Quality Assurance Procedures Related to Administration of Unsurfaced Roads

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The principle that the delivery of safe and effective road services is a duty owed to the road users provides the impetus for a quality assurance (QA) program. QA refers to all of the criteria and activities used to verify and audit road performance. Road conditions are measured in terms of pavement distress extent and severity, structural capacity, and riding quality. The most dominant surface distresses are roughness, potholes, dust, and rutting (plastic deformation under the wheel path). Simplified QA criteria are presented related to surface distress severity, traffic loading, maintenance expenditures, vehicle operating cost (VOC), and economic indicators such as net present value and internal rate of return. Construction and maintenance work procedures and their QA and quality control (QC) procedures are introduced. The choice between using rougher surfaces with more severe potholes and dust distresses and higher VOC is compared with the use of smoother roads that require higher maintenance and rehabilitation costs but save the users money. As an example, when the average daily traffic is equivalent to fifteen 12-ton trucks, road owners have a choice between (*a*) a dirt road that requires U.S.$2,800 in annual maintenance expenditures and will develop surface roughness of 14 m/km and medium to high severity of dust and potholes or (*b*) a silty sand surface with roughness of 10 m/km with a lower level of potholes and dust but higher rehabilitation and maintenance costs. Although the economic return of upgrading the dirt road to a silty sand surface is 12 percent, the road's owners may select to postpone the road improvement and spend less on rehabilitation and maintenance and allow a higher VOC. On any given road network the trade-off between spending on routine maintenance and saving in VOC should be carefully evaluated to provide a balance among user cost considerations, agency costs, and acceptable road performance.

Poorly built and maintained roads are expensive and inconvenient to taxpayers. The quality of work performed on roads is directly related to service life, future maintenance costs, level of service, and user costs. The principle that the delivery of safe and effective road services is a duty owed to the taxpayer or user is the basis for a quality assurance (QA) program. To obtain a reasonable degree of QA, proper design standards and specifications acceptable to the users should be established and enforced. Recognition of the inherent variability of construction requires establishment of a comprehensive set of design standards, long- and short-range work plans, material specifications, sampling and testing guides, and maintenance standards.

The term *quality* is that characteristic of a road network that provides a well-defined and acceptable level of performance in terms of service and life. "Quality" does not mean "perfection." If the objective of a roadway surface is to carry the anticipated traffic safely (service) for five years (life), then "quality" refers to those characteristics of the surface that are necessary to achieve that objective.

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Quality control (QC) ensures that proper materials and procedures are used and placed in a definite manner so that the end product will have the desired level of performance in terms of service and life. QC activities are specific steps taken during construction and maintenance to control the quality of materials and work.

QA refers to all of the activities necessary to verify, audit, and evaluate quality. It may also refer to the quality of data collected for use in a road surface management system.

The quality of a road network is influenced by activities other than field operations, as shown in Figure 1. Broad quality objectives are established in the planning stages of a project. Design implements those objectives and sets the specific levels of quality to be achieved. Finally, the preparation of plans and specifications establishes the rules under which the quality will be achieved. QA is concerned with all of these activities and how they affect the final quality of the product.

ENGINEERING CLASSIFICATION OF UNSURFACED ROADS

Experience indicates that unsurfaced roads can be classified into five principal categories (*1–5*). Type 1 is designated for natural earth roads built with limited engineering input using either labor-intensive methods or limited use of a motor-grader during the rainy season. These roads are frequently impassable, depending on whether they are in semiarid or subtropical areas, whether good or poor drainage conditions exist, and whether adequate maintenance is provided. Type 2 roads are composed of compacted silty sand constructed usually to widths of from 4 to 6 m. The thickness of the surface course on these roads varies between 10 and 30 cm and the design California bearing ratio (CBR) varies from 7 to 15, depending on the local environmental and drainage conditions. These roads usually have a surface life of 2 to 5 years if adequately maintained. Type 3 roads are constructed with a gravel or laterite surface from 12 to 35 cm thick and 4 to 6 m wide. These roads have a surface life of approximately of 5 to 7 years before resurfacing (pavement rehabilitation). Type 4 roads have stone surfaces with a range of width from 3 to 6 m and require minimum maintenance. These roads have a surface life of 20 to 30 years before strengthening or rehabilitation is necessary. Type 5 roads are normally about 7.2 m wide with high-quality screened or crushed gravels or stones that have a CBR of more than 40 and a surface life of 7 to 10 years.

