TRANSPORTATION TECHNOLOGY SUPPORT
FOR DEVELOPING COUNTRIES

COMPENDIUM 11

Decision Methodology for Maintenance and Upgrading: Costs, Traffic, and Benefits

Metodología de decisiones en la conservación y mejora: costos, tránsito y beneficios

Méthodologie de prise de décision en matière d'entretien et d'amelioration: coûts, trafic et avantages

prepared under contract AID/OTR-C-1591, project 931-1116,
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Notice

The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the committee responsible for the report were chosen for their special competence and with regard for appropriate balance.

This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

Cover photo: Localized maintenance problem after heavy rain near Rio Beni, Bolivia.

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The development of agriculture, the distribution of food, the provision of health services, and the access to information through educational services and other forms of communication in rural regions of developing countries all heavily depend on transport facilities. Although rail and water facilities may play important roles in certain areas, a dominant and universal need is for road systems that provide an assured and yet relatively inexpensive means for the movement of people and goods. The bulk of this need is for low-volume roads that generally carry only 5 to 10 vehicles a day and that seldom carry as many as 400 vehicles a day.

The planning, design, construction, and maintenance of low-volume roads for rural regions of developing countries can be greatly enhanced with respect to economics, quality, and performance by the use of low-volume road technology that is available in many parts of the world. Much of this technology has been produced during the developmental phases of what are now the more developed countries, and some is continually produced in both the less and the more developed countries. Some of the technology has been documented in papers, articles, and reports that have been written by experts in the field. But much of the technology is

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Descripción del proyecto

En las regiones rurales de países en desarrollo, el desarrollo de la agricultura, la distribución de víveres, la provisión de servicios de sanidad, y el acceso a información por medio de servicios educacionales y otras formas de comunicación, dependen en gran parte de los medios de transporte. Aunque en ciertas áreas los medios de ferrocarril y agua desempeñan un papel importante, existe una necesidad universal y dominante de crear sistemas viales que provean un medio asegurado pero relativamente poco costoso para el movimiento de gente y mercancías. La mayor parte de esta necesidad se solucionaría con la construcción de caminos de bajo volúmen que generalmente moverían únicamente de 5 a 10 vehículos por día y que pocas veces moverían tanto como 400 vehículos por día.

El planeamiento, diseño, construcción y mantenimiento de caminos de bajo volúmen para regiones rurales de países en desarrollo pueden ser mejorados, con respecto al costo, calidad, y rendimiento, por el uso de la tecnología de caminos de bajo volúmen que se encuentra disponible en muchas partes del mundo. Mucha de esta tecnología ha sido producida durante las épocas de desarrollo de lo que ahora son los países más desarrollados, y alguna se produce contínuamente en estos países así como en los países menos desarrollados. Parte de la tecnología se ha documentado en disertaciones, artículos, e informes que han sido escritos por expertos en el campo. Pero mucha de la tecnología no está documentada y existe principalmente en la memoria de aquellos que han desa-

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Description du projet

Dans les régions rurales des pays en voie de développement, l'exploitation agricole, la distribution des produits alimentaires, l'accès aux services médicaux, l'accès aux matériaux et aux marchandises, à l'information et aux autres services, dépendent en grande partie des moyens de transport. Bien que les transports par voie ferrée et par voie navigable jouent un rôle important dans certaines régions, un besoin dominant et universel éxiste d'un réseau routier qui puisse assurer avec certitude et d'une façon relativement bon marché, le déplacement des habitants, et le transport des marchandises. La plus grande partie de ce besoin peut être satisfaite par la construction de routes à faible capacité, capables d'accommoder un trafic de 5 a 10 véhicules par jour, ou plus rarement, jusqu'à 400 véhicules par jour.

L'utilisation des connaissances actuelles en technologie, qui sont accéssibles dans beauundocumented and exists mainly in the minds of those who have developed and applied the technology through necessity. In either case, existing knowledge about low-volume road technology is widely dispersed geographically, is quite varied in the language and the form of its existence, and is not readily available for application to the needs of developing countries.

In October 1977 the Transportation Research Board (TRB) began this 3-year special project under the sponsorship of the U.S. Agency for International Development (AID) to enhance rural transportation in developing countries by providing improved access to existing information on the planning, design, construction, and maintenance of low-volume roads. With advice and guidance from a project steering committee, TRB defines, produces, and transmits information products through a network of correspondents in developing countries. Broad goals for the ultimate impact of the project work are to promote effective use of existing information in the economic development of transportation infrastructure and thereby to enhance other aspects of rural development throughout the world.

In addition to the packaging and distribution of technical information, personal interactions with users are provided through field visits, con-

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rrollado y aplicado la tecnología por necesidad. En cualquier caso, los conocimientos en existencia sobre la tecnología de caminos de bajo volúmen están grandemente esparcidos geográficamente, varian bastante con respecto al idioma y su forma, y no se encuentran fácilmente disponibles para su aplicación a las necesidades de los países en desarrollo.

En octubre de 1977 el Transportation Research Board (TRB) comenzó este proyecto especial de tres años de duración bajo el patrocinio de la U.S. Agency for International Development (AID) para mejorar el transporte rural en los países en desarrollo acrecentando la disponibilidad de la información en existencia sobre el planeamiento, diseño, construcción, y mantenimiento de caminos de bajo volúmen. Con el consejo y dirección de un comité de iniciativas para el proyecto, el TRB define, produce, y transmite productos informativos a través de una red de corresponsales en países en desarrollo. Las metas generales para el impacto final del trabajo del proyecto son la promoción del uso efectivo de la información en existencia en el desarrollo económico de la infraestructura de transporte y de esta forma mejorar otros aspectos del desarrollo rural a través del mundo.

Además de la recolección y distribución de la

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coup de pays, peut faciliter l'étude des projets de construction, tracé et entretien, de routes à faible capacité dans les régions rurales des pays en voie de développement, surtout en ce qui concerne l'économie, la qualité, et la performance de ces routes. La majeure partie de cette technologie a été produite durant la phase de développement des pays que l'on appelle maintenant développés, et elle continue à être produite à la fois dans ces pays et dans les pays en voie de développement. Certains aspects de cette technologie ont été documentés dans des articles ou rapports écrits par des experts. Mais une grande partie des connaissances n'existe que dans l'esprit de ceux qui ont eu besoin de développer et appliquer cette technologie. De plus, dans ces deux cas, les écrits et connaissances sur la technologie des routes à faible capacité, sont dispersés géographiquement, sont écrits dans des langues différentes, et ne sont pas assez aisément accessibles pour être appliqués aux besoins des pays en voie de développement.

En octobre 1977, le Transportation Research Board (TRB) initia ce projet, d'une duré de 3 ans, sous le patronage de l'U.S. Agency for International Development (AID), pour améliorer le transport rural dans les pays en voie de développement, en rendant plus accessible la documentation existante sur la conception, le tracé, la construction, et l'entretien des routes à faible capacité. Avec le conseil, et sous la conduite d'un comité de direction, TRB définit, produit, et transmet cette documentation à l'aide d'un réseau de correspondants dans les pays en voie de développement. Nous espérons que le résultat final de ce projet sera de favoriser l'utilisation de cette documentation, pour aider au développement économique de l'infrastructure des transports, et de cette façon mettre en valeur d'autres aspects d'exploitation rurale à travers le monde.

ferences in the United States and abroad, and other forms of communication.

Steering Committee

The Steering Committee is composed of experts who have knowledge of the physical and social characteristics of developing countries, knowledge of the needs of developing countries for transportation, knowledge of existing transportation technology, and experience in its use.

Major functions of the Steering Committee are to assist in the definition of users and their needs, the definition of information products that match user needs, and the identification of informational and human resources for development of the information products. Through its membership the committee provides liaison with project-related activities and provides guidance for interactions with users. In general the Steering Committee gives overview advice and direction for all aspects of the project work.

The project staff has responsibility for the preparation and transmittal of information products, the development of a correspondence network throughout the user community, and interactions with users.

Information Products

Three types of information products are prepared: compendiums of documented information on relatively narrow topics, syntheses of knowledge and practice on somewhat broader

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información técnica, se provee acciones recíprocas personales con los usuarios por medio de visitas de campo, conferencias en los Estados Unidos de Norte América y en el extranjero, y otras formas de comunicación.

Comité de iniciativas

El comité de iniciativas se compone de expertos que tienen conocimiento de las características físicas y sociales de los países en desarrollo, conocimiento de las necesidades de transporte de los países en desarrollo, conocimiento de la tecnología de transporte en existencia, y experiencia en su uso.

Las funciones importantes del comité de iniciativas son las de ayudar en la definición de usuarios y sus necesidades, de productos informativos que se asemejan a las necesidades del usuario, y la identificación de recursos de conocimientos y humanos para el desarrollo de los productos informativos. A través de sus miembros el comité provee vínculos con actividades relacionadas con el proyecto y también una guía para la interacción con los usuarios. En general el comité de iniciativas proporciona consejos y dirección general para todos los aspectos del trabajo de proyecto.

El personal de proyecto es responsable de la preparación y transmisión de los productos informativos, el desarrollo de una red de corresponsales a través de la comunidad de usuarios, y la interacción con los usuarios.

Productos informativos

Se preparan tres tipos de productos informativos: los compendios de la información documentada sobre temas relativamente limitados, la síntesis del conocimiento y práctica sobre temas

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En plus de la dissémination de cette documentation technique, des visites, des conférences aux Etats Unis et à l'étranger, et d'autres formes de communication permettront une interaction constante avec les usagers.

Comité de direction

Le comité de direction est composé d'experts qui ont à la fois des connaissances sur les caractéristiques physiques et sociales des pays en voie de développement, sur leurs besoins au point de vue transports, sur la technologie actuelle des transports, et ont aussi de l'expérience quant à l'utilisation pratique de cette technologie.

Les fonctions majeures de ce comité sont d'abord d'aider à définir les usagers et leurs besoins, puis de définir leurs besoins en matière de documentation, et d'identifier les ressources documentaires et humaines nécessaires pour le développement de cette documentation. Par l'intermédiaire des ses membres, le comité pourvoit à la liaison entre les différentes fonctions relatives au projet, et dirige l'interaction avec les usagers. En général, le comité de direction conseille et dirige toutes les phases du projet.

Notre personnel est responsable de la préparation et de la dissémination des documents, du développement d'un réseau de correspondants pris dans la communauté d'usagers, et de l'interaction avec les usagers.

La documentation

Trois genres de documents sont preparés: des recueils dont le sujet est relativement limité, des subjects, and proceedings of low-volume road conferences that are totally or partially supported by the project. Compendiums are prepared by project staff at the rate of about 6 per year; consultants are employed to prepare syntheses at the rate of 2 per year. At least one conference proceedings will be published during the 3-year period. In summary, this project aims to produce and distribute between 20 and 30 publications that cover much of what is known about low-volume road technology.

Interactions With Users

A number of mechanisms are used to provide interactions between the project and the user community. Project news is published in each issue of *Transportation Research News.* Feedback forms are transmitted with the information products so that recipients have an opportunity to say how the products are beneficial and how they may be improved. Through semiannual visits to developing countries, the project staff acquires first-hand suggestions for the project work and can assist directly in specific technical problems. Additional opportunities for interaction with users arise through international and in-country conferences in which there is project participation. Finally, annual colloquiums are held for students from developing countries who are enrolled at U.S. universities.

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un poco más amplios, y los expedientes de conferencias de caminos de bajo volúmen que están totalmente o parcialmente amparados por el proyecto. El personal de proyecto prepara los compendios a razón de unos 6 por año; se utilizan consultores para preparar las síntesis a razón de 2 por año. Se publicará por lo menos un expediente de conferencia durante el período de tres años. En breve, este proyecto pretende producir y distribuir entre 20 y 30 publicaciones que cubren mucho de lo que se conoce de la tecnología de caminos de bajo volúmen.

Interacción con los usuarios

Se utilizan varios mecanismos para proveer las interacciones entre el proyecto y la comunidad de usuarios. Se publican las noticias del proyecto en cada edición de la *Transportation Research News.* Se transmiten, con los productos informativos, formularios de retroacción para que los recipientes tengan oportunidad de decir cómo benefician los productos y cómo pueden ser mejorados. A través de visitas semianuales a los países en desarrollo, el personal del proyecto adquiere directamente de fuentes originales sugerencias para el trabajo del proyecto y puede asistir directamente en problemas técnicos específicos. Surgen oportunidades adicionales para la interacción con los usuarios a través de conferencias internacionales y nacionales en donde participa el proyecto. Finalmente, se organizan diálogos con estudiantes de países en desarrollo que están inscriptos en universidades norteamericanas.

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synthèses de connaissances et de pratique sur des sujets beaucoup plus généraux, et finalement des comptes-rendus de conférences sur les routes à faible capacité, qui seront organisées complètement ou en partie par notre projet. Environ 6 recueils par an sont preparés par notre personnel. Deux synthèses par an sont écrites par des experts pris à l'extérieur. Les comptes-rendus d'au moins une conférence seront écrits dans une période de 3 ans. En résumé, l'objet de ce projet est de produire et disséminer entre 20 et 30 documents qui couvriront l'essentiel des connaissances sur la technologie des routes à faible capacité.

Interaction avec les usagers

Un certain nombre de mécanismes sont utilisés pour assurer l'interaction entre le personnel du projet et la communauté d'usagers. Un bulletin d'information est publié dans chaque numéro de *Transportation Research News.* Des formulaires sont joints aux documents, afin que les usagers aient l'opportunité de juger de la valeur de ces documents et de donner leur avis sur les moyens de les améliorer. Au cours de visites semi-annuelles dans les pays en voie de développement notre personnel obtient de première main des suggestions sur le bon fonctionnement du projet et peut aider à résoudre sur place certains problèmes techniques spécifiques. En outre, des conférences tenues soit aux Etats Unis, soit à l'étranger, sont l'occasion d'un échange d'idées entre notre personnel et les usagers. Finalement, des colloques annuels sont organisés pour les étudiants des pays en voie de développement qui étudient dans les universités américaines.

Foreword and Acknowledgments

This book is the thirteenth product of the Transportation Research Board's project on Transportation Technology Support for Developing Countries under the sponsorship of the U.S. Agency for International Development. The objective of this book is that it provide useful and practical information for those in developing countries who have direct responsibility for decisions on road maintenance and upgrading. Feedback from correspondents in developing countries will be solicited and used to assess the degree to which this objective has been attained and to influence the nature of later products.

Acknowledgment is made to the following publishers for their kind permission to reprint the selected text portions of this compendium: International Bank for Reconstruction and Development, Washington, D.C.; Permanent International Association of Road Congresses, Paris; and Transport and Road Research Laboratory, U.K.

Prefacio y agradecimientos

Este libro es el décimotercio producto del proyecto del Transportation Research Board sobre Apoyo de Tecnología de Transporte para Países en Desarrollo bajo el patrocinio de la U.S. Agency for International Development. El objetivo de este libro es el de proveer información útil y práctica para aquellos en países en desarrollo quienes tienen responsabilidad directa para las decisiones en la conservación y mejora de caminos. Se pedirá a los corresponsales en los países en desarrollo información sobre los resultados, para utilizarse en el asesoramiento del grado al cual se ha obtenido ese objectivo y para influenciar la naturaleza de productos subsequentes.

Se reconoce a los siguientes editores por el permiso dado para reimprimir las porciones de texto seleccionadas para este compendio. International Bank for Reconstruction and Development, Washington, D.C.; Permanent International Association of Road Congresses, Paris; y Transport and Road Research Laboratory, U.K.

Avant-propos et remerciements

Ce livre représente le treizième volume du projet du Transportation Research Board sur la Technologie des transports à l'usage des pays en voie de développement. Ce projet est placé sous le patronage de l'U.S. Agency for International Development. L'objet de ce recueil est de réunir une documentation pratique et utile qui puisse aider les personnes responsables de l'entretien et l'amélioration des routes. La réaction des correspondants des pays en voie de développement sera sollicitée et utilisée pour évaluer à quel point le but proposé de ce projet a été atteint, et pour influencer la nature des ouvrages à venir.

Nous remercions les éditeurs qui ont gracieusement donné leur permission de reproduire les textes sélectionnés pour ce recueil: International Bank for Reconstruction and Development, Washington, D.C.; Permanent International Association of Road Congresses, Paris; et Transport and Road Research Laboratory, U.K.

Appreciation is also expressed to libraries and information services that provided references and documents from which final selections were made for the selected texts and bibliography of this compendium. Special acknowledgment is made to the U.S. Department of Transportation Library Services Division and to the Library and Information Service of the U.K. Transport and Road Research Laboratory (TRRL).

Finally, the Transportation Research Board acknowledges the valuable advice and direction that have been provided by the project Steering Committee and is especially grateful to C.G. Harral, International Bank for Reconstruction and Development, W.R. Hudson, University of Texas at Austin, and E.C. Sullivan, Institute of Transportation Studies, Berkeley, who provided special assistance on this particular compendium.

También se reconoce a las bibliotecas y servicios de información que proveen las referencias y documentos de los cuales se hacen las selecciones finales para los textos seleccionados y la bibliografía en este compendio. Se hace un especial reconocimiento a la Library Services Division del U.S. Department of Transportation y el Library and Information Service del U.K. Transport and Road Research Laboratory (TRRL).

Finalmente, el Transportation Research Board agradece el consejo y dirección valiosos provistos por el comité de iniciativas, con especial reconocimiento a los señores C.G. Harral, International Bank for Reconstruction and Development, W.R. Hudson, University of Texas at Austin, y E.C. Sullivan, Institute of Transportation Studies, Berkeley, que prestaron ayuda especial para este compendio en particular.

Nos remerciements aussi aux bibliothèques et bureaux de documentation qui nous ont fourni les documents et les références utilisés dans les textes choisis et bibliographie de ce recueil. Nous remercions spécialement la U.S. Department of Transportation Library Services Division et les Library and Information Service of the U.K. Transport and Road Research Laboratory (TRRL).

Finalement, le Transportation Research Board reconnait la grande valeur de la direction et de l'assistance des membres du comité de direction et les remercie de leur concours et de la façon dont ils dirigent le projet, spécialement Messieurs C.G. Harral, International Bank for Reconstruction and Development, W.R. Hudson, University of Texas at Austin, et E.C. Sullivan, Institute of Transportation Studies, Berkeley, qui ont bien voulu prêter leur assistance à la préparation de ce récueil.

Overview

Background

Highway maintenance is generally defined as the preservation of roads. It represents an ongoing expense that increases in magnitude as a road network increases in size. The yearly cost of maintenance represents a small fraction of the construction replacement cost of the road network (approximately 1-3 percent). However, the total yearly cost of maintenance represents a sizable outlay of agency funds, often 50 percent or more of the total highway budget. These funds must be spent wisely and carefully to protect the original investment. Maintenance expenditures do not necessarily produce dramatic or even obvious results visible to the average citizen who usually has no criteria by which to evaluate various levels of maintenance. This often prompts some developing countries to fund new road construction at the expense of proper maintenance.

Historically, both developing and developed countries have made a continuing major effort to upgrade the complex decision methodology used in the planning and constructing of new roads. Maintenance programs have sometimes been considered a necessary evil and not worthy of serious study. Thus, two approaches to maintenance decision making evolved. Both substituted extremes for rational evaluations. First, proper maintenance consisted of keeping the roadway in "like-new" condition. Experience soon showed that no economy is strong enough to keep all roads this way. Second, road preserva-

Vista General

Antecedentes y alcance

La conservación vial generalmente se define como la preservación de caminos, y representa un contínuo gasto que aumenta a medida que aumenta la red vial. El costo anual de conservación es aproximadamente 1-3% de los costos de construcción de reemplazo de la red vial; pero representa un desembolso considerable de los fondos de la agencia, muchas veces un 50% o más del presupuesto vial total. Estos fondos deberán utilizarse cuidadosamente y con buen criterio para proteger la inversión original. Los gastos de conservación no se presentan en forma dramática ni obvia a los ojos de la persona media que no dispone del criterio necesario para evaluar los distintos niveles de conservación; y por esta razón algunos países en desarrollo apoyan la construcción de nuevos caminos, a costa de una correcta conservación.

Históricamente ha sucedido que los países en desarrollo y ya desarrollados se dedicaron a la

Exposé

Historique et description

On entend généralement par entretien routier le maintien des routes. L'entretien routier représente une dépense constante dont le montant augmente en même temps que le réseau routier s'aggrandit. Les dépenses annuelles d'entretien représentent une petite fraction du coût de la reconstruction du réseau routier (approximativement 1 à 3 pour cent). Toutefois, le coût annuel total de l'entretien représente une mise de fonds importante de la part de l'organisme routier, souvent 50 pour cent ou plus du budget routier total. Ces fonds doivent donc être dépensés de façon judicieuse et réflechie afin de sauvegarder l'investissement premier. Les dépenses d'entretien ne donnent pas nécessairement un résultat dramatique ou même simplement visible pour l'usager moyen, qui normalement n'a aucuns critères par lesquels il puisse juger des différents niveaux d'entretien. C'est ici la raison qui incite certains pays en voie de développement à investir leur capitaux dans la construction de routes nouvelles aux dépends d'un entretien adéquat.

Historiquement, les pays en voie de déveloption was viewed as relatively insensitive to the maintenance effort expended. This concept can lead to the use of maintenance budgets to redress construction fund deficiencies in times of fiscal restraint. However, roads will eventually deteriorate without some sort of maintenance and will become useless even if they carry no traffic.

Once the necessity for maintenance was established, the problem of allocating funds arose. The first allocation procedures distributed historically derived funds in direct proportion to the length of roadway involved. This criterion did not acknowledge that the environment, material constraints, and traffic may affect the maintenance costs of different roads in different degrees. It also did not evaluate the adequacy of funds previously appropriated for maintenance.

The next step was to substitute a subjective evaluation of empirical results as a decision tool. Historical costs were broken into two factors. The first was a constant that represented the base cost of maintenance necessary to keep the road from environmental deterioration. The second factor was the volume of traffic per day multiplied by a second constant that represented

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mejora de la compleja metodología de decisiones utilizada en el planeamiento y construcción de nuevos caminos. Los programas de conservación se consideraban a veces como una necesidad inevitable pero no dignos de cuidadoso estudio. De esta forma se desarrollaron dos métodos en el proceso de hacer decisiones con respecto a la conservación. Los dos empleaban medidas extremas en vez de evaluaciones razonables. El primero fué mantener el camino "como nuevo", que rápidamente demostró que no hay una economía lo suficientemente fuerte para soportar todos los caminos de esta forma. El segundo propuso el concepto de que la preservación del camino es relativamente insensitiva al esfuerzo de conservación expendido, y por lo tanto se pueden utilizar los fondos de conservación para reparar deficiencias en los fondos de construcción durante épocas de restricciones fiscales. Pero los caminos han de deteriorar sin alguna conservación, aún cuando no son utilizados.

Una vez establecida la necesidad de conservación surgió el problema de la distribución de fondos. Primeramente se distribuyeron los fondos históricamente asignados a la conservación en forma directamente proporcional a la extensión del camino involucrado. Este criterio no tomaba en cuenta que el medio ambiente, restricciones en el material, y el tránsito todos pueden afectar el costo de conservación de distintos caminos en distintos grados; ni tampoco evaluó la suficiencia de los fondos ya consignados a la conservación.

El próximo paso fué el de utilizar una evaluación subjetiva de resultados empíricos para llegar a una decisión. Los costos históricos se dividieron en dos factores; el primero siendo un constante que representaba el costo base de

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pement et les pays industrialisés sont toujours en train de fournir un effort majeur pour améliorer la complexe méthodologie de décision utilisée pour la planification et la construction de routes nouvelles. D'un autre coté, les programmes d'entretien sont quelquefois considérés comme une nuisance, nécessaire certes, mais pas digne d'études sérieuses. Deux approches pour la prise de décision en matière d'entretien se sont donc formées. Ces deux approches ont remplacé l'évaluation rationnelle par l'extrémisme. Tout d'abord, on a pensé qu'un entretien adéquat consistait en la tenue à neuf constante de la route. L'expérience a vite démontré qu'il n'existait aucune économie assez forte pour supporter d'entretenir les routes de cette façon. Ensuite, la théorie a été que la conservation routière était relativement insensible à l'effort d'entretien dépensé. Ce concepte peut conduire à l'utilisation du budget alloué à l'entretien pour rétablir le manque du budget de construction en temps de restriction fiscale. De toutes manières, les routes se détérioreront éventuellement en l'absence de quelque sorte d'entretien, et deviendront inutilisables même en l'absence de circulation.

Une fois que la nécessité d'entretenir les route fût établie, il se produisit le problème d'allocation des fonds. Les premières méthodes d'allocation distribuaient des fonds dérivés historiquement en proportion directe à la longueur de la route en question. Ce critère ne reconnaissait pas le fait que l'environnement, les exigences de matériaux et de circulation, peuvent affecter les coûts d'entretien de routes différentes à des degrées différents. Il ne prenait pas non plus en compte si les fonds alloués anteriéurement étaient suffisants ou non.

On prit ensuite comme instrument de décision, et comme substitution à ces méthodes, l'évaluation subjective de résultats empiriques. Les coûts historiques furent divisés en deux the additional traffic-induced costs on a roadway. This method also neglected the evaluation of the adequacy of funds previously appropriated for maintenance.

Finally, the concept of level of service and the impact on road-user costs were introduced into the determination of maintenance funding in an attempt to evaluate the adequacy of that funding. The economic evaluation of how much maintenance is enough is becoming the foundation for rational decision making in both maintenance and upgrading activities.

Compendium 11 is concerned with the techniques used to determine the amount of maintenance effort that is most beneficial to a nation's entire economy. The use of an economic evaluation of maintenance activities not only determines the most cost-effective level of maintenance for each roadway but also indicates the proper timing of each upgrading activity (graveling or surface treatment). The administration of maintenance programs and the improvement of low-volume road maintenance operations are discussed in another project publication—*Synthesis 1, Maintenance of Unpaved Roads* (see back cover).

Rationale for This Compendium

The economic evaluation of maintenance and

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conservación necesario para proteger el camino del deterioro por acción del medio ambiente; y el segundo, el volumen del tráfico diario multiplicado por un segundo constante que representaba los costos viales adicionales causados por el tránsito. Este método tampoco evaluó la suficiencia de los fondos previamente alocados a la conservación.

Finalmente se llegó a incluir el concepto de nivel de servicio y el impacto sobre los costos para el usuario del camino en la determinación de fondos a fin de evaluar la suficiencia de aquellos fondos. Ultimamente se está utilizando la evaluación económica de cuánta conservación es necesaria, como base para una decisión racional en lo que respecta a las actividades de conservación y mejora.

El Compendio 11 se ocupa de las técnicas que se utilizan para determinar cuánto esfuerzo de conservación es más provechoso para la economía total de una nación. El uso de esta evaluación económica no sólo ayuda a determinar el nivel efectivo de conservación en lo que respecta al costo, para cada camino, sino también indica el momento correcto para cada actividad de mejora (colocación de grava o tratamiento de superficie). La administración de los programas de conservación de caminos de bajo volumen y la mejora de las operaciones de dichos programas, se examinan en otra publicación del proyecto—*Síntesis 1, Conservación de caminos sin pavimentar* (véase el interior de la cubierta posterior).

Exposición razonada para este compendio

La evaluación económica de las actividades de

éléments. Le premier était une constante représentant le coût de base de l'entretien nécessaire pour que la route ne succombe aux dégradations dûes à l'environnement. Le deuxième élément ètait le traffic journalier multiplié par une seconde constante représentant le coût additionnel causé par le trafic. Cette méthode négligeait elle aussi l'évaluation de la suffisance des fonds alloués antérieurement pour l'entretien.

Finalement, les conceptes du niveau de service et de l'impact sur les coûts de la circulation, furent introduits dans le calcul budgétaire de l'entretien, de façon à essayer d'évaluer si celui-ci était suffisant. L'évaluation économique du niveau suffisant d'entretien forme la fondation d'une prise de décision rationnelle sur l'entretien et l'amélioration des routes.

Le recueil no. 11 a pour sujet les techniques utilisées pour déterminer le seuil d'entretien qui sera le plus avantageux à l'ensemble de l'économie d'une nation. L'évaluation économique des opérations d'entretien non seulement détermine le niveau d'entretien le plus rentable pour chaque route, mais aussi elle indique le seuil d'amélioration le plus favorable (graviers ou bitumage). L'administration des programmes d'entretien routier et le perfectionnement des opérations d'entretien des routes économiques sont discutés dans une des autres publications de notre projet—*Synthèse No. 1: L'entretien des routes non revêtues* (voir la dernière page du recueil).

Objectif de ce recueil

L'évaluation économique des travaux d'entretien et d'amélioration, est basée sur le principe que le rôle de l'entretien n'est pas purement de conserver la route. C'est plutôt de maintenir la condition de la surface routière de telle façon upgrading activities is based on the premise that the role of maintenance is not merely to preserve the road. Rather, it is to keep the road surface in a condition that will permit vehicles to operate at the cost level at which the total transport cost is lowest. Total transport cost is the sum of the construction, maintenance, and vehicle operating costs.

The economic evaluation of total transport cost is somewhat less complicated than the economic analysis used for highway feasibility studies. This is so because the total transport cost evaluates vehicle operating costs rather than the impact of the road on the social and general economic environment of the immediate area, the region, and the nation. The hard-to-quantify costs and benefits associated with regional development programs, which often serve as the economic justification for the construction of associated low-volume roads, affect the total transport cost only to the extent that they determine the volume and type of traffic on the road or system being evaluated.

Three factors have delayed the widespread adoption of the economic evaluation of maintenance and upgrading activities in developing countries:

1. The attitude of many officials toward the abstract nature of economic evaluations and the fact that recurrent expenditures for maintenance

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conservación y mejora se basa en la premisa de que la conservación no es solamente para preservar el camino, sino que es para mantener la superficie del camino en tal condición que permita la operación de vehículos a un nivel de costo en donde el costo total de transporte es el más bajo. El costo total de transporte es la suma de los costos de construcción, conservación y operación de vehículo.

La evaluación económica del costo total de transporte es un poco menos complicada que el análisis económico que se utiliza en los estudios de posibilidades viales. Es así porque el costo total de transporte evalúa los costos de operación de vehículo y no el impacto del camino sobre el ambiente económico social y general del área afectada, de la región, y de la nación. Muchas veces se utilizan los costos y beneficios difíciles de medir de los programas de desarrollo regionales como justificación económica para la construcción de caminos de bajo volumen asociada a tales programas; pero estos costos y beneficios únicamente afectan al costo total de transporte en que determinan el volumen y tipo de tránsito sobre el camino o sistema que se está evaluando.

Hay tres factores que han demorado el uso en gran escala de la evaluación económica de las actividades de conservación y mejora en los países en desarrollo:

1. La posición que muchos funcionarios toman con respecto a la naturaleza abstracta de las evaluaciones económicas, y el hecho de que los gastos periódicos de conservación generalmente han sido excluídos de apoyo económico por préstamos con bajo interés o subvención directa da agencias internacionales de ayuda. Ha estado faltando, entonces, una persuasión para

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qu'elle permette aux véhicules d'opérer au prix auquel les dépenses totales de transport sont les plus basses. Les dépenses totales de transport sont la somme des coûts de construction, d'entretien, et d'exploitation des véhicules.

L'évaluation économique des dépenses totales de transport est un peu moins compliquée que l'analyse économique utilisée pour les études de factibilité routière. Cela s'explique car le calcul des dépenses totales de transport considére le coût d'exploitation des véhicules plutôt que l'impact de la route sur l'économie sociale et générale du secteur proche, la région et la nation. Les coûts et avantages, difficiles à chiffrer, associés avec les programmes de développement régionaux, qui souvent servent de justification économique de la construction de routes à faible circulation, affectent la dépense totale de transport seulement en ce qu'ils déterminent les volumes et types de trafic sur la route ou le réseau que l'on est en train d'évaluer.

Trois facteurs ont retardé l'adoption généralisée de la méthode d'évaluation économique de l'entretien ou l'amélioration routiers dans les pays en voie de développement.

1. L'attitude de beaucoups d'administrateurs envers la nature abstraite de l'analyse économique et le fait que les dépenses périodiques d'entretien ont généralement été exclues du financement à bas interêt ou subventions directes par les organismes internationaux d'assistance. L'encouragement à investir dans des études économiques, comme critère de prise de décision en matière d'entretien routier, à donc été absent.

2. Le manque de volonté d'accepter le coût d'exploitation des véhicules (CEV) comme étant l'affaire du governement, ce qui empêche l'adoption du concepte de la dépense totale de transport. Bien que le gouvernement se recon-

activities have been generally excluded from funding with low-interest loans or outright grants from international aid agencies. The inducement to invest in economic studies as criteria for maintenance decision making has therefore been lacking.

2. The unwillingness to accept vehicle operating cost (VOC) as a government concern, which prevents the adoption of the total transport cost concept. Although construction and maintenance costs are the acknowledged responsibility of the government, some officials argue that VOC reductions are a benefit to private enterprise and should not be an investment criterion for public funds. This attitude refutes the use of nongovernmental benefits to determine the feasibility of the original construction of the road.

3. The lack of a firm data base for estimating maintenance needs, costs, and the impact on road users as well as future road deterioration. Maintenance activities are made up of many small components that are varied and sometimes unpredictable. They continue indefinitely and are extremely difficult to manage efficiently. They are also labor-intensive and depend on local labor productivity. Therefore maintenance costs are more difficult to predict than are construction costs. The common method of using previous national total maintenance costs, adjusted for expansion of the total system length and inflation, is unsatisfactory because (a) it does not account for cost variations from road to road due to traffic, materials, and environmental differences, and (b) it does not provide any as-

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invertir en estudios económicos como criterios en las decisiones sobre conservación.

2. Una desinclinación para aceptar el costo de operación de vehículo (vehicle operating cost: VOC) como asunto gubernamental, lo cual no permite la utilización del concepto del costo total de transporte. Aunque se acepta que los costos de construcción y conservación son la responsabilidad del gobierno, algunos funcionarios formulan que las reducciones de VOC benefician las empresas privadas y no deberán formar parte de criterios de inversión de los fondos públicos. Esta actitud contradice el uso de beneficios no gubernamentales para determinar la posibilidad de la construcción original del camino.

3. La falta de una base firme de datos para calcular las necesidades de conservación, costos, y el impacto sobre usuarios del camino asi como el deterioro futuro del camino. La conservación está formada por una variedad de componentes, a veces imprevisibles. Continúan en forma indefinida y son extremadamente difíciles de manejar eficientemente. Engendran mucho trabajo y dependen de la productividad de la mano de obra local. Por eso, los costos de conservación son más difíciles de pronosticar que los costos de construcción. El método común de utilizar previos costos totales de conservación nacionales, ajustados para la expansión de la extensión total del sistema y para la inflación, es insatisfactorio porque (a) no toma en cuenta las variaciones de costo de camino a camino debido al tránsito, materiales, y diferencias en el

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naisse responsable des coûts de construction et d'entretien, certains officiels soutiènnent que les réductions du CEV sont un avantage pour les entreprises privées et ne devrait pas constituer un critère d'investissement des fonds publics. Cette attitude dément l'utilisation d'avantages non-gouvernementaux pour déterminer la factibilité première de la construction de la route.

3. Le manque d'une banque de données solide pour estimer les besoins, les coûts et l'impact sur les usagers ainsi que les dégradations futures de la route. L'entretien routier se compose de beaucoup de petites opérations qui sont variées et quelquefois imprévisibles. Ces opérations continuent indéfiniment et sont extrèmement difficiles à gérer efficacement. Elles demandent l'emploi intensif de main-d'oeuvre et sont dépendantes de la productivité de la main-d'oeuvre locale. Ce qui explique que le coût de l'entretien est plus difficile à prévoir que celui de la construction. La méthode ordinaire qui est de se servir du total des dépenses nationales d'entretien des années précédentes, en tenant compte de l'accroissement du kilométrage et de l'indexation due à l'inflation, n'est pas satisfaisante car (a) elle ne tient pas compte des variations de coût d'une route à l'autre, causées par le trafic, les matériaux et les différences de l'environnement, et (b) elle ne fournit aucune assurance que les opérations d'entretien antérieures ètaient suffisantes ou appropriées.

Les effets de différents niveaux budgétaires de l'entretien sur la condition (et ensuite la dégradation) d'une route et par conséquent sur le coût aux usagers, n'ont été mesurés scientifiquement que récemment. Ils ne sont pas encore bien établis pour l'ensemble des opérations d'entretien, le trafic et les conditions d'environnement. Certains dex textes choisis (no. 4 et no. 6) de ce recueil décrivent un exercice important surance that previous maintenance activities were sufficient or appropriate.

The impacts of different levels of maintenance expenditures on road condition (and subsequent deterioration) and thence on road users' costs have only recently been measured scientifically. Such relations are not yet well established for the complete spectrum of maintenance activities, traffic, and environmental conditions incurred in different countries. Certain of the selected texts (Nos. 4 and 6) in Compendium 11 describe a major effort undertaken by various organizations to develop a data base for use in developing countries. Studies in Kenya and Brazil and, more recently, in India and the Caribbean are designed to provide a primary data base for estimating cost trade-offs for different design and maintenance standards for a wide range of conditions. The adjustments and techniques necessary to transfer these relations to other countries are also being developed.

This research has clearly established that even small changes in vehicle operating costs will play a major role in determining optimum maintenance policies. Maintenance and vehicle operating costs are related in the total transport cost concept by two key variables: (a) the road surface condition, particularly roughness, and (b) the volume and character of traffic using the road throughout its economic life.

Road roughness may be defined as a summation of the vertical displacements (oscillation) of a vehicle body, relative to its chassis, in response to variations in road surface profile when driven at a specified speed over a specified distance. Roughness measurement systems vary widely and include qualitative assessments by the engineer or riding-comfort rating panels, inexpensive axle-mounted bump integrators, and very complex and expensive profile-recording systems. The importance of this measurement in monitoring road performance and in measuring

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medio ambiente, y (b) no asegura que las actividades de conservación previas fueran suficientes o apropiadas.

Es únicamente recientemente que se han medido científicamente los impactos de distintos niveles de gastos de conservación sobre la condición del camino (y el subsecuente deterioro), y por lo tanto sobre los costos del usuario del camino. Tales relaciones no han sido bien establecidas para la variación completa de actividades de conservación, tránsito, y condiciones del medio ambiente encontradas en distintos países. Algunos de los textos seleccionados (Núms. 4 y 6) del Compendio 11 describen un esfuerzo importante por parte de varias organizaciones para desarrollar una base de datos a utilizarse en países en desarrollo. Los estudios en Kenya y Brasil, y más recientemente en la India y el Caribe, han sido diseñados para proveer una base primaria de datos para el estimado de trueques de costos para distintas normas de diseño y conservación para una gran variedad de condiciones. También se están desarrollando los ajustes y técnicas necesarios para transferir estas relaciones a otros países.

Estas investigaciones claramente establecen que aún los cambios más pequeños en los costos de operación de vehículos tendrán gran importancia en la determinación de la política de conservación óptima. En el concepto de costo total de transporte, los costos de conservación y operación de vehículo se relacionan a través de dos variables vitales: (a) la condición de la superficie de camino, en particular la rugosidad, y

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entrepris par plusieurs organismes pour développer une banque de données utilisable dans les pays en voie de développement. Des études faites au Kenya, au Brésil, et plus récemment aux Indes et dans les Caraïbes, sont conçues principalement pour fournir une banque de données capable d'estimer les accommodements budgétaires pour une gamme de normes de dimensionnement et d'entretien sous toutes sortes de conditions. Les adaptations et la technique nécessaires pour leur transfert aux autres pays sont en train d'être développées.

Cette recherche a établit clairement que même des petites différences dans le coût d'exploitation des véhicules joueront un rôle majeur dans la détermination des politiques d'entretien optimum. L'entretien routier et le coût d'exploitation des véhicules sont apparentés, dans le coût total du transport, par deux variables maitresses: (a) la condition de la surface de roulement, particulièrement l'uni, et (b) le volume et le genre de circulation qui utilisent la route durant sa vie économique.

L'uni de la surface de roulement peut se définir comme étant la somme des déplacements verticaux (oscillations) d'un véhicule par rapport à son chassis en réponse aux variations du profil de la surface de roulement quand ce véhicule est conduit à un vitesse spécifique pour une distance spécifique. Les systèmes de mesure de l'uni sont très variès et vont de l'évaluation qualitative par l'ingénieur, à l'estimamaintenance needs has stimulated much research in recent years to develop improved simplified systems appropriate to the needs of developing countries. Selected Text No. 7 summarizes the fundamental concepts and current work in this area.

The incremental values of various maintenance activities and the break-even or optimum value criteria for upgrading are based on current or predicted traffic volumes. Although the economist can reasonably determine these cost relations if the costs used are correct, the last two selected texts indicate that traffic volumes, either current or predicted, are very difficult to assess accurately.

Decision methodology for highway maintenance and upgrading should generally be based on economic trade-offs to ensure the lowest total transport cost. The three major elements of the economic evaluation after construction is completed — maintenance unit costs, vehicle operating costs, and average daily traffic — are difficult to determine exactly. However, any steps taken toward improving the data base and economic evaluation techniques will lead to better decision methodology. Even order-of-magnitude evalua-

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(b) el volumen y características del tránsito que lo utiliza a través de su vida económica.

La rugosidad del camino podría definirse como la suma de los desplazamientos verticales (oscilación) de la carrocería de un vehículo, con relación a su chasis, como reacción a variaciones en el perfil de la superficie de camino al ser manejado a una velocidad específica sobre una distancia específica. Hay una gran variedad de sistemas para medir la rugosidad, e incluyen asesoramientos cualitativos por parte del ingeniero, o un grupo oficial de personas que evalúan la comodidad de marcha; hasta medidores de rugosidad de poco costo, montados sobre el eje, y sistemas registradores de perfil muy complejos y costosos. La importancia de esta medición para la evaluación del rendimiento del camino y las necesidades de conservación ha estimulado últimamente mucha investigación para desarrollar sistemas simplificados mejorados para utilizarse en los países en desarrollo. El Texto Seleccionado N° 7 es el que resume los conceptos fundamentales y el trabajo que hasta el día se ha realizado en esta área.

Los valores incrementales de varias actividades de conservación y los criterios para la mejora de valor óptimo o valor "sin ganar ni perder", se basan sobre volúmenes de tránsito pronosticados o corrientes. Los dos últimos textos seleccionados indican que aunque los economistas pueden razonablemente determinar estas relaciones entre costos si los costos son correctos, los volúmenes de tránsito, corrientes o pronosticados, son muy difíciles de determinar con exactitud.

Se deberá generalmente basar la metodología de decisiones para conservación y mejora viales sobre trueques económicos, para así obtener el costo total de transporte más bajo. Son muy difíciles de determinar los tres elementos más importantes de la evaluación económica (costos de unidades de conservación, operación de

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tion de la qualité de roulement par une équipe d'experts, ou à des bump integrators montés sur l'essieu et bon marché, jusqu'aux analyseurs de profil en long, très compliqués et très chers. L'importance de ces mesures pour contrôler le comportement de la route et pour jauger les besoins d'entretien a stimulé beaucoup de recherches récemment pour développer des systèmes améliorés, simplifiés, et appropriés aux besoins des pays en voie de développement. Le texte choisi no. 7 fait une analyse sommaire des concepts fondamentaux de la question et de la recherche en cours. Les valeurs différentielles des différentes activités d'entretien et les critères de valeur à l'optimum et au seuil de rentabilité pour l'amélioration, sont basés sur les volumes de trafic actuels ou prévus. Bien que l'économiste puisse déterminer de façon raisonnable ces rapports entre les coûts si les coûts utilisés sont justes, les deux derniers textes choisis indiquent que les volumes de trafic, actuels ou prévus, sont très difficiles à évaluer avec précision.

Une méthodologie de décision pour l'entretien ou l'amélioration des routes devrait généralement être basée sur des compromis économiques pour assurer le plus bas prix total de transport. Les trois éléments principaux de l'évaluation économique, après que la construction soit finie — coûts unitaires de l'entretien, coût d'exploitation des véhicules, et traffic moyen journalier — sont difficiles à estimer avec précision. Cependant, chaque effort fourni pour améliorer la banque de données et les techniques d'évaluation economiques, conduiront à une meilleure méthodologie de prise de décision. Même les évaluations à l'ordre de grandeur conduisent à une meilleure estimation des prioritions lead to a better assessment of maintenance priorities than pure guessing. Many developing countries do not have the trained manpower or the financial resources to immediately institute maintenance economic evaluation as a decision-making tool. However, a comprehensive understanding of the components of the decision methodology for maintenance and upgrading can lead to a redirection of maintenance-planning resources into those activities that will eventually permit the development of more cost-effective programs.

Discussion of Selected Texts

The first text, *The Economic Issues of Highway Maintenance,* is excerpted from the *Economic and Finance Committee Report, XVIth World Road Congress, Vienna* (Permanent International Association of Road Congresses, 1979). It presents an economic perspective of highway maintence. It links the level of maintenance to traffic volume by economically balancing the extra costs associated with an improvement in service against the extra benefits yielded. This economic analysis approach, which will be expanded in later texts, satisfies the need to determine (a) the correct level of expenditure for maintenance, (b) the standards to be aimed at, and (c) an appropriate assessment method.

The text discusses (a) economic misconceptions about maintenance, (b) some of the current technical problems in translating the economic evaluation of maintenance into actual practice, and (c) some of the current directions of development in applying a full economic discipline to highway maintenance. It should be noted, when evaluating the percentages of maintenance budgets allocated to road surfaces in this text, that the roadways referenced here are ba-

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vehículo, y tránsito diario medio), que vienen después de la construcción. Sin embargo, cualquier esfuerzo para mejorar la base de datos y técnicas de evaluación económica mejorará la metodología de decisiones; y aún las evaluaciones de órden de magnitud llevan a un mejor asesoramiento de las prioridades de conservación, que lo que daría una pura suposición. Es cierto que muchos países en desarrollo no poseen el personal entrenado ni los recursos financieros necesarios para inmediatamente implementar la evaluación económica de conservación como herramienta en la toma de decisiones; pero un entendimiento comprensivo de los componentes de esta metodología de decisiones puede llevar a un realineamiento de los recursos para conservación y planeamiento, hacia las actividades que eventualmente permitirían el desarrollo de programas más efectivos en lo que respecta al costo.

