauged load cells as the sensors.
- **Weight-in-Motion:** Its main purpose is to provide continuous traffic data without interrupting the traffic flow. When combined with other sensors WIM can provide valuable data in the form of traffic volumes, axle weights for various vehicle classifications, and vehicle speeds. In addition, they permit measuring a large sample of vehicles during the duration of the survey. WIM stations can be operated for a short period of time (one to two days) or for longer periods (seven days or more) to determine daily variations. The frequency of surveys, the number of stations, the sample of the network, and the sample of the traffic dictate the quality level of the information (Paterson and Scullion, 1990). TRL (2004) is an excellent guide on all aspects of planning and executing axle load surveys.

Vehicle and axle weighing systems can also be characterized as static or dynamic as presented in Table 7.

Table 7 Truck Sensor Weighing Technologies

EQUIPMENT TYPE	TECHNOLOGY
Intrusive Devices	Inductive Loop
	Passive Magnetic
	Piezoelectric Sensor
	Pneumatic Road Tubes
Non-Intrusive Devices	Video Image Detection
	Passive/Active Infrared
	Radar
	Ultrasonic
	Passive Acoustic

4.8 Selecting the Traffic Monitoring Technology

Each of the technologies have advantages and disadvantages for collecting traffic data. Under the right conditions, most of the technologies are reliable. However, if used incorrectly, each can perform very poorly. As a consequence, operating more than one type of traffic monitoring technology is helpful to ensure successful data collection. As a guideline for selecting traffic monitoring and weighing equipment different agencies several authors have developed selection methodologies.

The Office of Highway Policy Information at FHWA published their "Traffic Monitoring Guide" (FHWA, 2001). The guide recommends a program structure for traffic volume counting, vehicle classification and truck weight measurements.

Martin et al. (2003) proposed a framework to help select detector technologies for traffic monitoring. The framework is composed by a series of questions. By answering the questions, a detector technology is evaluated on its data types, installation conditions, costs, data accuracy requirements, reliability, ease of installation and maintenance, power and data communication, and field experience. The technology should be selected based on all the above issues.

Hallenbeck and Weinblatt (2004) propose a methodology based on the following three different types of information to reach the final decision:

- Data collection needs of users;
- Data handling requirements and capabilities of the highway agency; and
- Characteristics of available makes or models of equipment (e.g., cost, reliability, and data provided)

4.9 Cost/Performance Analysis between Equipment

Suitability Indices were estimated using the same methodology applied for pavements. Table 8 presents the suitability ranking obtained for traffic counting and classification technologies.

Table 8 Suitability Ranking for Traffic Counting and Classification Technologies

EQUIPMENT CLASS	SUITABILITY RANKING
Video image	4.1
Radar	3.8
Pneumatic Tube	3.8
Active infrared	3.6
Passive infrared	3.6
Passive acoustic	3.6
Ultrasonic	3.6
Induction Loops	3.3
Magnetic	2.9

5 Implications for Developing Countries

Many developing countries have adopted, or are in the process of adopting, sophisticated data collection equipment. Transportation agencies in developing countries are grappling with the cost/performance dilemma: on one hand, they recognize the need to improve data collection accuracy and increase the extent of surveys on their networks, but on the other hand, funding is often a major limitation which inhibits their activities.

Two groups of developing countries were found in this study:

- those that have succeeded in improving data collection by incorporating high-quality measuring equipment; and
- poorer countries that lack sufficient private and public investment to afford measuring devices.

The poorer countries tend to use manual methods and, in some instances, inexpensive and/or low performing equipment. Since manual labour is cheaper in these countries, maintenance and operational costs of manual equipment and methodologies are affordable.

Taking into account the differences observed between these two groups, the following recommendations are made for location referencing, pavement, bridge and traffic collection technologies in developing countries:

- **Location Referencing:** Experience has shown that a linear location referencing system with appropriate ground markers will give accurate position data in the field. GPS is a useful technology for collecting data, but most data are still collected using a distance measuring instrument. Video logging offers many benefits to the agency when it comes to confirming the location of key assets and should be considered where practical.
- **Pavement Data Collection:** Many countries have not been able to sustain state-of-the art equipment. This is mainly because of high operating costs, use of imported survey vehicles, equipment recalibration performed overseas; and lack of training in new staff operating equipment. For this reason it is important that the overall suitability of the technology be carefully considered. On the basis of the cost/performance analysis, it is recommended that most agencies should be aiming at technologies in the range of 3 - 5 for cost and 3 – 5 for operational performance. In less developed countries, or those in the early stages of pavement management system development, preference should be given for equipment in the cost range of 4 – 5. In terms of what to collect, road roughness is one of the primary attributes used for road management. When supplemented by visual distress data, managers can make sensible investment decisions.
- **Bridge Data Collection:** Conducting regular surveys of bridge condition is the singularly most important data collection exercise that any agency can do. In this sense the main recommendation is to enhance visual surveys by: (i) adopting a comprehensive and sensible bridge data collection guide; (ii) implementing robust quality assurance procedures; (iii) providing extensive, and regular, training for staff; and, (iv) conducting regular surveys.
- **Traffic Data Collection:** The appropriate traffic data technology depends upon the type of survey to be conducted. In general, traffic classifiers are preferable to simple counters since the limited additional data they can supply are usually worth the additional cost. However, it is important to ensure that the vehicle classification system be appropriate for the vehicle fleet in the country. Weigh-in-motion technology, especially using low-cost piezoelectric sensors, allows for the traffic loading to be monitored which is very important for effective road management.

6 Conclusions

From literature review and results obtained from the cost/performance analyses the following general conclusions can be drawn:

- **Data collection is expensive.** It is essential that the road agency only collects the data which are required for its management purposes. This data should be collected at a frequency and a level which is appropriate for the decisions it is to be used for.
- **Dynamic measuring devices** for surface distress evaluation, roughness evaluation and, in some instances, texture measurement are strongly recommended. Portable equipment can be installed in local vehicles and can be used to collect a range of data through a single pass of a multi-functional vehicles. Data should be properly referenced by using a good referencing system, which ideally combines linear and spatial measurements. Where practical, video logging is desirable.
- **Bridge surveys** should be regularly programmed, and use manual techniques supplemented by key equipment.
- **Traffic surveys** should be done with a combination of permanent automatic sites and temporary counts, either manual or automatic. Weigh-in-motion is desirable on key links in the road network. Where practical, traffic classifiers should be used in preference to traffic counters since these will also report speeds and the individual vehicle classes for little additional cost.

In selecting any technology careful consideration needs to be given to (i) the initial cost, (ii) ongoing costs, and (iii) the ability of the agency to sustain the technology. It is often better to adopt less sophisticated technologies if they are more likely to be sustained given the agency's institutional and staffing arrangements.

7 References

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