The quality performance of unsurfaced roads is determined from the following primary pavement defects:

1. *Loose sand or gravel*: gravel or sand surface compacted loosely; gravel or sand in wind-rows parallel to the direction of traffic;

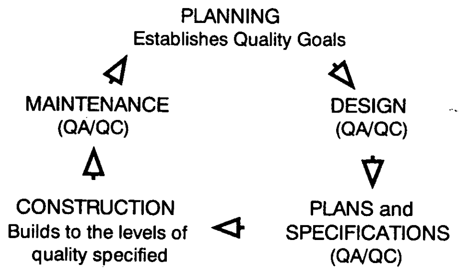

FIGURE 1 Quality assurance activities.

2. *Dust*: traffic action creating a dust cloud;
3. *Potholes*: bowl-shaped depressions in the road surface;
4. *Breakup*: subgrade soils coming up through the gravel surface, most likely to occur in the wheel tracks;
5. *Roughness*: series of closely spaced crests and valleys, usually more pronounced in the wheel tracks;
6. *Rutting*: surface depression in the wheel path;
7. *Flat or reverse crown*: slope of road flat, nonexistent, or reversed, with road edges higher than the center portion of the road surface;
8. *Distortion*: any deviation of road surface from its original shape (other than described for roughness or rutting), such as humps or dips; and
9. *Shoulder distress manifestation*: excessive height, ponding, vegetation growth, and so forth.

The possible causes of each defect (distress) and definitions of severity and extent are presented in the literature (*5–8*). Failure of unsurfaced roads is defined as rutting to a depth of 75 cm to 150 mm, roughness of 17 m/km (international roughness index), or more than 50 percent of the roadway surface affected by severe potholes (*3,9,10,12*).

CONSTRUCTION AND MAINTENANCE WORK PROCEDURES

The construction and maintenance responsibility of governmental agencies can be discussed in terms of who actually performs the work: a contractor or the agency's own forces (in-house projects).

The agency must establish the necessary procedures to ensure that construction and maintenance will be of an acceptable quality, regardless of who performs the work. These procedures will usually be formalized by ordinances, regulations, standard operating procedures, manuals, specifications, and contracts.

Road construction and maintenance contracts are usually let on a low-bid basis and must ensure adequate surface performance during the useful life of the road network. In other words, the contract establishes the work to be performed, the amount of reimbursement, specifications, and QA/QC procedures to be performed during the project's lifetime and the duties and responsibilities of the authorities and the contractor.

SPECIFICATIONS AND QUALITY CONTROL

Specifications are written instructions or precise descriptions of the product desired. Specifications answer the question "How do we order it?" and translate quality levels established by design into specific quality requirements. There are two common uses of the term *specifications*: general specifications and product specifications.

General specifications relate to contract requirements such as bidding conditions, control of work, legal responsibilities, payment, prequalification of contractors, and other considerations. Product specifications establish the requirements that the material, product, or services being purchased must meet. In construction, product specifications can be classified into the two general categories, recipe and performance.

Recipe Specifications

Also referred to as method specifications, recipe specifications describe what is wanted and how it is to be obtained. For a gravel pavement, the engineer would specify the CBR, moisture-density relationship, plasticity range, gradation and other requirements of the aggregate, the general types of equipment to be used, hauling, placing, rolling, and degree of compaction. Recipe specifications are currently the more frequently encountered type of product specification in the road industry and are primarily developed by experience. Disadvantages of recipe specifications include the following:

- Natural product variability is not adequately accounted for,
- Little or no recourse is available if the specifications were followed but the results were unsatisfactory,
- Materials sampling often does not yield a statistically significant or reliable result, and
- Little opportunity for innovation is allowed on the part of either contractor or engineer.

Advantages of recipe specifications are as follows:

- The inspectors and contractors involved with construction are familiar with the specifications,
- They are relatively easy to understand, and
- Clear guidelines are provided for those who are inexperienced in planning, supervising, and inspecting construction activities.