Presentación de los textos seleccionados

El primer texto, *The Economic Issues of Highway Maintenance* (Los problemas económicos de la conservación vial), fué extraído del *Economic and Finance Committee Report, XVIth World Road Congress, Vienna* (Permanent International Association of Road Congresses, 1979). Presenta una perspectiva económica en la conservación vial. Balancea los costos extras asociados con una mejora en el servicio con el aumento en beneficios; y así relaciona el nivel de

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tés d'entretien, que les simples conjectures. Beaucoup de pays en voie de développement n'ont ni l'effectif spécialisé, ni les ressources financières pour instituer immédiatement l'analyse économique comme instrument de prise de décision. Toutefois, s'il on comprend, en général, les différentes composantes de la méthodologie de prise de décision, on pourra être conduit à redistribuer le budget prévu pour l'entretien vers les opérations qui permettront le développement de programmes plus efficaces par rapport au coût.

Discussion des textes choisis

Le premier texte, *The Economic Issues of Highway Maintenance* (Economie de l'entretien des routes), est extrait du *Economic and Finance Committee Report, XVIth World Road Congress, Vienna* (Permanent International Association of Road Congresses, 1979). On y présente une perspective économique de l'entretien routier. On réunit le niveau d'entretien au volume de trafic en compensant le coût économique supplémentaire associé à une amélioration du service par les avantages supplémentaire qui en découlent. Cette approche d'analyse économique, que nous reprendrons en détail dans d'autres textes, permet de déterminer (a) le niveau correct de dépenses d'entretien, (b) les normes auxquelles on doit aspirer, et (c) une méthode d'évaluation adéquate.

On discute dans ce texte (a) les erreurs de conception en matière d'entretien, (b) les prosically paved. Most of the following texts, however, deal with unpaved or surface-treated roads.

The second text, ***Maintenance Costing Method for Low-Volume Roads,*** appeared in ***Highway Research Record 451*** (Highway Research Board, 1973). It presents a method of determining maintenance costs where there is no past maintenance history to build on. Any economic evaluation of level of maintenance must be based on costs. However, the use of historical costs to project future costs assures neither the adequacy nor the correct apportionment of maintenance funding.

This text acknowledges that maintenance costs are a function of traffic volume. It also notes that the availability and quality of construction materials, the climatic conditions, the topography, and the road design also affect maintenance costs. Therefore, two roads in different locations will incur different maintenance costs but will provide the same level of service to the same traffic volumes. A process is recommended of estimating maintenance costs. This method is similar to that often used to estimate construction unit prices in developing countries with no major construction experience (i.e., the selection of a package of construction equip-

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conservación con el volumen de tránsito. Este análisis económico, que luego será estudiado más ampliamente en subsiguientes textos, satisface la necesidad de determinar (a) el nivel correcto de gastos en la conservación, (b) las normas a las cuales se quiere llegar, y (c) un método apropiado de asesoramiento.

El texto habla sobre (a) conceptos económicos erróneos sobre la conservación, (b) algunos de los problemas técnicos que hoy en día ocurren en la conversión de la evaluación económica de conservación, a la práctica, y (c) algunos de los corrientes desenvolvimientos al aplicar una disciplina económica total a la conservación vial. Al evaluar los porcentajes de presupuestos de conservación asignados a las superficies de camino en este texto, se deberá notar que los caminos a los cuales aquí se refiere son básicamente pavimentados. Pero en casi todos los textos subsiguientes se habla de caminos sin pavimentar o con tratamiento de superficie.

El segundo texto, ***Maintenance Costing Methods for Low-Volume Roads*** (Método de calcular el costo de conservación en caminos de bajo volumen), apareció en ***Highway Research Record 451*** (Highway Research Board, 1973). Presenta un método para determinar los costos de conservación donde no existen antecedentes de conservación sobre los cuales basarse. Cualquier evaluación económica del nivel de conservación deberá basarse en costos; pero el uso de costos pasados para trazar costos futuros no asegura ni la suficiencia ni la distribución correcta de los fondos de conservación.

El texto reconoce que los costos de conservación son una función del volumen de tránsito, y además nota que también son afectados por la disponibilidad y calidad de los materiales de construcción, las condiciones climáticas, la topografía, y el diseño del camino. Por lo tanto, dos caminos en distintas ubicaciones incurrirán distintos costos de conservación pero proveerán

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blèmes techniques actuels qui découlent de l'application des méthodes économiques dans la pratique et (c) quelques tendances actuelles à l'application générale de méthodes économiques à l'entretien routier. On devra remarquer que dans ce texte, lorsque l'on évalue les pourcentages budgetaires alloués à l'entretien des chaussées, on parle généralement de chaussées pavées. La plupart des autres textes que nous allons citer, discutent de routes non-pavées ou de routes revêtues.

Le deuxième texte s'intitule ***Maintenance Costing Method for Low-Volume Roads*** (Méthode de détermination des frais d'entretien pour les routes à faible capacité, Highway Research Board, 1973). On y présente une méthode pour calculer les dépenses d'entretien dans le cas où on ne peut s'appuyer sur les dépenses des années précédentes. Une évaluation économique des niveaux d'entretien doit être basée sur les coûts. Toutefois l'utilisation des coûts des années précédentes pour la projection des coûts futurs ne garantit ni l'exactitude ni la répartition correcte des dotations d'entretien.

Ce texte reconnait que les coûts d'entretien sont fonction du volume de trafic. On y remarque aussi que la disponibilité et la qualité des matériaux de construction, les conditions climatiques, la topographie et le dimensionnement de la route influencent aussi les coûts d'entretien. Donc, deux routes situées en des endroits différents, auront des frais d'entretien différents, mais fourniront le même niveau de service au même volume de trafic. Un procédé est recommandé pour estimer les coûts d'entretien. Cette méthode est similaire à celle qui est souvent utilisée pour estimer les prix unitaires de construction dans les pays en voie de développement qui ment and the determination of the output versus the cost per time unit of that package). The maintenance costs can therefore be varied to account for the factors listed above by altering the output per time unit.

This text assumes a level of maintenance that will keep the roadways in a "like-new" condition. This situation neglects the trade-offs necessary to meet the economically correct level of expenditure for maintenance as described in the first text. The discussion that follows the text points this out and also indicates that some of the evaluation details are not included in the presentation. The text is included in this compendium for its conceptual value. A more detailed presentation — an actual breakdown of the equipment, labor, support costs, and maintenance output — is included in the next selected text.

The third text, ***Main Road Maintenance Costs,*** is a paper presented at the Pan African Conference on Highway Maintenance and Rehabilitation in Ghana (United Nations Economic Commission for Africa, 1977). It describes the procedures adopted in Upper Volta for the maintenance of earth roads (with a surfacing of selected material) and asphalt-surfaced roads. The maintenance of earth and gravel roads includes detailed costs for (a) manual maintenance, including the filling of road surface depressions and potholes, clearing of ditches and removal of undergrowth from the right-of-way; (b) resurfacing; (c) major reshaping; (d) minor reshaping; and (3) special anticorrugation maintenance. The maintenance of surfaced roads involves manual maintenance as described above. The exception is that the road patching

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el mismo nivel de servicio al mismo volumen de tránsito. Se recomienda un proceso para estimar los costos de conservación, el cual es similar al que seguidas veces se utiliza para calcular los precios unitarios de construcción en países en desarrollo sin gran experiencia en construcción (es decir, la selección de un conjunto de equipo de construcción y la determinación de la producción versus el costo por unidad de tiempo de este conjunto). Por lo tanto, para tomar en cuenta los factores mencionados arriba, los costos de conservación pueden variarse alterando la producción por unidad de tiempo.

Este texto asume un nivel de conservación que conservaría los caminos "como nuevos". Esta situación no toma en cuenta los trueques necesarios para satisfacer el nivel económico correcto de gastos para conservación, como se describió en el primer texto. La exposición que sigue al texto indica este problema y también que no se incluyen en la presentación álgunos de los detalles de evaluación. Se presenta el texto en este compendio por su valor conceptual. Se ha incluído en el siguiente texto una presentación más detallada — un análisis del equipo, la mano de obra, los costos de apoyo, y la producción total de los trabajos de conservación.

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n'ont pas beaucoup d'expérience de construction (c'est à dire la sélection d'un "assemblage" de matériel de construction adéquat et la détermination de la production de cet assemblage par rapport au coût par unité de temps). Les coûts d'entretien peuvent donc varier pour prendre en compte les facteurs dont nous avons parlé precédemment en modifiant la production par unité de temps.

On présume un niveau d'entretien qui gardera les routes en parfait état. Cette présomption néglige les compromis ou échanges monétaires qui sont nécessaires pour satisfaire le budget d'entretien économiquement correct qui est décrit dans le premier texte. La discussion qui suit le texte en fait la remarque et indique aussi que certains détails de l'évaluation ne sont pas inclus dans la communication. Ce texte est inclus dans notre recueil pour sa valeur conceptuelle. Un exemplaire plus détaillé qui comprend de matériel, la main-d'oeuvre, les matériaux, les frais généraux, et le résultat achevé, est donné dans le texte suivant.

Le troisième texte, *Main Road Maintenance Cost* (Coûts de l'entretien des routes principales), est une communication présentée au Ghana, lors de la Pan African Conference on Highway Maintenance and Rehabilitation (United Nations Economic Commission for Africa, 1977). On y décrit les prócédés adoptés en Haute-Volta pour l'entretien des routes en terre (avec addition de certains matériaux) et des routes avec revêtement asphaltique. L'entretien des routes en graviers et des routes en terre comprend le détail des coûts: (a) de l'entretien manuel y compris le reflachage, le traitement des nids de poule, le curage des fossés et le débroussaillement de l'emprise; (b) du rechargement; (c) du reprofilage important; (d) du petit reprofilage; et (e) des mesures spéciales d'entretien contre la tôle ondulée. L'entretien des routes revêtues comprend l'entretien manuel consists of applying cut-back asphalt with a binder distributor and the placing and rolling of surface chippings.

This text provides a specific example of the concept of construction equipment packaging as described in the previous text. It does not, however, break down the costs for different geographical conditions nor does it indicate the frequencies of each operation as a function of traffic volume. Therefore, there is no way of determining the level of service provided. It does provide the basic costs of the maintenance activities described. If the traffic volumes were known, the principles outlined in the next two texts could be applied to these costs to determine an economically efficient schedule of maintenance operations. This text therefore represents the first step that must be taken in the process of the economic evaluation of maintenance procedures.

To compare these costs to the costs given in dollars in the next text for similar operations is

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El tercer texto, ***Main Road Maintenance Costs*** (Costos de conservación de caminos principales), es una comunicación presentada en la Pan African Conference on Highway Maintenance and Rehabilitation en Ghana (United Nations Economic Commission for Africa, 1977). Describe los procedimientos adoptados en el Alto Volta para la conservación de caminos de tierra (con una capa superficial de material seleccionado) y caminos con superficie de asfalto. La conservación de caminos de tierra y de grava incluye costos detallados para (a) conservación manual, incluyendo el relleno de depresiones y baches en la superficie del camino, limpieza de zanjas y eliminación de maleza de la calzada; (b) renovación de la superficie; (c) grandes reformaciones; (d) pequeñas reformaciones; y (e) conservación especial anticorrugativa. La conservación de los caminos pavimentados consiste en lo manual presentado arriba. La excepción es que el bacheo del camino consiste en la aplicación de asfalto rebajado con un distribuidor de aglutinante y la colocación y arrollado de gravilla de superficie.

Este texto presenta un ejemplo específico del concepto del "conjunto" de equipo de construcción como se describió en el texto anterior; pero no detalla los costos para distintas condiciones geográficas ni indica la frecuencia de cada operación como función del volumen de tránsito. Por esta razón no es posible determinar el nivel de servicio que se provee. Pero sí presenta los costos básicos de las actividades de conservación que se describen. Si se conocieran los volúmenes de tránsito, los principios descritos en los siguientes dos textos se podrían aplicar a estos costos, para determinar un programa económicamente eficiente para las operaciones de conservación. Este texto, entonces, representa el primer paso a tomarse en el proceso de la evaluación económica de los procedimientos de conservación.

Es muy difícil comparar estos costos con los costos de operaciones similares dados en dólares en el próximo texto porque los costos en dólares en el Texto Seleccionado N° 4 no han sido identificados con respecto a la fecha. Sin embargo, se puede realizar un cambio aproximado

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que nous venons de décrire, exception faite du reflachage qui se fait en applicant du bitume fluidifié avec une pompe de liant, et du répandage et roulage des gravillons. Ce texte fournit un exemple spécifique du concept de "l'assemblage" du matériel de construction que nous avons décrit auparavant. Mais il ne donne pas en détail les coûts suivant la géographie et n'indique pas la fréquence de chaque opération comme fonction du volume de traffic. Il n'y a donc pas moyen de déterminer le niveau de service donné. Mais il donne quand même les coûts de base des différentes activités d'entretien qui sont décrites. Si les volumes de trafic étaient connus, les principes delineés dans les deux prochains textes pourraient être appliqués à ces coûts pour déterminer une stratégie d'entretien qui serait de bon rendement au point de vue économique. Ce texte représente donc le premier pas du processus total de l'évaluation économiques des opérations d'entretien.

Il sera très difficile de comparer ces prix à ceux donnés en dollars dans le texte prochain, pour la bonne raison que l'on ne donne pas la date à laquelle on a fait les calculs en dollars. Cependant si l'on converti approximativement le franc CFA 1976 en dollars on obtiendra 50 francs CFA = 1 franc métropole = 0.23± dollar U.S. Cette conversion permettra des comparaisons d'ordre de grandeur entre certains coûts en Haute-Volta et les chiffres de la Banque Mondiale, basés sur le Kenya.

Le quatrième texte est extrait de ***Evaluating the Economic Priority of Highway Maintenance*** (Evaluation de la priorité économique de l'entretien routier) et est une autre communication présentée au Ghana à la Pan African Conference on Highway Maintenance and Rehabilitation (United Nations Economic Commission for Africa, 1977). On présente une méthodologie pour déterminer l'impact économique de différents niveaux d'entretien. Les coûts unitaires very difficult because the dollar costs in Selected Text No. 4 are not identified in any time frame. However, a rough conversion of 1976 francs CFA to dollars is as follows: francs CFA 50 = 1 French franc = US$0.23±. This conversion will allow order-of-magnitude comparisons between some of the costs in Upper Volta and the Kenya-based World Bank figures.

The fourth text is excerpted from ***Evaluating the Economic Priority of Highway Maintenance,*** another paper presented at the Pan African Conference on Highway Maintenance and Rehabilitation in Ghana (United Nations Economic Commission for Africa, 1977). It presents the methodology for determining the economic impact of different levels of maintenance effort. The maintenance unit costs used in this type of an evaluation may be determined by using the methods described in the previous texts. The vehicle-user costs in this text were initially developed in Kenya. The actual calculations on which the conclusions of this text were drawn were developed by computer and by using the World Bank's Highway Design and Maintenance Standards Model (HDM). Copies of the HDM Computer Program and associated documentation may be obtained from the World Bank (see Reference No. 22). Another model, the Road

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de francos C.F.A. 1976 a dólares como sigue: 50 francos C.F.A = 1 franco francés = US$0,23± Este cambio permitiría comparaciones de órden de magnitud entre algunos de los costos en Alto Volta y las cifras del Banco Mundial en Kenya.

El cuarto texto fué extraído de ***Evaluating the Economic Priority of Highway Maintenance*** (Evaluación de la prioridad económica de la conservación vial), otra comunicación presentada en la Pan African Conference on Highway Maintenance and Rehabilitation celebrada en Ghana

(United Nations Economic Commission for Africa, 1977). Presenta la metodología para determinar el impacto económico de distintos niveles de esfuerzo de conservación. Los costos de conservación por unidad que se utilizan en este tipo de evaluación pueden determinarse utilizando los métodos descritos en los textos previos. Los costos para el usuario de vehículo en este texto se desarrollaron inicialmente en Kenya. Los verdaderos cálculos sobre los cuales se basan las conclusiones de este texto fueron desarrollados por computadora y utilizando el Highway Design and Maintenance Standards Model-HDM (Modelo para las normas de diseño y conservación viales) del Banco Mundial. Se pueden obtener copias del Programa de Computadora HDM y de la documentación perteneciente a ella del Banco Mundial (véase Referencia Adicional N° 22). Otro modelo, el Road Transport Investment Model — RTIM, desarrollado por el Transport and Road Research Laboratory, se describe en la Referencia Adicional N° 19.

La metodología se basa en la teoría de que los beneficios económicos de los gastos de conservación vial se componen de tres cosas básicas: (a) disminuciones en los costos del usuario (principalmente los costos de operación del vehículo en países en desarrollo); (b) disminuciones en los costos futuros de conservación y rehabilitación necesarios para proveer el

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d'entretien utilisés dans ce genre d'évaluation peuvent être déterminés en utilisant les méthodes décrites dans les textes précédents. Les coûts d'exploitation des véhicules, dans ce texte, ont été développés initialement au Kenya. Les calculs eux mêmes, sur lesquels les conclusions de ce texte reposent, fûrent développés en se servant d'un ordinateur et du logiciel HDM de la Banque Mondiale "Highway Design and Maintenance Standards Model (HDM)" (Modèle pour les normes de dimensionnement et d'entretien routiers). On peut obtenir des copies de ce logiciel HDM et de la documentation pertinente en s'adressant à la Banque Mondiale (voir réference no. 22). Un autre, le Road Transport Investment Model (RTIM) développé par le Transport and Road Research Laboratory est décrit dans la réference no. 19.

La méthodologie est basée sur la théorie que les avantages économiques des dépenses d'entretien routier comprennent trois élément de base: (a) réduction des coûts aux usagers (principalement des coûts d'exploitation des véhicules dans les pays en voie de développement), (b) réduction des futurs coûts d'entretien et de réfection nécessaires pour fournir le même niveau de service, si l'entretien préventif est fait à temps, et (c) réduction ou prévention des pertes économiques dûes à la fermeture de la route. Les évaluations sont faites en utilisant les méthodes différentielles d'entretien pour déterminer les avantages différentiels qui fourniront les taux de rentabilité optimaux. L'effet des caractéristiques initiales de la route, des genres de matériaux, du volume et de la charge par essieu du trafic, et du climat, est evalué par rapport aux

Transport Investment Model (RTIM), developed by the Transport and Road Research Laboratory, is described in Reference No. 19.

The methodology is based on the theory that economic benefits of highway maintenance expenditures are comprised of three basic components: (a) reductions in user costs (primarily vehicle operating costs in developing countries); (b) reductions in future maintenance and rehabilitation costs required to provide the same level of service, if preventative maintenance is done in a timely manner; and (c) reduction or prevention of the economic loss due to road closures. The evaluations are made by using incremental maintenance levels to determine the incremental benefit that provides the optimal rate of return. The effect of the original surface design, material types, volume and axle-load configuration of traffic, and climate are evaluated against the incremental maintenance levels through an assessment of road deterioration.

Because this evaluation tool is still under development, the empirical data base is somewhat limited. The results given in this text are for conditions existing in Kenya. The road deterioration evaluations are valid for the climate and types of road surfaces common to Kenya. The next selected text presents the same type of evaluation for West Africa (Chad). The program described in both this text and Selected Text No. 5 further assumes that routine maintenance (i.e., drainage clearance, shoulder maintenance, and vegetation control) is normal and that heavy grading and reshaping have no additional benefit compared to normal grading.

The portions of the text reprinted in this compendium include two case studies.The first is entitled ***Maintenance Policy Analysis for Unpaved***

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mismo nivel de servicio, si se realiza conservación preventiva oportunamente; y (c) disminución o prevención de la pérdida económica debida a clausuras de caminos. Las evaluaciones se realizan utilizando niveles de conservación incrementales para determinar el beneficio incremental que provee el nivel óptimo de ingresos. El efecto del diseño original de superficie, los tipos de material, el volumen y configuración del peso de eje del tránsito, y el clima se evalúan en comparación con los niveles incrementales de conservación a través de un asesoramiento del deterioro del camino.

Ya que este agente de evaluación todavía se está desarrollando, la base de datos empírica se encuentra algo limitada. Los resultados dados en este texto son para las condiciones existentes en Kenya. Las evaluaciones de deterioro de caminos son válidas para el clima y los tipos de superficies de camino que se encuentran en Kenya. El próximo texto seleccionado presenta el mismo tipo de evaluación para Africa Occidental (Chad). El programa que se describe en este texto y en el Texto Seleccionado N° 5 también asume que la conservación rutinaria (es decir, limpieza de desagües, conservación de los bordes, y control de la vegetación) es normal y que la nivelación y reformación extremas no proporcionarían beneficio adicional en comparación con la nivelación

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méthodes d'entretien différentielles par l'intermédiaire de l'évaluation de la déterioration de la route.

Comme cet instrument d'évaluation est encore en cours de développement, la banque empirique de données est quelque peu limitée. Les résultats qui sont donnés dans ce texte sont pour des conditions existantes au Kenya. Les évaluations de détérioration routière sont valables pour le climat et les types de surface routière communs au Kenya. Le texte choisi qui va suivre présente le même genre d'évaluation pour l'Afrique Occidentale (Tchad). Le programme qui est décrit dans ce texte et dans le texte no. 5 assume de plus que l'entretien courant (c'est à dire assainissement, entretien des accotements, contrôle de la végetation) est normal et que les grosses opérations de nivellement et de reprofilage ne présentent pas d'avantages additionnels, comparées au nivellement ordinaire.

Les portions du texte que nous avons réimprimées dans ce recueil comprennent deux études de cas. La première est intitulée ***Maintenance Policy Analysis for Unpaved Roads*** (Analyse de la stratégie d'entretien de routes non-revêtues); la deuxième s'appelle ***Economic Analysis to Determine When to Pave an Unpaved Road*** (Analyse économique pour déterminer le seuil de bitumage). Bien que ces études doivent être interprétées avec beaucoup de circonspection, à cause de la banque de données qui est limitée, elles représentent néanmoins la base fondamentale de la prise de décision quantitative sur le niveau optimal, la composition et la fréquence de l'entretien routier. La première étude affirme aussi que des niveaux peu élevés d'entretien des routes à faible capacité produi-

Roads; the second, *Economic Analysis to Determine When to Pave an Unpaved Road.* Although these case studies must be interpreted with considerable caution because of the limited data base used, they nevertheless present the basic fundamentals of quantitative management decision making about the optimum level, composition, and timing of highway maintenance efforts. The first case study also affirms that minimum levels of low-volume road maintenance yield extremely high economic returns. It further infers that regraveling of roads with low average daily traffic (ADT) rates may have a lower rate of return than providing higher grading frequencies for earth roads of comparable traffic volumes in areas where gravel is not readily available. Therefore, there is a need to carefully examine the individual components that make up the total maintenance program. High total economic benefits, which by themselves are sufficient to economically justify a high level of service, may conceal possible deficiencies in the individual components.

The second case study presents two economic criteria for determining whether a gravel road should continue to be maintained or should be paved (with a double bituminous surface treatment). The first criterion is the break-even

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normal.

Las porciones del texto que se reimprimen en este compendio incluyen dos estudios. El primero se titula *Maintenance Policy Analysis for Unpaved Roads* (Análisis de la política de conservación en caminos sin pavimentar); el segundo es *Economic Analysis to Determine When to Pave an Unpaved Road* (Análisis económico para determinar cuándo pavimentar un camino sin pavimentar). Aunque estos estudios deberán interpretarse cautelosamente por la base limitada de datos que se utilizó, presentan los fundamentos básicos de la toma de decisiones en la administración cuantitativa sobre el nivel, composición, y programación óptimos de los trabajos de conservación vial. El primer estudio también afirma que niveles mínimos de conservación de caminos de bajo volumen rinden ingresos económicos extremadamente altos. Además, infiere que la recolocación de grava en caminos con niveles bajos de tránsito diario medio (ADT) podría tener un nivel más bajo de ingresos que el proveer nivelaciones más frecuentes en los caminos de tierra con volúmenes de tránsito comparables, en las áreas donde no se encuentra disponible la grava. Por eso hay que examinar cuidadosamente los componentes individuales del programa total de conservación. Los grandes beneficios económicos, que por sí solos son suficientes para justificar un alto nivel de servicio, pueden ocultar posibles deficiencias en los componentes individuales.

El segundo estudio presenta dos criterios para determinar si un camino de grava se debe de conservar o pavimentar con un tratamiento bituminoso de superficie doble. El primer criterio es el volumen de tránsito de "sin ganar ni perder", definido como el ADT del año base en donde el valor actual neto de pavimentación iguala el dejar el camino con superficie de

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sent de très importants profits économiques. De plus on infère que le rechargement des routes qui ont un bas trafic journalier moyen (TJM) peut avoir un taux de rentabilité inférieur à celui qu'on obtiendrait en ayant une fréquence de reprofilage plus élevée pour les routes en terre qui ont le même volume de trafic, dans les endroits où le gravier ne se trouve pas facilement. Donc, il faut examiner soigneusement chaque composante de tout le programme d'entretien. Des avantages économiques élevés, qui par eux-mêmes seraient suffisants pour justifier un niveau de service élevé, peuvent cacher des déficiences dans les composantes individuelles.

Le deuxième cas d'étude présente deux critères économiques pour déterminer si une route en terre devrait continuer à être entretenue, ou si elle devrait être revêtue (avec un enduit superficiel bicouche). Le premier critère est le volume du trafic au seuil de rentabilité, défini comme le TJM de l'année de base auquel le bénéfice (actualisé) de revêtir la route égale celui de la laisser en terre. Le deuxième critère est celui du volume optimal de trafic, défini comme étant celui au dessus duquel le bénéfice (actualisé) de revêtir la route ne peut pas être augmenté en ajournant la construction. En autres termes économiques, ceci serait le point où le "bénéfice net annuel uniforme équivalent" (calculé en additionant au coût annuel uniforme équivalent, un facteur de revenu ou d'avantage) ne peut être augmenté par l'ajournement, ou le point où, soit le "coût annuel uniforme équivalent" (qui combine les coûts d'investissements et toutes les dépenses annuelles en une seule somme annuelle qui est équivalente à toutes les dépentraffic volume, defined as the base year ADT at which the net present value of paving just equals leaving the road in the current gravel status. The second criterion is the optimal traffic volume, defined as the traffic volume above which the net present value of paving cannot be increased by deferring the pavement construction to a later year. In other economic terminology, this would be the point where the equivalent uniform annual net return cannot be increased by deferment, or the point where either the equivalent uniform annual cost or the present worth of costs cannot be decreased by deferment.

This text recommends the use of the second criterion. Both break-even and optimal traffic volumes are very sensitive to normal discount rates and pavement construction costs. Thus, the values given in the text are not transferable from one economy to another. The principles of analysis are valid if the proper data are applied.

The fifth text, ***Engineering Economics of the Maintenance of Earth and Gravel Roads,*** was published in ***Transportation Research Record 702*** (Transportation Research Board, 1979). It describes a practical application of the methodology for the economic evaluation of maintenance

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grava. El segundo criterio es el volumen de tránsito "óptimo", definido como el volumen de tránsito por sobre el cual el valor actual neto de pavimentación no puede ser aumentado por la postergación de la construcción del pavimento hasta otro año. En otra terminología económica, éste sería el punto donde el ingreso neto anual uniforme equivalente no puede ser aumentado con una postergación, o el punto donde el coste anual uniforme equivalente o el valor actual de costos no puede ser disminuído por postergación.

Este texto recomienda el uso del segundo criterio. Los volúmenes de tránsito de "sin ganar ni perder" y óptimo son muy sensitivos en lo que respecta a tantos de descuento normales y costos de construcción de pavimento. Por eso los valores dados en el texto no son transferibles de una economía a otra. Los principios de análisis son válidas si se les aplica los datos correctos.

El quinto texto, ***Engineering Economics of the Maintenance of Earth and Gravel Roads*** (Economía política ingenieril de la conservación de caminos de tierra y de grava), fué publicado en ***Transportation Research Record 702*** (Transportation Research Board, 1979). Describe una aplicación práctica de la metodología para la evaluación económica de programas de conservación para caminos sin pavimentar con bajos volúmenes de tránsito, como se presentó en el primer estudio del texto previo. Afirma la teoría de que, con tal que los parámetros de geometría vial y del medio ambiente permanezcan fijos, los parámetros de deterioro de la superficie del camino (rugosidad media, profundidad de huella, y espesor de capa del material suelto) y el costo del usuario del vehículo pueden reducirse a un denominador común, el volumen de tránsito acumulativo (T). También afirma que las frecuencias óptimas de nivelación deberán modificarse para desarrollar un balanceo técnico apropiado entre la frecuencia de nivelación y otras operaciones de conservación rutinarias pero esenciales, especialmente

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ses durant la période analysée quand celles-ci sont étalées uniformément sur cette période), soit la valeur actuelle du coût ne peuvent pas être diminués par l'ajournement.

Dans ce texte, on recommande l'utilisation du second critère. Le volume de trafic au seuil de rentabilité et le volume optimal de trafic sont très sensibles au taux d'actualisation normal et aux coûts de construction du revêtement. Donc les valeurs données dans le texte ne sont pas transposables d'une économie à une autre. Les principes de l'analyse sont valables si l'on utilise les données correctes.

Le cinquième texte, ***Engineering Economics of the Maintenance of Earth and Gravel Roads*** (Economie de l'entretien des routes en terre et en graviers), a été publié dans le Transportation Research Record 702 (Transportation Research Board, 1979). On y décrit une application pratique de la méthodologie pour l'évaluation économiques de programmes d'entretien des routes non-revêtues à faible circulation, telles celles qui ont été présentées dans le cas d'étude no. 1 du texte précédent. On émet la théorie que les paramètres de dégradations de la surface de la route (rugosité moyenne, profondeur des ornières, et profondeur de matériau désagrégé) et le coût d'exploitation des véhicules peuvent être réduits à un dénominateur commun — le volume de trafic composé (T) — à condition que les paramètres routiers de géométrie et d'environment restent fixes. On reconnait aussi que les fréquences optimales de reprofilage devraient être modifiées pour développer un équilibre technique adéquat entre les fréquences de reprofilage et les autres opérations d'entretien périodique essentielles, particulièrement quand il s'agit de routes en terre. Une étude de rentabilité est utiliprograms for unpaved roads with low traffic volumes as presented in Case 1 of the previous text. It advances the theory that both the road surface deterioration parameters (mean roughness, rut depth, and depth of loose material) and the VOC can be reduced to a common denominator — cumulative traffic volume (T) — provided that road geometric and environmental parameters remain fixed. It also acknowledges that the optimal grading frequencies should be modified to develop an appropriate technical balance between grading frequency and other essential routine maintenance operations, particularly for earth roads. A benefit-cost analysis is used to evaluate various graveling alternatives for different ADT. The criterion used is the break-even traffic volume. The aggregation and smoothing of the Kenya-based data restrict this analysis to finding major trends. These trends, however, may serve as rules of thumb elsewhere. The only decision variables considered are grading, depth of gravel (at regraveling time), and whether to gravel an earth-surfaced road.

The maintenance program evaluated is similar in many respects to that described in the third text. Road gangs fill potholes, clean ditches and culverts, control vegetation, and perform spot regraveling as labor-intensive operations. Routine maintenance operations (grading, compacting, and dragging with tractor-drawn tires) are fully mechanized. The physical requirements for the maintenance program include equip-

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para los caminos de tierra. Se utiliza un análisis de beneficio/costo para evaluar varias alternativas de colocación de grava para distintos valores de tránsito diario medio. El criterio utilizado es el volumen de tránsito "sin ganar ni perder" El agregado y alisado de los datos provenientes de Kenya limitan este análisis a la búsqueda de las tendencias principales. Estas tendencias, sin embargo, pueden servir de reglas empíricas en otros sitios. Las únicas decisiones variables que se consideran son la nivelación, espesor de la grava (en el momento de recolocación de grava), y si es o no necesario colocar grava en un camino de tierra.

El programa de conservación evaluado es, en muchos instantes, semejante al descrito en el tercer texto. Equipos de trabajadores realizan el relleno de baches, limpieza de zanjas y alcantarillas, control de la vegetación, y recolocación de grava en áreas pequeñas con herramientas manuales. Las operaciones rutinarias de conservación tales como nivelación, compactación, y arrastre de neumáticos con tractor son realizadas mecánicamente. Los requerimientos físicos para el programa incluyen equipo, repuestos, talleres, y oficinas. Además, se han incluído (como inversión de fondos) los costos prorrateados de una actividad de entrenamiento que se consideró necesaria para implementar la nueva estrategia total de conservación.

El sexto texto, ***Effect of Simple Road Improvement Measures on Vehicle Operating Costs in the Eastern Caribbean*** (El efecto de medidas sencillas de mejora de caminos sobre los gastos de explotación de vehículos en el Caribe Oriental), fué también publicado en ***Transportation***

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sée pour évaluer différentes alternatives de matériaux graveleux pour différents TJM. Le critère utilisé est le seuil de rentabilité (volume de trafic). L'agrégation et l'égalisation des données provenant du Kenya limitent cette analyse à la recherche des tendances principales. Ces tendances toutefois peuvent être utiles empiriquement ailleurs. Les seules variantes de prise de décision qui sont considerées sont le reprofilage, la profondeur du gravier (au moment du rechargement) et si on doit ou non revêtir de gravier une route en terre.

La stratégie d'entretien évaluée est similaire sous beaucoup d'aspects à celle décrite dans le troisième texte. Des équipes d'ouvriers remplissent les nids de poule, curent les fossés et les ponceaux, contrôlent la végétation, font la réparation des flaches par point à temps. On utilise l'emploi intensif de la main-d'oeuvre pour ces opérations. Les autres opérations d'entretien courant (reprofilage, compactage et passages au tracteur tirant un traineau de pneus) sont entièrement mécanisés. Les besoins matériels du programme d'entretien comprennent les engins, les pièces détachées, les ateliers et les bureaux. En outre, ce programme contient aussi (comme mise de fonds initiale) les frais au prorata d'un programme de formation du personnel nécessaire pour l'implémentation de cette nouvelle stratégie d'entretien.

Le sixième texte, ***Effect of Simple Road Improvement Measures on Vehicle Operating Costs in the Eastern Caribbean*** (Effet de simple mesures d'amélioration routière sur le coût d'exploitation des véhicules en Caraïbe de l'Est), est tiré aussi du ***Transportation Research Record 702*** (Transportation Research Board, 1979). On décrit l'évaluation économique utilisée pour dément, spare parts, shops, and offices. In addition, this maintenance program includes (as a capital investment) the prorated costs of a training activity that was considered necessary to implement the new overall maintenance strategy.

The sixth text, ***Effect of Simple Road Improvement Measures on Vehicle Operating Costs in the Eastern Caribbean,*** was also published in *Transportation Research Record 702* (Transportation Research Board, 1979). It describes the economic evaluation used to determine the cost-effectiveness of a simple labor-intensive method for rehabilitating and maintaining badly deteriorated bituminous road surfaces on the Eastern Caribbean island of St. Vincent. This text shows the results of delayed maintenance on paved low-volume roads. It describes (a) a successful attempt to develop a rehabilitation program within the severe financial constraints of a developing country's limited budget and (b) the evaluation techniques used to determine the economic viability of that program. The rehabilitation evaluation is representative of the current state of analyses for rehabilitation and maintenance programs.

Research Record 702 (Transportation Research Board, 1979). Describe la evaluación económica utilizada para determinar el factor de eficacia, en lo que respecta al costo, de un método sencillo (realizado por mano de obra) de rehabilitación y conservación de superficies bituminosas muy deterioradas en la isla de San Vicente del Caribe Oriental. Este texto presenta los resultados de una conservación atrasada en caminos pavimentados de bajo volumen. Describe (a) un esfuerzo que resultó en buen éxito para desarrollar un programa de rehabilitación dentro de los severos límites financieros del presupuesto confinado de un país en desarrollo, y (b) las técnicas de evaluación que se utilizaron para determinar la viabilidad económica de ese programa. La evaluación de la rehabilitación es representativa del estado actual de los análisis para programas de rehabilitación y conservación.

El texto subraya la necesidad de un buen drenaje como primer paso en cualquier programa de conservación o mejora; y evalúa la magnitud de costos periódicos de drenaje en un programa de conservación de caminos pavimentados. Después de este proyecto de rehabilitación los fondos de conservación designados al drenaje son tres veces más que los designados al bacheo de superficie.

También demuestra el uso de la rugosidad de la superficie para medir el rendimiento del camino. Ahorros en los costos de operación de vehículo se relacionan directamente con la reducción de la rugosidad. La evaluación económica del proyecto se basa en reducciones medibles de la rugosidad de la superficie por medio de su rehabilitación, y reducciones en el costo de operación de vehículo debido a la mejora en la calidad de rodadura del camino.

Las cifras monetarias en este texto se dan en dólares del Caribe Oriental del año 1978. Los costos del texto deberán dividirse por 2,7 para llegar al valor en dólares Norteamericanos de

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terminer la rentabilité d'une méthode simple, à l'aide de l'emploi intensif de main-d'oeuvre, pour réhabiliter et entretenir des routes bitumées sérieusement détériorées dans l'ile de Saint Vincent. Ce texte expose le résultat d'une politique d'entretien différé sur des routes revêtues à faible circulation. On y décrit (a) une tentative, couronnée de succès, de réhabilitation routière dans le cadre des sévères contraintes monétaires du budget limité d'un pays en voie de développement, et (b) les techniques d'évaluation utilisées pour déterminer la viabilité économique de ce programme. L'évaluation de la reconstruction est représentative de l'état actuel des analyses de programmes de réhabilitation et d'entretien routiers.

On met l'emphase sur la nécessité première de fournir un drainage adéquat, dans un programme d'amélioration ou d'entretien. On évalue aussi l'ordre de grandeur du coût périodique du drainage dans un programme d'entretien de routes revêtues. Les dotations pour l'entretien, après ce programme de rèhabilitation prévoient presque trois fois plus d'argent pour l'entretien du système de drainage que pour le reflachage. On démontre aussi l'utilisation de la mesure de l'uni pour vérifier la performance de la route. Les économies de coût d'exploitation des véhicules sont rattachées directement à la réduction de la rugosité de la chaussée. L'évaluation économique du projet est basée sur la réduction mesurée de la rugosité, accomplie en réhabilitant la surface, et sur la réduction du coût d'exploitation des véhicules, dûe à l'amélioration de la qualité de roulement de la route.

On utilise le dollar local (Caraïbe de l'Est) pour

The text emphasizes the necessity of providing proper drainage as the first step in any maintenance or upgrading program. It also evaluates the magnitude of recurring drainage costs in a paved road maintenance program. The maintenance funding after this rehabilitation project includes almost three times as much money for drainage maintenance as for surface patching.

The text also demonstrates the use of surface roughness to monitor road performance. The savings in vehicle operating costs are related directly to the reduction in surface roughness. The economic evaluation of the project is based on measurable reductions in surface roughness through surface rehabilitation and the vehicle operating cost reduction due to the improved riding quality of the road.

The currency figures in this text are given in 1978 Eastern Caribbean dollars. The costs given in the text should be divided by 2.7 to give the values in 1978 U.S. dollars or by 5.2 to give the values in 1978 pounds sterling.

The seventh text, ***Outline of a Generalized Road Roughness Index for Worldwide Use,*** was also published in ***Transportation Research Record 702*** (Transportation Research Board,

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1978, o por 5,2 para el valor en libras esterlinas de 1978.

El séptimo texto, ***Outline of a Generalized Road Roughness Index for Worldwide Use*** (Esquema de un índice generalizado de rugosidad de camino para uso mundial), fué también publicado en ***Transportation Research Record 702*** (Transportation Research Board, 1979). El texto previo indica que los costos de operación de vehículo son una función de la rugosidad del camino. Los costos del usuario se relacionan especialmente a la rugosidad en caminos muy fragosos. En este momento existen varios métodos de medir la rugosidad de la superficie pero no hay una escala común de rugosidad para uso mundial.

El texto define la rugosidad y sus componentes. Describe las dos técnicas que comúnmente se utilizan para analizar los componentes de rugosidad, es decir la integración mecánica y la matemática. La integración mecánica, que es el método más común, consiste en el uso de un instrumento mecánico para automáticamente filtrar y resumir los datos de rugosidad de camino. Los instrumentos más utilizados corrientemente incluyen el perfilógrafo (Profilograph), el medidor PCA (PCA Roadmeter), el medidor Mays (Mays Meter), el rugosímetro Chloe (Chloe Profilometer), y el medidor BPR (BPR Roughometer), inclusive una versión que ha sido modificada por el TRRL del Reino Unido. La integración matemática, el segundo método, involucra el análisis matemático de una serie de distintos puntos hallados por un deslinde con vara y nivel topográficos.

Estos distintos análisis de rugosidad no son compatibles actualmente porque se han utilizado distintos tipos de dispositivo y ha habido

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les calculs. Les coûts mentionnés dans ce texte, doivent être divisés par 2,7 pour l'échange en dollars U.S. (1978), ou par 5,2 pour l'échange en livres sterling.

Le septième texte, ***Outline of a Generalized Road Roughness Index for Worldwide Use*** (Schéma d'un indice généralisé de l'uni d'une chausées, d'emploi universel), est aussi publié dans le ***Transportation Research Record 702*** (Transportation Research Board, 1979). Le texte précédent nous a indiqué que le coût d'exploitation des véhicules est fonction de l'uni de la surface. Les coûts aux usagers y sont particulièrement rattachés lorsque les routes sont très mauvaises. Acutellement, il y a plusieurs méthodes pour mesurer l'uni, mais il n'en n'existe pas d'échelle de calibration commune au monde entier.

Le texte donne une définition de la qualité de l'uni d'une chaussée et de ses composantes. On décrit les deux procédés utilisés généralement pour analyser les composantes, c'est à dire l'intégration mécanique et l'intégration mathématique. L'intégration mécanique, qui est la méthode la plus courante, utilise un appareillage mécanique pour filtrer et résumer automatiquement les données. Les instruments les plus utilisés actuellement, pour les mesures mécaniques et les résumés, comprennent le profilographe, le PCA Roadmeter, le Mays meter, le profilomètre Chloe, et le rugomètre BPR (est incluse aussi une version qui a été modifiée par le Laboratorie de recherches sur les transports et la route, Grand Bretagne). La seconde méthode, l'intégration mathématique consiste à analyser mathématiquement une série de points discrets obtenus avec la mire de nivellement.

Ces méthodes d'analyse ne sont pas actuellement compatibles. C'est à dire que les résultats d'un pays n'ont pas de rapport quantitatif ou significatif avec ceux d'un autre

1979). The previous text indicated that vehicle operating costs are a function of road roughness. User costs are particularly related to road roughness on very rough roads. At this time there are several methods of measuring surface roughness, but there is no common roughness scale for worldwide use.

The text defines roughness and its components. It describes the two techniques commonly used to analyze the components of roughness, namely mechanical integration and mathematical integration. Mechanical integration, the most common method, is the use of a mechanical device to automatically filter and summarize the road roughness data. The most common instruments in current use for mechanical measurement and summary include the Profilograph, the PCA Roadmeter, the Mays Meter, the Chloe Profilometer, and the BPR Roughometer (including a version that has been modified by the U.K. TRRL). The second method, mathematical integration, involves mathematically analyzing a series of discrete points found by a rod-and-level survey.

These various roughness analyses are currently not compatible — that is, the results from one country do not have a quantitative relation or meaning to those of another country. Different types of devices used and calibration problems between units of the same type are the reasons for this. This text proposes the development of a General Roughness Index to serve as a basis for comparison between individual mechanical devices and different types of mechanical devices. Such an index would enhance the use of surface profiles or roughness measurements throughout the world for (a) construction quality control; (b) location of abnormal changes in roads due to, for example, drainage or subsurface problems; (c) systemwide allocation of pavement maintenance resources; and (d) identification of pavement serviceability-performance histories.

The eighth text is ***A Review of Rural Traffic-Counting Methods in Developing Countries***

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problemas de calibración entre unidades del mismo tipo. Por eso los resultados de un país no tienen relación cuantitativa o significado para otro país. Este texto propone el desarrollo de un Indice General de Rugosidad que sirva como base de comparación entre los dispositivos mecánicos individuales y entre distintos tipos de dispositivo. Tal índice aumentaría el valor en utilizar perfiles de superficie o medidas de rugosidad en todo el mundo para (a) el control de calidad en la construcción; (b) la localización de cambios anormales en el camino debido a, por ejemplo, problemas de drenaje o subálveas; (c) distribución de recursos para la conservación del pavimento a través del sistema; y (d) identificación de antecendentes de la utilidad y rendimiento del pavimento.

El octavo texto es ***A Review of Rural Traffic-Counting Methods in Developing Countries*** (Un repaso de los métodos de conteo de tránsito rural en los países en desarrollo, Transport and Road Research Laboratory, U.K., 1972). Se ha incluído porque la tercera entrada principal de información en la evaluación económica de las es-

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pays. Ceci à cause de l'utilisation de différents appareils et de problèmes de calibration entre certains du même type. Ce texte propose le développement d'un "indice de l'uni universel" qui puisse servir de référence pour comparer chaque appareil mécanique individuellement, et les différentes sortes d'appareils mécaniques. Un tel indice intensifierait l'emploi des mesures des profils de la surface et de l'uni à travers le monde pour (a) le contrôle de qualité en construction; (b) la localisation de changements anormaux de la surface routière dûs par exemple à des problèmes de drainage ou de sous-sol, (c) les dotations pour l'entretien des chaussées de tout le réseau routier, et (d) l'identification des antécédents de viabilité et de rendement des chaussées.

Le huitième texte s'intitule ***A Review of Rural Traffic-Counting Methods in Developing Countries*** (Revue des méthodes de comptage de trafic dans les pays en voie de développement, Transport and Road Research Laboratory, U.K., 1972). Nous l'avons inclus, car la troisième composante principale de l'évaluation économique des stratégies d'entretien, est le nombre et le genre de véhicules utilisant la route à entretenir. (Les deux autres composantes étant le coût de l'entretien et le coût d'exploitation des véhicules.) En dépit des avertissements donnés dans le texte choisi no. 2, que la détermination du coût d'entretien varie d'un endroit à l'autre, et pour différents niveaux de service, et ceux du texte choisi no. 4 que la base de données empiriques concernant le coût d'exploitation est quelque peu limitée, aucun des textes précédents n'envisage la possibilité que la détermination du volume de trafic de base puisse être inexacte.

(Transport and Road Research Laboratory, U.K., 1972). It is included because the third major input to the economic evaluation of maintenance strategies is the number and type of vehicles using the roads to be maintained. (The other inputs are maintenance costs and vehicle operating costs.) In spite of the warnings given in Selected Text No. 2 that the determination of maintenance costs varies from place to place and for various levels of service and in Selected Text No. 4 that the empirical data base concerning vehicle operating costs is somewhat limited, none of the previous texts address the possibility that determination of the base traffic volume may be inaccurate.

This text reviews the methods of rural traffic counting in use in developing countries in 1970 and examines the accuracy of the resulting flow estimates. Although the duration, frequency, and timing of traffic counts vary for the different countries studied, all the counting techniques produce random samples of traffic volumes rather than a true ADT. The errors in ADT estimates from random counts are a function of the following:

1. The flow level of traffic (low traffic volumes are subject to greater errors than high traffic volumes),
2. The duration of the count (the accuracy of the resulting ADT estimates increases more or less in proportion to the square root of duration),
3. The repetition of the count (the errors from repeated counts are approximately proportional to the inverse of the square root of the overall duration of counting), and
4. The time of the count (the samples from different months or seasons vary in different degrees from the true ADT).

The ninth text is excerpted from ***The Sensitivity to Traffic Estimates of Road Planning in Developing Countries*** (Transport and Road Research Laboratory, U.K., 1973). It evaluates the impact on the decision-making process in planning road maintenance and improvement of the counting errors discussed in the previous text. This text assumes that the total maintenance

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trategias de conservación es la cantidad y tipo de vehículos que utilizan los caminos a conservarse. (Las otras entradas son los costos de conservación y los de operación de vehículo.) Aún cuando el Texto Seleccionado N° 2 menciona que la determinación de costos de conservación varía de lugar en lugar y para los distintos niveles de servicio, y el Texto Seleccionado N° 4 nota que la base empírica de datos respecto a los costos de operación de vehículo es algo limitada, ningún texto previo menciona que la determinación del volumen de tránsito base posiblemente sea errónea.

Este texto repasa los métodos de conteo de tránsito rural en los países en desarrollo en 1970 y examina la precisión de los estimados de flujo resultantes. Aunque la duración, frecuencia, y programación de los conteos de tránsito varían en los distintos países estudiados, todas las técnicas de conteo producen muestras al azar de volúmenes de tránsito en lugar de un verdadero ADT. Los errores de estimados de ADT calculados a base de conteos al azar son una función de lo siguiente:

On passe en revue les méthodes de comptage du trafic rural utilisées dans les pays en voie de développement, et on examine l'exactitude des calculs de flux de trafic. Bien que la durée, la fréquence et la période de l'année des comptages de trafic varient pour les différents pays étudiés, toutes les techniques de comptage produisent des comptages de traffic faits au hasard plutôt qu'un véritable trafic journalier moyen (TJM). Les erreurs dans le calcul du TJM fait au hasard sont fonction de:

1. Le niveau de flux du trafic (les petits volumes de trafic sont sujets à de plus grandes erreurs que les volumes de trafic très importants).
2. La durée du comptage (l'exactitude des calculs du TJM augmente plus ou moins en proportion à la racine carrée de la durée).
3. La répétition du comptage (les erreurs provenant de comptages répétés sont à peu près en proportion avec l'inverse de la racine carrée de la durée totale du comptage).
4. La période de l'année du comptage (les échantillons de mois différents ou de saisons différentes varient, à différents degrés, du TJM exact).

Le neuvième texte est extrait de ***The Sensitivity to Traffic Estimates of Road Planning in Developing Countries*** (La sensibilité de la planification routière aux calculs de trafic dans les pays en voie de développement, Transport and Road Research Laboratory, U.K., 1973). On évalue l'impact, sur le procédé de prise de décision en planification de l'entretien et de l'amélioration routiers, des erreurs de comptage, que nous cost per year per unit length is equal to a fixed sum plus the ADT times a constant. This assumption of estimating maintenance cost as a linear function of traffic is now outmoded, as is shown in the previous texts. However, it does permit the development of a simplified relation of traffic volumes to maintenance costs. The ratio of the percentage change in maintenance cost to the percentage change in traffic flow level is defined as the sensitivity ratio.

The sensitivity of criteria used for the economic justification for road improvements, as represented by the sensitivity of the Internal Rate of Return (IRR) to changes in the estimated present daily traffic and traffic growth, is tested against 10 road projects in developing countries. The analysis shows that the IRR is generally very sensitive to errors in estimates of present daily traffic and is somewhat less sensitive to errors in traffic growth. This is due, perhaps, because the

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1. el nivel de flujo del tránsito (hay mayor error en los volúmenes bajos de tránsito que en los volúmenes altos),
2. la duración del conteo (la exactitud de los estimados resultantes de ADT aumenta más o menos en proporción a la raíz cuadrada de la duración),
3. la repetición del conteo (los errores de repetidos conteos son aproximadamente proporcional a la inversa de la raíz cuadrada de la duración total del conteo), y
4. la programación del conteo (las muestras de distintos meses o temporadas varían en distintos grados del verdadero ADT).

El noveno texto fué extraído de ***The Sensitivity to Traffic Estimates of Road Planning in Developing Countries*** (La sensitividad de planeamiento vial en países en desarrollo a los estimados de tránsito, Transport and Road Research Laboratory, U.K., 1973). Evalúa el impacto del proceso de toma de decisiones en el planeamiento de conservación vial, y la diminución de errores de conteo examinados en el texto anterior. Este texto asume que el costo total de conservación por año por largo de unidad es igual a una cifra fija más ADT multiplicado por un constante. Se ha demostrado en los textos anteriores que esta suposición del estimado del costo de conservación como función lineal del tránsito es anticuado. Sin embargo nos permite desarrollar una relación simplificada entre volúmenes de tránsito y costos de conservación. La relación del cambio de porcentaje en el costo de conservación al cambio de porcentaje en el nivel de flujo de tránsito se define como la relación de sensitividad.

La sensitividad de criterios utilizados para la justificación económica para mejoras viales, como es representada por la sensitividad del Coeficiente de Ingresos Internos (Internal Rate of Return — IRR) a cambios en los estimados actuales del tránsito diario y el aumento de trán-

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avons discutées dans le texte précédent. Ce texte assume que le coût total annuel unitaire de l'entretien est égal à une somme fixe, plus le TJM, multipliés par une constante. Le fait d'assumer le coût d'entretien comme fonction linéaire du trafic est maintenant démodé, comme nous l'avons vu dans les textes précédents. Cependant, cela permet le développement d'un rapport simplifié entre le volume de trafic et le coût d'entretien. Le rapport du changement en pourcentage du coût d'entretien, au changement en pourcentage du niveau de flux du trafic, s'appelle le rapport de sensibilité.

La sensibilité des critères utilisés pour la justification économique des améliorations routières, représentée comme la sensibilité du taux de rentabilité interne (IRR) aux changements du trafic journalier actuel et futur, est mise à l'épreuve sur 10 projets routiers de pays en voie de développement. L'analyse montre que l'IRR est en général très sensible aux erreurs dans le calcul de trafic journalier actuel, et est quelque peu moins sensible aux erreurs dans le calcul de la croissance du trafic. Cela est dû, peut-être, à ce que l'actualisation des avantages des améliorations routières, réduit l'effet de incertitudes à long terme.

On évalue aussi la sensibilité du IRR: (a) à la composition du trafic actuel (la sensibilité augmente avec le pourcentages des véhicules lourds), (b) au trafic induit, et (c) aux changements de la composition du trafic avec le temps. Une discussion des erreurs communes dans le calcul des deux dernière projections de trafic est incluse.

Bibliographie

Les textes choisis sont suivis d'une brève bibliographie contenant les données de référence et discounting with time of the benefits from road improvement reduces the effect of long-term uncertainties.

The text also evaluates the sensitivity of the IRR to (a) the present traffic composition (the sensitivity increases as the percentage of heavy vehicles increases), (b) induced traffic, and (c) changes in traffic composition with time. It includes a discussion about common errors in the determination of the latter two traffic projections.

Bibliography

The selected texts are followed by a brief bibliography containing reference data and abstracts for 24 publications. The first 9 describe the selected texts. The other 15 describe publications related to the selected texts. Although there are many articles, reports, and books that could be listed, it is not the purpose of this bibliography to contain all possible references related to the subject of this compendium. The bibliography contains only those publications from which a text has been selected or basic publications that would have been selected had there been no page limit for this compendium.

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sito, se ensaya en 10 proyectos viales en países en desarrollo. El análisis indica que generalmente el IRR es muy sensitivo a errores en los estimados de tránsito diario actual, y algo menos sensitivo a errores en el aumento de tránsito. Esto es debido, quizás, a que con el paso del tiempo la disminución de los beneficios de mejoras viales, reduce el efecto de lo incierto a largo plazo.

El texto también evalúa la sensitividad del IRR a (a) la composición actual de tránsito (la sensitividad aumenta a medida que aumenta el porcentaje de vehículos pesados), (b) tránsito inducido, y (c) cambios en la composición del tránsito al pasar el tiempo. Incluye una sección que habla sobre errores comunes en la determinación de las dos últimas proyecciones de tránsito.

Bibliografía

Al final de los textos seleccionados el lector encontrará una breve bibliografía que contiene los datos y abstractos de referencia para 24 publicaciones. Las primeras nueve referencias describen los textos seleccionados. Las otras 15 describen publicaciones relacionadas con los textos seleccionados. Aunque existen muchos artículos, informes, y libros que podrían nombrarse, no es el propósito de esta bibliografía mencionar todas las posibles referencias que se relacionen con el tema de este compendio. Contiene únicamente aquellas publicaciones de las cuales se seleccionó texto y publicaciones básicas que se habrían seleccionado si no hubiera un límite al número de páginas en este compendio.

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les analyses de 24 publications. Les 9 premières s'en réfèrent aux textes choisis. Les 15 autres décrivent des publications apparentées au thème des textes choisis. Bien qu'il y ait beaucoup d'articles, rapports et livres qui pourraient être inclus, l'objectif de cette bibliographie n'est pas d'énumérer toutes les références possibles ayant rapport au sujet de ce recueil. Cette bibliographie se rapporte seulement aux publications dont nous avons choisi des extraits, ou à des textes de base que nous aurions choisis aussi s'il n'y avait pas de limite quant au nombre de pages de ce recueil.

Selected Texts

This section of the compendium contains selected pages from each text that is listed in the table of contents. Rectangular frames are used to enclose pages that have been reproduced from the original publication. Some of the original pages have been reduced in size to fit inside the frames. No other changes have been made in the original material except for the insertion of occasional explanatory notes. Thus, any errors that existed in the selected text have been reproduced in the compendium itself.

Page numbers of the original text appear inside the frames. Page numbers for the compendium are outside the frames and appear in the middle left or middle right outside margins of the pages. Page numbers that are given in the table of contents and in the index refer to the compendium page numbers.

Each text begins with one or more pages of introductory material that was contained in the original publication. This material generally includes a title page, or a table of contents, or both. Asterisks that have been added to original tables of contents have the following meanings:

*Some pages (or parts of pages) in this part of the original document appear in the

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Textos seleccionados

Esta sección del compendio contiene páginas seleccionadas de los textos catalogados en la tabla de materias. Se utilizan recuadros rectangulares para encerrar las páginas que han sido reproducidas de la publicación original. Algunas de las páginas originales han sido reducidas para entrar en los recuadros. No se han hecho ningunos otros cambios en el material original exceptuando algunas notas aclaradoras que de vez en cuando han sido agregadas. De esta forma, cualquier error que hubiera existido en el texto seleccionado ha sido reproducido en el compendio mismo.

Los números de página del texto original aparecen dentro de los recuadros. Los números de página para el compendio están fuera de los recuadros y aparecen en el centro del márgen izquierdo o derecho de cada página. Los números de página que se dan en el índice del compendio se refieren a los del compendio.

Cada texto comienza con una o más páginas de material de introducción que contenía la publicación original. Este material generalmente incluye una página título, un índice, o ambos. Los asteriscos que han sido agregados al índice original significan lo siguiente:

*Algunas páginas (o partes de página) en esta parte del documento original aparecen

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Textes choisis

Cette partie du recueil contient les sections extraites des publications indiquées à la table des matières. Les pages du texte original qui sont reproduites, sont entourées d'un encadrement rectangulaire. Certaines pages ont dû être réduites pour pouvoir être placées dans l'encadrement. Le texte original n'a pas été changé sauf pour quelques explications qui ont été insérées. Donc, si le texte original contient des erreurs, elles sont reproduites dans le recueil.

La pagination originale apparaît à l'intérieur de l'encadrement. La pagination du recueil est à l'extérieur de l'encadrement, soit à droite, soit à gauche de la marge extérieure des pages, et est celle qui est citée dans la table des matières et dans l'index du recueil.

Chaque texte commence par une ou plusieurs pages d'introduction qui étaient incluses dans le texte original. Ces pages sont généralement le titre, ou la table des matières, ou les deux. Des astériques ont été ajoutés à la table des matières d'origine, pour les raisons suivantes :

*Certaines pages, ou portions des pages, dans cet extrait du document original sont selected text, but other pages (or parts of pages) in this part of the original publication have been omitted.

**All pages in this part of the original document appear in the selected text.

The selected texts therefore include only those parts of the original documents that are preceded by asterisks in the tables of contents of the respective publications.

Broken lines across any page of selected text indicate those places where original text has been omitted. In a number of places, the selected text contains explanatory notes that have been inserted by the project staff. Such notes are set off within dashed-line boxes and begin with the word NOTE.

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en el texto seleccionado, pero otras páginas (o partes de página) en esta parte de la publicación original han sido omitidas.

**Todas las páginas en esta parte del documento original también aparecen en el texto seleccionado.

Por lo tanto, los textos seleccionados únicamente incluyen aquellas partes de los documentos originales que están precedidas por asteriscos en el índice de las publicaciones respectivas.

Líneas de guiones cruzando cualquier página del texto seleccionado significan que en ese lugar se ha omitido texto original. En varios lugares el texto seleccionado contiene notas aclaradoras que han sido introducidas por el personal del proyecto. Tales notas están insertadas en recuadros de guiones y comienzan con la palabra NOTE.

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incluses dans les textes choisis, mais d'autres pages (ou portion de pages) de l'édition originale ont été omises.

**Toutes les pages dans cet extrait du document original sont incluses dans les textes choisis.

Les textes choisis, donc, incluent seulement ces extraits des documents originaux qui sont précédés d'un astérique dans les tables des matières des publications respectives.

Les lignes brisées sur les pages des textes choisis indiquent les endroits où le texte original a été omis. A certains endroits, les textes choisis contiennent des explications qui ont été insérées par notre personnel. Ces explications sont entourées d'un encadrement en pointillé, et commencent toujours par le mot NOTE.

XVI[th] WORLD ROAD CONGRESS VIENNA SEPTEMBER 16–21, 1979

ECONOMIC AND FINANCE COMMITTEE REPORT

PERMANENT INTERNATIONAL ASSOCIATION OF ROAD CONGRESSES
SECRETARIAT GENERAL:
43, AVENUÉ DU PRÉSIDENT-WILSON, PARIS XVI^{e}
AUSTRIAN NATIONAL COMMITTEE:
A-1010 VIENNA 1, ESCHENBACHGASSE 9

CONTENTS

B. THE ECONOMIC ISSUES OF HIGHWAY MAINTENANCE

Introduction

1. For major new highway investment, most countries employ some sort of overall planning procedure: in some cases, such new investment has to pass a test of adequate economic return. In comparison, highway maintenance is something of a Cinderella: commonly there is as yet no unification and standardisation of assessment method within invididual countries. There is little in the way of the application of formal economic criteria to highway maintenance operations. Yet highway maintenance is obviously important, not least in terms of expenditure; in Great Britain for instance, expenditure on maintenance is running at about £500m per annum, approaching a half of all highway expenditure. To consider the subject as being a problem is therefore appropriate.

2. "Highway Maintenance" is not easy to define precisely. In fact, it is in practice very difficult to separate completely highway maintenance from minor road improvements, because the latter will often be carried out as part of the same operation. What we understand by "maintenance" is, strictly, road work carried out without altering the boundaries of an existing carriageway. But also, extra costs incurred during construction in order to save later maintenance (eg adopting an increased pavement thickness) could, in an ideal set of accounts, be attributed to maintenance rather than to construction itself.

3. In Great Britain, in common with other countries, road maintenance is a 5
highly decentralised activity. Central Government only has direct responsibility for maintaining trunk roads and motorways, albeit that these are the most heavily trafficked part of the network and incur about 15% of total expenditure. Local authorities are responsible for all the rest in the sense that they spend the money, decide the work to be carried out, and the particular maintenance standards to be aimed at. Local authority roads represent over 95% of the total network. But a large part of local authority maintenance work is funded by Central Government grant, the distribution of which is determined in discussion with the authorities' associations. It is in this context, and particularly to help local authorities in deciding their own priorities for maintenance, that there is an urgent need to determine in economic terms the correct level of expenditure for maintenance, the standards to be aimed at, and appropriate assessment method.

Economic Perspective and Issues

4. We adopt in this sub-report an economic perspective on highway maintenance. Economics is concerned with the allocation of available resources between alternative uses. In this context, we are concerned particularly with the *efficient* allocation of resources, questions concerning the distributional effect of allocations between various sectors of the community being here of lesser concern.

5. Given this perspective, a number of issues can be immediately identified. Some of these relate to misconceptions concerning the application of economic principles to highway maintenance; others to general difficulties of putting into practice a fully economic approach, at least at the present time. We deal with these in order.

6. Issues involving *misconceptions* from an economic point of view are as follows:

   i. There is a fairly widespread belief, among both engineers and members of the public, that highways should be perfectly maintained. For instance, it is believed that access should always be maintained, implicitly under even the worst winter conditions (and by "worst" here we ought perhaps to interpret the desire statistically, as say the worst winter in 50 years). It is also believed that pot holes, trips in footways, and so on represent some dereliction of professional duty: and often these beliefs are given legal sanction. Such views are in sharp contrast with a rational, economic perspective. The latter recognizes the extremely high cost of seeking perfection in such matters (for instance, the cost of all the extra equipment needed for the worst winter). It seeks instead simply to balance the extra costs associated with an improvement in service against the extra benefits yielded.

   ii. Closely related to this is a belief, held particularly by engineers, that a road is a national asset, the maintenance of which is therefore justified in its own right. This is erroneous because if a road is not used it is of no value; its value derives solely from its present and future use and is thus directly related to the traffic level. Road maintenance cannot be assumed so self-evidently necessary that no questioning of the scale and balance of resources involved is warranted.

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   iii. Correspondingly, any preconception, such as is sometimes held by finance ministries, that maintenance costs should be minimised, is also erroneous. It is wrong to imagine that in matters of maintenance the ideal is to get through a year having spent the least possible. Less maintenance means a lower quality of service given in the course of the year.

   iv. We wrote above of the traffic level as being the main determinant of value and thus maintenance expenditure. But we recognise additionally that road maintenance has a general beneficial effect on the environment or "quality of life". For instance, decisions are positively taken to maintain better embankments, because this makes them more pleasant, and other roadside features, such as road signs through their cleanliness.

   v. The annual cost of maintaining a stretch of road is typically only of the order of 1% of the cost of constructing it. From the above however, any argument for more maintenance based on the smallness of this *percentage* is irrelevant – although of course the *absolute* magnitude of the consequences may dictate priorities.

vi. Level of service criteria are commonly employed for maintenance decisions, as well as for new construction: simplicity of approach makes this desirable. If benefits are related fairly directly to level of service, this is obviously reasonable from an economic viewpoint as well. But the corresponding cost must always be considered, as our extreme winter example indicates. Moreover, the pressures on public expenditure now are such that a common level of service cannot be afforded for everyone on an equitable basis. This can readily be agreed for another extreme example: a man who takes himself off to live on Mont Blanc and demands, on equity grounds, that he is given the level of service in terms of road access that is a proper expectation in a modern society. This example raises some difficult distributional issues: but its general message is clear. There is some general recognition of this problem but at the same time there is some general expectation of equity.

vii. Finally, a frequent argument for increased maintenance funds is that their shortage will lead to the need for increased expenditure later, because roads will then be in worse condition. This argument is valid in principle; but its correctness depends on the increase in expenditure involved in delay and the discount rate applicable in comparing present and future expenditures.

A strong warning is thus necessary against a number of conceptual errors that are commonly made on the subject of highway maintenance. 7

7. We now turn to general issues in *putting into practice* a fully economic discipline for highway maintenance activities. These arise both from the highly disaggregated and from the amorphous nature of highway maintenance: firstly, many individual maintenance activities are extremely small in scale (consider again pothole repair), so that the control of all individual activities cannot be centralised; and secondly, many operations, particularly those of a "cyclical" character such as sign cleaning, gully emptying and grass cutting, are amorphous in nature. This has meant that it is very difficult for a government authority to know what is going on in highway maintenance as a general picture; it is furthermore difficult to establish standards for maintenance – both standards to aim at in repair and also intervention standards – that have any uniformity of application in all the variability of local circumstances, including particular local resource constraints. There is in fact a considerable tension between the whole concept of such engineering standards, intended for a uniformity of application, and a fully economic approach in which what is done should depend ideally on the particular benefits that are expected from the individual maintenance activity, the particular cost of the work involved, all subject to both national and local resources constraints in terms of expenditure and manpower.

Furthermore the latter will and should vary considerably over time, whereas the whole concept of standards is as something fixed and absolute.

8. This problem also appears in a different guise in the relationship between the overall expenditure budget available for highway maintenance, either national or for the particular area, and the myriad of individual maintenance activities on which this expenditure is incurred. Properly, the overall budget should reflect the myriad of perceived needs, each objectively assessed, for the future period in question; but the problems of the foresight, individual assessment, and aggregation needed to produce plans which vary with the overall resources available are such that all this is beyond current capabilities. Resource budgets, both national and local, naturally tend to have a strong stability in their own right. Conversely, the short lead time of maintenance works makes them a favourite focus for short-term changes in central government policy with regard to expenditure or employment. Both these factors may obviously be contrary to a truly efficient allocation of resources.

Some Current Technical Problems

9. At the present time, we cannot therefore say that the approach we advocate has been successfully translated into practice. There are also the following current problems of a *technical* nature that have to be overcome or resolved before we can be assured that highway maintenance operations have an efficient basis:—

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a. All maintenance operations have to be clearly categorised by distinct function for accounting purposes. At the margin, these distinctions will involve a degree of artifice. However, it seems likely that given a strong enough will, an acceptable national categorisation can be effected. An important initial division is between cyclical and non-cyclical (ie structural) maintenance. Examples of existing categorisations are shown in the attached tables for Belgium, the Federal Republic of Germany, France, Great Britain and Poland – as a result of effort over the last several years, a standard of classification for highway maintenance in England is now agreed by all concerned;

b. Standard measures of actual road condition have to be identified and agreed (eg rut depth, degree of cracking); in highway maintenance, a major problem is that there are few in the way of obvious, single measures to adopt. The use of machines, such as the Deflectograph for measuring pavement deflection to indicate residual life, and Scrim to indicate the coefficient of friction, may be desirable. This problem has naturally led to the adoption of comprehensive maintenance rating systems, such as the British CHART, aggregating the deficiences of a stretch of road in some weighted points rating, but which are nevertheless neither fundamental physically nor essentially economic;

c. There is also a need for definition of the basic structural characteristics of existing roads, because the appropriate solution to an obvious deficiency is often dependent on "what lies beneath the surface", and, particularly in the case of older, more minor roads, this latter is frequently unknown. The establishment of a road inventory for road maintenance purposes is a frequently expressed objective.

d. In the case of a pavement, it is presumably economic to re-surface rather than to await the need for a complete reconstruction. But the correct timing of resurfacing operations can be critically dependent on the rate at which a pavement deteriorates after the initial warning signals. There is still too little knowledge about rates of pavement deterioration, especially for the older, "undesigned" roads;

e. In Great Britain, at least, there is as yet insufficient available in the way of unit cost information for maintenance operations eg a "standard" cost for pot-hole patching. Obviously we cannot analyse a maintenance situation to determine the most efficient strategy if we do not know the costs of carrying out one type of operation compared with an alternative;

f. We know relatively little about the *benefits* of maintenance, for instance: reductions in speed with road conditions; rates of vehicle deterioration; accident rates. In this ignorance, the full cost benefit analysis approach cannot be applied. But we *do* know, if we accept that the prime purpose of roads is to carry traffic, that maintenance expenditure should be directly related to the traffic flow, and therefore not necessarily simply to the class of road. This does lead to the possibly useful concept of a *maximum* maintenance value for a particular road, corresponding to the maximum value of the benefits realisable by it;

g. In the absence of the complete cost benefit analysis, there must be resort to using engineering standards for maintenance operations. But such standards *must* be related to economic considerations; experience has shown that otherwise they will be impracticably luxurious. Standards must define both an intervention and a restoration level. Some countries already carry out their maintenance operations fairly consistently according to a national set of standards eg Finland;

h. Accepting its proper importance in determining maintenance decisions, the counting of traffic flow for the purpose is by no means straightforward. Traffic flow sensibly varies from link to link: it should therefore be identified for each link, which is a major task. Moreover in terms of damage, as opposed to benefits, it is heavy traffic, specifically heavy axles, which is responsible for pavement damage; there is currently no satisfactory, standardised way of carrying out heavy axle counts simply and comprehensively over the complete network;

i. The focus of the above remarks has been pavement maintenance, which typically constitutes a substantial fraction of the whole. However, there are many other types of maintenance operation, typically of a "cyclical" character, such as grass cutting, sign cleaning, gulley emptying. Any objective, economic analysis of these in the above terms is obviously more difficult still.

Some Current Directions of Development

10. The difficulties of applying a full economic discipline to highway maintenance are thus very considerable, far greater than in the highway construction field. In the state of affairs identified above, it is at least not clear that resources are being used efficiently on highway maintenance – with the problems exposed, and in the absence of better knowledge, it is only sensible to assume that much needs to be done before we have the assurance that the overall expenditure incurred on highway maintenance is too high; but also possible that it is too low. The total amount of public expenditure involved, and the resources it represents, justifies a considerable concern.

11. Such a concern has existed in England for more than a decade now. And in recent years, encouraging progress has been made in tackling some of the fundamental problems, by both central government and local government working in consort. The principle generally accepted is the economic one outlined in this paper, as far as it can be given sufficient
10 realisation. It is thus seen that maintenance expenditures should be related to the resulting benefits over time, taking into account the appropriate discount rate. This has been given expression in a formal economic model called PAVMO, which is focused on optimising expenditure decisions on particular stretches of road, by comparing cost streams with benefit streams. In some, but not all, situations, it could well be that decisions are appropriately taken on the basis of minimising the total discounted stream of costs and ignoring user benefits such as time savings and comfort. But further work needs to be done to make this model operational, particularly on the engineering inputs, as already indicated. One plan to provide such information is to carry out a series of site experiments in order to assess the user and maintenance costs associated with alternative maintenance strategies and treatments; but the very nature of the subject means that this would take several years to complete because of the need to obtain data over complete maintenance cycles.

12. One of the difficulties in the field of highway maintenance is that of obtaining pictures at a national level of what is going on, as already mentioned. But at the national level, a relatively straightforward way of endeavouring to judge the size of the national highway maintenance expenditure is from a knowledge of the trend of national road conditions over time. A time series of conditions on an adequate national sample of sites should at least indicate whether things are getting better or worse

(although it will be recognised that this is not the fully economic approach propounded above.) Such a survey has been established in England, called the National Road Maintenance Condition Survey, which is now in its third year, in which specific road defects are identified and measured on a large number of sample sites. Here the problem currently being faced is how to combine all these separate measurements to give a simple, overall indication of condition, the problem of Paragraph 9b. Also, as a separate piece of work, a regular analysis is carried out by central government of maintenance expenditure by sub-head for all local authority areas, using regression analysis with independent parameters such as traffic levels, kilometres of road in the area by class, etc, in order to see whether any clear pattern emerges between different authorities' spending on this relatively simple basis. This regression analysis is fairly sophisticated, although the need for further development is recognised, and it is not yet fully accepted by all concerned.

Final Remarks

13. Our whole address is directed towards an eventual, rational answer to the maintenance engineer's question: "What should I do?" Expenditure on highway maintenance is such that it is economically important, and severe financial restraints are likely to continue on it: thus the major determining factor is already economic, and we believe that it is only rational that the economic decisions on the use of the funds available should be economic as well. Much has been done in recent years, but much remains to be done, as we have seen. The alternative is that we must accept the need to forego the rational approach advocated. 11

14. A number of issues of principle has been identified in this sub-report, all of which in the end relate to the level of maintenance. The general answers to these issues – such as the concept of perfect maintenance – are clear enough, even if they as yet need to be given more detailed expression. A number of issues has also been identified in the general application of rational, economic methods, relating to the problem of the disaggregate and amorphous nature of highway maintenance work. These problems included those of specifying an appropriate information and control system, in identifying maintenance standards, and ensuring that the latter are economically sensible. There is a number of more detailed technical problems still to be overcome in the field before there is satisfactory progress: these include the difficult question of physical measurement for highway maintenance, the provision of adequate information in the form of a road inventory if it is considered desirable to go in this direction, a better understanding of the structural performance of pavements over time, and relating maintenance work in a rational manner with actual traffic flows.

15. In final summary, perhaps the complication of the whole subject of maintenance raises fairly acutely the issue of the simple hierarchical concept of management and decision-making. For instance, what degree

of freedom of action should be given to the foreman of a maintenance gang equipped to repair pot-holes? Is the foreman to be given discretion over which pot-holes he fills in, discretion which is justified because he is the "man on the spot", and because it is his responsibility to keep the resources in his charge utilised? But such freedom of action may be contrary to a more efficient treatment of the deficiency indicated by the pot-hole – for instance, an overlay might be a more desirable treatment. Similarly, the full feasibility of the hierarchical concept is questionable at the level of decision on the overall maintenance budget for the coming year. In text book terms this should be resolved against information representing the aggregation of all the separate, foreseen needs. In practice, such aggregation is well nigh impossible: for instance, what measures does one use at the different levels in the aggregation process to keep a proper indication of the relative severity of need; and more generally, is such a perfect hierarchical process administratively feasible? These are important questions, determining the nature of the technical information required for decision making, as well as the organisation of maintenance and responsibilities within it.

FEDERAL REPUBLIC OF GERMANY

Accounts Furnished by a Road Maintenance Centre

The accounts furnished by a road maintenance centre may be analysed in the following manner:

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		(on average)
1.	Maintenance of Carriageway	14.9%
2.	Maintenance of Structural Works	2.5%
3.	Maintenance of Installations of Drainage, Verges, Banks, etc.	11.2%
4.	Maintenance of Trees, Bushes, Shrubs, Grass etc.	18.3%
5.	Maintenance of Panels, Signs, Installations for Hazards, including Road Markings	8.6%
6.	Cleaning of Carriageways, Pavements, Cycle tracks, Verges, Banks, Ditches, Parking areas	3.0%
7.	Winter Maintenance, including Meteorological Hazard Signs	16.8%
8.	Traffic Safety Measures by Inspections of Road Sections, Accident Works, Diversions	5.2%
9.	Maintenance and Reparation of Equipment and Vehicles	13.0%
10.	Traffic Surveys, Land Surveys, Inspection of construction works	6.6%
		100%

This only concerns productive costs of maintenance activities, i.e. time lost by illness, holidays, etc., have not been taken into account.

BELGIUM

Road Maintenance Expenditure 1976

	State Highway Network	
	Expenses (Million F.)	*% of total expenditure*
Major Carriageway Works (Reconstruction, Haunching & Resurfacing)	847.836	21.70
Surface Dressing and Special Skid Treatments		
Patching and Minor Repairs	1.559.915	39.92
Drainage and Gulley Emptying		
Structural Works (Bridges and Remedial Earthworks)	73.021	1.87
Grass Cutting and Hedge Trimming	195.224	5.00
Sweeping and Cleansing	80.227	2.05
Traffic Signs and Pedestrian Crossings	44.270	1.13
Road Markings	174.914	4.48
Other Highway Works (Footways, Cycle Tracks, Kerbs, Fences and Barriers)	95.711	2.45
Winter Maintenance	371.058	9.50
Street Lighting	465.034	11.90
Total	3.907.210	100.00

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FRANCE

Maintenance Programme 1978

Main Stations

Carriageways and Side Roads	MF	%
Coordinated overlays	498	31
Ordinary Motorways	177	11
Preventive Maintenance of National Routes overlaid or in good condition	394	25
Curative maintenance of other National Routes		
agreed budget 134		
major repairs 40	174	11
Structural Works	59	4
Maintenance of Equipment	63	4
Car parks and Service areas	39	2.5
Winter Maintenance	74	4.5
Various	37	
Total Maintenance	1515	
Marking (exploitation)	70	5

Total Maintenance Expenditure for all roads in England 1976/77 (Nov. 1976 Prices)

Operations	Local Authority Roads		Motorways & Trunk Roads	
	Expenditure (£m)	% of Total Exp.	Expenditure (£m)	% of Total Exp.
Major Carriageway Works (Reconstruction, Haunching & Resurfacing)	83.1	22.4	13.60	30.7
Surface Dressing & Special Skid Treatments	23.5	6.3	1.01	2.3
Patching & Minor Repairs	44.5	12.0	2.95	6.7
Drainage & Gulley Emptying	18.5	5.0	2.26	5.1
Structural Works (Bridges & Remedial Earthworks)	8.5	2.3	3.65	8.3
Grass Cutting & Hedge Trimming	19.3	5.2	1.34	3.0
Sweeping & Cleansing	26.7	7.2	2.35	5.3
Traffic Signs & Pedestrian Crossings	16.2	4.4	3.54	8.0
Road Markings	6.0	1.6	1.19	2.7
Other Highway Works (Footways, Cycle Tracks, Kerbs, Fences & Barriers)	42.3	11.4	3.08	7.0
Winter Maintenance	19.0	5.1	4.18	9.4
Street Lighting	63.4	17.1	5.10	11.5
Total	371.00	100.00	44.25	100.00

POLAND

Maintenance expenditures for public roads from State Government Budget

	Estimation %
Major carriageway works reconstruction, haunching and resurfacing	41,5
Surface Dressing and minor maintenance works and repairs	16,0
Drainage and Gulley Emptying	4,9
Bridges repairs and maintenance works	2,8
Grass, trees and hedges maintenance works	2,6
Traffic signs and road markings	2,7
Sweeping and cleansing	0,5
Winter maintenance of roads	26,6
Other works	2,4
	100,0

HIGHWAY RESEARCH RECORD

Number 451 | Highway and Bridge Maintenance: Operations, Costs, and Modeling

6 reports
prepared for the
52nd Annual Meeting

Subject Areas

15	Transportation Economics
27	Bridge Design
40	Maintenance, General
41	Construction and Maintenance Equipment

HIGHWAY RESEARCH BOARD
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NATIONAL ACADEMY OF SCIENCES—NATIONAL ACADEMY OF ENGINEERING
Washington, D.C. 1973

CONTENTS

MAINTENANCE COSTING METHOD FOR LOW-VOLUME ROADS

Richard D. Bauman, University of Hawaii; and
Mathew J. Betz, Arizona State University

This paper summarizes the importance of maintenance as it applies to decisions regarding low-volume road system development, especially as related to economically developing countries. The importance of the decision to pave versus using local aggregates for road surfacing is presented. Specifically, the paper presents a method of estimating maintenance requirements and costs as developed for a transportation system planning activity in the Democratic Republic of the Sudan. Examples are presented of the types of cost relations established and the philosophy of developing these costs from basic considerations of equipment need and utilization rates. The paper emphasizes the fact that the total cost to the economy, in areas with limited road systems, varies with the mileage of roads of a particular surface type to be maintained. This is a consequence of economy of scale and equipment utilization. The development of fundamental input data involved 16 months of field exploration in Sudan.

IN most parts of the world, construction costs that are incurred when a transportation facility is put into operation are considered to be expenditures for national development and form a significant portion of the operating capital of any country. In fact, among expenditures for national development in the less developed countries, transport generally ranks first or second in magnitude. Costs of constructing new transport facilities have accounted for approximately one-third of all loans made by the International Bank for Reconstruction and Development and for one-fifth of American aid for development projects. Yet the lending agencies normally expect the borrowing countries to maintain facilities with little or no aid. A similar problem exists in the United States where no federal-aid money is available for maintenance.

It is becoming increasingly apparent that, as more and more roads are constructed within a country or a state, the maintenance costs continue to accumulate long after the money that financed the road construction has been spent. These maintenance costs are sizable, usually ranging from 23 to more than 40 percent of the total highway expenditures. But as the highway system of a region expands, the maintenance costs can increase to the point that they exceed the total expenditures previously spent for highways. For example, after the Interstate System is finished, many states will annually be spending more to maintain their portions of the Interstate System than they used to spend for new highway construction.

Because the cost of maintaining roads is great but the role of maintenance is not as politically glamorous or seemingly productive as is new road construction, there is a tendency to try to ignore highway maintenance costs when new roads are programmed for construction. In fact, instances have occurred where roads have been constructed but never maintained while new road construction continued.

To schedule the costs of maintaining a road system into the budget for overall highway expenditures, we need a systematic costing method that takes into consideration

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factors that cause maintenance costs to vary from highway section to section. Such a costing method is difficult to obtain because maintenance costs are usually not kept in a manner that allows one to correlate costs with highway design, environmental factors, and traffic loads, and little or nothing is available for new roads of new design.

This paper describes a procedure developed to predict maintenance costs of a proposed road system in Sudan. The procedural concepts may have utility for estimating highway maintenance costs on systems in other portions of the world.

IMPORTANCE OF MAINTENANCE

It must be emphasized that the failure to provide adequate support for highway maintenance results in decreased quality of service and deterioration of the initial investment. Once a highway facility has been constructed, any change in maintenance procedure will affect vehicle operating costs. Moreover, the amortization period of the construction costs can be affected by the maintenance provided after construction. This is further complicated by the fact that the quantification of this interrelation has not as yet been established.

As road facilities are extended and improved, maintenance commitments accumulate. The magnitude of this is often not realized. In the feasibility study of any one facility, the annual maintenance charge, in absolute terms, will most likely be smaller than the annual construction costs or user costs. However, for nationwide systems, maintenance costs can amount to substantial sums, especially from the viewpoint of governmental road expenditures. This is due to the fact that maintenance costs are a continuing cost that accumulates as the system is improved and expanded.

In the planning for any system of low-volume roads, especially in developing countries, the importance of proper maintenance must be emphasized and its probable costs indicated. Too often, maintenance is done as needed or as funds are available. The fact that maintenance needs to be initiated upon termination of construction is seldom noted. Deferring of such maintenance can mean the deterioration of the level of service, necessity for higher future expenditures, and possible loss of investment. Thus, the planning for maintenance should have an important position in the development of low-volume road systems.

When this is done, the developing countries will necessarily realize that it is important to construct a system to a level within the countries' ability to properly maintain it. The availability of skilled and semiskilled personnel and financial considerations must be considered. Roads that are inadequately maintained can result in a poorer overall system then would be obtained by a well-maintained system of roads with an initially lower type of surface. Thus, it is realized that the decision to pave or not to pave is of primary importance in system planning.

ROAD MAINTENANCE OPERATIONS

For costing purposes, maintenance operations can be subdivided into three general categories: routine maintenance, emergency maintenance, and periodic resurfacing of the roadways. It is virtually impossible to predict or schedule emergency maintenance factors. These are due to unusual occurrences caused by flooding, earthquakes, military action, and so forth. Because of the relatively rare occurrence of these needs and the conditions under which the work is performed, there is little information concerning their costs. Therefore, this type of maintenance is not considered in this paper.

The periodic resurfacing of roads includes the addition of gravel or the addition of a bituminous surface treatment, which is required on a relatively regular basis because of the effects of time and traffic on the road surface. The methods, equipment, and costs involved are essentially the same as used during the initial construction procedure and can be costed in a similar manner.

The costing method discussed in this paper is concerned with routine road maintenance, i.e., that which has to be conducted on a continuing basis. This can be subdivided into the following operations: surface and shoulder maintenance, maintenance of drainage facilities, maintenance of the roadside, maintenance of traffic control devices, and maintenance of bridges and other major structures. Discussions of each of these as related to gravel versus paved surfaces can be found in the literature (1).

In summary, important consequences of a decision to use a bituminous-treated surface affect the necessary maintenance, the equipment to be used, the skill level of the maintenance personnel, the overall costs, and the foreign exchange costs. Generally, the maintenance of surface and shoulders of graveled roads can be accomplished with light trucks, tractors, some type of drag (which can be locally manufactured), and possibly motor graders. This work can be done by relatively unskilled personnel. The same is not true for the bituminous surface, with respect to either the day-to-day patching operation or the periodic resurfacing. For many countries, the cost of bitumen represents a foreign exchange expenditure.

The general cost of maintenance within the United States increases as one moves from a gravel to a bituminous surface roadway. The relative expenditure for surface maintenance decreases. One of the observed problems in a number of developing countries has been a tendency to concentrate almost solely on surface maintenance. Recommendations by the International Road Federation as applied to Latin America indicated the need for greater emphasis on nonsurface maintenance (2).

The decision to pave or not to pave has little impact on many nonsurface maintenance procedures but may affect the level of effort. An example is the necessity for more roadside maintenance for paved roads because of the higher expectancy levels of the public and because of the fact that the paved travel way is generally narrower than the available travel way on a gravel road (which often includes shoulder areas).

The maintenance of traffic control devices is another example of increased cost required for paved surfaces. In most of the developing countries, when roadways are paved they are relatively narrow two-lane roads. It is therefore important from a safety standpoint to properly sign and stripe the roadway. The striping represents a substantial expenditure that is incurred yearly under most conditions. Roadway paints are relatively specialized items and represent a foreign exchange cost. Figures published by the Highway Research Board for the United States indicate that the cost of materials amounts to almost 80 percent of the total cost of highway marking (3). In addition, the equipment in this operation is specialized and has to be imported. Trained operators are necessary. Trained personnel to properly maintain the equipment itself is also important.

MAINTENANCE COSTING METHODOLOGY

What follows is a description of a maintenance cost-estimating methodology developed for a major portion of Sudan. These costs along with construction and vehicle operating costs were prepared for inclusion in a total transportation analysis that led to the development of a multimode transportation plan for the country. The project was conducted by personnel at Arizona State University under subcontract to Lockheed Aircraft International, Inc. The basic engineering information was obtained in the field during a 16-month period in 1966 and 1967. The following presents an example of the type of maintenance equipment requirements and costs relations developed. As a part of the project, separate sets of these relations were presented for the various types of surface for each of the homogeneous areas identified (4).

Total road maintenance needs are a function of the road design, soil and environmental conditions, and traffic characteristics. The interrelation among these, as related to maintenance, is most complex and unquantified even for the most developed systems. In most cases, road maintenance is considered to be a function of traffic volume only, assuming both a fixed-cost and a variable-cost component. For example, Bonney (5) has derived an expression to indicate the maintenance costs of gravel roads: Total annual cost per mile = 496 + 13Q, where Q = daily traffic flow in vehicles per day. Actually, for any specific surface type, both the fixed cost and the variable costs will differ depending on the availability and quality of construction materials, the climatic conditions, and the topography of the area.

Significance of Homogeneous Cost Areas

Because the various items that make up the maintenance cost change depending on the location of the road as well as the road design, the total maintenance cost will vary from area to area within a country even if traffic volumes are equal in each area. Therefore, the first step in the maintenance costing procedure is to divide a region into areas of similar pavement design with equal cost of maintenance materials and maintenance equipment.

For Sudan, the equal cost areas were defined based on information gathered by the field team and on laboratory tests concerning soil characteristics, construction material availability, and water availability. The northern section of Sudan was divided into 13 areas as shown in Figure 1. Each area, A through M, displays homogeneous characteristics that tend to cause all construction and maintenance activities and costs in the area to be similar. Thus, within each area it was assumed that the distance between wells is constant, the distance between gravel sources is constant, and the physical design of the pavement structure is constant. Because each area is distinct, it follows that the construction and maintenance requirements in each area are different from those in other areas.

Preparation of Construction Equipment Packages

Knowing the areas of similar cost, our next step was to actually determine the costs associated with each area. The subject of road maintenance costing is only rarely discussed in the literature. Apparently nothing factual has been written concerning development of procedures for forecasting construction and maintenance costs for a road system. In many areas, future costs of road construction and maintenance can be determined by studying existing costs. This was impractical in Sudan because few roads have been constructed or maintained.

20 In the past, when individuals have forecast maintenance costs, most studies have used a fixed cost per mile for all maintenance on roads of a certain design. At the same time, planners have used relatively accurate costs for vehicle operation on the road. Actually, the analysis problem is as sensitive to changes in construction and maintenance costs as it is to changes in vehicle operating costs. Fixed cost-per-mile estimates lead to serious errors in the analysis because there is considerable economy of scale. For example, the cost of maintaining 1 mile of gravel road might be $2,500, whereas the cost of maintaining 40 miles of the same road might be $1,100 per mile. Within certain limits, which vary from project to project, the larger the project is the lower the unit price is. This economy of scale is most noticeable at the low production rates prevalent in most underdeveloped countries that can only afford to build and maintain a few miles of road each year. In light of this, it was concluded that maintenance cost formulation that considered the economy of scale of a project would best solve the analysis problem.

The issue was how to compute costs that would reflect economy of scale for an area with no history of costs on similar projects available. The problem was resolved by using the normal bidding procedures utilized by contractors for road maintenance projects. The procedure entailed determining the pavement design prevalent in the area, selecting a package of construction equipment required to handle the maintenance tasks, and costing the maintenance price per mile for projects of varying length.

For each homogeneous cost area shown in Figure 1, a package of construction equipment necessary to complete the maintenance activities was selected. This was done by selecting appropriate equipment units and then combining the units into groups termed equipment packages. For example, an equipment package for maintenance of an earth road could consist of two dump trucks, one rubber-tired roller, one water truck, one front-end loader, and one motor grader.