Performance Specifications

Also referred to as end-result specifications, performance specifications describe how the completed product must perform, in other words, what kind of surface defects (loose gravel, dust, potholes, breakup, rutting, and roughness) will be allowed during the project lifetime and an acceptable level of their severity. Performance specifications give the contractor considerable freedom in choosing how to satisfy the requirements, and the primary responsibility for quality control is placed on the contractor. The engineer monitors the contractor's quality control and accepts or rejects the work and the contractor invoice. Performance specifications are statistically oriented and are based on random sampling techniques, with acceptance on a lot-by-lot basis (a lot being a given quantity of material, i.e., 1,000 tons of material or a day's production).

Disadvantages of performance specifications include the following:

- Full implementation requires statistical procedures that may be difficult for small governments to administer;
- The additional responsibilities placed on the contractor may result in higher bid prices, at least initially; and
- The lack of specific "how to" specifications requires experienced and competent inspectors and contractors.

Advantages of performance specifications include the following:

- A realistic picture of the true quality of a product or material is provided to the engineer;
- The relative freedom allowed contractors encourages innovation, which should eventually result in lower prices; and
- There should be a decrease in inspection requirements and expenses.

Enforcement

Specifications establish contractual requirements; road authorities and contractors must assume that the contracted price fairly compensates the successful bidder for all costs associated with complying with the specifications. In terms of QA, performance goals cannot be met if any step in the process falls short. Specifications establish requirements that represent the culmination of planning and design efforts. Inspection, sampling, and testing are QC procedures designed to enforce the specifications and to monitor and achieve acceptable levels of surface distress. In other words, on the basis of the actual road conditions (in terms of the development of potholes, rutting, roughness, and dust) during the lifetime of the project, a decision is made to approve or reject the contractor invoice.

Road Surface Inventory Information

Planning the Inventory

The road surface inventory is the process of collecting and assembling data to properly implement a surface management program (*1,2,8*). Most agencies probably already have some type of inventory. It might be simply a map showing all roads maintained by the agency or complete construction project files containing information such as date of construction, project length, width, and pavement type. An inventory, in a format that can be easily recalled and used, should contain all the basic information that identifies and describes each section and is needed to make sound management decisions. Inventory data, once established, do not change often. They will only change as maintenance, rehabilitation, or reconstruction changes basic section characteristics or as traffic levels change. Condition information, on the other hand, is constantly changing and will require updating at regular intervals.

A good inventory does not require the use of a sophisticated computer system. A carefully planned inventory can be as simple or as sophisticated as the user desires. Data forms and system files can be designed to permit manual operation initially and also to provide a smooth transition to computer applications at some point in the future. Whether to use a manual file or a computer is strictly a local choice.

Defining Section Boundaries

The first step in an inventory is to divide the road system into manageable segments called sections. The minimum number of sections that adequately define the road network will be the most economical and easiest to maintain.

Sections are defined so that the pavement within their boundaries is consistent in terms of physical characteristics and factors that contribute to deterioration. Any of the following would define the boundary between two sections: (*a*) a change in road width or in pavement surface type and (*b*) traffic, drainage, and subgrade characteristics. In addition, geographic or man-made boundaries may offer or force section limits, such as rivers or streams, city or township limits, and county or district lines. In deciding where to locate section boundaries, it should be remembered that once established, boundaries take on a somewhat permanent nature. Every effort should be made to reference sections to permanent, recognizable, and safe landmarks. The concept of dynamic segmentation may also be used if section limits are expected to change because of construction project overlap or subdivision into smaller sections.

Essential Information

The inventory process should be as simple as possible while still collecting the required information. Assembling inventory information should be accomplished in three phases: (*a*) determine the types of data needed, (*b*) determine which data currently exist in office records, and (*c*) determine the remaining data that must be gathered by the survey team. The essential information to be considered includes section description (boundaries and name and number of route), functional and administrative classification, surface structure (thickness and material characteristics), construction and maintenance history, cost data, traffic, geometry and drainage characteristics, and other data (signs, guardrails, location of utility drainage structures, etc.).

Describing and Delineating Sections

Identification of sections used for inventory and data collection to uniquely describe the area of influence within the road network is a critical first step that can have long-term repercussions if not done in a logical manner. Once the sections are described, thought must be given to assigning a numbering or naming system to them. It is important in assigning section identifiers to consider how the inventory data will be stored and how the section identifier will be used to easily recall data. There are several recommended methods for setting up sections and assigning numbers. These include using existing street names or route numbers, assigning coded numbers to sections, using a link-node system, setting up a unique alternative numbering system, or using a computerized geographical information system.