Next, the total hourly cost to own and operate each package was computed. This procedure involved obtaining hourly ownership and operating costs for each unit in the package and summing the individual costs to compute the total hourly costs. Severe depreciation rates recommended either by the Association of General Contractors Ownership and Expense Manual or by equipment manufacturers were utilized.

In most cases, a single package was not suitable for handling a wide range of production rates on a project. Large-sized units of equipment can be used to maintain a small project, but they cannot be used economically. Therefore, each package was customized to fit a specific range of project sizes, with the size and type of units in each package varying with the size of the projects.

The customizing procedure involved grouping specific sizes and types of construction units into packages and then determining the productivity-cost relations for each package. Thus, for an activity involving the maintenance of a gravel road, one package was selected for maintenance rates up to 230 miles per year at traffic volumes below 25 ADT, and the size of the package was increased as the traffic volume on the road increased. Typical packages suitable for maintaining unsurfaced roads in Sudan are given in Table 1.

Formulation of Maintenance Cost Equations

It is a much simpler procedure to estimate costs of a maintenance project for a highway that has a definite length and location than it is to estimate costs where the road length and completion time are variables. But, for planning purposes, the latter is the case. Use of the equipment package concept simplifies the costing process but also points up the economic consequences of inefficient use of construction equipment packages. As is shown in Figure 2, for a specific construction package the cost per mile decreases as the production rate increases until the operational efficiency of the package is exceeded, then the cost per mile begins to increase. The challenge is to develop equipment packages suited for the anticipated range of productivity.

For the Sudan project, maintenance costs were split into two categories: expected routine maintenance and resurfacing. Maintenance cost experience in Ghana and Nigeria found that resurfacing costs range from 30 to more than 50 percent of the total annual maintenance expenditure. The equipment package requirements for routine maintenance are different than the requirements for resurfacing.

Routine Maintenance Costs in Sudan

As previously indicated, the routine maintenance on aggregate roads is basically the maintenance of the riding surface and the elimination of road roughness. For bituminous surfaces, it involves the patching of potholes, the maintenance of signs and markings, and the general "housekeeping" of roadsides and drainage facilities. Figure 3 shows the expected typical relations between normal maintenance costs in Sudan and traffic volume for an earth, rock road. The routine maintenance costs of bituminous-surfaced roads operating at low-traffic volumes are relatively independent of traffic volume. This cost was estimated at $1,200 per mile for a surface treatment, $1,340 per mile for a road mix, and $1,130 per mile for a hot-mix road.

Resurfacing Costs

Gravel and bituminous surfaces require periodic resurfacing in order to maintain the standard of the roadway. The resurfacing operations for both gravel and bituminous surfaces are essentially the same in equipment, material, and personnel as those required for initial construction. The costs prepared assume the optimum use of the smallest particular construction package based on a 40-hour week. The costs were converted to annual costs by simple division of the resurfacing cost by the expected period of resurfacing. No interest calculations were included because the period of resurfacing is relatively short.

In the case of roads surfaced with crushed rock, it was assumed that the surface would be rebuilt every 6 years, and at that time 4 in. of new crushed rock would be added. In the case of roads surfaced with gravel, it was assumed that the surface would be rebuilt every 6 years, and at that time 6 in. of new gravel would be added. The resurfacing cost was determined by prorating the initial construction cost. General experience with gravel roads throughout Africa indicates that with moderate traffic volumes, gravel roads tend to lose about 1 in. of gravel per year. This rate of gravel

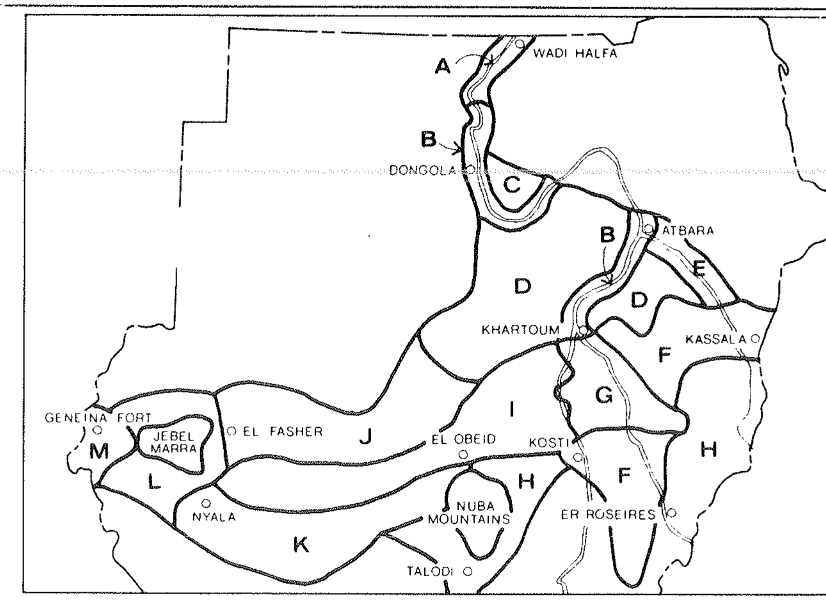


Figure 1. Areas of homogeneous construction and maintenance costs in Sudan.

Table 1. Minimum equipment packages required for routine maintenance of unsurfaced roads.

Traffic Volume (ADT)	Road Surface: Earth	Gravel	Crushed Rock
0 to 24	One 5-yd truck One 2,000-gal water truck One ½-yd front-end loader One motor grader	One 5-yd truck One 2,000-gal water truck One ½-yd front-end loader One motor grader	One 5-yd truck One 2,000-gal water truck One ½-yd front-end loader One motor grader
25 to 49	Two 5-yd trucks One roller One 2,000-gal water truck One ½-yd front-end loader One motor grader	One 5-yd truck One roller One 12-ton truck One 2,000-gal water truck One 1-yd front-end loader One motor grader	Two 5-yd trucks One 2,000-gal water truck One ½-yd front-end loader One roller One motor grader
50 to 99	One 5-yd truck One 12-ton truck One 2,000-gal water truck One roller One 1-yd front-end loader One motor grader	Two 5-yd trucks Two 12-ton trucks Two rollers Two 2,000-gal water trucks Two 1-yd front-end loaders One motor grader	Two 5-yd trucks One 12-ton truck One 2,000-gal water truck One roller One 1-yd front-end loader One motor grader
100 to 399	One 5-yd truck Three 12-ton trucks Two 2,000-gal water trucks Two 1-yd front-end loaders Two rollers Two motor graders	Two 5-yd trucks Three rollers Six 12-ton trucks Three 2,000-gal water trucks Two 1-yd front-end loaders Two motor graders	One 5-yd truck Four 12-ton trucks Two 2,000-gal water trucks One 1-yd front-end loader Two rollers Two motor graders

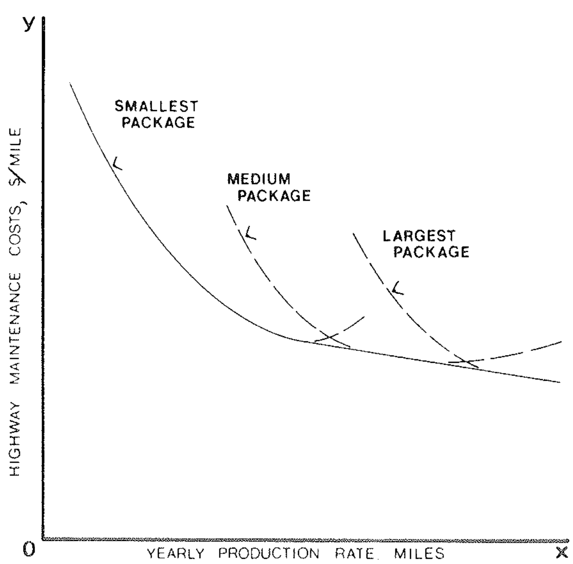
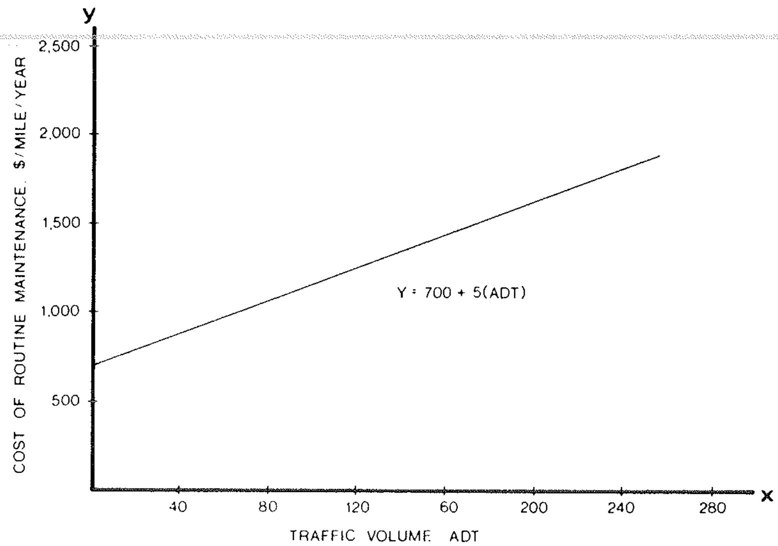


Figure 2. Equipment package cost-productivity relation.

Figure 3. Routine maintenance costs and traffic volume of earth-surfaced road.



loss is relatively constant for a moderate range of traffic volumes because the dragging operation tends to have a greater effect on aggregate loss than does traffic per se. The assumption that the Sudanese crushed-rock roads will lose only ⅔ in. per year was based on the fact that the aggregate used in the construction has particle interlocking characteristics not found in natural gravel. Usually, natural gravels have rounded particles that do not provide much mechanical particle interlocking. The Sudanese crushed-rock aggregate will be highly angular, and it is therefore expected that there will be a much higher degree of mechanical interlock between particles and, therefore, a decreased rate of loss. The different annual costs for certain areas for resurfacing reflect the influence of the differential length of haul from aggregate sources.

The calculation of the resurfacing cost for bituminous roadways was based on the cost of a single surface treatment repeated every 5 years. Experience has shown that this operation generally must be repeated every 4 to 6 years to counteract the effects of both traffic and aging. These costs were estimated assuming the equipment packages were being utilized efficiently and the costs were represented on an average dollar-per-mile basis.

SUMMARY

As previously indicated, the variation of maintenance costs with basic variables is currently ill-defined although they represents a significant public expenditure. That these costs can be evaluated over time when maintenance needs are met under specific known conditions is admitted. However, Sudan at this time does not have significant experience in the road maintenance procedures within its own area to quantify any cost or productivity data. This is a situation common to most developing countries and even to some states. Due to the economy of scale associated with maintenance costs and the cost variance caused by variables such as project size, construction material availability, topography, in-place soil conditions, and productivity of the labor force, generalized fixed-cost estimates are inaccurate. The equipment package costing methodology outlined in this paper presents a technique that allows estimation of maintenance costs in areas where no maintenance cost experience is available and allows consideration of economy of scale.

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DISCUSSION

Bertell C. Butler, Jr., Byrd, Tallamy, MacDonald and Lewis, Falls Church, Virginia

Bauman and Betz's paper presents a maintenance costing methodology that should be valuable in developing maintenance cost for new highway systems. In particular, it should be very useful to planners as they develop transportation programs in developing countries.

The authors' paper has properly stressed the importance of maintenance for low-cost roads, particularly as a factor in the planning and decision process. They placed the maintenance impact on total highway expenditures between 23 and 40 percent. An examination of the maintenance expenditures made for county and township roads in the United States during the past 15 years reveals that an average of 63 percent of total highway expenditures was spent for maintenance (6). The type of road system they discuss seems closer to the county-township type of system than the state system where the maintenance percentage for the same period was 18 percent.

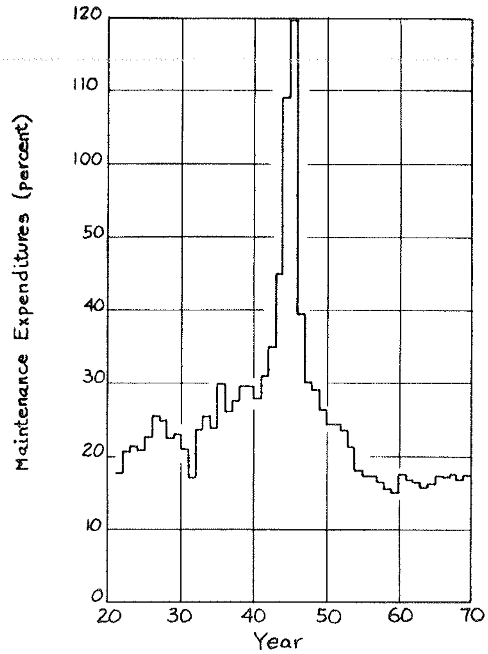
As the highway system of a region expands, the maintenance expenditures continue to increase. There also is considerable evidence in the literature to suggest that these maintenance costs further increase as traffic volumes grow. However, as a percentage of total expenditures, the picture is not so clear. Figure 4 shows the percentage of total highway expenditures for state highway maintenance in the United States. Disregarding the war years of the 1940s, there is no evidence of any general increase with time. Rather, both the capital outlay and the maintenance expenditure portions grow together.

The impact of increased traffic volume on maintenance is revealed by comparing a sampling of high- and low-volume state highway expenditures. The high-volume states averaged $24,000 per mile on maintenance, which reflected 25 percent of total road construction expenditures. This can be compared with $1,250 per mile and 13 percent for the low-volume states (6).

The authors were faced with the need to develop maintenance cost estimates for a total highway program budget. Realistic costing is needed to allow for variations in the physical and operational environments of the roads in various areas of the country. This was particularly critical to the Sudan study where a wide variation was expected in the mileage of a given pavement design from area to area. The estimating procedure developed responds to the need for having more than a single fixed maintenance cost that can be applied to roads in the planning process.

The authors divided Sudan into areas of similar pavement design and equal material and equipment cost. They then selected the equipment units that would be needed to maintain the pavement design assumed for an area, a given level of traffic volume, and a limited range of mileage of roads. The equipment was then placed into what the authors termed an equipment package, and the total hourly cost to own and operate the package was computed. The authors are not clear on how the entire maintenance cost

Figure 4. Maintenance expenditures as percentage of total state highway costs.



was included in their cost equation, i.e., as part of the equipment package or in support of the equipment package. In developing resurfacing costs, the authors note that the equipment package cost was based on a 40-hour week use assumption. No such notation is included for the maintenance equipment package. Therefore, the basis for developing hourly cost for the equipment is not clear. Some mention of the assumed range of use would be helpful. Also, an indication of some of the other assumptions that must have been made related to frequency of equipment assignment to each mile of road, treatment of supervisory cost, labor and material requirements, and housing and administrative costs would be useful additional information. However, it is assumed that the equipment package generated a total cost that could be converted to a per-mile maintenance cost by assuming a mileage in each homogeneous cost area. The model shown in Figure 3 was apparently the result of plotting per-mile expenditures from like areas of road design and mileage for different traffic volumes.

The method of costing presented by the authors was reportedly used to generate various matrices of unit maintenance cost by type of road surface and region for varying system mileage and traffic volume. The inclusion of such a matrix would have been a useful addition to the paper. Nevertheless, this paper should prove a valuable addition to the present literature on the maintenance of roads in developing areas.

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Better knowledge of road maintenance costs would be welcome in every country, but the relative paucity of information and the need to examine various road design and maintenance strategies in developing countries make better information on maintenance costs particularly important in these countries. In the United States and Western Europe, high traffic volumes, high values attached to motorists' time, and relatively low cost of capital usually make it more economical to incur higher initial costs to construct roads to higher standards to minimize road-user and maintenance costs. In developing countries, however, traffic volumes and values attached to motorists' time are often much lower, and capital is much costlier, so that staged construction, with lower initial design standards and higher road-user and maintenance costs, may be the optimum strategy. In some of these countries, relative labor abundance makes labor-intensive methods of construction and maintenance more feasible, which has important but relatively unexplored implications for road design and maintenance.

Thus, Bauman and Betz are quite correct in seeking to gain greater understanding of road maintenance costs in developing countries and to develop methods for quantifying and predicting them. Certainly, the approach they developed in Sudan, which is similar to the work by Soberman in Venezuela, constitutes an improvement over existing procedures in many cases where the only data are average total maintenance outlay per mile of network. Formulation of maintenance costs in the form Y = a + b(ADT) does take into account the fact that there may be certain expenditures, such as the costs of administration, or other economies of scale when traffic volumes expand. Developing separate relations for different types of road in different homogeneous cost regions is a further improvement.

However, this approach does not go deeply enough to answer many of the questions that need answering. Predicting maintenance outlays in this manner implicitly assumes a given maintenance policy, when in fact we want to investigate what maintenance policy should be. If one is to examine alternative maintenance strategies, it is necessary to distinguish the physical deterioration of the road from the response to that deterioration. The effect of different maintenance standards on the physical condition of the road and the effect in turn of various road conditions on road-user costs must be established, as well as the costs of the different maintenance routines. If, in addition, one is to determine the best technology to effect a given maintenance standard, it will be necessary to generate the whole set of alternative technologies specified in terms of outputs achieved by a given set of inputs (equipment packages) and prices of the various inputs.

Measurement of the physical deterioration of roads of different designs and the effect of alternative maintenance policies thereon ultimately requires some longer term experimentation, which presumably was outside the authors' terms of reference. Least is known concerning the deterioration of earth and gravel roads (of various geological compositions), but fortunately this can be measured relatively easily because deterioration occurs rather rapidly if regular maintenance is withheld. A 2-year period of study is quite sufficient to observe significant change in the condition of unpaved roads. It is more difficult to establish deterioration relations for paved roads because deterioration occurs much more slowly. The only alternative to long-term experiments would be cross-section analysis of pavements of various ages in various degrees of deterioration. However, because of the problems in defining the original construction standards of those pavements, as well as the use and the maintenance they have received over the years previous to the study, we would not be optimistic about this approach. Thus, deterioration relations for paved roads may have to be derived from time-series analysis of observations collected over several years from roads built to carefully controlled standards and subjected to normal use.

Various approaches may be used to establish the effect of different maintenance standards on road-user costs. A direct experimental approach, involving operation of a fleet of instrumented test vehicles over experimental road sections where the condition of the road surface is measured, may provide accurate information on the effect of different maintenance standards on vehicle speed and fuel consumption. A sample survey of road users, including establishment of a well-controlled set of cost accounts for a representative sample of types of vehicles operating over roads in various states of maintenance, will yield additional information on vehicle depreciation and maintenance costs.

If one wishes to relax the assumption of a fixed maintenance technology and determine the optimum technology, it is necessary to scan the whole set of feasible alternative technologies. The authors' specification of equipment packages, or input-output vectors, is thus a step in the right direction, but it is not clear that they have systematically generated the whole set of alternative technologies (or a reasonable approximation thereto). What do they mean when they say that the equipment package was "customized to project size?" What exactly does "project size" mean? Also one would like them to specify the sources of the economies of scale they envisage. Is it simply fixities in administrative costs when either the mileage of the system or the traffic densities increase? Or do greater traffic densities or greater network mileage make different technologies with lower variable costs more economical? It is not easy to see this intuitively, but ultimately the question is an empirical one.

We at the World Bank have been very much concerned with these questions, particularly the trade-offs between road design standards and maintenance costs and the effect of different technologies thereon. Since 1969, we have been working in conjunction with other institutions to develop the methodology and empirical data necessary to determine optimum highway design and maintenance strategies for low-volume rural roads, assuming initially a fixed technology for construction and maintenance. The U.K. Transport and Road Research Laboratory, working in collaboration with the World Bank, has been conducting empirical research in Kenya since early in 1971 on road-user costs and road deterioration relations for alternative design standards and alternative maintenance policies. We hope to have completed the initial field studies of these relations by July 1973, but the study will have to be continued in order to gain longer time-series observations on paved road deterioration. At the same time, we are hopeful that similar studies may be undertaken in India and Brazil to capture a wider range of physical and economic environments. The World Bank also has under way studies on the technical and economic feasibility of alternative civil construction technologies involving different combinations of labor and equipment. An initial survey of existing evidence reached the conclusion that it is technically feasible to use labor-intensive methods of construction for most activities involved in constructing highways, including higher standard highways, and that these techniques may be economically feasible under certain circumstances in labor-abundant economies. The next phase of the study will concentrate on the adaptation of road design to labor-intensive and intermediate technologies and its implications for road design and maintenance strategies and the problems of implementing changes in technologies, design, and maintenance strategies.

Samuel F. Lunford, Arizona Highway Department

The authors discuss the importance of maintenance costs in the planning of highway systems, especially with regard to its effect on the overall economic well-being of an emerging nation. A most interesting consideration not normally imposed on the maintenance engineer-economist in this country is the major effect that foreign exchange expenditures have on the decision-making process when the physical designs to be utilized in the system are evaluated.

In the citation on the lack of formal costing knowledge of highway maintenance activities, the authors present the same general observations that others have struggled with in attempting to develop forecasting systems or formulas. For many years, maintenance cost data have been collected, summarized, and published in terms of average costs per mile of various types of designs with very little consideration of the relations among highway design, environmental factors, traffic loads, and social structure of the community. The application of such past per-mile average cost data can result in a completely inadequate financial and organizational plan for any highway system, whether considering an emerging nation without a transportation history or a highly developed community with a sophisticated network and years of experience.

The emphasis on the importance of maintenance is well made as a major element in system planning and design. The magnitude of accumulating maintenance requirements is rapidly forcing highway administrators in this country and on the international scene to focus more attention on scientific research and economic evaluations of maintenance practices. In recent years this has resulted in the so-called new maintenance management systems in many states.

These new maintenance management systems and the accompanying performance budget methods of analyzing maintenance cost factors have been highly publicized and reported in literature during the past 10 years. It was disappointing to find no mention or consideration of these highly developed techniques in maintenance costing.

In approaching the costing of maintenance operations in an environment without a past history to relate to, the authors categorize maintenance into routine, emergency, and periodic resurfacing. Emergency maintenance factors are immediately dismissed as impossible to predict or schedule. Resurfacing maintenance is analyzed as essentially the same as initial construction procedures and therefore costed in the same manner. It appears, then, that the important contribution this paper offers is a new approach to forecasting the probable costs for routine recurring maintenance under the unique conditions and limitations of an emerging underdeveloped nation and the effect of this cost on the long-range financial requirements to protect the original investment.

Although emergency maintenance might logically be a minor cost factor, it should be considered, especially with regard to the effects of natural occurrences on underdesigned highway systems. Weather history and severe seasonal weather conditions are generally well known, and the problems of maintenance operations involving design deficiencies for all weather conditions can be ordinarily recognized and can be adequately provided for by anticipating certain average activity requirements to provide capability to restore damaged or interrupted transportation services.

The costing of routine road maintenance planning values is most difficult with known existing systems. The complexities of analysis presented in this described project, to predict with confidence the cost of maintenance values for various design considerations on a nonexisting highway system, is approached in a new and unique manner. Such an approach offers a new opportunity to make further research and extend present concepts of the state of the art.

Without a history base to quantify the many variables of maintenance activities, the authors devised what might be called a system of common denominators. By grouping similar environmental characteristics, a system of homogeneous cost areas was developed in which it can rationally be assumed that all construction, maintenance, and cost factors will be similar. This same rationalization is used by several states in establishing regional performance standards for maintenance activities.

The second common denominator presented for evaluating costs was the construction equipment package. This approach is unique in concept, but it is not clearly defined in the paper, especially with regard to what activities or level of service is considered in creating the equipment packages for comparative evaluation. It would seem that a quality standard or a level of service must also be determined to establish an equipment package. The tolerance of wear or deterioration with a frequency of service requirements must certainly be involved in determining either the equipment package or the area that a given equipment package might cover. The paper intimates that such analysis was considered within the project development, but it does not dwell on how the service-level variables were constructed to determine the equipment package. Some additional development of these factors would clarify the concept of relating maintenance cost predictions on the assignment of cost factors to the hourly operation of a given equipment staffing required to perform the level of maintenance necessary to support and protect the transportation investment.

The authors have injected an analysis consideration, which provides a realistic approach to adjusting cost data, not heretofore observed by the reviewer in other maintenance cost projection exercises. The "economy-of-scale" adjustment to operational data emphasized in this paper has been observed and considered in many construction program cost estimates, but its application to maintenance cost projections may be one of the important contributions presented here and also might possibly be a subject for further research in relation to maintenance cost factors.

In summary, the project described certainly appears to have been challenging, and the approach to analysis was innovative and unique. The importance of maintenance costs to the total design considerations and financial planning of transportation systems is well presented. The homogeneous cost areas, the equipment package, and the economy-of-scale concept are analysis techniques that might be further researched for useful relations.

The paper offers an important reference background for refining the art of long-range maintenance cost predictions particularly as related to new transportation systems in emerging nations.

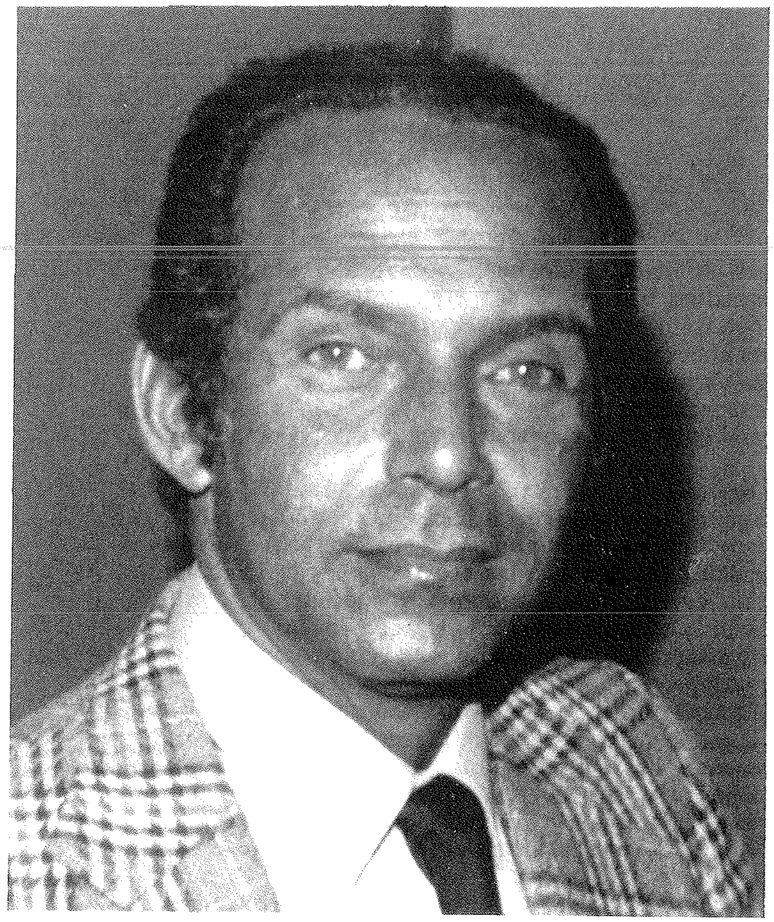
AUTHORS' CLOSURE

The basic elements in the discussions focus around issues concerned with assumptions used in the derivation of the equations and with appropriate policies for maintenance of a road system when funds are limited. Butler discusses the cost assumptions and raises significant questions concerning the methodology used in the derivation of the cost equations. Harral discusses important policy issues. Lanford's discussion overlaps into both policy and cost issues. This response to the discussions will attempt to clarify some of the assumptions and derivation procedures as well as comment on the policy issues.

The first major area of concern seems to relate to the cost formulation process. The process of deriving the cost formula for an equipment package was to assemble the equipment units and manpower into a package, calculate all costs on an hourly basis, expand costs to an annual basis using number of work hours per day and number of workdays per week typical in Sudan, estimate the maximum productivity of each package in terms of number of miles of two-lane road per year, and develop cost curves by holding annual equipment package costs constant and varying package productivity, thus achieving a variable cost-per-mile output. The costs used in each package were derived based on relations among hourly costs to own and operate the units of construction equipment in each package, labor costs for equipment operators and supervisory personnel, and material costs. The operational life of each unit of equipment was computed in terms of total hours of life based on manufacturer's recommendations and assuming severe operating conditions. Utilizing this technique, the economy-of-scale characteristics of an equipment package become apparent as the efficiency of utilization of the package increases.

The application of the level-of-service concept for processes concerned with routine maintenance is significant and could be used to quantify policy decisions. For the Sudan project, it was assumed that the equipment packages would operate so as to maintain all roads in their respective areas at a level sufficient to preserve the roadway in a condition as close to the original as possible. This required assumptions concerning frequency of machining, daily productivity, and material replacement based on empirical data from other studies. All assumptions are discussed in detail in the original report (4). This meant that the maintenance policy proposed for Sudan assumed a high level of service. At first glance, this assumption may not appear to be the most appropriate policy for a country with low traffic volumes on nearly all its roads and with limited funds. However, the policy for maintenance cannot be considered in an isolated context. Instead, the policy for maintenance must be considered together with the policies concerned with design and construction. If stage design techniques are properly used and a road is never overdesigned, a high level of service for maintenance appears to be the appropriate policy.

Study of the trade-offs between road design standards and maintenance policies and costs was beyond the scope of this project. But the trade-offs represent a highly significant area of concern. So the World Bank projects described by Harral, when completed, should produce some very useful data.



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UNITED NATIONS ECONOMIC COMMISSION FOR AFRICA

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MAIN ROAD MAINTENANCE COSTS

by

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This conference paper has been produced through the co-operation of the Overseas Unit of the Transport and Road Research Laboratory Department of the Environment Department of Transport, the Overseas Development Administration of the Foreign and Commonwealth Office, of the United Kingdom, and the Governments of France and the Federal Republic of Germany The assistance provided by the Government of the Republic of Upper Volta is gratefully acknowledged.

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MAIN ROAD MAINTENANCE COSTS

ABSTRACT

The procedures adopted for the maintenance of earth roads and surfaced roads is described. Information is given on the staff required per unit of work, together with details of the equipment needed for both manual and mechanised maintenance, and the materials to be used in the operation.

Costs are given in each case for staff, equipment and materials, leading to the calculation of unit costs and total costs for each type of work. Budget details are given for each type of maintenance work at 1976 prices and wages, increased by quoted percentages to 1977 values.

The currencey quoted is the Franc CFA (Francs CFA 50 = 1 French Franc)

1. MAINTENANCE OF EARTH ROADS

1.1 Introduction

The work on earth roads involves both manual and mechanised maintenance.

Manual maintenance is a matter of filling in road surface depressions, pot holes etc., clearing of ditches and removal of undergrowth from the right of way. The work is carried out by teams of roadmen under the supervision of district surveyors who are each responsible for a number of road sections.

Mechanised maintenance consists of resurfacing, i.e. the addition of selected material to the road base which also serves as a wearing course, and of reshaping operations. The reshaping can consist of major work on the carriageway and a reconditioning of the ditches or it can be a minor operation involving the levelling of local surface deformations (depressions, corrugations) so as to provide a better riding surface.

1.2 Basic data for calculating maintenance costs

1.2.1 Manual maintenance (by road sections) It is assumed that one maintenance worker is required per 10 to 15 km of road. The number of men in a maintenance team is limited by the possibilities concerning their displacement or local movement. A tipper lorry is allocated to each team and the capacity of this vehicle determines the maximum number of men available for work on a road section. On average these vehicles can each carry three men in the cab, including the driver, and eight men plus their eq.ipment in the rear. Thus a team consists of:

	1 ganger
	1 driver
	10 labourers
Total:	12 men per team

This team can maintain a total of 120 km of road for 1,870 hours of work per year (170 hours per month for 11 months and 1 month paid leave).

1.2.2 Mechanised maintenance

1.2.2.1 Resurfacing The equipment used for resurfacing, given the average transport distances involved (rarely exceeding 6 km) consists typically of the following:

1 bulldozer, 180 h.p.
1 grader, 120 h.p.
1 loader, 80 h.p.
2 tanker lorries, 220 h.p., 10,000 litres capacity
1 motorised pneumatic roller, 220 h.p., 15 t weight
1 towable pneumatic roller, 6t maximum load
1 agricultural tractor, 60 h.p.
4 tipper lorries, 10t capacity
1 tipper lorry, 6t capacity

In principle two sets of the above equipment will be allocated to a resurfacing site and in addition the following will be available:

1 supervisory van
1 workshop trailer

The average progress of a resurfacing site is estimated as 600 m^3 of additional compacted material laid on the road per 7 hour working day.

Allowing for bad weather it is estimated that the resurfacing teams work for a total of 160 days per calender year.

1.2.2.2 Major reshaping Equipment for this operation consists typically of: 35

2 to 3 graders, 120 h.p.
1 towed pneumatic roller
1 agricultural tractor, 60 h.p.
1 supporting lorry, 3.5t capacity

The average progress for major reshaping is estimated as 5 km of road per working day.

If we consider the atmospheric conditions that must apply for this reshaping operation (the earth must be humid - not soaked or dry) and hence the need to work at the beginning or the end of the rainy season and in any case as allowed by the frequency of the rainfall then it is estimated that the major resurfacing teams work for a total of 60 days per calender year.

1.2.2.3 Minor reshaping The equipment for this operation consists typically of:

2 to 3 graders, 120 h.p. (the number depending on the width of the carriageway being treated)

1 supporting lorry, 3.5t capacity

The average progress for minor reshaping is estimated as 20 km of road per working day with a total of 140 working days per calender year.

1.3 Costs of each item

1.3.1 Manual maintenance (by road sections)

1.3.1.1 Staff

	Francs/hour
Ganger	136
Driver	123
10 Labourers	851
	1,110
Paid leave (1/12)	92.5
	1,202.5
Social charges, employer's contributions (18.5%)	222
	1,424

		Francs
Staff costs per year:	1,424 x 1,870 =	2,662,880
Site allowances (4%)		106,515
Total staff costs per year:		2,769,395

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1.3.1.2 Minor equipment

5% of 2,662,880	133,144

1.3.1.3 Use of 3.5t SG4 lorry (40,000 km/year)

	Francs	
Depreciation	891,200	
Repairs	1,086,000	
Fuel	526,400	
Lubricants	130,000	
	2,633,600	2,633,600
	TOTAL:	5,536,139

1.3.1.4 Cost per km of road

Cost per km: $\frac{5,536,139}{120}$ = 46,134

say 46,000 F

1.3.2 Resurfacing.

1.3.2.1 Staff

	Francs/hour
1 bulldozer driver	132
1 grader operator	121
1 loader operator	121
2 tanker lorry drivers (2 x 129)	258
1 roller operator	116
1 agricultural tractor driver	116
4 tipper lorry drivers (4 x 129)	516
1 supporting lorry driver	129
1 tally man	194
1 foreman	150
2 labourers (2 x 74)	148
	2,001

			Francs/hour
For a site having two teams:	2,001 x 2	=	4,002
1 site foreman			250
1 supervisory van driver			116
1 watchman			107
			4,475
Paid leave (1/12)			372
			4,847
Social charges, employers contribution (18.5 %)			896
			5,743

			Francs
Staff costs per year	1870 x 5,743	=	10,739,410
Site allowances (4 %)			429,576
			11,168,986
Total staff costs per year:			say 11,170,000

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1.3.2.2 Equipment.

Equipment	Use in km or hours per year	Costs in 10^3 F CFA				
		Depreciation	Repairs	Fuel	Lubricants	Totals
Bulldozer	0960 h	2,923	4,080	1,056	341	8,400
Grader	800 h	2,124	2,222	705	320	5,371
Loader	1120 h	4,267	4,133	986	370	9,756
Tanker lorry	2 x 24,000 km	2,400	2,462	1,550	216	6,628
Motorised roller	640 h	792	715	423	64	1,994
Towed roller	640 h	89	136	-	2	227
Agricultural tractor	640 h	219	148	324	60	751
4 tipper lorries	4 x 24,000 km	4,704	6,336	3,072	624	14,736
6t lorry	32,000 km	1,344	1,184	704	160	3,392
Total		18,862	21,416	8,820	2,157	51,255
Total per site - (A) (2 sets of equipment)		37,724	42,832	17,640	4,314	102,510
Supporting equipment						
Supervisory van	40,000 km	468	580	470	56	1,574
Workshop trailer	160 days	168	176	-	2	346
Total - (B)		636	756	470	58	1,920
Complete total - (A + B)		38,360	43,588	18,110	4,372	104,430

1.3.2.3 Total annual expenditure

	Francs
Annual staff costs	11,170,000
Annual equipment costs	104,430,000
Total	115,600,000

1.3.2.4 Costs per m³

Output per year:

$$600\ m^3 \times 160\ \text{days} = 96,000\ m^3$$

Costs per m^3: $\frac{115,600,000}{96,000} = 1,200$ F

1.3.3 Reshaping The graders are used as follows:

60 days per year for major reshaping, i.e. for 30 per cent of the total time
140 days per year for minor reshaping, i.e. for 70 per cent of the total time

1.3.3.1 Staff costs - major reshaping

	Francs/hour
3 grader operators (3x121)	363
1 lorry (6t) driver	129
1 foreman	150
1 towed roller operator	116
2 labourers (2x74)	148
	906
Paid leave (1/12)	75
	981
Social charges, employers contributions (18.5 %)	181
	1,162

			Francs
Staff costs per year:	1870 x 1,162 x 30%	=	651,882
Site allowances (4 %)			26,075
			677,957
Total staff costs per year:		say	678,000

1.3.3.2 Staff costs - minor reshaping.

	Francs/hour
3 grader operators	363
1 lorry driver	129
1 foreman	150
	642
Paid leave (1/12)	53
	695
Social charges, employers contributions (18.5 %)	128
	823

		Francs
Staff costs per year:	1870 x 823 x 70% =	1,077,307
Site allowances (4 %)		43,092
		1,120,399
Total staff costs per year	say	1,120,000

1.3.3.3 Equipment.

Equipment	Use in km or hours per year	Costs in 10^3F CFA				
		Depreciation	Repairs	Fuel	Lubricants	Totals
3 graders 3.5t lorry	3x1000 h 32,000 km	7,965 596	8,334 604	2,643 421	1,197 75	20,139 1,696
Total		8,561	8,938	3,064	1,272	21,835
Towed roller plus towing vehicle	800 h	385	355	405	77	1,222
Total	—	8,946	9,293	3,469	1,249	23,057

Total equipment costs per year:

		Francs
Major reshaping	23,057,000 x 30%	6,917,000
Minor reshaping	21,835,000 x 70%	15,284,000

1.3.3.4 Costs per km - major reshaping

	Francs
Annual staff costs	678,000
Annual equipment costs	6,917,000
	7,595,000

Cost per kilometre $\frac{7,595,000}{60 \text{ days} \times 5 \text{ km}} = 25,316$

say 25,500

1.3.3.5 Costs per km - minor reshaping

	Francs
Annual staff costs	1,120,000
Annual equipment costs	15,284,000
	16,404,000

Cost per kilometre $\frac{16,404,000}{140 \text{ days} \times 20 \text{ km}} = 5,858$

say 6,000

1.4 Special anti-corrugation maintenance.

This is a previously established technique that was adopted and improved for use in UPPER VOLTA commencing in 1972.

The technique is only applied in the dry season and on heavily trafficked roads. A metal frame fitted with levelling blades is towed behind an agricultural tractor so as to remove the early formation of any corrugations. Two such equipments are required to deal with 80 km of road per day over a carriageway width of 6m. These equipments are in use, on average, for 130 days per year.

This type of maintenance being unconventional has not been classified with the more usual procedures considered in sections 1.1, 1.2 and 1.3.

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1.4.1 Costs of anti-corrugation maintenance

1.4.1.1 Staff

	Francs/hour			Francs
Tractor driver	116			
Paid leave	10			
	126			
Social charges, employers contribution (18.5 %)	23			
	149			
Staff costs per year	1870 x 149	=		278,630
Site allowances (4 %)				11,145
				289,775
Total annual staff costs (2 tractors)	289,775 x 2	=		579,550

1.4.1.2 Equipment

Equipment	Use per year (hours)	Costs in 10^3F CFA			
		Deprec-iation	Repairs and replacement parts	Fuel and lubricants	Totals
2 tractors	2 x 900	616	418	1,078	2,112
2 scrapers	2 x 900	360	216	-	576
Total		976	634	1,078	2,668

1.4.1.3 Costs per km of road

	Francs
Annual staff costs	579.550
Annual equipment costs	2,688,000
	3,267,550

		Francs
Cost per kilometre	$\frac{3,267,550}{130 \text{ days} \times 80 \text{ km}}$	314
		say 320

2. MANUAL MAINTENANCE OF SURFACED ROADS

2.1 Introduction

This work is carried out by teams on sections of road as for the earth roads except that the reshaping and filling-in of pot holes etc is replaced by manual patching of the bituminous surface and of the road base where necessary.

Thus the team involved will be as defined for the manual maintenance of the earth roads. Additional equipment will however be required namely a binder distributor and a light-weight vibrating tandem roller (0.7t). Chippings and the binder will also need to be provided on the site. The costs will therefore be as follows: 43

2.2 Staff

	Francs
Annual cost (see section 1.3)	2,769,395

2.3 Minor equipment

Annual cost (see section 1.3)	133,000

2.4 Additional equipment

Equipment	Use in km or hours per year	Costs in 10^3F CFA					
		Depreciation	Repairs		Fuel	Lubricants	Totals
			Replacement parts	Workshop labour *			
Light lorry	40,000 km	891	803	283	527	130	2,634
Distributor	700 h	165	95	36	185	21	502
Vibrating roller	700 h	331	169	76	206	34	816
Totals		1,387	1,067	395	918	185	3,952

* Overseas department (Departement Outre Mer)

2.5 Road building materials.

Binder (cut back): 800 litres/day x 100 days = 80,000 litres/year
= 80 t/year

44 Chippings: $\frac{80t \times 50 \text{ litres/m}^2}{5 \text{ kg/m}^2}$ = 800 m^3/year

			Francs
Costs:	80t x 80,000F	=	6,400,000
	800m^3 x 14,500F	=	11,600,000
	Total		18,000,000

2.6 Total annual expenditure

	Annual costs (F)
Staff	2,769,000
Minor equipment	133,000
Additional equipment	3,952,000
Road building material	18,000,000
Total	say 24,854,000

2.7 Cost per km of road.

Assuming that the road patching team proceeds at the same rate as for the earth roads (120 km/year) then the cost per km of surfaced roads is:

	Francs
$\frac{24,854,000}{120}$	207,000
	say 210,000

From the preceding calculations this cost per km can be broken down as follows:

	Francs	Per cent
Wages	18,999	9.1
Social charges	3,515	1.7
Site allowances	901	0.4
Minor equipment	1,134	0.5
Depreciation	11,718	5.6
Replacement parts	9,009	4.3
Workshop labour	3,339	1.6
Fuel	7,749	3.7
Lubricants	1,554	0.7
Road building materials	152,082	72.4
	210,000	100.0

Road maintenance - type of work		Amount of work	Unit cost F CFA	Total cost 10⁶ F CFA	Total cost breakdown (10^6 F CFA)													
Code No.	Description				Wages (1)	Social charges (2)	Allowances (3)	Small tools and equipment (4)	Construction materials (5)	Other consumable materials (6)	Road marking (7)	Road studies (8)	Operational resources (9)	Fuel (10)	Lubricants (11)	Replacement parts (12)	Workshop labour and overheads (13)	Depreciation (14)
00	Quarries	3,900 km	3,700	14.43	1.05	0.20	0.05	-	-	-	-	-	-	1.79	0.57	4.39	1.80	4.58
01	Manual maintenance by road sections	3,900 km	46,000	179.40	72.79	13.46	3.45	4.40	-	-	-	-	-	17.11	4.19	26.04	9.15	28.75
02	Minor reshaping	22,400 km	6,000	134.40	7.40	1.37	0.36	-	-	-	-	-	-	17.61	7.26	38.30	13.04	49.06
03	Reshaping plus compacting	2,400 km	25,500	61.20	4.42	0.82	0.21	-	-	-	-	-	-	8.39	3.50	16.89	5.57	21.60
04	Search for borrowing sites	350 km	22,000	7.70	-	-	-	-	-	-	-	7.7	-	-	-	-	-	-
05	Resurfacing	336,000 m^3	1,200	403.20	31.92	5.88	1.50	-	-	-	-	-	-	63.17	15.46	112.9	38.98	133.39
06	Anti-corrugation maintenance	124,800 km	320	39.936	5.68	1.06	0.37	-	-	-	-	-	-	11.11	2.0[illegible]	6.61	1.12	11.9[illegible]
07	Civil engineering structures	-	-	174.20	31.20	5.80	1.90	1.50	50.00	2.50	-	2.3	-	18.92	4.14	20.0[illegible]	6.97	29.57
08	Bailey bridges	4 bridges (2km)	50.10⁶F	200.00	-	-	-	-	200.00	-	-	-	-	-	-	-	-	-
09	Maintenance of surfaced roads	600 km	210,000	126.00	11.40	2.11	0.54	0.68	91.25	-	-	-	-	4.65	0.93	5.41	2.00	7.05
10	Overhead costs: administrative areas, sub-divisions, districts	-	-	95.27	22.00	4.07	0.30	3.50	-	4.00	10.00	-	10.00	10.80	1.30	12.20	4.70	12.40
	Totals			1,435.736	187.86	34.77	8.28	10.16	341.25	6.50	10.00	10.00	10.00	153.55	39.15	242.74	83.33	298.14
	Increases for 1977				15 %	-	-	-	10 %	-	-	-	-	10 %	10%	10 %	15%	-
	Totals including 1977 increases			1,561.180	216.03	39.96	10.23	10.16	375.57	6.50	10.00	10.00	10.00	168.90	43.06	267.01	95.82	298.14

3. BUDGET DETAILS, MAIN ROAD MAINTENANCE (1976 prices and wages)

EVALUATING THE ECONOMIC PRIORITY OF HIGHWAY MAINTENANCE

SOME EXPLORATORY ANALYSES

by

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Paper to be presented at the Pan African Conference
on
Highway Maintenance
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EVALUATING THE ECONOMIC PRIORITY OF HIGHWAY MAINTENANCE

SOME EXPLORATORY ANALYSES

I. Introduction

1.1 More than US$10,000 million is spent each year on highway construction and maintenance by governments in the developing countries in Africa, Asia and Latin America and the costs for vehicle operation borne by road users is undoubtedly a much larger magnitude. The data do not permit us to distinguish how much of government outlay is spent on maintenance and how much on new construction, but it is clear that new construction is much larger than maintenance in most African countries which are still developing and upgrading their networks, while in some countries in Latin America and Asia, where the existing network is already very large, maintenance expenditures are increasingly overtaking new construction.

1.2 In North America and Europe high traffic volumes, high values attached to motorists travel time savings and relatively plentiful capital dictate high design standards and high maintenance standards. With several thousand vehicles per day, even minute savings in operating costs of the vehicle justify very large expenditures to maintain the road in like-new condition. Thus, until recently, very little attention has been given in the scientific literature to t e problem of determining economic levels of road maintenance. But circumstances in developing countries are different -- traffic volumes are low, incomes and values attached to travel time savings are low, and above all there is a shortage of financial resources in general and foreign exchange in particular.

1.3 The severe competing demands for limited resources dictates that African and other developing countries pay more attention to the economic design of highways and maintenance programs. But how are we to estimate the economic return on maintenance outlays? What is the benefit to society of another dollar (or pound or franc) spent on maintenance compared to another dollar spent on new roads? -- or new investment in some other sector? Is it more economical to spend a bit more money to construct a stronger pavement initially and thereby save future outlays on maintenance or, alternatively should we follow a stage construction strategy, economizing on the initial construction and paying a bit more in the way of maintenance and upgrading cost later on, when uncertainties about traffic growth will have been resolved? How much, or how little, should we spend to maintain paved roads and how much to maintain gravel and earth roads? Does it matter much if maintenance outlays are postponed during years of financial stringency?

1.4 These are questions which urgently need answering. These are questions to which we in the World Bank and our colleagues in the U.K. Transport and Road Research Laboratory, in the Kenyan Ministry of Works, and at the Massachusetts Institute of Technology have been seeking answers over the past decade. More recently further large studies on these matters have been undertaken by the Government of Brazil with assistance from the United Nations Development Program and from the University of Texas. Although many of the questions cannot yet be answered in a fully satisfactory, scientific manner, I am glad that we can at least report some significant progress.

1.5 Before I enter into a detailed technical discussion, let me summarize some significant facts. In the World Bank we are currently funding some 20 to 25 highway projects per year. In the fiscal year ending June 30, 1977, 20 projects were approved involving Bank loans or IDA credit totalling US$650 million, which on average constituted about 36 percent of the total costs of the project so that the total costs of the project constituted US$1,800 million. 1/ Substantial highway maintenance components were included in 10 of these projects, while the remaining 10 projects were constituted primarily of new construction components. An economic rate of return was calculated for 5 of the maintenance components and for all of the new construction components. The rate of return for the maintenance components averaged 63 percent per annum with a range from 20 to 118 percent, while the rate of return for new construction averaged 22 percent, with a range from 14 to 53 percent.

1.6 Such high rates of return should not be surprising. It is simple common sense that the annual benefit which would yield a return of 22 percent for new road construction costing, say, $250,000 per kilometer would calculate as a much higher return on the much smaller amount of maintenance necessary to keep that road functioning reasonably well once the investment has been sunk. The inference that one draws -- that maintenance activities tend to have a much higher economic return than new construction -- is absolutely correct so long as maintenance outlays are kept as low as they have been in most developing countries. The further inference is that some shifting of funds to road maintenance even at the expense of new investment in roads or other sectors is of utmost importance if we are to obtain maximum benefit from available resources.

1.7 One need add only a few small words of caution. High overall or average rates of return can mask some components which individually have a much lower or even negative return when one compares the incremental cost with the incremental benefit. One such example is the regravelling of very low volume roads where local conditions make this very costly -- we shall examine this case in some detail below.

1.8 A further and more important caveat is that maintenance activities are difficult to administer. They are notoriously prone to inefficiency, with a high percentage of the budget being used to support administration and the payrolls, and relatively little of the budget actually meeting the direct expenditures on the road itself. Is it any wonder that Finance Ministers are reluctant to see further monies allocated to highway maintenance if they see that 60, 75 percent or even more is consumed in administrative overheads? Inevitably one is forced to ask the question whether it is more resources which are required or simply more efficiency in the utilization of

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1/ In addition, US$103.1 million of Bank financing was made available for feeder roads costing a total of $233.8 million through agricultural and rural development loans.

the existing maintenance budget. The correct answer, I believe, in the context of the very limited maintenance budget in most African countries today, is that a good measure of both is required -- both more funds for maintenance and greater efficiency in their utilization. In the following remarks we will limit ourselves primarily to the issue of evaluating the economic priority of different maintenance activities, while others will address the important issue of how to improve the efficiency of maintenance operations.

II. Analytical Framework

A. The State of the Art

2.1 The basic problem in determining economic design and maintenance standards for a given road project is to predict, in a specified location, total road transport costs -- construction plus maintenance plus road user costs -- as a function of the road design and maintenance standards which may be adopted. The objective is to search out that combination of standards which result in minimum total costs to society, including the costs to road users as well as the costs borne by the highway authority. To have a generally applicable tool, one must know the effects of different environments (terrain, climate, traffic, driver behavior) on the different cost components. To search many alternative design and maintenance strategies to determine the most economic, there must be a capability for the rapid calculation of alternative cost streams (which may extend to twenty years or more).

2.2 Therefore in 1969 the World Bank, in conjunction with research institutions in the United States, United Kingdom and France, initiated a major program of research to develop a new decision-making framework for evaluating alternative design and maintenance strategies for low volume roads. Phase I of the study, conducted by a research group at the Massachusetts Institute of Technology and completed in 1971, developed a conceptual framework for inter-relating construction, maintenance and vehicle operating costs so that total highway costs may be minimized. 1/

2.3 However, it was concluded from Phase I, which included an extensive survey of the engineering literature, that sound empirical evidence was lacking for many of the cost relationships necessary to determine economic design and maintenance strategies particularly for low cost pavement designs, gravel and earth roads. Consequently, subsequent efforts have focused largely on empirical research involving field collection of primary information on the underlying engineering relationships, particularly vehicle speed and road user costs, and road deterioration related to design and maintenance standards. The first such study commenced in East Africa (Kenya) in 1971 and was completed in 1975. That study 2/ was conducted by

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1/ F. Moavenzadeh, et al. Highway Design Standards Study Phase I: The Model. World Bank Staff Working Paper No. 96 (January 1971). See the Report Series on the Road Transport Planning Program for Developing Countries by the Technology Adaptation Program at the Massachusetts Institute of Technology, Cambridge, Massachusetts, for the Agency for International Development, U.S. Department of State. Winter 1977.

2/ H. Hide, S. W. Abayanayaka, I. Sayer and R.J. Wyatt, The Kenya Road Transport Cost Study: Research on Vehicle Operating Costs. TRRL Report LR 672, and J. W. Hodges, J. Rolt and T. E. Jones, The Kenya Road Transport Cost Study: Research on Road Deterioration. U.K. Department of the Environment TRRL Report LR 673 (Crowthorne, Transport and Road Research Laboratory, 1975). (Hereinafter cited "Kenya Study").

the U.K. Transport and Road Research Laboratory (TRRL) in collaboration with the Kenya Ministry of Work and the World Bank. The Kenya study has largely succeeded in providing a new decision-making framework and data base for determining design and maintenance strategies for low volume roads applicable to Kenya, to other parts of Africa and elsewhere where conditions are similar.

2.4 The Transport and Road Research Laboratory redeveloped and extended the original MIT/IBRD model based on its research in Kenya and elsewhere. 1/ The two models have salient features in common but differ in detail. The original MIT model and subsequent TRRL (RTIM) model were designed as tools to evaluate total transport costs on one route. The output formats are simply in terms of cost and the models do not include endogenous facilities for economic comparisons between alternatives. Therefore, a collaborative effort was undertaken in 1976-77 to develop a unified Highway Design and Maintenance Standards Model (HDM) to incorporate the best features of the MIT and RTIM models. Except for the integration of the construction cost submodel this work has now been completed, and the HDM provides a consistent model that is flexible and easy to use. 2/ This model is now being used by government planning agencies and the World Bank to design maintenance programs and evaluate proposed projects in several countries. Possibly its most important use will be at the stage of the feasibility study where it can be used to evaluate many alternative designs and time staging strategies. It can be made available to government agencies and consulting groups. In common with any large scale computer program, it requires several man weeks of effort to learn how to make effective use of it. We are finding, however, that once it has been mastered, subsequent applications are very quick and very economical.

2.5 Although we are at the present time using the model to analyze a number of projects in South America as well as both West and East African countries, the extent to which the results from Kenya are valid in other regions is not clear. Research on road deterioration was limited to the climate and types of road surfaces common to Kenya: predominantly surface dressings on cement stabilized bases and four types of gravel roads (lateritic, quartzitic, volcanic and coral). Very little information was gained on the behavior of earth roads nor anything on the type of sand-clay engineered surfaces that are used in other areas of Africa. Extreme geometric conditions were not studied, although further complementary studies in Ethiopia, Scotland and Brazil will soon be filling this gap. The research also focussed on low volume roads with free flowing traffic typical of Kenya. The effect of vehicle flow interactions, including non-motorized vehicles, on total costs and the relationship of these to road width and geometric standards was not

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1/ R. Robinson, H. Hide, J. W. Hodges and J. Rolt. A Road Transport Investment Model for Developing Countries. U.K. Department of the Environment, TRRL Report LR 674 (Crowthorne, Transport and Road Research Laboratory, 1975). (Hereinafter cited "RTIM Model").

2/ This work was performed by Prof. F. Moavenzadeh and colleagues of MIT, in collaboration with Dr. R. Robinson of the Overseas Unit, TRRL, and the Transportation Department of the World Bank.

researched in the Kenya study; in Asia and much of Latin America the volume and composition of traffic is quite different and a more important variable. Since many of these issues are more important in non-African countries, further research is being focused there. A large-scale study similar in purpose to the Kenya study was initiated in Brazil from July 1975 1/ and a similar study is just getting underway in India 2/ to develop the necessary relationships appropriate to those environments. However, in the interim of about two years before further research is completed in these regions we shall continue to apply the model based largely on the Kenyan relationship supplemented by results of research elsewhere as they become available.

B. The Highway Design and Maintenance Standards Model (HDM)

2.6 The HDM model is used to predict the costs of different highway design and maintenance options, including different time staging strategies, either for a given road project on a specific alignment, or for a group of links or for the different links of an entire highway network. It can quickly estimate the total costs for large numbers of alternative designs and maintenance policy combinations on a year by year basis for as many as 30 years or longer as required, and thus be used to search for the alternative with the lowest total cost. In fact the model can evaluate in the same computer run up to 20 different road links, each with up to 10 segments with different design standards. Each link can have a different traffic volume. Further, up to 5 different maintenance policies can be implemented on each segment of the road. Each link or segment can be upgraded at any time in the life-cycle of the project (e.g., from earth to gravel or from gravel to paved) and the paved road can be realigned or widened. All estimates of maintenance and vehicle operating costs are first made in physical quantities, and then prices and unit costs are applied to determine the total market and economic costs. Shadow prices and rates may be applied if desired.

2.7 The model also gives the results of economic analysis (total discounted transport costs, rate of return, net present value and first year benefits) for comparison of any combination of two alternatives as desired by the user. Finally, the model has the capability to analyze sensitivity of economic results for changes in key variables such as construction costs, traffic growth rates, discount rates and value of passengers' time. Thus the model is very flexible and offers great computational power. The model, however, does not provide a traffic forecast, which must be specified by the user. Similarly, the model does not calculate the regional income or

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1/ A project financed by the Government of Brazil and the United Nations Development Program and being executed by the Empresa Brasileira de Planejamento de Transportes (GEIPOT) with the assistance of the University of Texas, Austin. The World Bank is the executing agency for UNDP.

2/ A project financed by the Government of India and the World Bank, to be executed by the Central Road Research Institute of New Delhi.

value added benefits of feeder roads, nor the unit value of time savings, nor accident costs, but it does provide facility for these items to be fed in from separate estimates if desired.

2.8 It is the interrelationships among construction costs, road maintenance costs and road user costs, which are the principal focus of the analysis and these interrelationships may be depicted as shown in Figure 1.

2.9 Road Design and Construction Costs. The horizontal alignment is specified in terms of the average degree of curvature per kilometer and is used for predicting vehicle speed which then affects vehicle operating costs. The vertical alignment is used for predicting vehicle speed and fuel consumption and also loss of material for gravel roads; the vertical alignment is also a major determinant of earthworks cost. It can be specified in terms of average rise and fall per kilometer or in the RTIM model as vertical curves and the intersection points of the tangent lines. If no vertical alignment is available, one can be designed by the RTIM model using a method based on the TRRL program "Venus". 1/

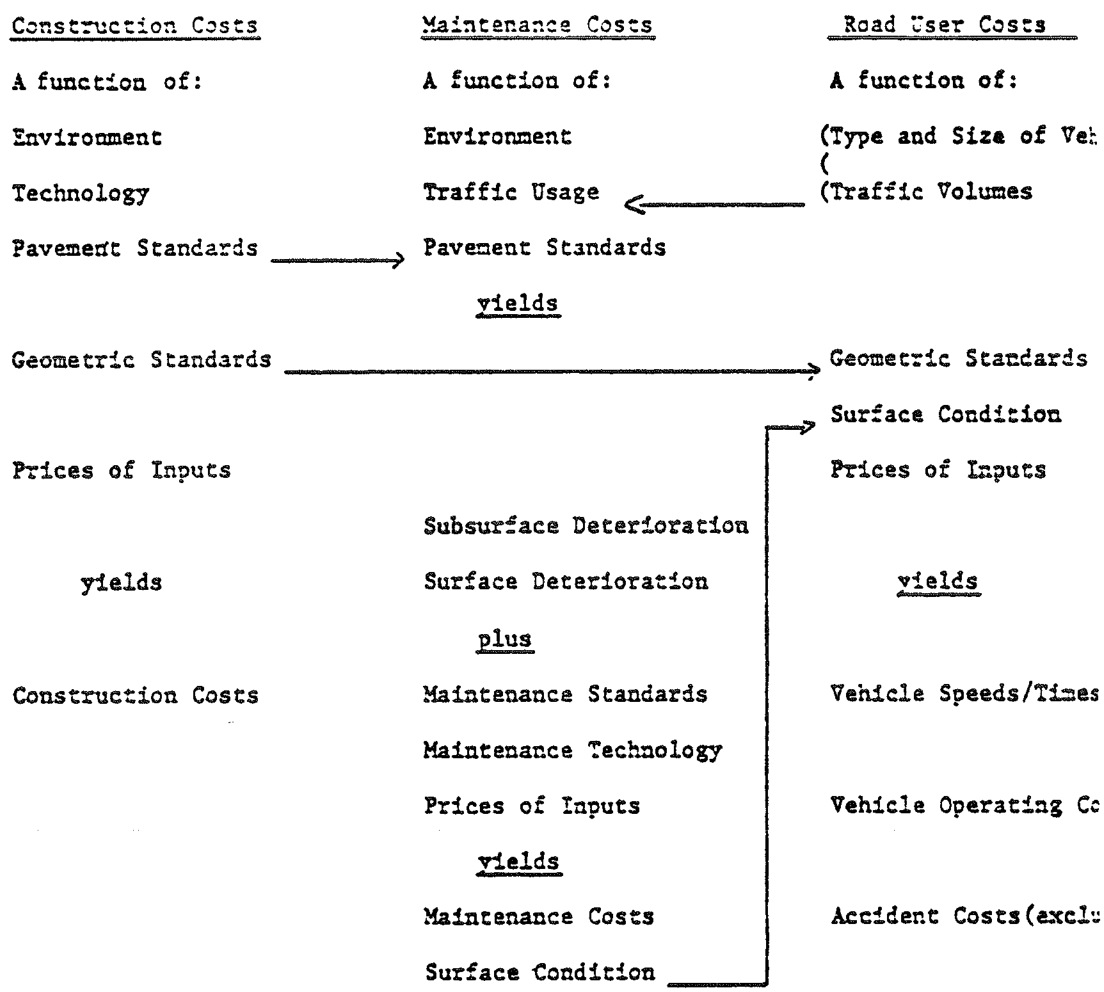
2.10 For pavements up to six material layers may be specified. Each is identified by its thickness and material type. The strength of the subgrade, subbase and base is specified in terms of California Bearing Ratio (CBR), except for a chemically stabilized base which is defined by the unconfined compressive strength; asphalt surfaces are defined by the strength coefficient. These are used to determine a Modified Structural Number which is used as an index of pavement strength. For gravel roads, only one pavement layer is used and, for earth roads, there are no pavement layers. Shoulders may be earth, gravel or paved and are specified in the same way as for the main carriageway.

2.11 Where there is either new construction or reconstruction, construction costs may be specified exogenously from available engineering estimates, or alternatively, the RTIM model has the capability for calculating an estimate of construction costs from given topographical data and specifications for horizontal and vertical geometry, geotechnical data and pavement design standards and unit costs.

2.12 Road Deterioration and Maintenance Costs. The maintenance sub-model performs the important function of linking construction standards (and costs), road maintenance standards (and costs), and road user costs through the road deterioration relationships. Although maintenance is normally a small portion of total costs, the model considers road deterioration and maintenance policies in some detail because vehicle operating costs are significantly affected by road surface condition, and the life of the investment and future rehabilitation costs are heavily dependent on the timeliness of maintenance.

1/ R. Robinson. A Further Computer Method for Designing the Vertical Alignment of a Road: Program Venus II. Department of the Environment, TRRL Report LR 458. Crowthorne, 1972 (U.K. Transport and Road Research Laboratory).

FIGURE 1


Construction Costs
A function of:
Environment
Technology
Pavement Standards
Geometric Standards
Prices of Inputs
yields
Construction Costs
Maintenance Costs
A function of:
Environment
Traffic Usage
Pavement Standards
yields
Subsurface Deterioration
Surface Deterioration
plus
Maintenance Standards
Maintenance Technology
Prices of Inputs
yields
Maintenance Costs
Surface Condition
Road User Costs
A function of:
(Type and Size of Veh
(
(Traffic Volumes
Geometric Standards
Surface Condition
Prices of Inputs
yields
Vehicle Speeds/Times
Vehicle Operating Co
Accident Costs (exclu

2.13 Road deterioration is a function of the original surface design, material types, the volume and axle load configuration of traffic, climate and the maintenance policy specified. The input data to the road maintenance sub-model includes initial road roughness and, for existing paved roads, pavement age and cumulative standard axles that the road has carried since new (in the most heavily trafficked lane). In addition different maintenance policies must be specified. Maintenance options for paved roads include patching, surface dressing, overlaying and reconstruction and for unpaved roads, grading and regravelling, in addition to other routine maintenance (drainage, shoulders and vegetation control). For each year that the road is open to traffic, the model then predicts the deterioration of the road surface as vehicles travel along it. Having predicted the conditions of the road, the model calculates the quantities for each of the maintenance tasks required by the specified policy, and then applies unit costs to determine total maintenance costs for the given year, and similarly for each subsequent year.

2.14 Road User Costs. Road user costs are determined for each year that the road is open to traffic using the relationships developed in the Kenya study and supplemented by subsequent research. Travel time costs may also be added to these, if desired, and can be found from the product of the value of passengers' time, which may be input to the model, and journey time which is found from the road length and the average vehicle speeds.

2.15 Both vehicle speed and fuel consumption are calculated endogenously for each vehicle type. Vehicle speed is a function of average rise and fall, horizontal curvature, and road width, and, in addition, for unpaved roads surface roughness, moisture content, and rut depth; for medium and heavy goods vehicles, it is also a function of power/weight ratio. Fuel consumption is a function of speed, rise and fall, and for unpaved road, also roughness and looseness; for medium and heavy goods vehicles it is also a function of the power/weight ratio, and in addition of gross vehicle weight for medium goods vehicles.

2.16 The cost of vehicle maintenance (parts and labor) is calculated using the new vehicle price, the distance travelled by the vehicle since new and the roughness of the roads it has traversed. Tire costs are related to the roughness of the road and, for heavy vehicles only, to the gross vehicle weight.

2.17 For depreciation, there are two methods of calculation. The first method relates depreciation to average speed, annual kilometrage and vehicle life, all of which must be specified exogenously. In the second method, depreciation is a function of vehicle age and annual kilometrage of which annual kilometrage exogenously specified to the model and vehicle age is estimated endogenously by the model based on the originally specified age distribution of the fleet.

2.18 In addition, the model calculates crew costs, interest charges on capital invested in vehicles, and standing costs using exogenously specified data on average annual crew hours, interest rate, vehicle prices, and standing cost coefficients. The model considers separately up to eight classes of vehicles: passenger cars, light commercial vehicles, buses and up to five classes of heavy commercial vehicles. Market and economic prices of vehicles, tires, gasoline, diesel, lubricants, maintenance labor, crew, value of time and standing costs are input to the model. For the five classes of heavy vehicles brake horse power, unladen weight, average load, and equivalence factors also are required as input data. Initial traffic volumes and traffic growth rates are also input for each vehicle type. The future traffic forecasts can be specified in a variety of ways to allow any type of traffic growth function to be simulated.

C. The Economic Benefits of Alternative Maintenance Policies

2.19 The economic benefits of highway maintenance expenditures are comprised of three basic components:

(i) reductions in user costs: principally vehicle operating costs, also passenger time savings, and accident cost savings;

(ii) reductions in the level of future maintenance and rehabilitation expenditures which will be required to maintain the same service standard if maintenance is not done in a timely manner;

(iii) reduction or prevention of the economic loss due to road closures.

2.20 Reductions in vehicle operating costs are normally by far the largest component. Only under extreme conditions do other benefits approach the same order of magnitude, e.g. where traffic volumes are of the order of 10 vehicles per day or less. Avoidable future maintenance and rehabilitation expenditures which will be incurred if preventive maintenance is not done when needed can become very large, however, in relation to normal maintenance - a poignant example of the old adage that "a stitch in time saves nine." Reduction or prevention of road closures is primarily of concern with respect to earth and low volume gravel roads where there is some question as to the economic feasibility of (re) gravelling to all-weather standards. Evaluating the economic loss due to road closure gives rise to some interesting theoretical speculations, which strongly suggest that the losses are not of a large order of magnitude from an economic perspective, since road users stockpile goods to be transported and otherwise adapt their behavior. But we have no really satisfactory empirical measures of either the economic or social costs of road closures.

2.21 Figure 2 depicts the benefits which arise from the different maintenance activities, first from an a priori conceptualization and second from the type of relationships which have been derived or inferred from field research and incorporated into the HDM model. It is to be noted that we currently have no definite, quantified relationships on the benefits of four

FIGURE 2: ECONOMIC BENEFITS OF HIGHWAY MAINTENANCE - CONCEPTUAL FRAMEWORK

Maintenance Activity	Surface Type	Impact: Idealized	Impact: Current Model
A. Routine Maintenance			
1. Drainage Clearance	Paved, Unpaved	Reduces water penetration of road structure, decreating deterioration of structural strength and surface condition.	None: assumes "normal" maintenance.
2. Shoulder Maintenance	-do-	Reduces shoulder erosion and roughness, decreasing pavement ravellin vehicle operating costs (VOC) and accidents.	-do-
3. Vegetation Control	-do-	Improves lateral vision and increases vehicle speeds.	-do-
4. Dragging	Lateritic Gravels	Reduces roughness increases vehicle speeds, reduces vehicle operating costs.	None, but could be arbitrarily specified as some fraction of the effect of grading operation.
5. Normal Grading (no wetting or compaction)	Gravel, Earth	Improves surface condition (roughness, rut depth), increases vehicle speeds, reduces vehicle operating costs.	Fully incorporated as measured by Kenya study.
6. Patching of Cracks and Potholes	Paved	(a) Reduces water penetration of road structure thereby decreasing deterioration of structural strength, rate of growth of road roughness and hence vehicle operating costs.	Fully incorporated as measured by Kenya study and extrapolated for extreme conditions.
		(b) Patching increases immediate surface roughness for small cracks, but decreases immediate roughness for severe cracking and potholes.	No effect on immediate level of roughness.

Maintenance Activity	Surface Type	Impact: Idealized	Impact: Current Model
B. Periodic Maintenance and Rehabilitation			
1. Heavy Grading & Reshaping (wetting and compacting)	Gravel, Earth	Restores shape, improves drainage reducing rate of deterioration, increases vehicle speeds, reduces vehicle operating costs.	No additional benefit compared to normal grading.
2. Gravelling	Gravel, Earth	(a) Creates higher strength, reducing rate of surface deterioration, increasing vehicle speeds and reducing vehicle operating costs.	Fully incorporated as measured by the Kenya study for gravel roads; earth roads arbitrarily assumed to have rate of deterioration (roughness) 15X faster than gravel roads in the absence of any evidence.
		(b) May increase or decrease immediate roughness depending on pre-existing condition and quality of gravel.	Assumes same immediate roughness after grading for both earth and gravel roads (=3250 mm/km).
		(c) Preserves all weather characteristics.	Does not calculate estimate of economic loss due to road closures but exogenous estimate may be specified.
3. Resealing (single or double bitum. surface dressing)	Paved	(a) Reduces water penetration etc. (see Patching)	Fully incorporated.
		(b) May decrease slightly immediate roughness of badly patched surface, but may increase slightly roughness of smoothly polished surfaces.	No effect; thought to be negligible in effect on vehicle speeds and operating costs.

Maintenance Activity	Surface Type	Impact: Idealized	Impact: Current Model
4. Asphalt Overlays	Paved	(a) Reduces water penetration etc. (see Patching).	Fully incorporated.
		(b) Restores/increases structural strength, reducing rate of deterioration to new condition.	Fully incorporated from AASHO Illinois Test results and Asphalt Institute.
		(c) Reduces immediate roughness to new asphalt concrete level.	Fully incorporated from Kenya study.
5. Reconstruction	Paved	Similar effects to overlay except reconstruction with light bituminous surface likely to have different deterioration including greater susceptibility to cracking and water penetration than heavy asphalt concrete overlay.	Assumes same behavior as asphalt concrete overlay with equal structural number.

of the basic routine maintenance operations: drainage clearance, shoulder maintenance, vegetation control and surface dragging. It is, of course, easy to conceive what type of impact either lower or higher levels of expenditure on these components might have, but we do not have any creditable measurements. Thus, for the present time, we are forced simply to assume that a certain level of expenditure for these routine items is required as a part of the overall maintenance policies, and it is not possible to predict the optimum level.

2.22 In the following three chapters we shall examine applications of the HDM model to estimate the benefits of different maintenance activities.

III. Case Study I: Maintenance Policy Analysis for Unpaved Roads

A. Introduction

3.1 In a recent case we employed the HDM model to do an extensive engineering-economic analysis of a proposed country-wide maintenance program for unpaved roads. The purpose of the analysis was two-fold: first, to ascertain the economic feasibility of the road maintenance program as a whole; and, second, to determine an economically efficient scale and composition of the program. The first objective is, of course, the standard economic criterion in any public project evaluation. The second objective, in an attempt to advance one step further, calls for a systematic analysis of a whole spectrum of alternative maintenance policies to arrive at an optimal (or at least more efficient) allocation of equipment and manpower resources among different road types and traffic volumes.

B. Basis of the Analysis

3.2 The HDM model was used to simulate total costs for road maintenance and vehicle operation over a 16-year period. The simulation predicted gravel loss and road deterioration of the road surface (roughness, rut depth and looseness) and the effect thereof on speeds and operating costs. The methodology for predicting unpaved road performance is described in some detail in Annex 1. In addition, since earth roads can be closed during wet weather, an approximation was made for the economic cost of road closure.

C. Specification of Inputs

3.3 The base input data employed, which are similar in level of detail to that required for the typical road maintenance feasibility study, fall into four major categories:

(i) Road Data: engineering characteristics of the existing road system--surface types, geometry and length of each type. (Table 3.1)

(ii) Traffic Data: traffic composition, present volumes, and growth rates (Table 3.2)

(iii) Vehicle Data: technical characteristics, utilization and capital costs of the different vehicles and prices of the basic inputs in vehicle operation (Table 3.3)

(iv) Maintenance Cost Data: unit costs of the various maintenance activities, capital costs and productivity of equipment (Table 3.4)

3.4 In analyzing a road maintenance program on a country wide or network basis it is necessary to reduce the input data to a size manageable to the analyst as well as the computer program. In this study the data simplification was done by aggregating the road sections into few (less than 20) classes by surface type, geometric characteristics, and traffic volume -- each class represented by average characteristics. The timing of major operations (e.g., gravel resurfacing) -- which would actually be spread over time over small road sections -- was specified for a single average year. Such data simplification enables an easier and more meaningful interpretation of analysis results to be made. The actual programming of maintenance activities can more easily be done once the basic economic results have been established.

D. Specification of Maintenance Policies

3.5 Maintenance policies for unpaved roads include drainage and vegetation control, dragging (with rubber tires, chains, or small trees), emergency repairs for washouts and weak spots, grading, and gravel resurfacing. Grading and regravelling, which typically constitute the majority of an unpaved roads maintenance program, were analyzed explicitly using the HDM model. As noted in Section II it is not possible to evaluate other routine maintenance activities separately; but since they are essential to road serviceability, their costs were included in the total.

3.6 Even after the entire road network has been reduced to a few classes, it is still difficult to explore maintenance policy alternatives for all classes exhaustively. The approach taken in this study was therefore to single out some "typical" maintenance strategies for detailed analysis. Insights gained from the prototypical cases would serve to guide the development of alternative maintenance policies for the entire road system. 65

3.7 The following paragraphs present the results of detailed policy analysis performed for Road Section 1, actually a group of engineered, laterite road links totalling 480 kms.

E. Findings

3.8 Grading Frequencies. The effect of more frequent grading is to improve road surface condition and thereby increase vehicle speeds and decrease vehicle operating costs at the expense of some increase in maintenance costs. Table 3.5 summarizes results of three grading frequencies for Road Section 1, with regravelling and without. With regravelling, the road was assumed to retain its lateritic surface throughout the planning horizon; without regravelling, the road was assumed to revert to an earth road with the (much more rapid) deterioration characteristics of non-clay earth material (see Annex 1). With the exception of the grading frequency, all cases include the same amount of routine maintenance and 30 rubber tire dragging passes per year. A first observation is that the economic returns of any of the grading policies are generally high and are positive even at traffic volumes as low as 10 vehicles per day, as indicated by the ratios of net present values to maintenance outlays ranging from about 2 to 7 in the without regravelling case. Second, the relative economic benefits of different grading frequencies are very similar, implying a wide range of substitutability between maintenance and vehicle operating costs. The "flatness" of the optimal blading frequencies (at which the net present value is maximized) is depicted in Figure 3.1. In both with and without regravelling cases, the optimal blading frequencies expressed in the number of vehicle passes per blading operation is essentially constant for 30-90 vehicles per day base year traffic--after allowing for time-dependent road deterioration as described in Annex 1. At less than 30 vehicles per day time-dependent road deterioration begins to take effect and slightly increases the optimal blading frequency for laterite surface.

3.9 The frequency of one grading in 7,000 vehicle passes, which is optimal for lateritic roads, implies one grading every 140 days (roughly every five months) for a base traffic of 50 vehicles per day, but only one grading in 350 days (or once per year) where traffic is only 20 vehicles per day. Also as expected, when the "without regravelling" cases are compared to the "with regravelling" cases, it is seen that the optimal grading frequency is generally twice or more for the former case, indicating that increases in grading costs offset savings in regravelling costs to some extent when the road reverts to earth standards.

3.10 Regravelling. The effect of regravelling is to provide a riding surface which can withstand traffic better than that of natural terrain and permit all-weather usage. Withholding regravelling was assumed in the analysis to cause a gravel road to lose the surface material and ultimately revert to a non-clay earth road whereupon vehicle operating costs and grading costs rise much faster. Recognizing the fair-weather-only service characteristics of an earth road, a crude estimate of the economic losses due to road closure under the withholding regravelling policy was made based on the storage and interest costs arising from the necessity to store the goods which would otherwise be transported without delay; the magnitude of the costs for storage facilities is a function of the maximum length of closure.

3.11 Table 3.6 summarizes the results of the analysis of regravelling for varying road widths, including allowances for economic losses due to road closure, alternatively, for one-month and two-month maximum closure periods. The "optimal" blading frequencies of 7000 and 3000 vehicle passes per blading were used for the with and without regravelling respectively. For the given price of $11.06 per cubic meter for regravelling, the breakeven traffic volumes (which are the minimum traffic volumes over which regravelling can be economically justified) under different assumptions are summarized below:

	Breakeven Traffic Volume (base year ADT)
7-meter width	more than 90
6-meter width	50-60
5-meter width	40-50

Note, however, as discussed in Chapter IV below, the breakeven traffic criterion will always indicate regravelling should take place earlier (i.e. at a lower traffic volume) than is economically optimal.

3.12 Figure 3.2 shows the graphs of maintenance costs for regravelling and no regravelling, broken down into regravelling, and blading and other activities, plotted against traffic volume. It is seen that although the total maintenance outlay is greater under regravelling, the cost of blading is substantially lower. In Figure 3.3 the breakeven traffic volume is plotted against the unit cost of regravelling per cubic meter for regravelling widths of 5, 6 and 7 meters, and at 10 and 20 percent discount rates, with a 2-month stockpiling period used in all cases. As illustrated in Figure 3.4 the difference in total net present value between regravelling and no regravelling (as compared to the net present value relative to doing no maintenance at all) is not very sensitive to the traffic volume. This suggests that from the economic efficiency standpoint, the choice of whether to withhold regravelling is not extremely crucial over a substantial range of traffic volume where neither the cost of regravelling nor the opportunity cost of capital is excessive, since the increase in vehicle operating cost savings are about equally offset by the savings in the cost of regravelling. However, under severe financial stringencies where capital budgets imply opportunity costs of capital at much higher rates, or where local conditions make regravelling a very expensive operation, regravelling of very low volume roads will not be economical.

3.13 In reducing the width of regravelling only the savings in regravelling cost (in direct proportion to width) have been reflected in the economic benefits. In fact, the traffic intensity is expected to be greater over a narrower road width, thereby causing more rapid deterioration (rutting in particular and gravel loss to some extent). There would likely be a marginal increase in road grading costs and possibly a small increase in vehicle operating costs which have not been incorporated in Table 3.6 or Figure 3.3. 67

F. Comparison of Alternative Policies for Regionwide Maintenance Program

3.14 Based on the results of parametric analysis of basic maintenance policies discussed in the preceding section, four alternative maintenance policies were specified for the entire unpaved road network, as summarized in Table 3.7. The alternatives were developed for widely different levels of maintenance expenditures. Policies 1 and 2 include regravelling on some major road sections whereas policies 3 and 4 do not. Two levels of blading frequencies are compared each for the regravelling and without-regravelling cases; we have in the regravelling case the "optimal" blading frequency and a frequency twice the optimal, and in the without-regravelling case the optimal and one-half the optimal frequency. (Note that Policies 2 and 3 are identical for Road Sectons 5-12).

3.15 The "optimal" blading frequencies in Policies 2 and 3 (in months between successive bladings) were derived based on the results of previous analyses which indicated that the optimal number was approximately 7000, 5000, and 3000 vehicle passes between bladings for the lateritic, sand-clay and earth surface materials, respectively. The blading intervals were computed by rounding off as shown in Table 3.7C. For the low traffic level (6 vehicles per day), the time-dependent weathering effect became significant and a somewhat higher blading was specified. Because of the "flatness" of the optima, the rounding errors would not have significant effect on the net benefits computed.

3.16 The summary of results in Table 3.8 shows that all policies have high positive net benefits relative to their maintenance outlays. Policy 3, for which the discounted maintenance cost is about one-half and two-thirds those of Policies 1 and 2, respectively, has a total net present value exceeding those of the other policies by greater than 10 percent. This suggests the importance of examining a wide range of alternative policies in order to obtain a reasonably cost-effective road maintenance program.

F. Conclusions

3.17 Notwithstanding the limitations in the methodologies, the results from the policy analysis of unpaved road maintenance have led to the following principal conclusions:

(i) The economic benefits of maintaining unpaved roads in reasonable minimum serviceable condition are extremely high and are positive even for traffic volumes as low as 10 vehicles per day.

(ii) As maintenance standards are increased beyond the minimum levels the returns to additional outlay for routine maintenance of unpaved roads tend to about equal the additional costs. In fact at higher levels of routine maintenance there appears to be a rather broad range over which net present values of different standards are quite similar.

(iii) The economic return to achieving minimum standards of routine maintenance (specifically grading) tend to exceed the returns to regravelling by wide margins.

(iv) Where local conditions make regravelling very expensive and/or where financial stringencies imply high opportunity costs of capital, regravelling of lower volume roads is likely to be uneconomical.

(v) The purpose of road maintenance program economic evaluation should be not only to justify a project proposal but also to search for a reasonably cost-effective solution, in an incremental, systematic manner over a wide spectrum of alternative policies. There is a need to examine carefully the individual components which make up the total maintenance program, since the high total economic benefits, which are themselves sufficient to economically justify the program, may conceal many possible deficiencies in the individual components.

TABLE 3.1

CASE STUDY I - Etude de Cas I

INITIAL ROAD CHARACTERISTICS
Caractéristiques initiales de la route

Section	Geometric Standard a/ Classification géometrique a/	Surface Material Matériaux de couche de roulement	Length (km) Longueur (km)	Base Year ADT TJM de l'anneé de base	Width of Wearing Course (meters) Largeur de la couche d'usure (metres)	Initial Surf Thickness (c Epaisseur initiale de la couche roulement
1	Engineered	Laterite	431	45	7.0	2.0
2	Etudieé	Latérite	190	20	7.0	2.0
3		Mix - Mélange	131	45	7.0	2.0
4	Engineered	1/3 Sand - Sable	53	20	7.0	2.0
5	Etudieé	2/3 Clay - Argile	190	6	7.0	2.0
6	Partially Eng.	Latérite Laterite	79	45	5.0	2.0
7	Partially Eng.	Mix - Mélange	132	45	5.0	2.0
8	Etudieé par-	1/3 Sand - Sable	150	20	5.0	2.0
9	tiellement	2/3 Clay - Argile	259	6	5.0	2.0
10		Natural	210	45	5.0	-
11	Track - Piste	Terrain	753	20	5.0	-
		Terrain naturel	2503	6	5.0	-

a/ Because of lack of data the following geometric standards were assumed for each road section:

Average rise and fall = 3%
Average horizontal curvature = 175 degrees/km

a/ Due au manque de donneés, les hypothèses suivantes ont été faites pour chaque section routiere:

Pente moyenne = 3%
Degré de sinuosité = 175 degrés/km

TABLE 3.2

Tableau 3.2

CASE STUDY I - Etude de Cas I

BASE YEAR AVERAGE DAILY TRAFFIC BY VEHICLE TYPE a/
Trafic journalier moyen de l'année de base par type de véhicule a/

Traffic Level Volume du Trafic		Light Goods Vehicle Camion-nette	13-tonne Truck Camion 13 t.	27-tonne Truck Camion 27 t.	38-tonne Truck Camion 38 t.	Total
A		16	9	11	9	45
B		7	4	5	4	20
C		2	1	2	1	6

a/ For each traffic level and each type of vehicle the annual percentage growth of 2 percent was assumed.

a/ Un accroissement annuel de 2 pourcent a été admis pour chaque volume de trafic et chaque type de véhicule;

TABLE 3.3
TABLEAU 3.3

CASE STUDY I - Etude de Cas II

VEHICLE CHARACTERISTICS AND COSTS
Caractéristiques techniques et coût des véhicules

DESCRIPTION	Light Goods Vehicle Camionnette	13-Tonne Truck Camion	27-Tonne Truck Camion	38-Tonne Truck Camion	Description
PHYSICAL CHARACTERISTICS AND UTILIZATION		Données techniques et l'utilisation			
Brake Horse Power	86	130	160	250	Puissance au frein
Payload (Tonnes)	1	7	14	24	Charge utile (tonnes)
Gross Vehicle Weight (Tonnes)	2.7	13.0	27.0	38.0	Poids total en charge (tonnes)
Fuel Type	Gasoline essence	Diesel gas oil	Diesel gas oil	Diesel gas oil	Carburants
Annual Operating Hours	800	800	1200	1200	Nombre d'heures de l'utilisation du véhicule par an
Annual Crew Hours	2000	2000	2000	2000	Nombre d'heure de personnel de conduite par an
Annual Kilometerage	25000	25000	25000	35000	Kilomètrage annuel
Average Vehicle Life (years)	4	6	6	6	Durée de vie du véhicule (ans)
UNIT COSTS					Prix et coût unitaire en US$
New Vehicle Cost ($/vehicle)	5763	18184	31143	49486	Prix d'un véhicule neuf
Tire Cost ($/tire)	69.1	395.5	395.5	395.5	Prix d'un train de pneumatiques
Maintenance Labor Cost ($/hour)	0.41	0.41	0.41	0.41	Coût horaire du personnel d'entretien
Crew Cost ($/hour)	0.49	0.42	0.42	0.42	Coût horaire du personnel de conduite
Fuel Cost ($/litre)	0.33	0.33	0.33	0.33	Coût du carburant (litre)
Lubricating Oil Cost ($/litre)	1.54	1.54	1.54	1.54	Coût du lubrifiant (litre)

TABLE 3.4 - Tableau 3.4

CASE STUDY I - Etude de Cas I

UNIT MAINTENANCE COSTS
Coûts unitaires d'entretien

Maintenance Operation - Opérations d'entretien			Unit Cost - Coût unitaire	
Regravelling Rechargement	Laterite - Latérite 10 cm thickness - 10 cm d'épaisseur		$11.06	Per cubic meter in place Par m^3 mis en place
	Sand-Clay 15 (cm) thickness Sable-Argile - 15 cm d'epais-seur		$ 8.63	
Dry Grading - Reprofilage			$91.00	Per km of blading Par km remise au profil
Grading with Compaction - Reprofilage (avec compact-age)			$439.00	
Spot Emergency Repairs - Point à temps			$ 6.89	Per cubic meter in place Par m^3 mis en place
Rubber Tire Dragging - Gratte tôle à pneus			$ 2.37	Per km of dragging Par km traîné
General Routine Maintenance Entretien Courant	Productivity of one maintenance unit (km) Rendement d'une unité d'entretien (km/an)	200 150 100	$107.0 $147.0 $214.0	Per km per year Par km/an

Notes:

(i) These costs include operating costs, overhead and equipment amortization but do not include workshop and training costs which do not differ substantially from policy to policy.
(ii) Except for regravelling and general routine maintenance, 35 percent of the unit costs were assumed to be equipment amortization.
(iii) The regravelling costs are estimates for work done by contractors.

Notes:

(i) Ces coûts comprennent les coûts d'exploitation, les frais généraux, l'amortissement du matériel, mais pas les coûts d'atelier et de formation du personnel, lesquels ne diffèrent pas sensiblement d'une méthode à l'autre.
(ii) A l'exception des opérations de rechargement et de l'entretien courant, 35% des coûts unitaires des opérations ont été considérés être l'amortissement du matériel;
(iii) Les coûts de rechargement correspondent à l'éstimation de travaux qui seront effectuès par des entreprises de travaux publics.

TABLE 3.5 - Tableau 3.5

CASE STUDY I - Etude de Cas

Discounted Benefits and Costs for Various Grading Frequencies and Traffic Levels for Regravelling and No Regravelling

Avantages et coûts actualisés pour différentes fréquences de reprofilage et différents volumes de trafic, avec et sans rechargement

Discount Rate = 10 percent - Taux d'actualisation = 10 pourcent

Discounted Costs a/ Benefits ($ million)	Grading Frequency No; of Vehicle passes/blading Frequence de reprofilage. Nombre de passages de vehicules par remise au profil	Base Year Average Daily Traffic Trafic journalier moyen de l'anneé de base							Avantages/coûts actualisés a/ ($ million)
		10	30	40	50	60	70	90	
		With Regravelling - Avec rechargement							
Vehicle Operating Cost Savings a/	4000	3.69	18.95	26.30	34.28	40.91	48.07	61.88	Economies sur le coût de fonctionnement des véhicules
	7000	3.50	18.[illegible]	25.83	33.69	40.29	46.91	61.05	
	10000	3,27	18.43	25.33	33.14	39.64	46.64	60.06	
Maintenance Costs	4000	4.50	7.35	7.68	8.20	8.72	10.03	11.13	Coûts d'entretien
	7000	4:33	6.85	7.02	7.36	7.73	8.87	9.64	
	10000	4,27	6.65	6.75	7.03	7.33	8.40	8.94	
Net Present Value	4000	-0.81	11.60	18.62	26.08	32.19	38.04	50.75	Valeur actualiseé nette
	7000	-0.83	11.84	18.81	26.33	32.56	38.50	51.41	
	10000	-0.99	11.78	18.58	26.11	32.31	38.24	51.12	
		Without Regravelling - Sans rechargement							
Vehicle Operating Costs Savings a/	2000	4.18	17.07	24.26	31.92	38.26	45.10	58.13	Economies sur le coût de fonctionnement des véhicules
	3000	3.54	16.53	23.50	30.97	37.15	43.81	56.49	
	5000	3.24	15.47	21.98	29.10	34.93	41.23	53.21	
Maintenance Costs	2000	2.05	3.10	3.88	4.65	5.43	6.20	7.75	Coût d'entretien
	3000	1.30	2.32	2.85	3.36	3.88	4.40	5.43	
	5000	1.09	1.71	2.02	2.33	2.64	2.95	3.57	
Net Present Value a/	2000	2.13	13.97	20.38	27.27	32.83	38.90	50.38	Valeur actualiseé nette
	3000	2.24	14.21	20.65	27.61	33.27	39.41	51.06	
	5000	2.15	13.76	19.96	26.77	32.29	38.28	49.64	

a/ Relative to the do-nothing (zero maintenance) case.

a/ Par rapport au cas de "ne rien faire" (entretien zero).