Geographical Information Systems

A geographical information system (GIS) provides a modern method of numbering and locating sections using computer technology. A coordinate system is used to store the network-wide map on the computer. The sections are then defined by the coordinates of the end points. Sections can be selected or identified directly on the computer screen map by pointing to the correct road or circling a group of roads in a certain area. GIS is becoming more and more popular, but it is still considered a highly advanced technology, which may not be appropriate for some local governments.

Automated Data Collection

A data format does not necessarily require written documentation. However, once it has been determined what information will be collected and how that information will be organized, an economical and convenient process may be to program a simple data collection routine on a hand-held computer. Such a device can be readily used in the field to directly enter the inventory data. The data can then be electronically transferred to a microcomputer in the office for processing and storage. This procedure significantly reduces the volume of documentation, labor, and errors associated with the use of paper forms. The entire step of data entry from the forms into the computer and checking the entries is eliminated. Hand-held, notebook-style computers are relatively inexpensive and easy to program. They are ideally suited for field data compilation as part of a road surface management system. Road survey vehicles are also available for use in automating the inventory data collection. On-board computers are used to accept the data directly in the field.

Conducting an Inventory

Whether an automated or manual inventory procedure is used, certain basic principles should be followed. A two-person survey team should be used to conduct the physical inventory. The team members should have a basic knowledge of (*a*) road location and classification, (*b*) the inventory data format, (*c*) the concept of sections and reference points, and (*d*) the existing record system of the agency.

Road Surface Condition Information

Surface Condition Survey

A condition survey is the process of collecting data to determine the surface structural integrity; type, amount, and severity of distress; and overall riding quality of the roadway. Unlike inventory information, surface condition changes constantly and must be reevaluated on a regular basis. Condition surveys provide a rational and consistent method of allocating limited resources. By monitoring the road surface condition using the methods described here, the local agency should be able to (*a*) prioritize maintenance activities, (*b*) prepare long-range programs, (*c*) determine effects of budget reductions and deferred maintenance, (*d*) schedule future surface maintenance activities, and (*e*) track performance of various surface designs and materials.

Types of Surveys

Three types of condition surveys are applicable to unpaved surfaces: distress survey, roughness evaluation, and structural testing. The distress survey involves identifying the various distress types and the extent and severity of each. Roughness evaluation measures the ride quality of the roadway. Roughness is itself only an important distress type as well as an indicator of other distress. It can also be used to prioritize visual distress surveys. According to World Bank research on the Highway Design and Maintenance (HDM) Model, roughness and material loss from the surface are the primary types of distresses that characterize the deterioration of unpaved roads (*10*).

Since the AASHO Road Test (1965), several measurement procedures have been developed to quantify roughness levels on road surfaces. Many of these measures are summary statistics derived from precise measurements of road profile. Others involve measurement of the response of a roughness meter. Once a roughness meter is calibrated to one of the profile-based statistics, the direct output of the roughness meter can be converted to an estimate of the standardized roughness statistic. Currently, the most widely accepted roughness statistic is called the international roughness index (IRI). Other similar statistics include the quarter-car index (QI) and the standard Mays meter number (MO). All of these statistics are similar in derivation in that they are initially obtained by a mathematical manipulation of the surface profile elevations.

Structural testing may be destructive or nondestructive. Destructive testing involves soil borings or test pits with a materials analysis to determine bearing values. Nondestructive testing consists of measuring either deflections or load response and correlating the results to known values. Structural data are not routinely collected for network-level surface monitoring by most agencies. Normally these date are used for structural evaluation and design on an individual-project basis. Exact location and frequency of structural testing within specified road sections should be carefully determined before seeking testing services. The tests should be limited to locations where distress and roughness surveys indicate potential structural problems. The results of these tests reflect the degree of structural adequacy that exists in the pavement structure.

Planning Roughness Surveys

Surface condition data are needed to adequately assess maintenance and rehabilitation needs. It is necessary to accurately and methodically determine the current surface conditions to ensure that decisions for scheduling and implementing maintenance and rehabilitation projects are based on the best and most recent information. This information must be collected using standard procedures so that results can be compared over time.

It is recommended that the entire network be surveyed for roughness initially and the resulting data be correlated with the distress data by surface type. With this information, roughness can be used as an indicator of other problems and can help prioritize sections needing more expensive distress surveys. Roughness alone can be used to determine maintenance strategies. However, greater benefits result when roughness data are evaluated along with other types of surface distress data.