Compendium 11 Text 4

FIGURE 3.1

CASE STUDY I - Etude de Cas I

EFFECT OF BLADING FREQUENCY ON VEHICLE OPERATING
Effets de la fréquence de la remise au profil sur les économies relatives

COST SAVINGS AND MAINTENANCE COSTS
aux coûts d'exploitation des véhicules et aux coûts d'entretien

(Base Year ADT=50; 10% interest)
(TJM de l'anneé de base = 50; taux d'intérêt 10%)

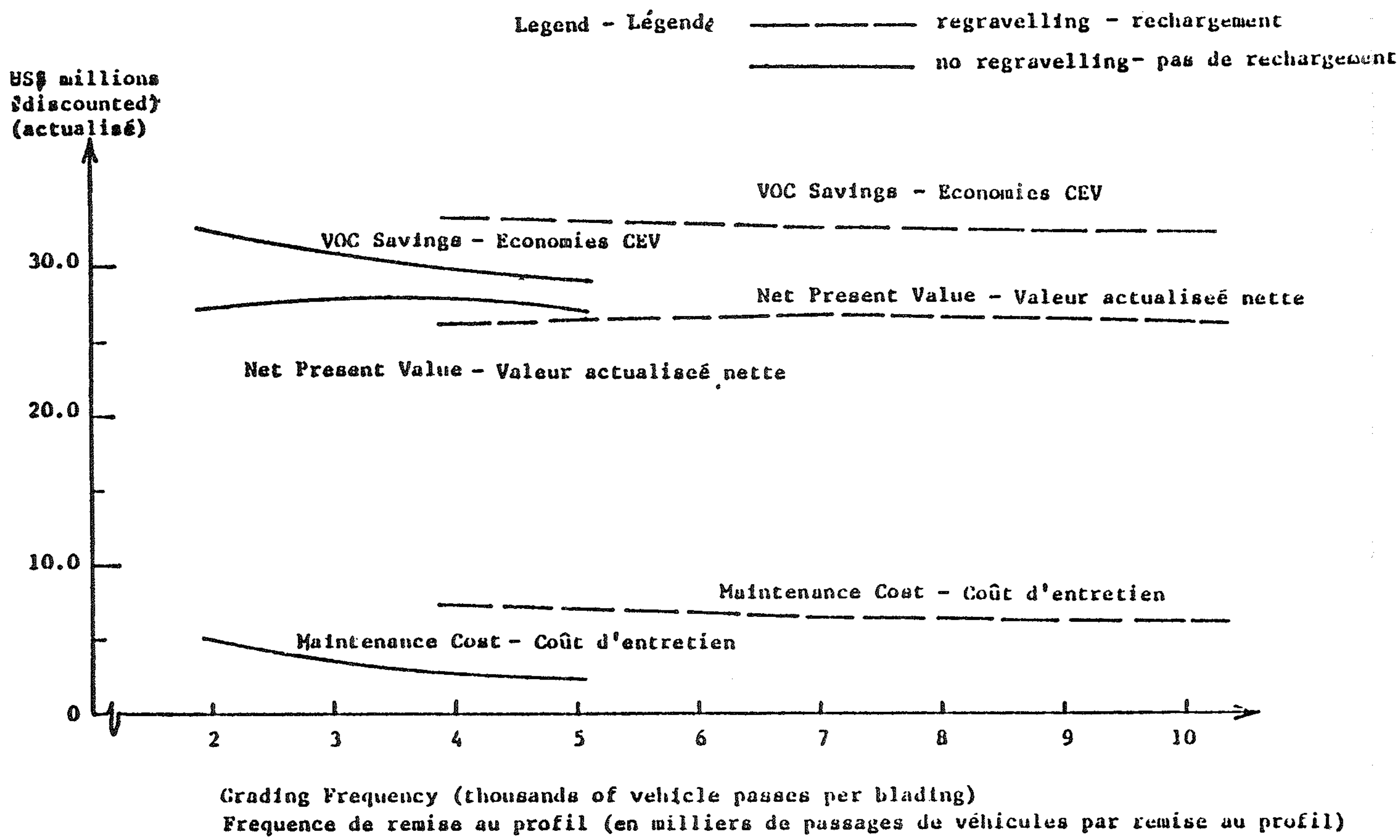


TABLE 3.6

TABLEAU 3.6

REGRAVELLING VS. NO REGRAVELLING: EFFECTS OF ROAD WIDTH AND ROAD CLOSURE PERIOD ON NET PRESENT VALUE

RECHARGEMENT PAR RAPPORT AU NON RECHARGEMENT: EFFETS DE LA LARGEUR DE LA ROUTE ET DES PERIODES DE FERMETURE A LA VALEUR ACTUALISEE NETTE

(Road Section 1: Engineered, Latérite, 480 km)

(Section Routière 1: Etudiée, Latérite, 480 km0

	Net Present Value ($ million) Valeur actualisée nette ($ million)					
Case / Base Year ADT Cas / TJM de l'anneé de base	30	40	50	60	70	90
RG1: Regravelling over 7-meter width Rechargement sur 7 m de largeur	11.84	18.81	26.33	32.56	38.50	50.41
RG2: Regravelling over 6-meter width Rechargement sur 6 m de largeur	12.40	19.66	26.91	33.15	39.10	51.13
RG3: Regravelling over 5-meter width Rechargement sur 5 m de largeur	12.97	19.95	27.49	33.74	39.71	51.86
NG1: No regravelling; assuming 2-month stockpiling Pas de rechargement; supposant 2 mois de stockage	13.60	20.04	27.00	32.66	38.80	50.45
NG2: No regravelling; assuming 1-month stockpiling Pas de rechargement supposant 1 mois de stockage	13.90	20.34	27.30	32.96	39.10	50.75
NG3: No regravelling; assuming no road closure Pas de rechargement; supposant pas de fermeture de la route	14.21	20.65	27.61	33.27	39.41	51.06

Note: Under regravelling, dry blading is done every 7000 vehicle passes; under no regravelling, every 3000 vehicle passes.

Note: En cas de rechargement la remise au profil est effectuée tous les 7000 passages de véhicules; en cas de non rechargement,tous les 3000 passages de véhicules.

FIGURE 4.2

CASE STUDY II - Etude de Cas II

BREAKDOWN OF MAINTENANCE COSTS FOR REGRAVELLING AND NO REGRAVELLING
Decomposition du coût d'entretien avec et sans rechargement

(discounted over 16 years at 10%)
(actualiseé sur 16 ans à 10%)

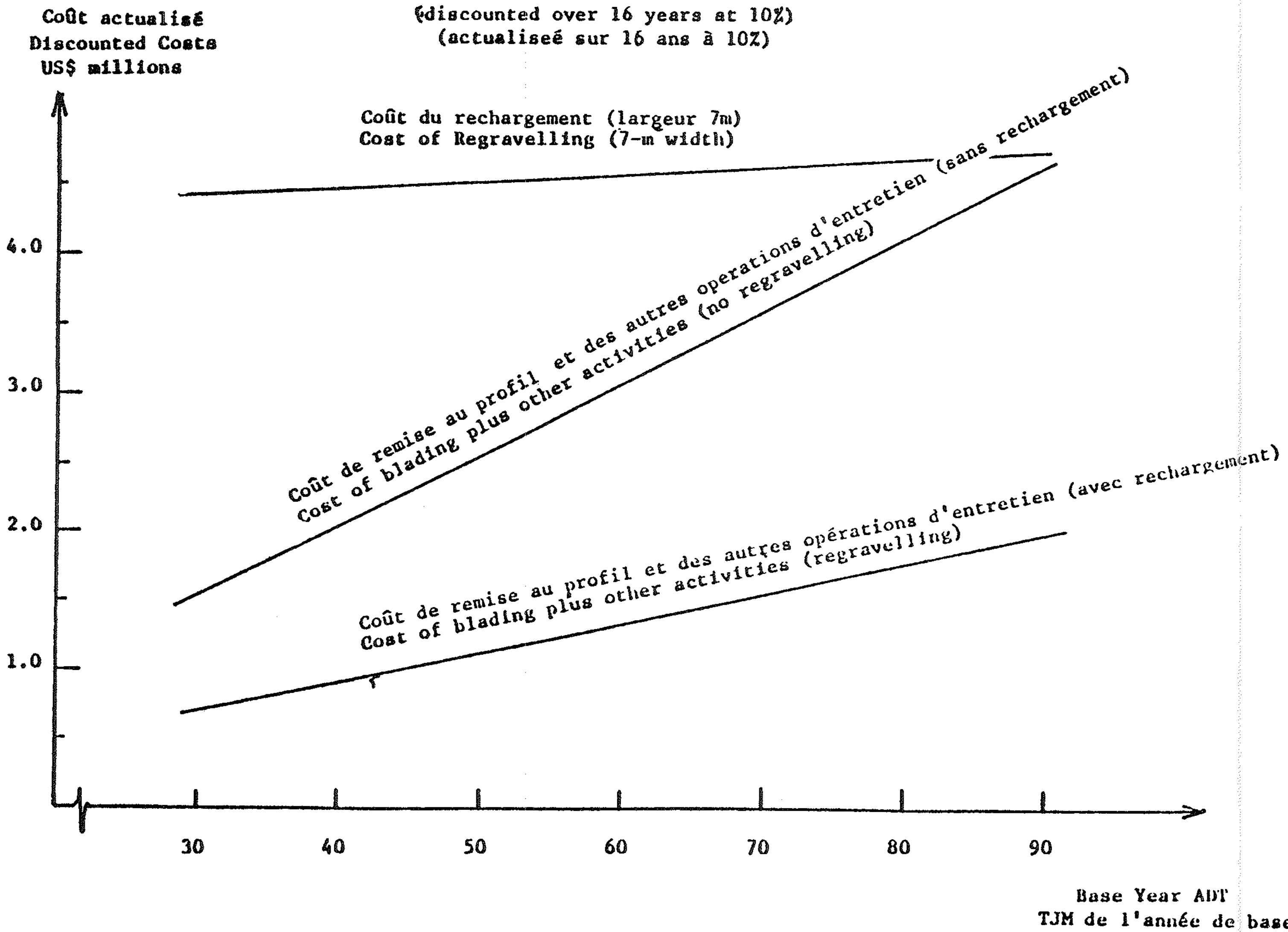


FIGURE 3.3

CASE STUDY I - Etude de Cas I

BREAKEVEN ADT vs. UNIT REGRAVELLING COST
TJM seuil de rentabilité contre coût unitaire du rechargement

(2-month stockpiling)
(stockage 2 mois)

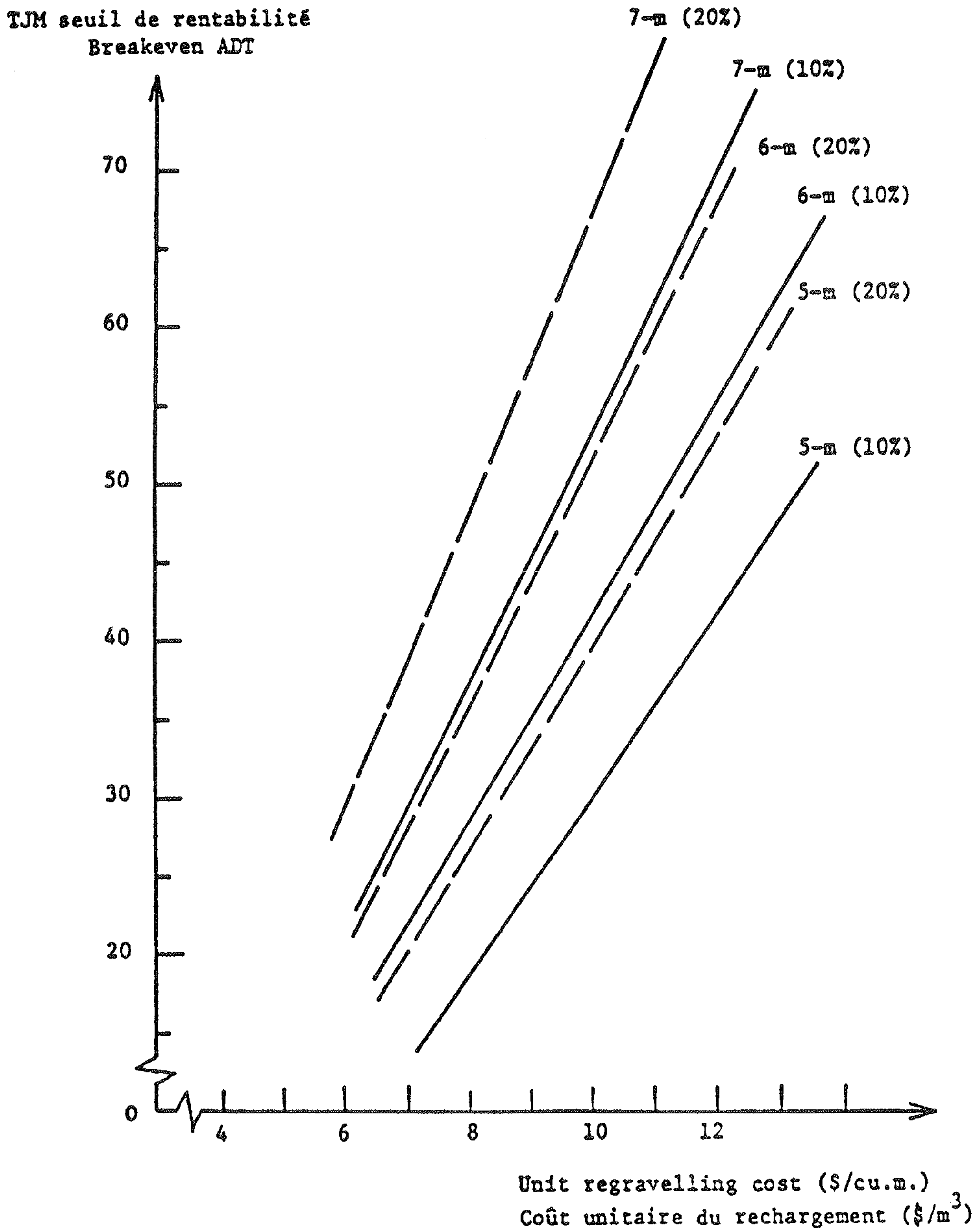


FIGURE 3.4

Reduction de la valeur actualisée nette due
à la selection d'une methode moins économique
REDUCTION IN NET PRESENT VALUE DUE TO
SELECTING LESS ECONOMICAL POLICY

Regravelling width = 6 m
Largeur du rechargement = 6 m

Stockpiling period = 2 months
Stockage = 2 mois

Discount rate = 10 percent
Taux d'actualisation = 10 pour cent

Réduction de la valeur actualiseé nette
(en pourcentage de la valeur actualisée nette
de la méthode choisie)

Reduction in Net Present Value
(in percent of net present value of preferred policy)

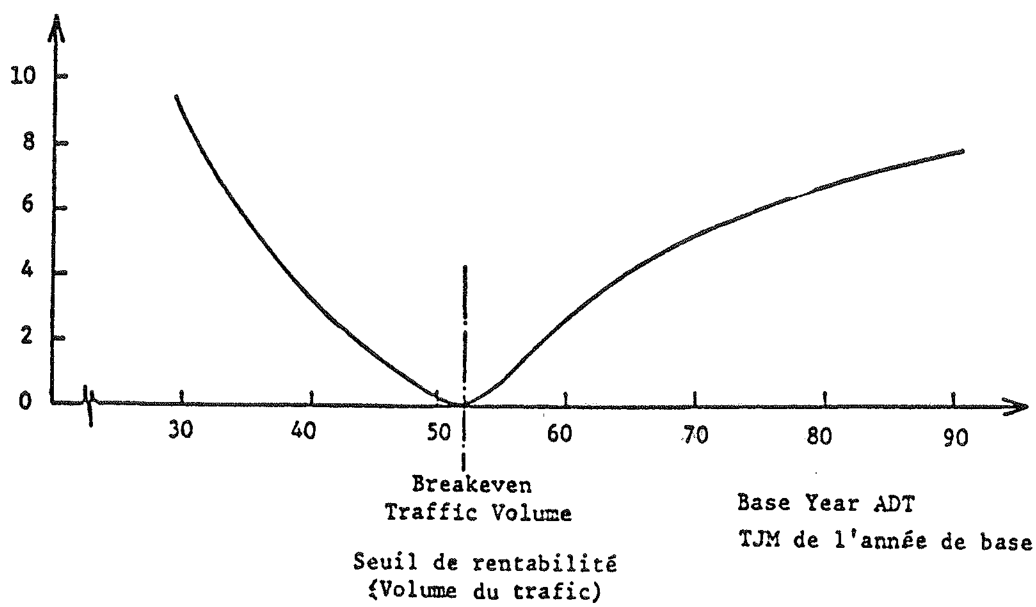


TABLE 3.7 - Tableau 3.7

CASE STUDY I - Etude de cas I

A. Summary Description of Incremental Maintenance Policies

A. Description sommaire des méthodes differentielles d'entretien en ordre décroissant

Policy Méthode	Maintenance Level Niveau d'entretien	Summary Description Description sommaire
1	High	Regravel only Sections 1 through 4, first in year 3 and thereafter when needed (at minimum depth of 20 mm); double grading frequencies in Policy 2.
1	Elevé	Rechargement seulement sur sections 1 à 4, pour la première fois à l'an 3 et après quand nécessaire (épaisseur minimum 20 mm); fréquences doubles des reprofilages pour la méthode 2.
2	Medium High	Regravel only Sections 1 through 4 as in Policy 1; grade at "optimal" frequencies.
2	Assez Elevé	Rechargement seulement sur sections 1 à 4 comme pour la méthode 1, reprofilages à fréquence "optimale".
3	Medium low	No regravelling; grade at "optimal" frequencies same as Policy 2 for Sections 5 through 12).
3	Moyen	Pas de rechargement; reprofilage à fréquence "optimale" (comme pour la méthode 2 sur sections 5 à 12);
4	Low	No regravelling; halve the grading frequencies in Policy 3;
4	Bas	Pas de rechargement; réduit de moitié les fréquences de reprofilages de la méthode 3;

... continue

TABLE 3.7 (continued)

TABLEAU 3.7 (continuation)

B. Summary of Maintenance Standards for Incremental Policies

B. Sommaire de critères d'entretien pour les méthodes différentielles en ordre décroissant

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Road Section / Section routière			Grading Frequency (months between grading) / Fréquence des reprofilages nombre de mois entre reprofilages				Spot Repairs (cu. m/km/year) / Point à temps (m^3/km/an)	Rubber Tire Dragging (pass/yr) / Gratte-tôle à pneus	Routine Maintenance (km/unit/year) / Entretien courant (km/unite/an)
Section / Section	Description / Description	Base Year ADT / TJM de l'annee de base	Policy / Méthode 1	2	3	4	All Policies / Toutes les méthodes		
1	Engineered Etudiée	45	2½	5	2	4	-	30	150
2	Laterite Latérite	20	6	12	6	12	-	20	200
3	Engineered Etudiée	45	2a/	4a/	2	4	-	-	100
4	Sand-clay Sable-argile	20	4a/	8a/	6	12	-	-	150
5		6	6	12	12	24	-	-	-
6	Partially Eng. Etudiée partial. Laterite Latérite	45	1	2	2	4	50	30	150
7	Partially Eng. Etudiée partial.	45	1	2	2	4	50	-	100
8		20	2½	5	5	12	50	-	150
9	Sand-clay Sable-argile	6	6	12	12	24	50	-	-
10		45	1	2	2	4	25	-	150
11	Track Piste	20	2½	5	5	12	25	-	200
12		6	6	12	12	24	-	-	-

a/ One pass of grading with watering and compaction for every 2 passes of dry grading.
a/ Un reprofilage avec arrosage et compactage pour 2 passages de reprofilage à sec.

... continue

TABLE 3.7 (Continued)

TABLEAU 3.7 (Continuation)

C. Derivation of "Optional" Blading Frequencies for Incremental Policies
Détermination des fréquences facultatives de remise au profil pour méthodes differentielles en ordre décroissant

	Laterite Latérite	Sand-Clay Sable-Argile	Earth Terre
(a) Approximately optimal number of vehicle passes per blading Nombre optimal approximatif de passages de vehicules par remise au profil	7000	5000	3000
(b) Base Year Traffic = 45 vpd Trafic de l'anneé de base = 45 vpj			
(a) ÷ (45 vpd x 30) vpj	5.2	3.7	2.2 mos
Rounded Value Valeur arrondie	5	4	2 "
(c) Base Year Traffic - 20 vpd Trafic de l'anneé de base = 20 vpj			
(a) ÷ (20 vpd x-30) vpj	11.7	8.3	5.0 "
Rounded Value Valeur arrondie	12	8	6 "
(d) Base Year Traffic = 6 vpd Trafic de l'anneé de base = 6vpj			
(a) ÷ (6 vpd x 30) vpj			16.7 " 12 "

TABLE 3.8 - Tableau 3.8

CASE STUDY I - Etude de Cas I

DISCOUNTED BENEFITS AND COSTS FOR INCREMENTAL MAINTENANCE POLICIES a/
Avantages et coûts actualisés des méthodes différentielles d'entretien a/

ROAD SECTION NUMBER Numero de la section routière		1	2	3	4	5	6	7	8	9	10	11	12	All Sections Ensemble des Sections
DESCRIPTION - Description		Engineered Laterite Latérite étudieé		Engineered Sand - Clay Sable - Argile Étudiée			b/	Partially Eng. Sand-Clay Sable-Argile etudieé partiellement			Track - Piste			
BASE YEAR ADT TJM de l'anneé de base		45	20	45	26	6	45	45	20	6	45	20	6	
LENGTH (km) - Longueur (km)		481	190	131	53	190	79	132	150	259	210	753	2503	5118
VEHICLE OPERATING COST SAVINGS (relative to do-nothing case) ($ million)	Policy Méthode 1	28.80	4.05	8.24	1.22	0.70	4.58	8.03	3.33	0.96	15.16	18.38	13.45	106.47
	2	28.16	3.93	8.07	1.19	0.64	4.36	7.65	3.10	0.88	14.45	17.18	12.18	101.79
Economies sur le coût de fonctionnement des véhicules (par rapport au cas "ne rien faire" ($ million)	3	26.56	3.57	7.60	1.06	0.64	4.36	7.65	3.10	0.88	14.45	17.18	12.18	99.23
	4	23.88	3.00	6.84	0.88	0.52	3.92	6.88	2.49	0.71	13.05	13.82	9.66	85.66
MAINTENANCE COSTS ($ million)	Policy Méthode 1	7.54	2.25	3.17	0.82	0.30	1.02	1.73	1.03	0.90	2.43	3.51	3.93	28.63
Coûts d'entretien ($ million)	2	6.64	2.10	2.47	0.68	0.15	0.65	1.11	0.75	0.70	1.44	2.67	1.96	21.32
	3	3.04	0.52	0.86	0.15	0.15	0.65	1.11	0.75	0.70	1.44	2.67	1.96	14.00
	4	1.91	0.37	0.55	0.11	0.07	0.46	0.80	0.59	0.59	0.95	1.93	0.98	9.31
VEHICLE OPERATING COST SAVINGS MINUS MAINTENANCE COSTS	Policy Méthode 1	21.26	1.80	5.07	0.40	0.40	3.56	6.30	2.29	0.06	12.73	14.45	9.52	77.84
	2	21.52	1.83	5.60	0.51	0.49	3.71	6.54	2.35	0.18	13.01	14.51	10.22	80.47
Economies sur le coût de fonctionnement des véhicules moins coûts d'entretien	3	23.52	3.05	6.74	0.91	0.49	3.71	6.54	2.35	0.18	13.01	14.51	10.22	89.23
	4	21.98	2.63	6.29	0.77	0.45	3.46	6.08	1.90	0.12	12.10	11.89	8.68	76.35

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a/ All four policy options include allowances for routine maintenance.

b/ Partially engineered laterite.

a/ Les quatre méthodes prévoient des défauts pour l'entretien courant.

b/ Latérite étudiée partiellement.

IV. Case Study: Economic Analysis to Determine When to Pave an Unpaved Road

A. Economics of Staged Construction

4.1 A problem which often arises in the development of Bank-financed road maintenance programs is the question of whether a gravel road should continue to be maintained or should it be paved. The effect of paving a road is, of course, to upgrade the riding surface, thereby reducing vehicle operating cost and the amount of routine maintenance -- which also alleviates maintenance management problems in many developing countries. In some cases improvements in road geometry are also provided at the time of construction. In this study we will focus only on paving. But it should be emphasized that paving and geometric upgrading should be examined in a step-wise manner, so that any possible economic deficiencies in each step can be detected.

4.2 One economic criterion for deciding whether to pave is that of "breakeven traffic volume". Here, the breakeven traffic volume is defined as the base year ADT at which the net present value of paving just equals leaving the road in the current gravel status. If the base year ADT exceeds the breakeven traffic volume the relevant internal rate of return would be greater than the discount rate used in the net present value computation, and the construction is therefore economically justified. However, the breakeven criterion is not the best criterion to rely on, since it is possible in most cases to defer construction to some future time at which the cost savings in maintenance and vehicle operations foregone in the years before construction are more than offset by the savings in interest on the construction capital. This is particularly done in cases where traffic volumes increase with time, so that at the breakeven traffic volume the early smaller benefits, which by themselves do not justify immediate construction, are "subsidized" by the larger benefits in later years.

4.3 The preferred decision rule is the "first year benefits" criterion. The first-year rule says that the road should be paved when the ratio of the net first-year benefits to the construction cost equals the relevant interest rate or "opportunity cost" of capital. In a situation where the budget is strictly limited the relevant interest rate is in fact the return on the marginal highway project which must be foregone, which may be several times the market rate of interest. Certain conditions are needed to ensure that the first-year rule will yield the correct solution: but these are ordinarily met by road paving projects 1/. Normally the breakeven traffic volume falls

---

1/ Conditions required to ensure that the first-year benefits criterion yields the correct solutions for optimal training are: (i) the construction costs do not change over time relative to other costs (but equi-proportionate inflation of construction, maintenance and user costs would not matter); (ii) the benefits due to construction depend only on calendar time and are not dependent on the time at which the investment is made; and (iii) net benefits in the first year after construction are greater than in the preceding years and less than in the subsequent years; and (iv) net benefits in subsequent years after construction continue indefinitely. Although these conditions appear very restrictive, relatively minor violations are not likely to affect the solution.

below the volume at which immediate construction is justified under the first-year rule. That is, the breakeven criterion always suggests earlier construction although considerations of economic efficiency (and often budget constraints) suggest otherwise.

B. The Case Study

4.4 In the following section a single road section will be examined in some detail to illustrate the method of analysis to determine breakeven traffic volume, and the "optimal" traffic volume under the first-year rule, and the relationships of these two criteria to the costs of construction and regravelling at different discount rates.

4.5 The inputs, which are in the same form as in Case Study I, are summarized in Tables 4.1 - 4.3 for road and traffic data, vehicle data and maintenance and construction cost data, respectively.

C. Time Streams of Benefits and Costs

4.6 In using the first-year rule the extension of the benefits and cost streams beyond 20 years is essential to ensure that conditions for use of this criterion are satisfied. 1/ For this case study the net present value of paving was computed as follows:

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$$NPV = \sum_{t=0}^{19} \frac{B_t}{(1+r)^t} - \frac{C_o}{(1+r)^T} + \frac{S}{(1+r)^{19}}$$

where B_t = net benefits for year t (savings in vehicle operating and maintenance costs)

r = discount rate

C_o = initial construction cost

T = construction year (Note: B_t = 0 before construction year)

S = "salvage value" of the project in the project's final year (assuming a 20-year planning horizon)

The salvage value, S, was estimated using the following simplified formula:

$$S = \sum_{t=19}^{\infty} \frac{B_{19}}{(1+r)^t} - C_v$$

1/ Specifically condition 3 as given footnote 1 to para. 4.3.

where B_{19} = net benefits for year 19; and C_v = cost of an overlay. The first term implies that the stream of net benefits beyond the planning horizon is constant and equal to the project's last-year net benefits. The second term implies that an overlay is provided immediately after the planning period. 1/

D. Findings

4.7 In the following paragraphs two basic policies will be examined, paving and no paving. Under the paving policy, unless noted otherwise, pavement construction is assumed to be provided in the first year of the planning horizon. Under the no paving policy, the road is assumed to remain unpaved throughout the planning horizon, with gravel replenishment provided when needed. The maintenance standards of these two policies are specified in Table 4.4. In this study, no generated traffic due to pavement construction is assumed; therefore the policies can be compared on the basis of the total discounted costs, which consist of vehicle operating costs, and maintenance costs, and, for the paving policy only, the initial capital outlay. (If there were significant additional traffic generated from paving the road, then these benefits -- approximately equal to one-half of the operating cost savings per vehicle -- would be added in.)

Behavior of Maintenance and Vehicle Operating Costs

4.8 Figure 4-1 shows graphs of total discounted maintenance costs for paving and no paving plotted against the base year traffic volume (for a given set of maintenance and construction costs, at 11% discount rate). The maintenance costs under both policies vary virtually in a linear fashion with the traffic volume. The maintenance costs remain relatively constant over a wide range of traffic volumes under the paving policy but not so under the no paving policy. As expected, except for traffic volumes under 100 vehicles per day (vpd), the unpaved road maintenance costs are greater. Over 200 vpd per day the maintenance costs for unpaved surface are twice those of paved surface. However, maintenance costs represent a very small proportion of total outlays. As illustrated in Figure 4.2, the ratio of maintenance costs to vehicle operating costs decreases very rapidly as the traffic volume increases. Vehicle operating cost savings are the dominant factor in the paving decision.

Determining the Breakeven Traffic Volume

4.9 The breakeven traffic volume can be determined graphically by plotting the discounted total costs for both policies against the base year ADT, as shown in Figure 4-3 for a given set of construction and maintenance costs at 11% discount rate. The intersection of the curves, where the net present value of paving just equals the no paving strategy determines the breakeven traffic volume. The effect of a higher interest rate is examined below.

1/ An examination of results indicated that no overlay would be needed during the 20-year planning for the traffic range of interest. But a terminal overlay is assumed for simplicity nevertheless.

Determining the Optimal Traffic Volume

4.10 We define the optimal traffic volume as the traffic volume above which we cannot increase the net present value of paving by deferring construction to a later year. As illustrated in Figure 4-4, we can graphically determine the optimal traffic volume by plotting the net benefits in the year immediately after construction or the first-year net benefits (expressed in percent of the initial construction cost), against the base year ADT. According to the first-year criterion, 11% discount rate the optimal traffic volumes are 301, 447 and 592 vpd, respectively. It should be noted that since we have assumed a 15-cm gravel surface thickness initially, no regravelling costs are reflected in the first-year net benefits. As a result, in this particular comparison, the optimal traffic volume, are unaffected by regravelling cost.

Comparison of Breakeven and Optimal Traffic Volumes

4.11 The optimal and breakeven traffic volumes are compared by plotting them against the discount rate, regravelling cost and pavement construction cost, as shown in Figure 4-5, 4-6, and 4-7.

4.12 As discussed in para. 4.3, the optimal traffic volumes are substantially higher than the breakeven, meaning that it is always preferable to defer construction until traffic reaches the optimal level. Referring back to Figures 4-3, and 4-4, the breakeven volume of 308 vpd corresponds to the 447-vpd optimal volume. This implies that if the base year traffic volume is 308 vpd and growing at 7%, the best time to pave would be year 6, not year 1 as suggested by the breakeven criterion. Postponing construction to year 6 would forego the savings in (discounted) vehicle operating and maintenance costs during the first five years equal to US$2.14 million. On the other hand the interest savings gain in deferring capital investment of US$6.0 million by 5 years amounts to US$2.44 million. Therefore, the net present value of construction deferment equals US$0.31 million.

4.13 If the base year traffic volume is 447 vpd, i.e., the optimal volume for the given set of costs at 11% interest, then paving immediately would yield savings in (discounted) vehicle operating and maintenance costs of US$8.49 million relative to not paving; with the construction cost of US$6.0 million the net present value of the project equals US$2.49 million. Although this net present value is only less than 4% of the total discounted costs of either alternative it is quite substantial relative to the capital outlay.

4.14 As Figure 4-5 illustrates, both optimal and breakeven traffic volumes are extremely sensitive to the discount rate within the range of 5 to 20%. As expected, high opportunity cost of capital tends to discourage capital investment as reflected in high optimal and breakeven traffic volumes corresponding to high discount rates.

4.15 In Figure 4-6, the breakeven traffic volume is shown to be relatively insensitive to the unit cost of regravelling over a range of US$3.0 to 11.00 per cu. m., while Figure 4-7 shows both breakeven and optimal volumes to be very sensitive to the pavement construction cost.

TABLE 4-1

ROAD, ENVIRONMENTAL AND TRAFFIC CHARACTERISTICS

A. Road Characteristics

	Before Construction	After Construction	
Length	6.85	6.85	km
Surface Width	8.0	7.0	meters
Shoulder Width	0.0	2.2	meters
Average Rise and Fall	4.0	4.0	percent
Average Horizontal Curvature	120.0	120.0	degrees/km
Surface Material	Laterite	double bitumenous surface treatment (DBST)	
Surface Thickness	15.0	3.0	cm
Subgrade CBR	-	8.0	present
Initial Roughness	3250	3250	mm/km
Initial Structural Number	-	3.5	

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B. Environmental Characteristics

Altitude	900	meters
Wet Season Length	6	months
Dry Season Length	6	months
Annual Rainfall	800	millimeters

C. Traffic Characteristics

Traffic Composition:	Passenger Cars	65	percent
	Light Goods Vehicles	4	"
	Buses	6	"
	Trucks-11 tonne	8	"
	Trucks-22 tonne	14	"
	Trucks-42 tonne	3	"

Traffic Growth Rate: 7 percent annum for all vehicle types

TABLE 4-2 - Tableau 4-2

CASE STUDY II - Etude de Cas II

VEHICLE CHARACTERISTICS AND COSTS
Caractéristiques et coûts des vehicules
(U.S. dollars - dollars U.S.)

Description	Passenger Cars Voiture	Light Goods Vehicle Camionnette	Bus Autobus	11-tonne Truck Camion 11 t.	22-tonne Truck Camion 22 t.	40-tonne Truck Camion 40 t.
Physical Characteristics and Utilization / Caractéristiques physiques et utilisation						
A:						
1. Fuel Type	essence Gasoline	essence Gasoline	gas-oil Diesel	gas-oil Diesel	gas-oil Diesel	gas-oil Diesel
2. Brake horsepower	90	140	200	163	217	307
3. Gross weight (tonnes)	1.5	7.5	15.0	15.0	22.0	40.0
4. Axle equivalency factor	Apprx. 0	0.11	2.55	2.55	2.46	13.66
5. Average crew hours	560	3,600	4,800	3,840	4,800	4,800
6. Average operating hours	320	1,500	2,000	1,000	2,000	2,000
7. Annual kilometerage	13,000	64,000	64,000	64,000	64,000	64,000
8. Average vehicle life (years)	6	5	5	5	5	5
Unit Costs - Coûts unitaires						
B.						
1. New vehicle cost ($/vehicle)	3,250	9,020	40,350	14,250	21,340	50,000
2. Tire cost ($/tire)	24	60	165	150	188	202
3. Maintenance labor ($/hour)	9.30	6.85	6.15	6.15	6.15	8.55
4. Crew cost ($/hour)		2.45	3.10	2.70	2.45	4.90
5. Fuel cost ($/litre)	0.37	0.37	0.19	0.19	0.19	0.19
6. Lubrication oil cost/$/litre)	1.19	1.19	1.19	1.19	1.19	1.19
7. Overhead (% of operating cost)	15	15	15	15	15	15
8. Ratio of spare parts to new vehicle cost	0.72	0.86	0.85	0.85	0.85	0.85

A 1. Carburant
2. Puissance au frein
3. Poids total en charge, tonnes
4. Facteur d'equivalence par essieu
5. Moyenne d'heures du personnel de conduite
6. Moyenne d'heures de l'operation
7. Kilomètrage annuel
8. Dureé de vie moyenne du véhicule (ans)

B 1. Coût d'un véhicule neuf (S/véhicule)
2. Coût d'un pneumatique (S/pneu)
3. Main-d'oeuvre d'entretien (S/heure)
5. Coût des carburants (S/heure)
6. Coût des lubrifiants (S/litre)
7. Frais généraux (en pourcent de fonctionnement)
8. Coût des pièces de rechange par rapport au coût du véhicule neuf.

TABLE 4-3 - Tableau 4-3

CASE STUDY II - Etude de Cas II

UNIT MAINTENANCE COSTS
Coût unitaire d'entretien

A. Unpaved Road
Routes en terre

Remise au profil	Grading	USS	34.9	per km. pass.	par km pass.
Point à temps (rechargement localisé)	Spot regravelling	USS	8.9	per cu. m.	par m^3
Rechargement en gravier	Gravel resurfacing	USS3;5-10.5		per cu. m.	par m^3
Entretien courant	Routine maintenance	US	175.0	per km. per year	par km/an

B. Paved Road
Routes Revêtues

Point a temps	Patching	USS	4:38	per sq. m.	par m^2
Enduit superficiel	Surface dressing	USS	0.89	per sq. m.	par m^2
Tapis d'enrobés	Overlay	USS	87.0	per cu. m.	par m^3
Entretien courant	Routine maintenance	USS	687.0	per km. per year	par km/an

TABLE 4-4 Tableau 4-4

CASE STUDY II - Etude de Cas II

MAINTENANCE STANDARDS - Niveaux d'entretien

A. Unpaved Road - Routes en terre

1. Grade every 6000 vehicle passes.
2. Replace 30% of gravel loss but not more than 100 cu. m. per year.
3. Resurface when gravel thickness reaches 5.0 cm. using lateritic gravel to a restored thickness of 15 cm.
4. Provide routine maintenance which includes drainage, vegetation, shoulder and miscellaneous activities;

1. Remise au profil tous les 6000 passages de véhicules.
2. Remplacer 30% du gravier perdu par usure, mais pas plus de 100 m^3 par km/an.
3. Rechargement quand la couche de roulement est réduite à 5,0 cm. en utilisant gravier latéritique afin d'atteindre une épaisseur compactée de 15 cm.
3. Entretien courant relatif au drainage, à la végétation, aux accôtements et travaux accessoires;

B. Paved Road - Routes revêtues

1. Patch 50% of unpatched cracks but not more than 700 sq. m./km/year.
2. Surface dress when unpatched cracks exceed 30% road surface area;
3. Overlay when roughness exceeds 3750 mm/km using asphalt concrete paving of 5,0 cm.
4. Provide routine maintenance.

1. Point à temps de 50% des dégradations localiseés, mais pas plus de 700 m^2/km/an;
2. Enduit superficiel quand les dégradations localiseés dépassent 30% de la surface du revêtement.
3. Tapis d'enrobés de 5.0 cm. d'épaisseur quand la rugosité dépasse 30% de la surface du revêtement.
4. Entretien courant.

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FIGURE 4.1

CASE STUDY II - Etude de cas II

DISCOUNTED MAINTENANCE COSTS vs: TRAFFIC VOLUME

Coûts d'entretien actualisés par rapport aux volumes du trafic

Discount Rate = 11%
Regravelling Cost = US$ 7.0/m^3
Paving Cost = US$ 60,000/km

Taux d'actualisation = 11%
Coût du rechargement = US$ 7 0/m^3
Coût du revêtement = US$ 60,000/km

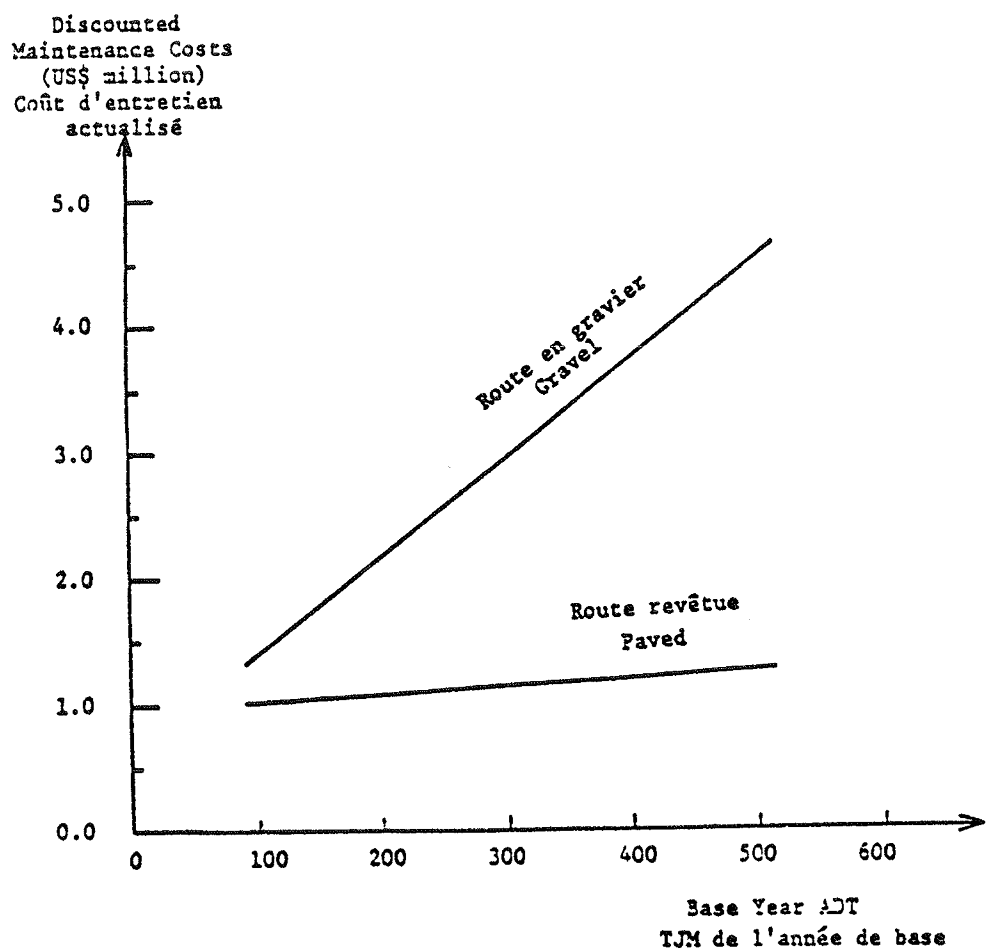


FIGURE 4.2

CASE STUDY II - Etude de cas II

RATIOS OF DISCOUNTED MAINTENANCE COSTS TO DISCOUNTED VEHICLE OPERATING COSTS

Discount Rate = 11%
Regravelling Cost = US$ 7.0/m^3

Rapport entre les coûts d'entretien actualisés et les coûts actualisés du fonctionnement des véhicules

Taux d'actualisation = 11%
Coût du rechargement = US$ 7.0/m^3

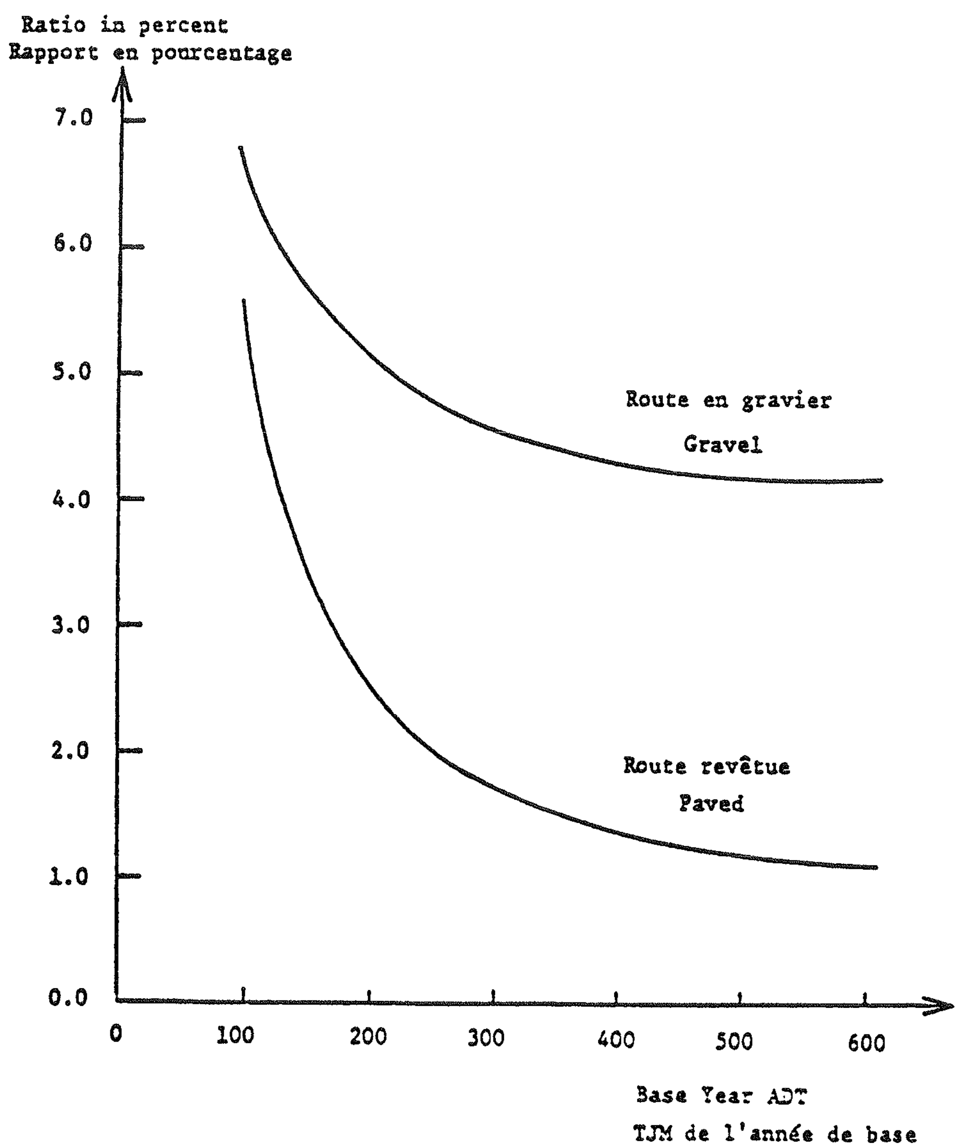


FIGURE 4.3

CASE STUDY II - Etude de Cas II

DISCOUNTED TOTAL COSTS vs: TRAFFIC VOLUME

Coûts totaux actualisés par rapport aux volumes du trafic

Discount Rate = 11%
Regravelling Cost = US$ 7.0/m^3
Paving Cost = US$ 60,000/km

Taux d'actualisation = 11%
Coût de rechargement = US$ 7.0/m^3
Coût de revêtement = US$ 60,000/km