An educated decision should be made as to the method of roughness surveying. For continuity of information and to allow comparison of results to determine deterioration, the same method and equipment should be used from year to year. If a change in method is necessary, a method of correlating results will be needed.

Survey Frequency

The frequency of surveys depends upon several factors. These include surface type, age, current condition, average daily traffic, axle loadings, drainage characteristics, and weather factors. Of these factors, current condition, axle loadings, and drainage are the most important.

Traffic loadings are usually relatively consistent within each road class. Therefore, if traffic and axle loading data are not readily available, it may be reasonable to assign survey frequency by functional classification. For instance, principal roads might be inspected annually, secondary roads every 2 years, and penetration roads every 4 years. Routine maintenance inspections may be required more often because of the relatively rapid deterioration experienced on unpaved surfaces.

Frequency also depends on the surface condition of individual sections. New roads or roads in good condition require less frequent inspections than roads that are experiencing high rates of deterioration.

Environmental Considerations

Rural road administration, including construction, improvement, rehabilitation or maintenance work, and environmental protection or remediation activity, is a complementary aspect of the same agenda (*11,12*; Greenstein and Ehrlich, another paper in this Record). The inclusion of environmental QA/QC in road development is well recognized. QA procedures specify cleaner and safer project sites for the local communities and the construction workers during both the rehabilitation and operation of roads and bridges. These QA procedures should address applicable environmental regulations known to be getting more rigorous.

In order to optimize expenditures and develop practical environmental QA and QC procedures for any given project, it is common to adopt an environmental classification system. According to the Inter-American Development Bank (IDB) (*11*), projects are classified in four environmental impact categories: beneficial, neutral, moderate or potentially negative, and significantly negative. The World Bank (IBRD) classifies projects in three categories:

- Complete environmental analysis is required because the project may have diverse and significant environmental impacts,
- Limited environmental analysis is appropriate because the project may have well-identifiable and manageable environmental impacts, and
- Environmental analysis is not usually necessary because the project is unlikely to have significant environmental impacts.

For each type of rural road or bridge project, QA/QC should identify and address the protection procedures related to

1. Protection of areas with endangered fauna or flora or with particularly vulnerable ecosystems;
2. Elimination of barriers to movement in areas with conservation-worthy or particularly large wildlife populations;
3. Protection of areas with significant historic and cultural remains or landscape elements of importance to the local population;
4. Prevention of regressive or progressive erosion;
5. Minimization or prevention of the use of scarce material resources;
6. Limitation of accessibility to protected areas or to vulnerable natural resources;
7. Legal and physical protection of the local population with regard to cultural conservation, land use, and ownership of land;
8. Minimization of changes in traditional resource exploitation related directly or indirectly to the project;
9. Modifications of natural drainage patterns and groundwater characteristics and quality;
10. Air and water pollution control related to road or bridge construction and maintenance;
11. Minimization and control of noise and dust during the construction, maintenance, and operation (use) stages;
12. Minimization of the effects of increased motorized traffic on nonmotorized transportation economy;
13. Prevention of illegal timber cutting and illegal land clearing;
14. Prevention of illegal invasion by squatters poaching on the homelands of indigenous people;
15. Preservation of wetland;
16. Control of soil and water contamination and management of construction and hazardous materials;
17. Enhancement of employee and workplace safety features;
18. Protection of archeological sites, and
19. Management of ecosystems and conservation of biodiversity.

Environmental QA is obtained through the implementation of a set of guidelines that describe the above environmental impact prevention procedures and mitigating prevention or correction procedures related to road administration, allocation of responsibilities, and cost recovery of environmental damage.

Environmental QC procedures are the site-specific or detailed environmental requirements that, together with the general guidelines, are an integral part of the project specifications. These specifications must precisely define the environmental parameters and the ways to measure changes during the implementation and operation of the project, for example, the allowable levels of noise and dust during the construction period and methods of measurement, methods and parameters to monitor water quality before and after construction, means to design erosion control measures taking into consideration soil and climatic characteristics; optimum gradation and plasticity to reduce dust during traveling after construction of unpaved roads, and optimum size of embankment and drainage facilities to minimize alteration to the natural drainage pattern and obstacles to wildlife. The environmental QA guidelines and the QC procedures should be constantly updated to meet international and local standards and legislative requirements.

Maintenance Management

The main objective of road maintenance planning is to determine the relationship between the projected surface conditions and the most economical and affordable level of rehabilitation and maintenance expenditures that the road users are able and willing to incur. To achieve this goal, it is necessary first to determine the relationship between the projected traffic and surface performance. In predicting surface performance, each failure criterion should be developed to take care of each specific distress, namely, surface deformation (roughness, rutting, flat or reverse crown, distortion);

surface defects (loose sand or gravel, dust, potholes, breakup); and shoulder distress. Once the allowable surface distress during the road's operation are determined, an economic analysis is carried out to select the most practical construction and maintenance activities together with the appropriate QA procedures.

As an example, a projected traffic volume range from 27,000 to 216,000 medium-sized 12-ton trucks may be selected to analyze the performance of an unsurfaced road network. For a life expectancy of 15 years, the foregoing traffic volumes vary from 5 to 40 trucks (12-ton) per day, respectively, or between 25 and 200 average vehicles per day (*1–3,7*). The selected quality criteria of the road network are as follows:

1. Maximum allowable roughness should be 10 to 17 for adequately maintained to rough surfaces, respectively. Usually, the higher the traffic volume is and the better the surface materials are, the lower is the maximum allowable roughness;
2. The maximum allowable amount of potholes should not exceed 50 percent of the roadway surface and the dimensions of individual potholes should not exceed 300 mm in width and 100 mm in depth (*3,5,10*). (Note: The roughness and pothole *failure* criteria are compatible and are usually associated with subgrade or pavement rutting of 75 to 100 mm under the wheel path.)
3. Less than 50 percent of the roadway should be affected by dust, and the severity of the dust cloud should be moderate or slight so that vehicles are still visible to other vehicles in front or behind or to on-coming traffic.

The engineering classifications for the road network surface materials are (*a*) silty clay (A-6) with a design CBR of 5 to 6, (*b*) silty sand (A-2-4) with a design CBR of 12 to 14, and (*c*) local gravel materials (A-1) with a design CBR of 18 to 20. The life expectancy in terms of number of axle passes on these types of surface materials is determined according to the following equation (*8,13*):

$$C = 0.1138N^{0.172}P^{0.580}Q^{0.490}$$

where

C = soaked CBR of surfacing material, in percent (C varies between 4 and 20);
N = design number of cumulative equivalent single wheel loads of P;
P = 40 kN and tire pressure Q;
Q = 550 kPa (equivalent approximately to that of a medium-sized 12-ton truck).

According to the equation, the life expectancy in terms of cumulative 12-ton trucks is 50, 10,000, and 140,000 repetitions for a surface CBR of 5, 12.5, and 20 of silty clay, silty sand, and gravel, respectively. For these three typical materials, Table 1 presents the relationship between the projected average daily traffic (ADT) of representative trucks (12-ton); type of surface; net present value (NPV) of construction, maintenance, and VOC calculated for a project lifetime of 15 years and discount rate of 10

TABLE 1 Cycle Cost Analysis Versus Surface Roughness

	DIRT ROAD			SILTY SAND ROADS					GRAVEL ROADS				
	NPV*$1000			NPV*$1000					NPV*$1000				
ADT 12 tons	Roughness M/KM	Rehab./ Maint.	VOC	Roughness M/KM	Const./Rehab.	Maint.	VOC	IRR %	Rough- ness	Const./ Rehab.	Maint.	VOC	IRR %
5	10	12.2	13.4	10	11.3	4.2	13.4	<5					
10	10	21.3	26.8	10	14.6	7.6	26.8	<5	10	22.7	11.4	26.8	<5
15	14	21.3	49.7	10	21.5	9.1	40.2	12	10	28.0	13.7	40.2	<5
20	17	21.3	77.0	10	30.3	12.2	53.7	68	10	28.0	15.2	53.7	7
25				12	39.9	11.4	74.6		10	28.0	17.5	67.0	24
30				14	39.9	13.7	99.4		10	28.0	19.0	80.5	37
40				17	49.4	21.3	153.3		10	28.0	20.5	107.3	102

ADT = Average Daily Trucks of 12 Tons.

NPV = Net Present Value (15 years of life expectancy, 10 percent discount rate).