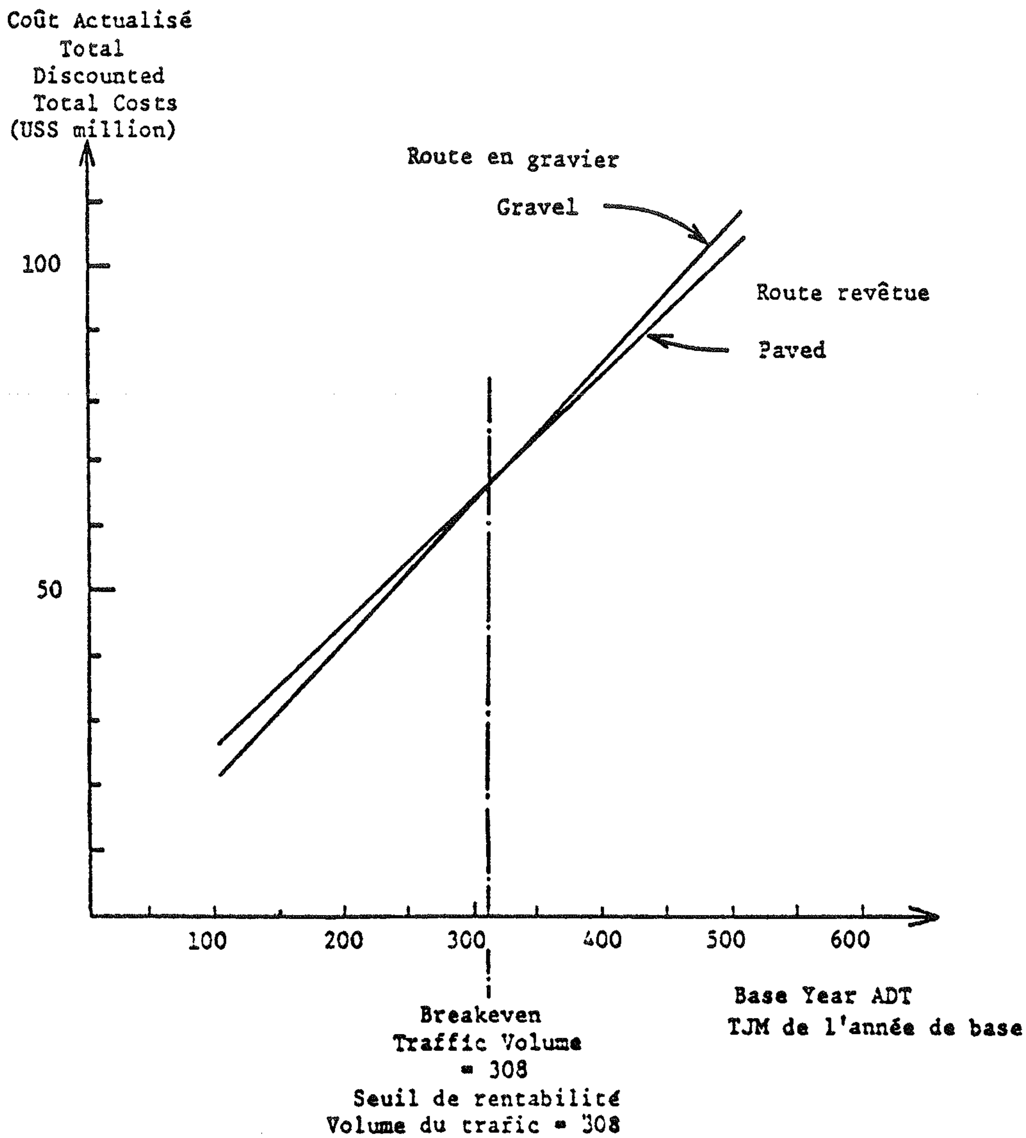


FIGURE 4.4

DETERMINING OPTIMAL TRAFFIC VOLUMES

Détermination du volume optimal de trafic

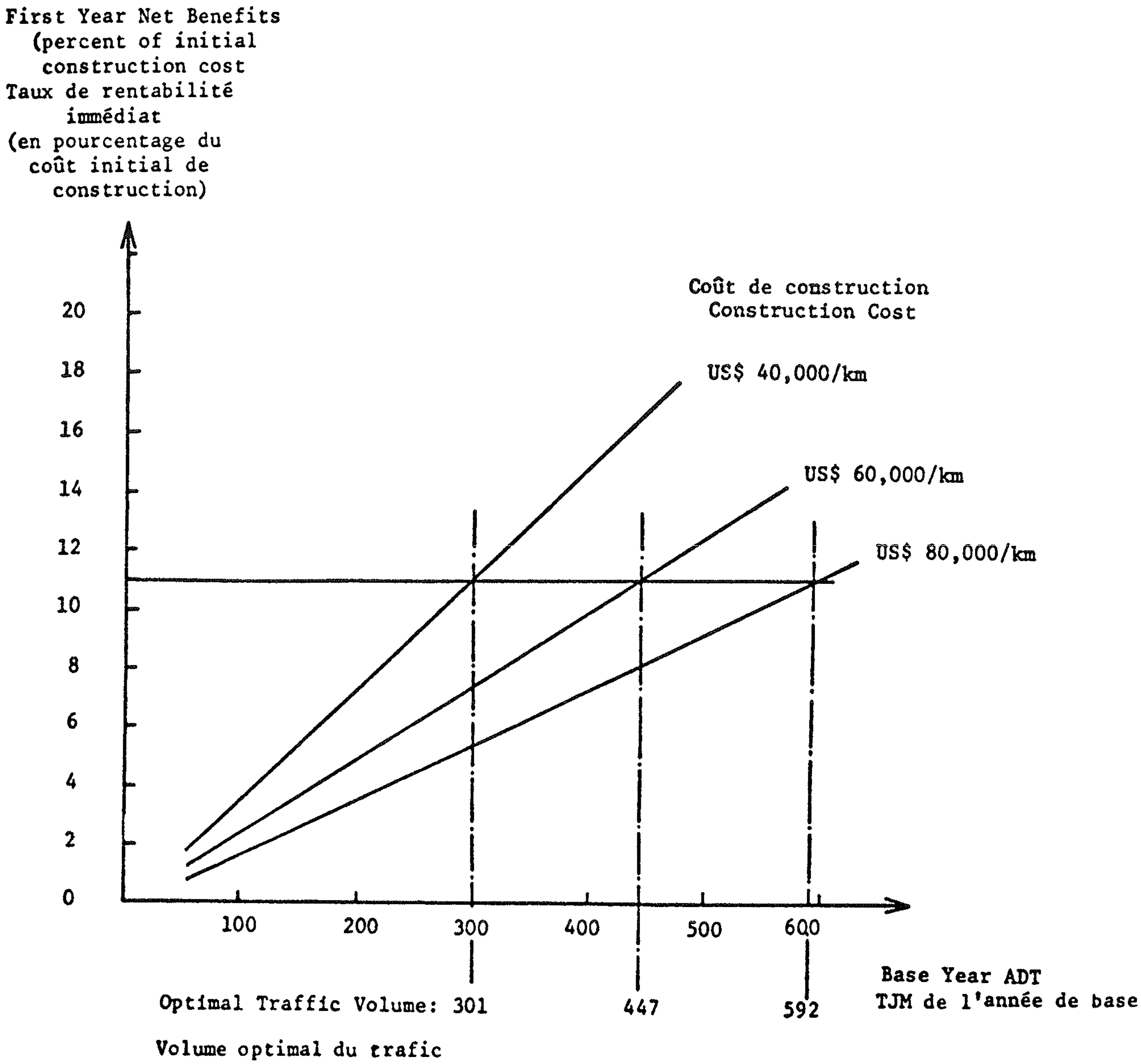


FIGURE 4.5

BREAKEVEN AND OPTIMAL TRAFFIC VOLUMES vs. DISCOUNT RATE

Seuil de rentabilité et volume optimal du trafic par rapport au taux d'actualisation

Regravelling Cost = US$ 7.0/m3
Paving Cost = US$ 60,000/km

Coût du rechargement = US$ 7:0/m^3
Coût du revêtement : US$ 60,000ûkm

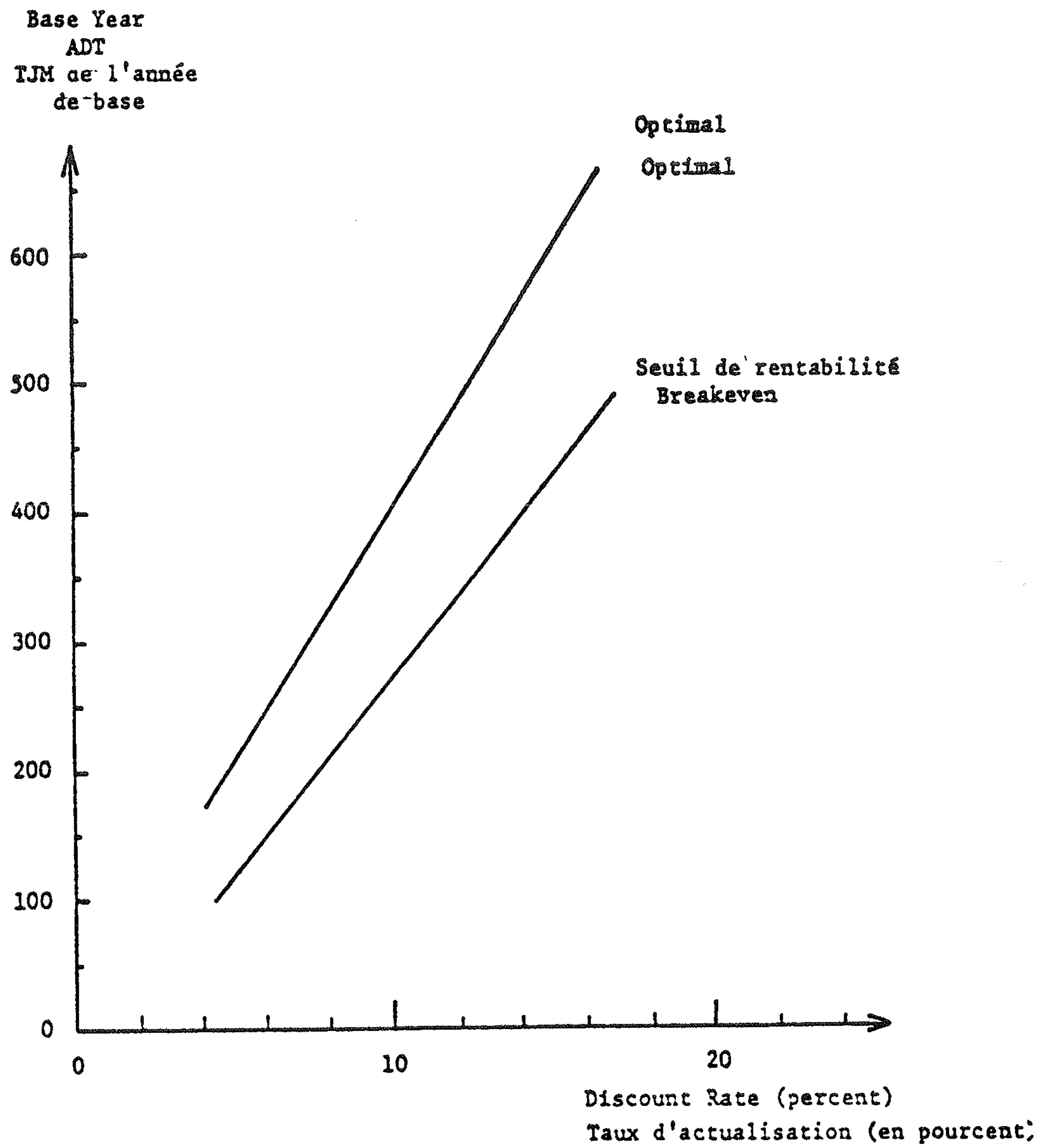


FIGURE 4.6

BREAKEVEN AND OPTIMAL TRAFFIC VOLUMES vs. REGRAVELLING COST

Volumes du trafic, à l'optimum et au seuil de rentabilité par rapport au coût de recharg

Discount rate = 11%
Paving Cost = US$ 60,000

Taux d'actualisation = 11%
Coût du revêtement = US$60,000

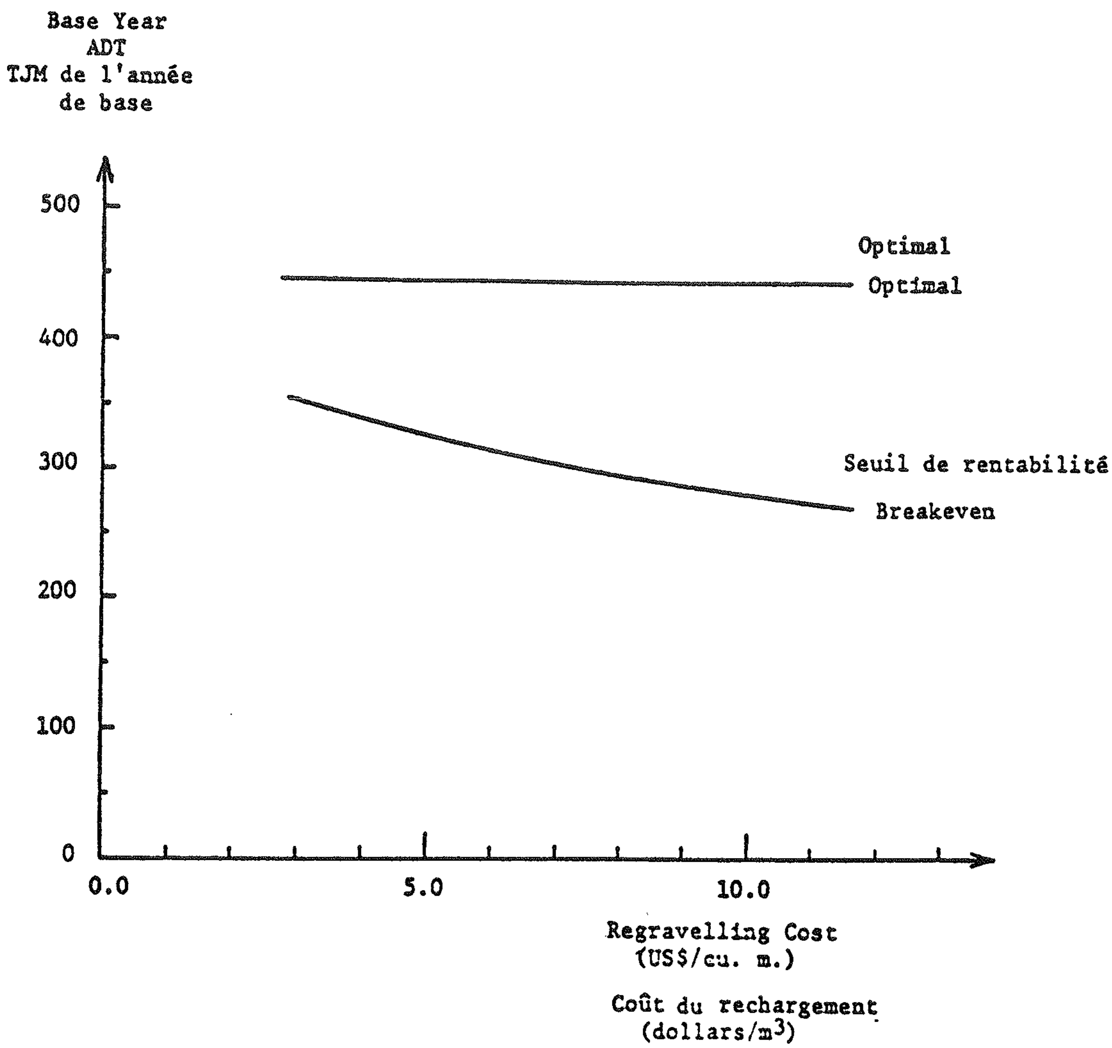


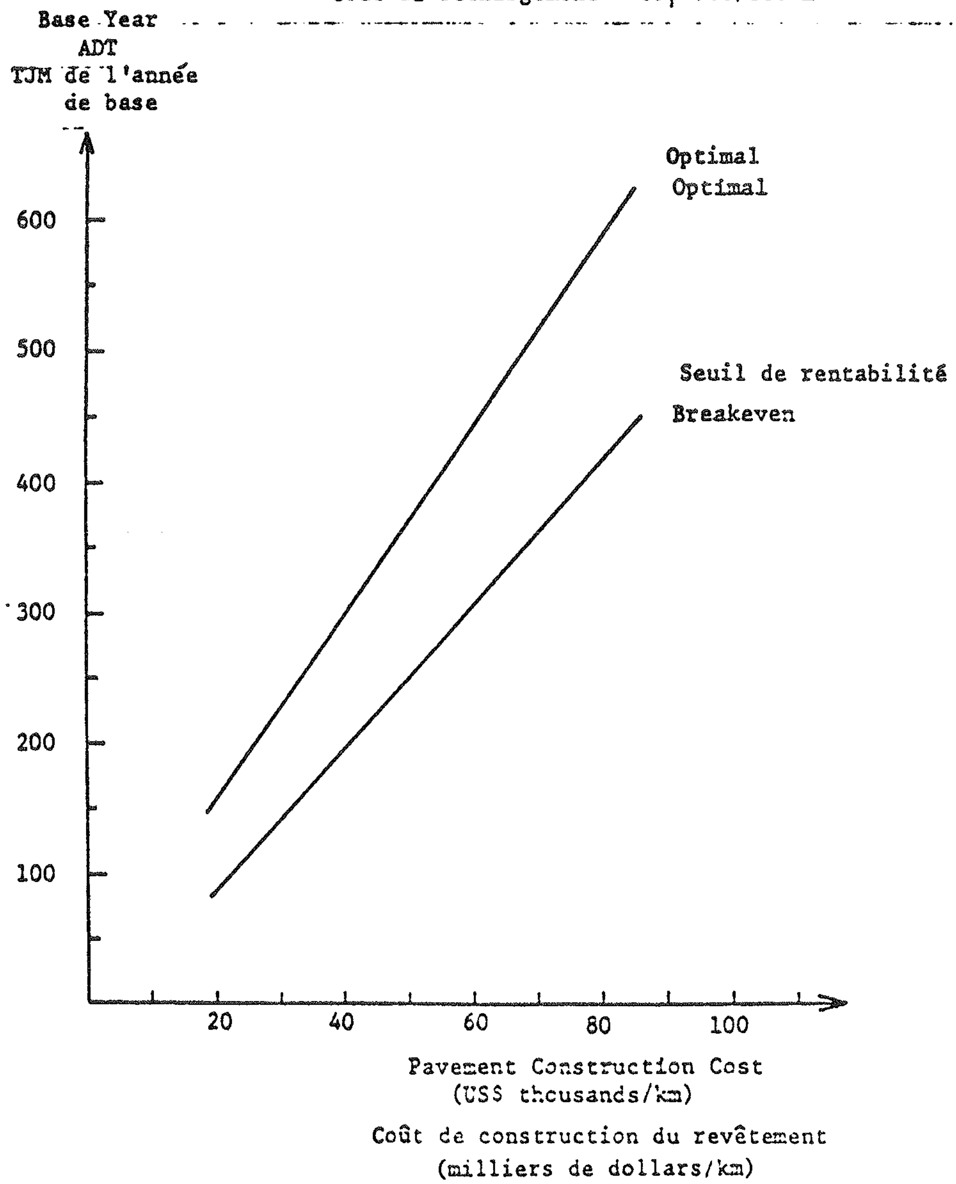
FIGURE 4.7

BREAKEVEN AND OPTIMAL TRAFFIC VOLUMES vs; CONSTRUCTION COST

Volumes du trafic, à l'optimum et au seuil de rentabilité par rapport au coût de constructic

Discount Rate = 11%
Regravelling Cost = US$ 7.0/cu. m

Taux d'actualisation = 11%
Cout du rechargement = US$ 7.0/cu. m



VI. Conclusions

6.1 It must be recognized that the basis for quantitative management decision making about the optimum level, composition and timing of highway maintenance activities has heretofore been very limited, and there are very many important gaps in the scientific data base today. Thus one should not attach too much precision to the results presented above, which must be interpreted with considerable caution. Nonetheless some strong conclusions do emerge and other rather interesting hypotheses are suggested which warrant further consideration.

6.2 First, it is quite clear that the return to minimum levels of highway maintenance, generally well in excess of current levels in most African countries, yield extremely high economic returns. In fact, economic returns for increased maintenance outlays in this range greatly exceed returns for new investments in roads and virtually every other sector of the economy. Only outlays for maintenance of other existing infrastructure approach the same levels.

6.3 As a consequence of this fact the World Bank and increasingly other lending agencies are focusing first priority attention on the development of effective maintenance programs. We must all recognize that it makes no sense to invest in new roads if the existing roads are deteriorating prematurely—a fraction of the resources required for new construction can maintain the existing infrastructure adequately and avoid the necessity of costly, premature rehabilitation. This conclusion is quite firm and will survive any uncertainties in the data basis.

6.4 Some further very interesting ideas have been advanced, but must be considered more tentative since they may be sensitive to measurement errors in the underlying engineering relationships, or the assumptions we have had to employ where there is in fact no scientific data base. One of these is the proposition that the (re) gravelling of low volume roads will typically have a much lower return than providing higher grading frequencies for earth roads of comparable volumes. In fact where financial stringencies are particularly acute and/or local conditions dictate very high costs for regravelling—as in several regions of Africa—regravelling of roads will not be economical. Better let them revert to earth roads and provide a somewhat higher grading frequency, or possibly a higher level of labor-intensive maintenance.

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NOTE: The deleted section deals with paved roads and traffic volumes which are beyond the scope of this project.

6.6 Finally, I would like to close these remarks on a slightly different note. I am glad that the issue of maintenance management--how to do more maintenance for less money--is to receive much attention at this conference from other speakers who are better qualified to address this issue. However, there is one important dimension that I want to introduce which has been the subject of another large research undertaking in which we have been engaged: the issue of appropriate technology. When we recently reviewed performance under past highway projects financed by the World Bank in 43 countries we discovered that a uniform problem in almost all maintenance activities has been the poor utilization achieved from expensive, imported equipment. Not only does it require large amounts of scarce foreign exchange to purchase equipment, and usually a substantial amount of foreign technical assistance before local institutions can be developed, the importation of fuel and spare parts is often blocked altogether so that we have the specter of expensive equipment simply lying idle for long periods of time; in one country no more than 60 working days per year is being achieved, due in large measure to immediate constraints on the supply of fuel and spare parts. Increasingly the question has been raised as to whether these heavily capital-intensive, heavily foreign-exchange-dependent technologies are not inappropriate to the needs of the developing countries. The results of research done over the past six years strongly indicate that labor-intensive or intermediate technologies can be technically and economically feasible for the principal tasks of civil construction and maintenance in those countries where labor is abundant provided that due attention is paid to effective organization and management, to the use of proper tools and to the health and nutrition of the work force. Only the tasks of long distance haulage (generally 5 kilometers or more), and high quality compaction and finishing (as in asphalt concrete surfaces) are necessarily more economical by equipment-intensive methods. Of course, this presents no surprise to most of you in this audience who have seen road maintenance in Africa done over the years by manual methods under the cantonnage and length man systems. What is perhaps more surprising is that major earthworks, and materials production and handling tasks (both gravel quarrying and production of crushed stone to macadam size) are likely to be done more economically today by labor-intensive methods in those countries where labor wages are below about US$1.00 or even $1.50 per day (in 1976 prices). This will include some 20 countries in Africa and about an equal number in Asia and Latin America. Even as wealthy a country as Mexico, where unskilled labor wages of about $3.00 per day were paid, more than 75,000 kilometers of rural access roads were constructed since 1970 at an average cost of $12,500 per kilometer, which was said to be equal to the costs at which these roads would have been constructed by local contractors. Of equal importance, more than 80,000 man-years per year of productive employment were created. Thus the World Bank is now actively exploring ways and means to facilitate the use of labor-intensive methods in civil construction and maintenance where it appears these methods would be economically efficient. We are already working with some important pilot programs initiated by governmental agencies in Kenya, Lesotho, Benin, and Chad and would be pleased to work with other countries who may be interested in developing programs or improving existing programs to use labor-intensive methods efficiently.

ROAD DETERIORATION RELATIONSHIPS IN THE HDM MODEL

1. While extensive research has been conducted in North America, Europe and Australia into the performance of high standard pavements and the effects of different axle loads thereon, only limited research has been carried out on low standard pavements, and to our knowledge, no comparable research on physical deterioration relationships for gravel and earth roads has been undertaken heretofore. Thus, the Kenya study (Ref. 7) constituted a major step forward in this field and provides the basis from which further research in Brazil and elsewhere is proceeding. Until the results of those further studies are available, the Kenya study relationships must serve as a basis to represent a wide range of conditions and environments that in some instances will be quite different from those in Kenya. For this reason certain modifications have been introduced into the Kenya relationships. This note records the current road deterioration relationships employed in the HDM model. Subsequent modifications will be made as new research results become available.

A. Unpaved Road Deterioration Relationships

2. Deterioration of unpaved roads is measured in terms of surface roughness, rutting, depth of loose surface material and also, for gravel roads, loss of gravel. Deterioration is caused by two factors, viz. traffic and time related weathering effects; the latter is likely to be a major factor primarily in the case of extremely low volume roads and/or severe climatic conditions particularly when combined with severe terrain (steep gradients) where erosion is difficult to control. The Kenya study did not succeed in isolating the time related weathering effect from the traffic effect, except for the effect of rainfall on gravel loss. Consequently, an arbitrary adjustment has been made to reflect these effects in the HDM model; however, this effect is significant only at extremely low traffic volumes. The Kenya study also was able to give only very limited attention to earth roads, and as a consequence no serious scientific information is yet available which permits prediction of earth road deterioration. Until such information becomes available, the HDM model, like the TRRL RTIM model, simply assumes the relationships conjectured by the original MIT research effort. These assume that predominantly clay roads deteriorate approximately four times as fast as laterite roads, and other earth roads deteriorate approximately 16 times as fast.

3. We list in Tables 1 and 2 below the deterioration equations as employed by the RTIM model, which have been subsequently modified for time related weathering effect. We note that in Kenya the TRRL observed that unpaved roads were becoming impassable as surface roughness approached 14,000 mm and the maximum rut depth was about 75 mm. In the HDM model these limits are assumed to be the conditions for total road failure for both paved and unpaved roads.

ANNEX 1
Page 2

Table 1

Deterioration of gravel roads

Surface roughness

Lateritic, quartzitic and volcanic gravels

(1) $R = 3250 + 84\ T - 1.6\ T^2 + 0.016\ T^3$

Coral gravels

(2) $R = 6500 + 58\ T - 1.0\ T^2 + 0.017\ T^3$

where

R = mean roughness in the wheel-tracks measured in mm/km by a fifth-wheel bump integrator towed at 30 km.p.h.

T = cumulative traffic volume in both directions which has used the road since grading, measured in thousands of vehicles.

Rutting

Lateritic gravels

(3) $RD = 11 + 0.23\ T - 0.0037\ T^2 + 0.000073\ T^3$

Quartzitic, volcanic and coral gravels

(4) $RD = 17.5 + 0.73\ T$

where

RD = rut depth measured in millimeters under 2 meter straight edge.

T = cumulative traffic volume in both directions which has used the road since grading, measured in thousands of vehicles.

Table 1 (continued)

Gravel loss

(5) $$GL_A = f \left[\frac{T_A^2}{T_A^2 + 50} \right] (4.2 + 0.092\ T_A + 3.50\ R_L^2 + 1.88\ VC)$$

where

f = 0.94 for lateritic gravels

= 1.1 for quartzitic gravels

= 0.7 for volcanic gravels

= 1.5 for coral gravels

T_A = annual traffic volume in both directions measured in thousands of vehicles.

R_L = annual rainfall measured in meters.

VC = rice and fall (vertical curvature) expressed in meters per kilometer.

GL_A = annual gravel loss measured in millimeters.

Surface looseness

Roads graded in moist conditions

(6) Lateritic and coral gravels
LD = 1.0

Quartzitic and volcanic gravels

(7) $$LD = 5\ e^{-0.35\ T} + 1.5$$

Roads graded in dry conditions

Lateritic, quartzitic, volcanic and coral gravels.

(8) $$LD = 14\ e^{-0.23\ T} + 1.5$$

where

LD = depth of loose material measured in millimeters.

T = cumulative traffic volume in both directions which has used the road since grading, measured in thousands of vehicles.

Table 2

Deterioration of earth roads

Surface roughness

for roads other than clay

(9) $R = 3250 + 1255\ T$

for clay roads

(10) $R = 3250 + 314\ T$

where

R = mean roughness in mm/km.

T = cumulative traffic volume in both directions which has used the road since grading, measured in thousands of vehicles.

Rutting

(11) $RD = 14 + 1.2\ T$

where

RD = rut depth measured in millimeters under a 2 meter straight edge

T = cumulative traffic volume in both directions which has used the road since grading, measured in thousands of vehicles.

Surface looseness

Roads graded in moist conditions

(12) $LD = 5\ e^{-0.35\ T} + 1.5$

Roads graded in dry conditions

(13) $LD = 14\ e^{-0.23\ T} + 1.5$

where

LD = depth of loose material measured in millimeters.

T = cumulative traffic volume in both directions which has used the road since grading, measured in thousands of vehicles.

4. Time-related road deterioration. Since no experimental data are available on the pure effect of climate on unpaved road deterioration, the following tentative relationship has been employed:

$$R = 2000\ R_f$$

where R = annual increase in surface roughness (mm/km) due to weather alone; and R_f = annual rainfall in meters. This equation is based on the subjective judgment that for 2000 mm average annual rainfall, a newly graded road without any traffic loading should last about five years.

NOTE: The deleted section deals with paved roads and traffic volumes which are beyond the scope of this project.

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NATIONAL ACADEMY OF SCIENCES
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ENGINEERING ECONOMICS OF THE MAINTENANCE OF EARTH AND GRAVEL ROADS

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This paper presents a methodology for the economic evaluation of maintenance programs for unpaved roads with low traffic volumes (under 250 vpd), a situation commonly encountered in rural areas in developing countries. The technique, drawing heavily on the road deterioration and user cost relationships developed in the IBRD/TRRL Kenya Road Transport Cost Study, involves a dynamic model that relates vehicle operating costs to traffic-induced road deterioration. The proposed methodology requires a two-step procedure: first to determine economically optimal and technically appropriate maintenance strategies; and second to apply these strategies to assess the economic value of the global road maintenance program. The incremental economic analysis used in the methodology permits the differentiation of benefits, in the form of vehicle operating cost savings, between routine and periodic maintenance. The use of the evaluation technique is demonstrated by application to a road maintenance program. Although the proposed method requires the use of multiple regression analysis and elementary calculus, graphical methods can be used as an alternative.

Cost-effective road maintenance practice is becoming a priority objective in most countries of the world since relatively nominal maintenance expenditures (about US$100-1000 per km in case of unpaved roads) can extend the life of existing infrastructure and postpone the need for its renewal. Although the economic value of road maintenance is manifest, its quantification is necessary to determine economically efficient levels of maintenance expenditures. Intensive research by the World Bank over the last decade suggests that the largest benefits of highway maintenance accrue in the form of vehicle operating cost (VOC) savings and that these are often the dominant factor in reaching economically optimal highway maintenance policy choices. In fact, vehicle operating costs on an unpaved road surface in good condition can be about 30-40% lower than if the surface were not adequately maintained.

The traditional approach to quantification of benefits due to good road maintenance takes the form of a static economic model that assumes fixed and often arbitrary levels of VOC under "good" and "poor" road maintenance conditions; the VOC difference comprising the benefits from good maintenance. This subjective method of analysis often results in suboptimal investment decisions relative to the scale and intensity of maintenance operations, such as the frequency of grading operations and the periodicity of gravelling(8).

The proposed method of analyzing road maintenance programs for unpaved roads is based on a dynamic analysis that relates vehicle operating costs to road surface conditions as they are affected by traffic and modified by maintenance operations. Traffic-induced road deterioration is defined in terms of roughness, rut depth, and depth of loose material. The corresponding vehicle speeds and VOC are also estimated as a function of surface condition parameters, because the road geometric and environmental factors influencing VOC remain unchanged under normal maintenance operations.

The Analytical Framework

The mathematical models that relate road surface condition and vehicle operating costs to traffic were developed under the IBRD/TRRL research program in Kenya (2, 3, 5). A review of the background references is necessary for an understanding of the methodology presented in this paper as limitations of space preclude a thorough discussion of these relationships.

Road Deterioration Relationships

Lateritic Gravels Roads

$$R = 3250 + 84\,T - 1.62\,T^2 + 0.016\,T^3 \qquad (1)$$

$$RD = 11 + 0.23\,T - 0.0037T^2 + 0.000073T^3 \qquad (2)$$

$$LD = 1.5 + 14e^{-0.23T} \qquad (3)$$

$$GL_a = 0.94\frac{T_a^2}{T_a^2 + 50}(4.2 + 0.092T_a + 3.5\,R_1^2 + 1.88\,VC) \qquad (4)$$

Sand-Clay Earth Roads

$$R = 3250 + 785\ T \quad (5)$$

$$RD = 14 + 1.2\ T \quad (6)$$

$$LD = 1.5 + 14e^{-0.23T}\text{; under dry grading with } LD \geq 10.0 \text{ mm.} \quad (7)$$

$$LD = 1.0\text{; under wet grading} \quad (8)$$

Tracks

$$R = 3250 + 1255\ T \quad (9)$$

$$RD = 14 + 1.2\ T \quad (10)$$

$$LD = 1.5 + 14e^{-0.23T}\text{; with } LD \geq 10.0 \text{ mm.} \quad (11)$$

where:

- R = mean roughness (mm/km)
- RD = rut depth (mm)
- LD = depth of loose material (mm)
- T = cumulative traffic volume in both directions since last grading (thousands of vehicles)
- GL_a = annual gravel loss (mm)
- T_a = annual traffic volume in both directions (thousands of vehicles)
- R_1 = annual rainfall measured in meters
- VC = rise and fall, vertical curvature (%)

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Vehicle Operating Cost Relationships

In the Kenya Study relationships, if certain physical characteristics of the road (such as geometrics, altitude and moisture regime) are fixed vehicle speeds and consumption of fuel, tires, spare parts, and maintenance labor can be estimated as a function of surface condition descriptors, R, RD, and LD (4). The average road geometric and environmental characteristics assumed in estimating speed and VOC components were: moisture content, 3%; average rise, 30 m/km; average fall, 30 m/km; average horizontal curvature, 175 degrees/km; and average altitude, 375 m. Oil consumption was also estimated from the results of the Kenya Study while for vehicle depreciation and crew costs the method recommended in de Wielle's work (1) was used. Composite VOC, obtained by adding the individual costs of VOC components, were calculated for the four representative vehicles--light goods vehicle (VL), single-unit truck (CMS), medium truck-trailer (CMR) and heavy truck-trailer (CLR)--used in the example demonstrating the application of the proposed analysis method to a road maintenance program. The physical characteristics and costs of these vehicles are shown in Table 1.

Table 1. Vehicle characteristics and costs

Vehicle Type	Light Goods Vehicle (VL)	Single Unit Truck (CMS)	Medium Truck-Trailer (CMR)	Heavy Truck-Trailer (CLR)
Physical Characteristics and Utilization				
Brake Horse Power	86	130	160	250
Payload (t)	1	7	14	26
Gross Vehicle Weight (t)	2.5	13	27	38
Fuel Type	Gas.	Diesel	Diesel	Diesel
Annual Operating Hours	800	800	1,200	1,200
Annual Crew Hours	2,000	2,000	2,000	2,000
Annual Kilometerage	25,000	25,000	25,000	35,000
Average Vehicle Life (yr.)	4	6	6	6
Unit Costs (net of taxes)				
New Vehicle (US$/veh.)	5,765	18,185	31,145	49,485
Tires (US$/tire)	69	395	395	395
Maintenance Labor (US$/hr.)	0.40	0.40	0.40	0.40
Crew Cost (US$/hr.)	0.50	0.40	0.40	0.40
Fuel (US$/litre)	0.33	0.30	0.30	0.30
Lub. Oil (US$/litre)	1.40	1.40	1.40	1.40

Unified Road Deterioration and Vehicle Operating Cost Relationships

A review of Kenya Study relationships showed both road surface deterioration parameters (R, RD, LD) and VOC could be reduced to a common denominator--cumulative traffic volume (T), provided that road geometric and environmental parameters remained fixed. This special characteristic of the two relationships was

Table 2. Vehicle operating cost equations

Road Surface and Vehicle Type	VOC Estimation Equation	Maximum T[a]	Number of Observations	R^2	Standard Error of Estimate	Upper Bound Limit on VOC (US$ Equivalent)
Laterite[b]						
Light Goods Vehicle	$VOC=213.32+0.0094T^2$	100	19	0.985	1.85	310
Single Unit Truck	$VOC=392.44+0.0216T^2$	100	19	0.991	3.27	610
Medium Truck-trailer	$VOC=692.98+0.0422T^2$	80	19	0.984	8.53	1020
Heavy Truck-trailer	$VOC=861.93+0.0557T^2$	80	19	0.984	10.95	1225
Sand-Clay[c]						
Light Goods Vehicle	$VOC=207.02+12.87T-0.2496T^2$	30	17	0.987	6.72	370
Single Unit Truck	$VOC=385.96+18.56T-0.2660T^2$	30	17	0.994	8.39	710
Medium Truck-trailer	$VOC=676.29+34.73T-0.4365T^2$	30	17	0.996	16.96	1350
Heavy Truck-trailer	$VOC=833.83+51.40T-0.7947T^2$	30	17	0.996	22.49	1675
Track						
Light Goods Vehicle	$VOC=206.86+21.51T-0.8051T^2+0.003T^4$	30	17	0.986	7.42	370
Single Unit Truck	$VOC=384.54+31.04T-1.0593T^2+0.004T^4$	30	17	0.991	10.32	710
Medium Truck-trailer	$VOC=675.07+58.37T-1.9396T^2+0.008T^4$	30	17	0.992	19.23	1350
Heavy Truck-trailer	$VOC=831.15+86.49T-3.0527T^2+0.012T^4$	30	17	0.990	28.99	1675

[a] T=Cumulative traffic volume between gradings in both directions ('000 vehicles).
[b] Applies to gravel roads with at least 2 cm of laterite surface.
[c] Applies to earth roads and gravel roads with less than 2 cm of laterite surface.

Note: VOC = vehicle operating cost (US$/1,000 km)

Table 3. Vehicle operating costs as a function of traffic and road surface characteristics

Road Surface	T	R	RD	LD	VOC Estimate[a] VL	CMS	CMR	CLR
Gravel Road: (Laterite Surface)	0	3250	11.0	15.5	213.32	392.44	692.88	861.93
	1	3332	11.2	11.1	213.33	392.46	693.02	861.98
	10	3944	13.0	2.9	214.27	394.60	697.20	867.49
	20	4410	14.7	1.6	217.09	401.09	709.86	884.20
	30	4744	16.5	1.5	221.81	411.91	730.96	912.30
	50	5400	22.4	1.5	236.89	446.52	798.49	1001.11
	80	7794	43.1	1.5	273.67	530.89	963.09	1218.24
	100	11450	70.0	1.5	307.61	608.76	-	-
Maximum VOC[b]					310.00	610.00	1020.00	1225.00
Earth Road: (Sand-Clay Surface)	0	3250	14.0	15.5	207.20	385.96	676.29	833.82
	1	4035	15.2	11.1	219.64	404.25	710.58	884.78
	5	7175	20.0	10.1	265.08	472.11	839.02	1079.89
	10	11700	26.0	10.0	310.74	544.95	979.92	1304.11
	20	14000	38.0	10.0	364.53	650.73	1196.23	1543.38
	30	14000	50.0	10.0	373.47	706.97	1325.18	1659.38
Maximum VOC[b]					375.00	710.00	1350.00	1675.00
Earth Track:	0	3250	14.0	15.5	206.86	384.54	675.07	831.15
	1	4505	15.2	11.0	227.57	414.52	731.51	914.58
	5	9525	20.0	10.0	294.81	513.53	919.45	1188.03
	10	14000	26.0	10.0	344.45	593.12	1072.97	1402.98
	20	14000	32.0	10.0	360.80	646.98	1197.22	1535.71
	30	14000	50.0	10.0	373.47	706.97	1325.81	1659.38
Maximum VOC[b]					375.00	710.00	1350.00	1675.00

[a] Vehicle operating cost estimate (US$/1000 km).
[b] Maximum VOC corresponds to an average speed of 10-15 km/hr.

used to formulate a unified relationship that would permit direct VOC estimation as a function of cumulative traffic volume (T), bypassing all intermediate steps requiring estimation of vehicle speed and VOC components as a function of surface condition parameters. The unified VOC estimation equations were obtained by regressing composite VOC with cumulative traffic (T), for three road surface types (Table 2). The interaction among cumulative traffic, road surface condition variables and the related VOC is shown in Table 3.

Estimation of Benefits due to Reduced Vehicle Operating Costs

With the use of VOC equations shown in Table 2, savings in vehicle operating costs during a given time period (normally one year for purposes of discounting) can be estimated directly as follows:

1. Calculate an average VOC equation by weighting the VOC equations for different vehicles by their respective percentages in the traffic distribution.
2. Use the average VOC equation to:
(a) sum the operating costs of vehicles accumulated between gradings during one year, for a given maintenance strategy (e.g. 2 gradings per year and other required routine maintenance);
(b) sum the operating costs of vehicles accumulated between gradings during one year, for an alternate maintenance strategy (e.g. regravelling, 2 gradings per year and other required routine maintenance).
3. Determine incremental benefits (VOC savings) due to the alternate maintenance strategy as the difference between the summed VOC for the two maintenance strategies.

Mathematically, this can be expressed as:

$$\text{VOC Savings} = \int f(T)_1 dT - \int f(T)_2 dT \qquad (12)$$

where: $f(T)_1$ = VOC equation corresponding to maintenance strategy 1 111
$f(T)_2$ = VOC equation corresponding to alternate maintenance strategy 2

This procedure simplifies the calculation of benefits and does not equire discrete addition of vehicle operating costs. For example, VOC benefits from two gradings per year, as compared to one grading per year on a sand-clay earth road, for a traffic stream containing only light vehicles (VL) can be expressed as:

$$B = 1000\int_0^X (207.02 + 12.87T - 0.2496T^2)dT$$

$$- 2(1000)\int_0^{X/2}(207.02 + 12.87T - 0.2496T^2)dT$$

$$= 1000\left(12.8T\left(\frac{x^2}{2} - \frac{x^2}{4}\right) - 0.2496\left(\frac{x^3}{3} - \frac{x^3}{12}\right)\right) \qquad (13)$$

where: x = accumulated number of vehicles per year in thousands
B = VOC savings in US$/1000 km.

Application to Economic Analysis of a Maintenance Program

The foregoing analytical procedure was applied to evaluate the economic value of a maintenance program for a network of 5,300 km of unpaved roads and tracks in West Africa. The area covered by the maintenance program is characterized by a dry climate with an average rainfall of about 1,100 mm per year. The average altitude is about 375 m with a flat to rolling terrain. As deposits of good lateritic gravels are not plentiful, a mechanically stabilised sand-clay mixture has been used as the wearing course on some unpaved roads.

The Maintenance Program

The maintenance program was designed to cover both routine and periodic maintenance (regravelling) activities. Fully mechanized routine maintenance operations consisted of grading, compacting, and dragging with tractor-drawn tires. Other operations such as filling potholes, clearing ditches and culverts, vegetation control, and spot regravelling were placed under the responsibility of road gangs. Each gang consisted of 25 laborers under the direction of a sector chief with responsibility for a road maintenance sector covering 100-200 km.

The physical requirements for the maintenance program included provision of equipment plus an initial stock of spare parts, workshop equipment, construction of equipment sheds, improvements to the workshops, construction of spare parts store, offices for equipment inventory control and inspection, and buildings to serve as administrative centers for the road sectors. To meet the requirements for mechanics, operators, and other skilled staff, a comprehensive training program including technical assistance and equipment for a training center was instituted. Senior administrative and technical staff needs were met by provision of a technical assistance team, whose functions included training of local staff and development of the necessary capability for equipment maintenance, and planning and execution of road maintenance works.

Sequential Economic Evaluation Procedure

The evaluation of the maintenance program followed a sequential procedure involving classification of roads included in the maintenance program, determination of appropriate maintenance strategies and the overall economic assessment of the maintenance program. After the road network was categorized broadly according to its engineering and traffic characteristics, an appropriate maintenance strategy was determined for each road surface type by calculating the incremental VOC savings associated with the improved maintenance operations. This was followed by determination of overall economic benefits (VOC savings), which were then compared with maintenance costs to evaluate the economic returns for the routine and periodic maintenance components of the maintenance program.

Table 4. Classification of road network for economic analysis of the maintenance program

Network Category	Length (km)	Base ADT (vpd)	Distribution of Traffic %VL	%CMS	%CMR	%CLR
Gravel Roads[a]	395	48	45	15	25	15
Gravel Roads	79	38	45	15	25	15
Gravel Roads	276	15	45	15	25	15
Earth Roads[b]	63	40	45	15	25	15
Earth Roads	181	36	45	30	0	25
Earth Roads	175	17	45	30	0	25
Earth Roads	49	34	45	15	25	15
Earth Roads	150	17	45	15	25	15
Earth Roads	259	10	45	30	0	25
Major Tracks[c]	99	29	45	15	25	15
Major Tracks	846	17	45	15	25	15
Major Tracks	72	13	45	55	0	0
Minor Tracks	1544	5	45	55	0	0
Minor Tracks	1130	7	45	15	25	15
TOTAL	5318					

[a] All gravel roads have a wearing course of lateritic gravels.
[b] All earth roads have a wearing course of a mechanically stabilized sand-clay mix.
[c] Most tracks follow the natural ground profile and may have a few drainage structures.