IRR = Internal Rate of Return.

percent; road roughness; and economic analysis in terms of internal rate of return (IRR). The procedures to determine construction, maintenance, and VOC costs are presented elsewhere (*7,9,13*).

Table 1 summarizes the planning options for the road network. For example, for a low traffic volume of 5 to 10 trucks, which is equivalent to 10 to 60 vehicles per day, it appears that the use of dirt roads is feasible. With an annual maintenance cost of $1,600 to $2,800/km, it is possible to comply with the specified QA criteria, namely, roughness of 10 and less than 50 percent of roadway surface affected by small to medium-sized potholes. When the traffic volume increases to 15 and 20 trucks per day, maintenance is not sufficient to keep the surface in the desirable condition. Under elevated annual maintenance costs of $2,800 daily, a traffic increase to 15 and 20 trucks will cause an increase of roughness from 10 m/km to 14 and 17 m/km, respectively. These elevated roughness levels are associated with moderate potholes (20 to 50 percent of the surface affected) and extensive potholes (over 50 percent of the roadway surface affected). The dimensions of severe potholes usually exceed a width of 300 mm and a depth of 100 mm. The VOC increases 237 and 43 percent with the increase of surface roughness index from 10 to 14 and 17 m/km, respectively. In these circumstances, the economic return of upgrading the dirt road to a better pavement of silty sand is 12 and 68 percent for an ADT of 15 and 20 trucks per day, respectively. In these cases, the road users or owners may select between lower construction and maintenance costs and higher VOC.

As an example, for an ADT of 15 trucks, the required annual maintenance cost of a dirt road to maintain the surface roughness at a level of 14 m/km and moderate to low potholes and dust is $2,800. On the other hand, to maintain a roughness level of not more than 10 m/km on a silty sand, it is necessary to invest $5,250 for pavement resurfacing each third year in addition to an annual expenditure of $1,200 for routine maintenance. The annual VOC is $6,534 for the dirt road (roughness = 14) and $5,292 for the silty sand surface (roughness = 10) (Table 1). Although the economic return of upgrading a dirt road to a silty sand road is 12 percent when the ADT equals 15 trucks, the road users may select to invest less in rehabilitation and maintenance and more in VOC. A similar conclusion is applicable to the improvement of a silty sand road to a gravel road when the ADT equals 25 trucks. In this case (see Table 1), although the economic return to improve the silty sand road to a gravel surface is 24, the users may want to avoid the initial improvement cost of $25,000/km and the average annual maintenance cost of $2,300 and pay a higher annual maintenance and resurfacing cost ($6,750/km) and higher VOC for the rougher surface (12 m/km versus 10 m/km). When the daily traffic volume increases to 40 trucks or more, the silty sand surface cannot meet the quality criteria of roughness not to exceed 17 m/km and pothole severity not to exceed 50 percent of the roadway surface with individual potholes less than 300 mm in diameter and less than 100 mm deep. In this case, the economic return of upgrading the silty sand surface to a gravel surface is 102 percent (see Table 1).

Once the different types of road surface are implemented, the trade-off decision of spending on maintenance versus saving on VOC, it should be left to the road users to analyze the cycle cost options of road network maintenance and the consequent ramifications for the quality of traveling. As an example, to ensure a representative roughness of 10 m/km and medium to low severity of potholes and dust on a silty sand surface serving an ADT of 15 trucks (12 tons), it would be necessary to invest $1,200/(year·km) in routine maintenance and $5,250/km each second year on pavement resurfacing and rehabilitation. In this case, the estimated annual VOC is $5,292 and the total net present value of rehabilitation, maintenance, and VOC for a 15-year life expectancy is $21,500/km, $9,129/km, and $40,251/km, respectively (see Table 1). Reduction of the biannual resurfacing cost from $5,250 to $3,600 and $3,100 results in an increase of surface roughness from 10 to 13 and 14, respectively. Consequently, the annual VOC increases from $5,292 to $6,210 and $6,534, respectively. This reduction of the resurfacing costs during a lifetime period of 15 years results in a negative economic return of 23 and 36 percent, respectively.

Road users should select between optimizing the expenditures of maintenance and VOC versus reduction in maintenance costs, which accelerates surface deterioration and increases VOC. Each rural road network should be administered according to the needs and financial capabilities of its users.

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