Classification of the Road Network

The unpaved road network of about 5,300 km, varied from all-weather gravel (laterite-surfaced) roads to tracks. The base-level average daily traffic (ADT) on the network ranged from about 50 vpd on the laterite-surfaced roads to less than 10 vpd on the tracks. As the road network had not been functionally classified, it was categorized according to its engineering and traffic characteristics (Table 4). An average traffic growth rate of 3% per annum was assumed over the analysis period.

Determination of Maintenance Strategies

Maintenance policies for unpaved roads included drainage and vegetation control, dragging (with rubber tires), emergency repairs resulting from washouts and weak spots, grading, and resurfacing with gravel. As no definite, quantified models are available to evaluate benefits from four of the basic routine maintenance operations--drainage clearance, vegetation control, shoulder maintenance and surface dragging--it was assumed that a certain level of expenditures for these routine items was required as part of the overall maintenance policies. For grading and gravelling, which consituted the major maintenance operations it was necessary to determine: (i) appropriate grading strategies for various classes of roads included in the maintenance program; and (ii) the traffic level at which surfacing with gravel would be economically justified.

Grading Frequency

The effect of more frequent grading is to improve the condition o. the road surface and thereby lower vehicle operating costs. The vehicle operating costs corresponding to various grading frequencies for a given type of road surface were obtained by

$$\Sigma VOC = N \int_0^{x/N} f(T)_w \, dT \qquad (14)$$

where:

- ΣVOC = cumulative vehicle operating costs in one year corresponding to a grading frequency, N/year (US$/km);
- x = cumulative number of vehicles during one year in thousands;
- N = grading frequency (number of bladings/year); and
- $f(T)_w$ = average VOC equation obtained by their respective share in the traffic stream.

The incremental benefits (reductions in vehicle operating costs) due to additional grading were obtained as:

$$\Delta VOC = \Sigma VOC_N - \Sigma VOC_{N+1} \qquad (15)$$

where:

- ΔVOC = Incremental reduction in vehicle operating costs (US$/km)
- ΣVOC_N = Cumulative VOC per annum for a grading frequency, N/year (US$/year)
- ΣVOC_{N+1} = Cumulative VOC per annum for a grading frequency N+1/year (US$/year).

By equating the incremental benefits associated with progressively increasing grading frequencies with the incremental unit cost of grading (US$80/km); optimal grading frequencies were established for various

Table 5. Effect of grading frequency on vehicle operating costs for lateritic gravel roads

Grading Frequency (number/year)	Cumulative Vehicle Operating Costs, ΣVOC (US$/year)	Incremental Reduction in VOC, ΔVOC (US$/year)
ADT = 10 vpd		
1	1,670.00	-
2	1,669.60	0.40
ADT = 30 vpd		
1	5,020.04	-
2	5,011.38	8.66
ADT = 50 vpd		
1	8,400.98	-
2	8,360.85	40.13
ADT = 70 vpd		
1	11,833.29	-
2	11,723.17	110.12
3	11,702.78	20.39
ADT = 90 vpd		
1	15,377.50	-
2	15,103.47	274.03
3	15,058.09	45.38
ADT = 120 vpd		
1	20,774.76	-
2	20,219.14	555.62
3	20,116.25	102.89
4	20,080.24	36.02
ADT = 150 vpd		
1	26,489.33	-
2	25,404.15	1,085.18
3	25,203.19	200.96
4	25,132.86	70.33
ADT = 200 vpd		
1	36,819.60	-
2	34,247.33	2,572.27
3	33,768.93	478.40
4	33,604.26	164.67
5	33,522.09	80.17
ADT = 250 vpd		
1	48,436.01	-
2	43,412.04	5,023.97
3	42,481.67	930.37
4	42,156.04	325.63
5	42,005.32	150.72
6	41,923.45	81.87
7	41,872.82	50.63

levels of base ADT. Where increment... benefits were larger than US$400/km (the cost of grading with compaction), the grading operation was supplemented with compaction. The incremental (marginal) reduction in VOC with increase in grading frequency for a lateritic gravel surface is shown in Table 5 with levels of base ADT varying from 10-250 vpd. A similar analysis was carried out for earth roads with a sand-clay surface and earth tracks; the results are summarized in Table 6. The optimal grading frequency from an economic standpoint is defined as the breakeven point where incremental reduction in vehicle operating costs due to an additional grading (or grading with compaction) operation is equal to the incremental cost of one grading (or grading with compaction) operation. It was found that at least one grading per year was economically justified on all of the three surfaces whenever the base ADT was more than 5 vpd, when compared with the null alternative (no grading at all). The frequency of grading, however, is a function of surface type and level of traffic; a laterite (gravel) surfaced road requiring a considerably lower frequency of grading than a sand-clay (earth) road or an earth track, for the same level of traffic intensity. The optimal grading frequency on gravel roads was found to be less sensitive to traffic, changing from 1 to 6 gradings/year with ADT varying from 30-250 vpd. For an earth road, the optimum varied from 1 grading/year at an ADT of 10 vpd to about 17 gradings/year for a base ADT of 120 vpd. The optimal grading frequencies obtained by the preceeding analysis were used as benchmarks and, where warranted, modified in the light of local experience and climatic conditions to arrive at operational routine maintenance strategies that maintained an appropriate technical balance between grading frequency and other essential routine maintenance operations, particularly for earth roads. As a result, the grading frequencies for gravel roads were slightly increased while those for earth roads and tracks were reduced (Table 7).

Table 6. Economically optimal frequency of grading operations

Road and Surface Type	ADT (vpd)	Optimal Grading Frequency (Gradings/year): Without Compaction[a]	With Compaction[b]	Total
Gravel Road: (laterite)	10	1	0	1
	30	1	0	1
	50	1	0	1
	70	1	1	2
	90	1-2	1	2-3
	120	1	2	3
	150	1-2	2	3-4
	200	2	3	5
	250	3	3	6
Earth Road: (sand-clay)	10	1	0	1
	30	2	2	4
	50	4	3	7
	70	6	4	10
	90	7	5	12
	120	10	7	17
Track: (earth)	5	1	0	1
	10	2	0	2
	30	4	1	5

[a] Unit Cost of grading = US$80/km
[b] Unit Cost of grading with compaction = US$400/km

Gravelling

Surfacing an earth road with gravel provides a riding surface which can better withstand the deleterious effects of traffic and environment, thereby permitting all-weather usage. The serviceability of the road is considerably enhanced, while routine maintenance requirements become less stringent. In addition, the better surface quality results in lower vehicle operating costs.

In order to determine the breakeven traffic volume at which surfacing an earth road with gravel or resurfacing an existing gravel road would be economically justified, a benefit/cost analysis was carried out comparing the cost of four gravelling alternatives with benefits resulting from differences in VOC on gravel and earth surfaces with base ADT ranging from 30 to 90 vpd. The gravelling alternatives considered were:

Alternative:

A - 10 cm thickness; 6 m width with 0.5 m shoulders.

B - 10 cm thickness; 7 m width with 0.5 m shoulders.

C - 15 cm thickness; 6 m width with 0.5 m shoulders

D - 15 cm thickness; 7 m width with 0.5 m shoulders.

Routine maintenance strategies shown in Table 7 were assumed for the two surface types as required. Benefits at a given base ADT were then calculated as:

Table 7. Routine maintenance strategies adopted for the maintenance program

Road Type	Gravel Roads					Earth Roads					Tracks		
Base ADT (vpd):	10	30	50	70	90	10	30	50	70	90	5	10	30
Dry Grading (operations/year)	1	2	2	2	2	1	1	1	2	2	1	1	2
Grading with Compaction (operations/year)	-	-	-	-	-	-	1	1	1	2	-	-	-
Spot Repairs (m^3/km)	-	-	-	-	-	-	25	50	50	50	-	-	25
Light Routine Maintenance[a] (km/year/sector)	-	200	150	100	50	-	150	100	50	50	-	-	200
Dragging[b] (No. of operations)	-	20	30	50	90	-	-	-	-	-	-	-	-

[a] Filling potholes, drainage and vegetation control, shoulder maintenance, etc.
[b] With tractor-drawn tires.

$$B_{PV} = \Sigma_{a=1}^{n} \left(N_E \int_0^{x_a/N_E} f(T_E)\, dT - N_G \int_0^{x_a/N_G} f(T_G)\, dT \right) pwf_a(i,n) \qquad (16)$$

where:

- B_{PV} = present value of difference in vehicle operating costs between gravel and earth surfaces summed over a period of one regravelling cycle (US$/km);
- n = analysis period = regravelling cycle (years);
- x_a = cumulative number of vehicles during year "a" in thousands;
- N_E = grading frequency for earth surface (number/year);
- N_G = grading frequency for gravel surface (number/year);
- $f(T_E)$ = average vehicle operating cost equation for earth road;
- $f(T_G)$ = average vehicle operating cost equation for gravel road; and
- $pwf_a(i,n)$ = present worth factor for period a, discount rate i, and analysis period n.

For this analysis, the average VOC equations for gravel and earth roads are given as:

$$VOC_G = 457.39 + 0.0264T^2 \qquad (17)$$

$$VOC_E = 445.20 + 24.97T - 0.3806T^2 \qquad (18)$$

with 45% VL, 15% CMS, 25% CMR, and 15% CLR with VOC expressed in US$/1000 km. The details of the analysis are presented in Table 8.

The regravelling cycle in years, obtained by dividing the thickness of the gravel surface by the average annual gravel loss, was taken as the analysis period. Discounted VOC savings were obtained as the present value of the difference in vehicle operating costs between gravel and earth surfaces over the analysis period as given by Equation 17. The net present value, then, was given as the difference between VOC savings and the corresponding cost of gravelling. The breakeven ADT for the four gravelling alternatives was taken as the ADT at which the net present value becomes zero. At a discount rate of 12% (assumed to be approximately equal to the opportunity cost of capital), it was shown that regravelling alternative B was economically justified for all roads with a base ADT of at least 47 vpd. Accordingly, 395 km of gravel roads with an average base ADT of 48 vpd (Table 4) were included for gravel surfacing in the maintenance program; the design standards for regravelling comprised a 7m wide running surface, 0.5m wide shoulders, and a 10cm thickness.

Table 8. Benefit cost analysis to determine breakeven ADT for gravelling

Base ADT[a] (vpd)	Average Annual Gravel Loss[b] (cm)	Regravelling Cycle for Gravel Thickness (years)		Cost of Gravelling (US$/km) Alternatives				Present Value of VOC Savings (US$/km) at 12% Discount Rate		Net Present Value (US$/km)			
		10 cm	15 cm	A	B	C	D	A,B	C,D	A	B	C	D
30	0.98	10	15	7,165	8,265	10,745	12,400	3,270	3,960	-3,895	-4,995	-6.785	-8,440
50	1.26	8	12	7,165	8,265	10,745	12,400	8,300	10,390	1,135	35	-355	-2,010
70	1.40	7	11	7,165	8,265	10,745	12,400	9,845	12,860	2,680	1,580	2,115	460
90	1.54	6	10	7,165	8,265	10,745	12,400	10,830	14,950	3,665	2,565	4,205	2,550

Alternative:	A	B	C	D
Breakeven ADT:	43	47	50	58

[a] Traffic growth: 3% per annum.
[b] From equation 4 with R_1 = 1.1 m; VC = 3%.

Economic Evaluation of the Maintenance Program

The economic evaluation of the maintenance program consisted of an engineering-economic assessment of the condition of the road network and the associated vehicle operating costs with and without the maintenance program. Without the maintenance program, it was estimated that effective road maintenance would decrease systematically and eventually cease in about four years. Maintenance output for with and without maintenance program conditions is given in Table 9.

Table 9. Maintenance output with and without maintenance program

	Without Maintenance Program Routine Maintenance				With Maintenance Program	
Year	Gravel Roads (km)	Earth Roads (km)	Tracks (km)	Total (km)	Routine Maintenance[a] (km)	Regravelling (km)
1	474	161	965	1,600	-	-
2	474	161	565	1,200	1,800	100
3	474	161	165	800	5,318	100
4	400	-	-	400	5,318	100
5		-			5,318	95
6		-			5,318	-
7		-			5,318	-
8		-			5,318	-
9		-			3,545	-

[a] Distribution of roads and tracks as shown in Table 4.

The economic rates of return for the maintenance program (separately for routine and periodic maintenance components), were calculated by relating the incremental cost of equipment and other maintenance inputs to the corresponding incremental benefits in the form of reduced vehicle operating costs, resulting from improved road maintenance brought about during the economic life of the equipment.

The incidence and magnitude of vehicle operating costs and related benefits as a function of accumulated number of vehicle passes and level of road maintenance with and without the maintenance program is demonstrated in Figure 1. Although the proposed method of economic analysis requires the use of statistical regression analysis and elementary calculus, to estimate VOC savings, it can be seen from Figure 1, that such VOC estimates can be alternately determined by preparing templates consisting of graphed average VOC curves and then measuring the area under these curves for given maintenance strategies.

Benefit/Cost Analysis of Routine Maintenance

Costs for routine maintenance included (i) capital expenditures for maintenance and workshop equipment, an initial supply of spare parts, buildings, and related technical assistance, and (ii) recurrent maintenance expenditures for fuel, spare parts and labor, incremental to the amount spent without the maintenance program. Using procedures discussed in the preceding sections, benefits were calculated in terms of reduced VOC resulting from improved routine maintenance. The benefits were accumulated over the 14 classified sections and grouped in three categories. The economic life of equipment was estimated to average about 8 years while the salvage value of buildings at the end of the analysis period was estimated at 50% of initial cost. Other than the roads to be regravelled under the maintenance program at the rate of about 100 km per annum during the first four years of the maintenance program, gravel roads with less than 2 cm of laterite surface were treated as earth roads for purposes of the economic analysis of routine maintenance. The results of the benefit/cost analysis are presented in Table 10. The economic rate of return for routine maintenance operations under the maintenance program was estimated at 74%

Figure 1: ECONOMIC BENEFITS FROM MAINTENANCE

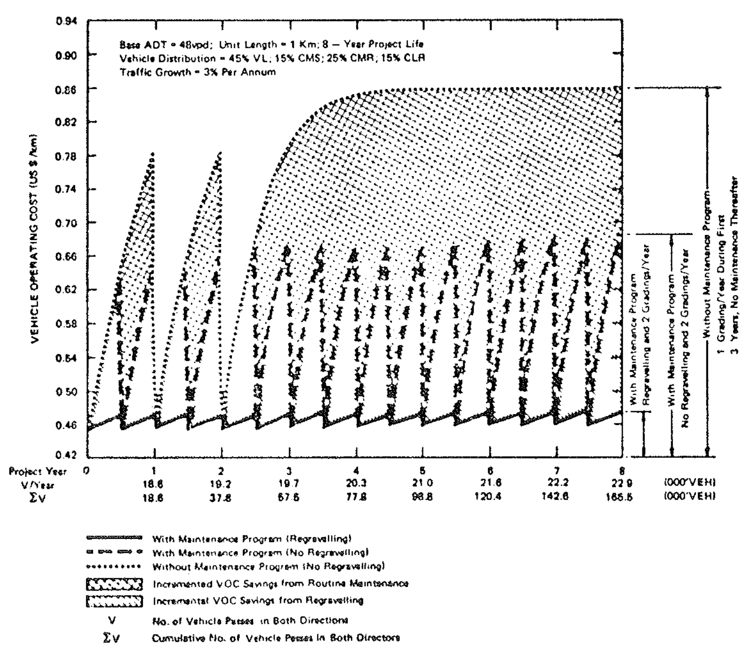

Table 10. Routine maintenance - benefit/cost analysis

	COSTS (US$ million)						BENEFITS (US$ million)			
	Capital Investment			Recurrent Maintenance Costs			Incremental VOC Savings			
Year	Equipment & Spare Parts	Buildings	Technical Assistance	With Project	Without Project	Incremental Costs[a]	Gravel Roads (750 km)	Earth Roads (877 km)	Tracks (3691 km)	Total (5318 km)
1	1.473	0.708	0.621							
2	2.945	1.416	0.621	0.493	0.493	-	0.227	0.231	1.149	1.607
3			0.621	1.479	0.410	1.073	1.116	1.335	4.138	6.589
4				1.479	0.410	1.073	1.098	2.056	4.253	7.407
5				1.479	0.244[a]	1.236	1.079	2.694	4.525	8.298
6				1.479	0.244	1.236	1.351	2.891	4.809	9.050
7				1.479	0.244	1.236	1.831	2.960	4.887	9.678
8				1.479	0.244	1.236	2.869	3.028	4.974	10.871
9				1.479	0.244	1.236	3.232	2.981	5.060	11.270
10		-1.062[b]		1.479	0.244	0.742	2.212	2.120	3.461	7.794

IRR = 74.1%
B/C @ 12% = 3.17

[a] Salaries for permanent road maintenance staff.
[b] Salvage value of buildings.

corresponding to a benefit/cost ratio of 3.17 at a 12% discount rate.

Benefit/Cost Analysis of Periodic Maintenance (Regravelling)

The cost of periodic maintenance included expenditures for equipment and technical assistance, and operational recurrent costs over the 4-year regravelling program. The average regravelling output was estimated at about 100 km per year with a total output of 395 km. A 50% salvage value was applied at the end of the regravelling program, because equipment would have been used for only one-half of its 8-year economic life. Since the regravelling cycle was calculated to be about 8 years, while only about 100 km would be regraveled each year, the residual thickness of the gravel at the end of the analysis period was also assigned a terminal value. The annual gravel loss was estimated to be about 12.6 mm per annum. The benefits from regravelling were taken as the incremental reduction in vehicle operating costs, additional to the reduction effected under routine maintenance, and expressed as:

$$\Delta B = (VOC_2 - VOC_0) - (VOC_1 - VOC_0) \qquad (19)$$

where:

ΔB = Incremental benefits from regravelling (US$ million).

VOC_0 = Vechicle operating costs under the null alternative--one grading/year and other routine maintenance operations for initial three years of the program; no maintenance thereafter (US$ million).

VOC_1 = Vehicle operating costs under maintenance alternative '1',--2 gradings/year and other routine maintenance operations over an 8-year period (US$ million).

VOC_2 = Vehicle operating costs under maintenance alternative '2',--regravelling at 100 km/year over 4 years, 2 gradings/year and other routine maintenance over an 8-year period (US$ million).

Then,

$VOC_1 - VOC_0$ = VOC savings under maintenance alternative '1'.

$VOC_2 - VOC_0$ = VOC savings under maintenance alternative '2'.

or,

$$\Delta B = VOC_2 - VOC_1$$

The results of the analysis are presented in Table 11. The incremental rate of return for regravelling operations was estimated at 17%, corresponding to a benefit/cost ratio of 1.26 at a discount rate of 12%.

Sensitivity Analysis

The specific risk elements related to the maintenance program were increase in costs and possible shortfalls in the projected maintenance output. A sensitivity analysis was carried out to evaluate the effect of these parameters on the economic return of the maintenance program components (Table 12).

If routine maintenance were confined to the most

Table 11. Regravelling - benefit/cost analysis

	Costs (US$ millions)				Benefits		
					VOC Savings (US$ millions)		
Year	Equipment	Technical Assistance	Recurrent Expenditure	Salvage Value of Remaining Gravel Surface	Alternative 1	Alternative 2	Net Incremental Benefits Alt. 1 - Alt. 2
1	1.832						
2		0.080	0.464		0.683	0.802	0.099
3		0.080	0.464		0.718	1.030	0.312
4		0.080	0.464		0.746	1.280	0.534
5	-0.916	0.080	0.464		0.785	1.611	0.820
6					2.648	3.662	1.014
7					2.694	3.763	1.069
8					2.747	3.881	1.134
9				-0.579	2.798	3.999	1.201

IRR = 17.2%
B/C @ 12% = 1.26

Table 12. Sensitivity analysis

	IRR (%)
A. Routine Maintenance - IRR=74.0%; B/C@12%=3.17	
Effect of Reduced Maintenance Output	
Network Maintenance:	
5,300 km[a]	74.1
3,500 km	63.0
1,800 km	26.6
Effect of Reduced Equipment Utilization	
Economic Life of Equipment:	
8 years[a]	74.1
7 years	73.0
6 years	71.3
Effect of Cost Increases	
Increase in Costs:	
5%	70.3
10%	66.9
15%	63.8
20%	60.8
Effect of Increase in Benefits	
Increases in Benefits:	
5%	77.9
10%	81.8
B. Regravelling - IRR=17.2%; B/C@12%=1.26	
Effect of Reduction in Annual Output of Regravelling	
Kilometers Regravelled per Year:	
100 km[a]	17.2
80 km	12.4
Effect of Increase in Cost of Regravelling	
Increase in Costs:	
5%	16.1
10%	15.0
20%	13.0
Effect of Increase in Benefits from Regravelling	
Increase in Benefits:	
5%	18.4
10%	19.5

[a] As assumed under the maintenance program.

important road links (about 3,500 km of roads and tracks), it would have an economic return of about 63%. If the training program failed to produce sufficient personnel to expand maintenance operations, or if a shortage of recurrent funds limited maintenance to current levels (about 1,800 km), routine maintenance would yield an estimated economic return of about 27%. The economic return for routine maintenance was relatively insensitive to reduced equipment life and the corresponding reduction in maintenance output during the later years of the program, showing only a 3 percentage point drop in the rate of return with equipment life reduced from 8 to 6 years. A 20% increase in costs would lower the economic return to 61% while a 5% increase in benefits, a distinct possibility resulting from a probable traffic growth in excess of the assumed 3% would raise the economic return to 78%.

Relative to regravelling operations, a 20% reduction in the annual regravelling output from 100 km to 80 km would lower the economic return to 15% while a 10% increase in benefits would raise it to 20%.

Conclusions

An attempt has been made in this paper to present an improved economic analysis method for the evaluation of road maintenance programs for unpaved roads. The method employs some of the latest research findings related to traffic-induced deterioration of unpaved roads and its effect on vehicle operating costs. This evaluation technique removes much of the subjectivity from estimation of vehicle operating costs as they are affected by the quality and scale of maintenance operations and provides the analyst a tool for determining economically optimal levels of routine and periodic maintenance. The analysis can be carried out with a portable hand calculator without recourse to expensive and time-consuming computer-based models. Some of the salient conclusions of the maintenance program example described in the paper are:

1. Efficiently executed routine maintenance operations yield a very high economic return and can help to offset the need for early renewal of the road infrastructure.
2. Once an earth road is surfaced with gravel, routine maintenance requirements become less stringent and require a lower frequency of grading operations.
3. The optimal grading frequencies resulting from economic analysis should be used only as guidelines in the design of maintenance programs; where necessary, they should be modified to reflect actual operational conditions.
4. The minimum breakeven ADT at which gravel surfacing of earth roads becomes economically justified varies from about 45-60 vpd, depending upon the design standards used.

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EFFECT OF SIMPLE ROAD IMPROVEMENT MEASURES ON VEHICLE OPERATING COSTS IN THE EASTERN CARIBBEAN

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The paper describes the effect on vehicle operating costs of a simple labour-intensive method of rehabilitating and maintaining badly deteriorated bitumen surfaced roads in the Eastern Caribbean. The techniques developed for the rehabilitation and maintenance of the roads are described, and the equipment, materials and manpower required are listed. The rehabilitation and maintenance system is a simple one restricted to providing adequate drainage, filling the potholes in the road and providing a minimum seal over the whole road surface. The reduction in vehicle operating costs resulting from the improvement in the riding quality of the road surface is shown to be sufficient to recover the rehabilitation costs in a very short time even at flows as low as 100 vehicles per day. The majority of the roads included in this scheme are of low strength, have low geometric standards and have traffic flows ranging from 50 to 1500 vehicles per day. All the roads have been trafficked for at least one year since being rehabilitated and some for two years. During this time little or no damage to the surface has taken place.

Introduction

This report describes the cost-effectiveness of a simple labour-intensive method of rehabilitating and maintaining badly deteriorated bituminous road surfaces.

The method used to improve the road surfaces was developed in the Eastern Caribbean island of St Vincent by one of the authors whilst Regional Public Works Advisor to the British Development Division in the Caribbean. Data on vehicle operating costs were obtained from an investigation into vehicle operating costs being undertaken by TRRL in the Eastern Caribbean and from an earlier study(1). The cost-effectiveness of the operation is calculated by comparing the cost of the improvements with the savings in vehicle operating costs resulting from the improved riding quality of the road surfaces.

All the roads included in the analysis are of low strength having a modified structural number of less than 3,(2) and have high horizontal and vertical curvature (at least 300 degrees/km and up to 100m/km respectively). They carry between 50 and 1500 vehicles per day and have all been trafficked for between one and two years since rehabilitation.

As the improvements were carried out to the road surface only there was no change in road geometry but the riding quality of the road surface was improved. Riding quality has been measured using a vehicle mounted bump integrator unit. The roughness values obtained were then converted to the corresponding towed 5th wheel bump integrator value(1). The road surface roughness as measured by this method reduced from 7000mm/km before the improvements to an average of 4000mm/km on completion of the restoration of the road surfaces. Details of these roughness measurements for a representative sample of the roads are given in Table 1, and their locations are shown on the map in Figure 1.

All costs are quoted net of tax in Eastern Caribbean dollars (EC$2.7 = US$1: EC$ 5.2 = £1 sterling).

The situation prior to the Rehabilitation Programme

St Vincent has 320 kilometres (200 miles) of bituminous surfaced roads and, with the exception of 24 kilometres (15 miles) which have been reconstructed over the last 10 years, they had received little if any surface maintenance since they were first bituminised in the period 1950-1968. This neglect had resulted in serious deterioration of the running surface characterised by extensive potholing and crazing, as shown in Figure 2. If a 'pothole' is defined as having a minimum diameter of 150mm (6") and a minimum depth of 25mm (1"), then by 1976 incidences of one pothole per linear metre of road were commonplace, and in many cases the whole width of the road surface had been broken up, forcing traffic to drive on the boulder base. The method of construction adopted when the roads were originally bituminised was basically grouted macadam. A loose layer of 25mm (1") stones was laid over a boulder base, blinded with 13mm (½") stones and then penetrated with bitumen and finished off with a layer of 6mm (¼") to dust. Whilst this method of construction provides a reasonably waterproof finish initially, it has the disadvantage that once water gains access through the finished surface it easily penetrates the porous 25mm (1") layer down to the base, lifting off large areas of surfacing.

Between 1968 and 1976 the St Vincent Government, using grants from the UK Ministry of Overseas Development, reconstructed 8 kilometres (5 miles) of the Leeward (West Coast) Highway and 16 kilometres (10 miles) of the Windward (East Coast) Highway. In addition in 1978 the reconstruction of a further 19 kilometres (12 miles) of the Windward Highway was started using funds provided by the European Development Fund. However with reconstruction costs of the order of $300,000 per kilometre ($½ million per mile) it was clear that because of limitations on funds the remainder of the road network could not be reconstructed in this way.

The amount available for maintenance of bitumen roads in the Recurrent Annual Budget is only $800,000 or $2500 per kilometre ($4000 per mile) approximately and the Roads Maintenance Department found that these funds were sufficient only to repair the worst of the potholes with premixed bituminous macadam. It was not possible to undertake a maintenance and surface dressing programme sufficient to arrest the decline of the road surface condition. To alleviate this situation the UK Ministry of Overseas Development in 1975 approved a grant to establish a Pilot Road Maintenance Unit on St Vincent to train local staff in maintenance procedures and to develop a cheap, labour-intensive method of rehabilitating the road system in order that its continued maintenance could be financed within the recurrent budget allocation.

The Rehabilitation and Maintenance Programme

The rehabilitation and maintenance of a typical broken bituminous road surface comprises the following activities:

1. Clean and improve side and cross drainage.
2. Repair the potholes, bringing the road profile as nearly as possible to its original shape.
3. Surface dress or otherwise waterproof the repaired surface.
4. Maintain the road so repaired by:-
(a) Keeping the drains clean.
(b) Repairing minor potholes as they appear and before they become major ones.

Drainage

Since the side drains and road culverts had become blocked and overgrown and numerous landslides had not been cleared, the initial cleaning of the side drains was carried out using a grader, a front end loader, and dump trucks. The cost of this operation ranged from $1250 to $2500 per kilometre ($2000 to $4000 per mile). Thereafter it has been possible to maintain the drains in good order at a cost of $950 per kilometre ($1500 per mile) per year.

Repairing Potholes

The normal method of repairing potholes is to trim off the sides, prime with MCO grade bitumen and fill with a premixed bituminous macadam. This was the method most extensively used in St Vincent. In order to make maximum use of labour the premix was mixed by hand and this was found to be more effective and cheaper than machine mixing. The cost of hand mixed material is about $93 per cu. metre ($70 per cu. yard) as compared with $113 per cu. metre ($85 per cu. yard) for material made by a Spotmix machine and $142 per cu. metre ($107 per cu. yard) for material bought commercially. It was found that 10 to 50 cu. metres of premix were required per kilometre (20 to 100 cu. yards per mile) depending on the state of the road and its width. The cost of providing and laying this material ranged from $1240 to $6200 per kilometre ($2000 to $10,000 per mile).

In order to reduce the costs of patching still further a method of grout patching was evolved (Figure 3). This consisted of brushing clean the area to be repaired, priming with an RC 2 grade bitumen, filling the hole with a suitably graded stone (the grading being dependent on the size of the hole), grouting with RC 2 bitumen and blinding with sand. Although rather crude, this method was quick and produced a watertight patch. It was also less extravagant on materials since the hole was not squared off and was therefore of smaller volume than when filled with premix.

Surface Dressing

It was soon found that roads repaired as described above quickly deteriorated again, especially during the rainy season. Water soon penetrates to the road base through crazing in the bitumen surface, through small potholes which have not been repaired, and through patches. For example the 8 kilometre (5 mile) long Vigi Highway required the expenditure of the following sums for repairing potholes over a twenty month period:-

Date	Cost of repairing 8 kilometres
Nov.75	$10,000
Mar.76	$25,000
Oct.76	$23,000
April/June 77*	$18,000

*immediately prior to surface dressing

Clearly the repair of potholes alone was insufficient to arrest the deterioration and it was necessary to waterproof the road surface by some inexpensive means. Accordingly a programme of surface sealing was started in November 1976. After experimenting with various forms of surface dressing, including spray and chippings and slurry sealing, it was found that the most effective method was labour-intensive sandsealing. This had the following advantages:

1. It could be readily adapted to labour-intensive methods.
2. It used an easily obtainable and cheap surfacing material.
3. It provided a dense, waterproof finish.
4. It caused the minimum disruption to traffic.

The method of sandsealing employed is as follows:

1. RC 2 bitumen is poured on the road surface at a rate of approximately 0.27 litres/sq. metre (0.2 gals/sq. yard).

2. It is then spread with rubber squeejees.
3. The bitumen is then covered with a layer of sand 25 to 30mm thick.
4. The sand is then lightly rolled.

These steps are shown in Figures 4, 5 and 6 and a completed road in Figure 7. At normal daytime temperatures in St Vincent (over 70°F) the RC 2 does not need heating and can therefore be poured straight from the drums.

The cost for a kilometre of 3.7 metre (12 ft) wide road is:

RC 2 Bitumen	6000 litres	@$0.42 per litre	$2500
Sand	100 cu-metres	@$7.50 per cu-metre	$ 750
Roller	6 days	@$35 per day	$ 210
Labour	177 man days	@$7 per day	$1240
Small tools etc			$ 300
		Total	$5000

or approximately $1.35 per sq. metre ($1.10 per sq.yd).

Regular Maintenance

Side Drainage. As mentioned above the recurrent maintenance cost for keeping clear side drains and culverts is approximately $950 per kilometre per year, which equates to one man per 1.6 kilometre (1 mile) per year plus a few hundred dollars extra for emergencies. In some instances the method adopted for this maintenance is to give one labourer the responsibility for keeping clear one kilometre of road, but usually casual gangs are employed to clear specific lengths. In either case the importance of keeping the side drains clear to stop water from getting into the road base cannot be over-emphasised.

Surface Maintenance. The object of the rehabilitation and surface dressing programme is to bring down the costs of regular surface maintenance to manageable proportions and in this the programme has succeeded. The first stretch of 8 kilometres (5 miles) to be sandsealed on the Leeward Highway has not required patching since it was sealed in the period November 1976 to May 1977. The more heavily trafficked Vigi Highway was sandsealed in early 1977 and to date (May 1978) has only required minor pothole patching on one occasion at a total cost of $360.

A mobile patching gange of 8 men has been formed equipped with minor tools such as hand rammers and a flat-bed truck for transport. This gang patrols the sealed roads in a 3-month cycle, patching with premix or grouting any small failures as they occur.

The cost of this gang per day is as follows:

Materials	$150
Labour	$ 80
Vehicle	$ 45
Tools etc	$ 5
	$180

Assuming a working year of 200 days the cost of one gang per year is $36,000. A gang can maintain 100 kilometres (70 miles) of rehabilitated road in this way, hence three units will be capable of covering all the bituminous roads in the country at a cost of $108,000 per year when the 240 kilometres (150 miles) included in the rehabilitation programme has been sealed.

Cost of the Rehabilitation and Maintenance Programme

The average rehabilitation costs are given below but in practice they vary from road to road as can be more clearly seen in Table 1.

1.	Re-establishing earth side-drains	$1900 per kilometre ($3000 per mile)
2.	Patching potholes	$4300 per kilometre ($7000 per mile)
3.	Sandsealing	$5000 per kilometre for 3.7 metre road ($8000 per mile for a 12 ft. wide road)
		$6200 per kilometre for a 4.6 metre road ($10,000 per mile for a 15 ft wide road)

Maintenance costs after rehabilitation are:-

1.	Drainage	$950 per kilometre ($1500 per mile)
2.	Surface patching after rehabilitation	Average $300 per kilometre ($500 per mile)

1st year	Nil	
2nd year	$ 60 - $ 190 per km ($100 - $ 300 per mile)	) Depending) on the
3rd year	$190 - $ 620 per km ($300 - $1000 per mile)	) traffic volume

Future maintenance costs are a matter of conjecture but the indications are that total recurrent costs for maintenance when the programme is completed will be:

Drainage	320 kilometres (200 miles	@ $ 950 = @ $1,500)	$300,000
Surface patching	3 patching units	@ $36,000 =	$108,000
			$408,000

This is well within the annual maintenance budget and leaves $400,000 for additional surface dressing, widening and improvements.

The life of the sandseal cannot be predicted with any certainty as the first stretch was only completed in November 1976. However, observation indicates that on lightly trafficked roads a life of 5 to 10 years can be expected.

The Effect of the Improvements on Surface Roughness

The roughness of the roads included in this programme was measured using a vehicle mounted Bump Integrator Unit. Roughness measurements were taken before, during and after the rehabilitation operations. Typical results, together with rehabilitation and surfacing costs, are given in Table 1.

On the worst roads on the island roughness of nearly 10,000mm/km were recorded, whilst those recently completely reconstructed gave readings as low as 2500mm/km. It was found possible in the rehabilitation programme to reduce roads from 7000mm/km down to 4500mm/km by patching, and to achieve a further reduction to 4000mm/km by sand-sealing.

Derivation of the Vehicle Operation Costs

Methodology

The method used to calculate the vehicle operating costs for this evaluation is the same as that used in the TRRL Kenya study(1) where the various components of total vehicle operating costs were considered separately on a quantity rather than a cost basis: the cost at any particular time being obtained by applying the relevant unit costs in operation at that time.

The components of total vehicle operating cost used in compiling the figures calculated for this study were as follows:-

1. Fuel consumption.
2. Oil consumption.
3. Spare parts.
4. Maintenance labour.
5. Tyre consumption.

As the geometry of the road system in St Vincent is the main factor controlling the speed of vehicles rather than the condition of the road surface and distances travelled are short, very little change in journey times between various points on the island has occurred since the road improvements. The average annual useage of vehicles has also changed little and therefore the value of time and overheads has been virtually unchanged, although in the case of the latter there may have been a slight reduction due to the fall in vehicle maintenance requirements.

Vehicle Types Evaluated

Three types of vehicle were considered to be sufficient for the purpose of this study to represent the overall vehicle population travelling on the roads of St Vincent. They are:

1. A "European type" saloon car with a 1600cc petrol engine, three years old and having covered 32,000 kilometres (20,000 miles).
2. A large van with a 2000cc petrol engine and carrying capacity of 1 tonne, three years old and having covered 48,000 kilometres (30,000 miles).
3. A 7 tonne carrying capacity truck with a 5000cc engine, three years old and having covered 64,000 kilometres (40,000 miles).

Vehicle Operating Costs for each Vehicle Type

The following tables give the cost per kilometre, net of tax, for the components of vehicle operating cost included in the analysis both before and after the improvements to the road surfaces at the unit costs prevailing in 1978.

1. 1600cc saloon car (European type)

component	before	after
fuel	0.06	0.06
oil	0.01	0.01
parts	0.09	0.04
labour	0.04	0.02
tyres	0.08	0.04
total	0.28	0.17

ratio $\frac{\text{before}}{\text{after}} = 1.65$

reduction in cost = $0.11 per km ($0.18 per mile)

2. 2000cc 1 tonne van

component	before	after
fuel	0.07	0.07
oil	0.01	0.01
parts	0.12	0.06
labour	0.04	0.02
tyres	0.09	0.04
total	0.33	0.20

ratio $\frac{\text{before}}{\text{after}} = 1.65$

reduction in cost = $0.13 per km ($0.21 per mile)

3. 5000cc 7 tonne truck

component	before	after
fuel	0.11	0.11
oil	0.02	0.02
parts	0.11	0.07
labour	0.04	0.03
tyres	0.16	0.08
total	0.44	0.31

ratio $\frac{\text{before}}{\text{after}} = 1.42$

reduction in cost = $0.13 per km ($0.21 per mile)

The unit prices used in deriving these figures are:

	Car	Van	Truck
Vehicle cost	$20,000	$25,000	$45,000
Fuel (litre)	$0.49	$0.49	$0.40
Oil (litre)	$0.67	$0.67	$0.67
Labour (hour)	$6	$6	$6
Tyres	$72	$112	$260

At these prevailing units prices the direct savings in operating costs per vehicle kilometre realised by upgrading the road surfaces so that the surface roughness is reduced from 7000mm/km to 4000mm/km is $0.11 for a car, $0.13 for a 1 tonne van and $0.13 for a 7 tonne truck.

The relationships used to calculate the quantities of fuel, oil, spare parts and tyre consumption and to estimate the number of maintenance labour hours, are given in the TRRL Kenya Study report(1) and the Transportation Research Board, Special Report 160(3).

The Cost Effectiveness of the Road Improvements

In order to assess the cost savings likely to result from the improvements made to the roads, it is necessary to take into account both the cost of the initial rehabilitation and the likely future costs of maintaining the roads.

The average cost of rehabilitating one kilometre of road is ₲11,200 (₲18,000 per mile) made up as follows:

improving drainage	₲ 1900 per kilometre
filling potholes	₲ 4300 per kilometre
sand sealing	₲ 5000 per kilometre
total	₲11,200 per kilometre

This is a once and for all expenditure provided that the annual maintenance programme described below is adhered to. The costs of this programme are:

clearing drains	₲ 950 per kilometre
patching potholes	₲ 340 per kilometre
re-sealing	₲5000 per kilometre

The first two operations are carried out each year, but resealing is only undertaken when necessary, depending on the level of traffic on each particular road. Although none of the rehabilitated roads have yet reached the stage where further resealing is necessary the condition of those which have been trafficked for two years since being upgraded suggests that further resealing will not be necessary for at least another year for the most heavily trafficked roads. Three years has therefore been taken as the frequency with which the most heavily trafficked roads carrying at least 1000 vehicles a day will require resealing and four, five, six and seven years has been assumed for roads carrying 600-1000, 200-600, 100-200 and less than 100 vehicles a day respectively.

As stated above the savings in vehicle operating costs per vehicle kilometre resulting from the upgrading of the roads are ₲0.11, ₲0.13 and ₲0.13 for cars, light commercial and heavy commercial vehicles respectively. These give an average figure of ₲0.12 for all vehicles on the basis of the proportions of the different vehicle types in St Vincent.

In the analysis the cost effectiveness of the scheme is examined at various levels of traffic. The costs and benefits are discounted back to the base year in which reconstruction takes place and the number of years it takes to recover the initial reconstruction cost is calculated. The present best estimate of the rate of growth of traffic in St Vincent and the discount rate currently being used to assess road improvement schemes in the LDC's of the Eastern Caribbean are both 10%. Although some information existed on the cost of previous maintenance on the Vigi Highway, there was not sufficient to be able to include this generally in the analysis.

Table 2 compares the costs and benefits for each traffic level considered. It can be seen from the table that the cost of rehabilitating any road with traffic flows of more than 300 vehicles a day is recovered through savings in vehicle operating costs in the first year but it takes progressively longer at lower flows (2 years at 200 veh/d, 5 years at 100 veh/d) until at 50 veh/d it takes 12 years.

This progression is illustrated more clearly in the graph shown in Figure 8.

Summary

The simple labour-intensive methods of road rehabilitation and maintenance described in this paper were developed because of the necessity to find a cheap way of improving the roads of St Vincent. Full scale reconstruction was too expensive to be applied to the majority of the 320 kilometres (200 miles) of surfaced roads in need of rehabilitation.

The methods described will enable all the surfaced roads to be improved and maintained within the present annual maintenance budget, leaving some resources for improvements to the gradient, width and alignment of the roads each year. The savings in vehicle operating costs due to the improvement in the condition of the road surface equal the cost of the improvements to all the roads included in the scheme within two years, and from then on the net annual vehicle operating cost savings will substantially exceed the annual cost of maintaining the roads.

The labour-intensive method of sealing which has been adopted permits a very flexible approach to the management of road maintenance, it being possible to switch a maintenance gang from one area to another at a few hours' notice.

The maintenance technique adopted has greatly reduced the cost of operating vehicles in St Vincent and at the same time has increased the amount of work which can be carried out on the roads within the fixed budget available to the Roads Department.

Acknowledgements

This study was carried out jointly by the Overseas Unit of the Transport and Road Research Laboratory, United Kingdom (Head of Unit, J N Bulman), and the British Development Division in the Caribbean. The paper is published by permission of the Director, Transport and Road Research Laboratory. The assistance of the Chief Engineer and staff of the Roads Department of the Ministry of Works in St Vincent is gratefully acknowledged.

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Table 1

Rehabilitation costs and surface roughness of some individual roads

Reference number	Location of road	Length kms	Rehabilitation costs* per km			Roughness (mm/km)			Vehicles per day
			Drainage	Patching	Sealing	Before patching	After patching	After sealing	
1	Vigi Highway (Mesopotamia - Arnos Vale)	8	$2500	$6200	$6200	7900	4300	3900	1540
2	Leeward Highway (Layou - Barouallie)	6.5	$2000	$2500	$5600	7500	4800	3800	250
3	Montreal Road	4	$1300	$6200	$5000	9300	5800	5400	560
4	Vermont Road	4	$1600	$3000	$5000	7500	4400	4200	140
5	Calder Road	3	$2500	$6200	$5300	9300	4800	4500	180
6	Clare Valley	2.5	$1000	$2000	$5000	7000	4600	4300	110

*Eastern Caribbean dollars. 1978 prices.

Table 2

The time taken to recover rehabilitation costs on low flow roads
(all costs are in EC dollars for 1 km of road)

Traffic flow (Veh/d)	Rehabilitation cost ($ x 10^6)	Annual maintenance cost ($ x 10^6)	Annual VOC savings ($ x 10^6)	Net annual savings per year ($ x 10^6)	Number of years to recover rehabilitation cost
400	0.0112	0.0023	0.0158	0.0135	0.8
300	0.0112	0.0023	0.0119	0.0096	1.2
200	0.0112	0.0022	0.0079	0.0057	2
150	0.0112	0.0021	0.0060	0.0039	3
100	0.0112	0.0021	0.0040	0.0019	5
50	0.0112	0.0020	0.0020	0.0000	12

Figure 1. MAP of St. Vincent showing the roads included in the rehabilitation scheme.

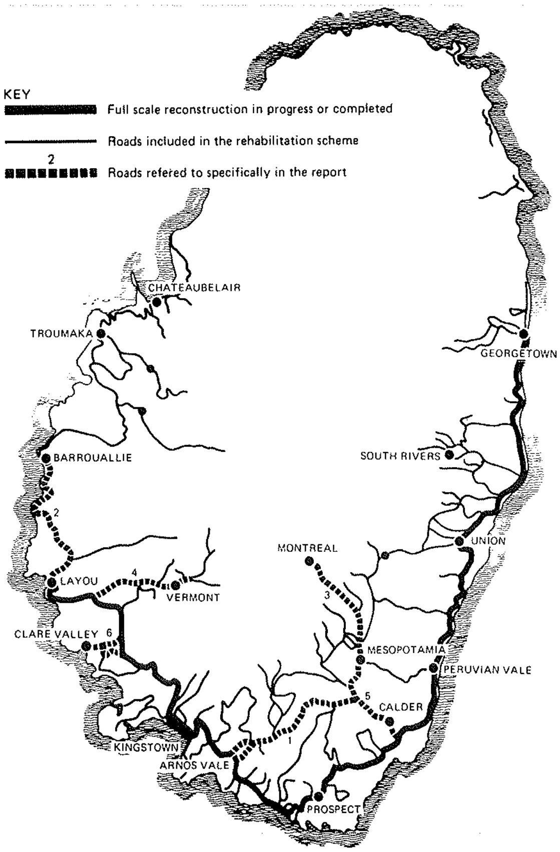

Figure 2.

Figure 3.

Figure 4.

Figure 5.

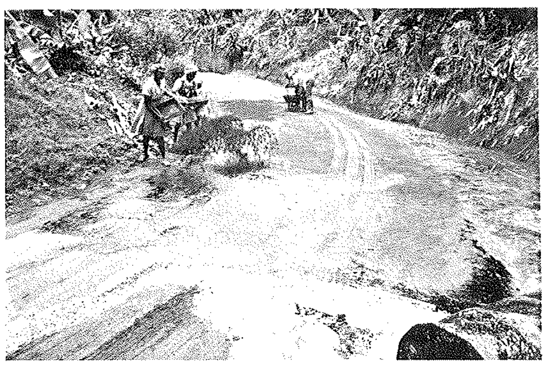

Figure 6.

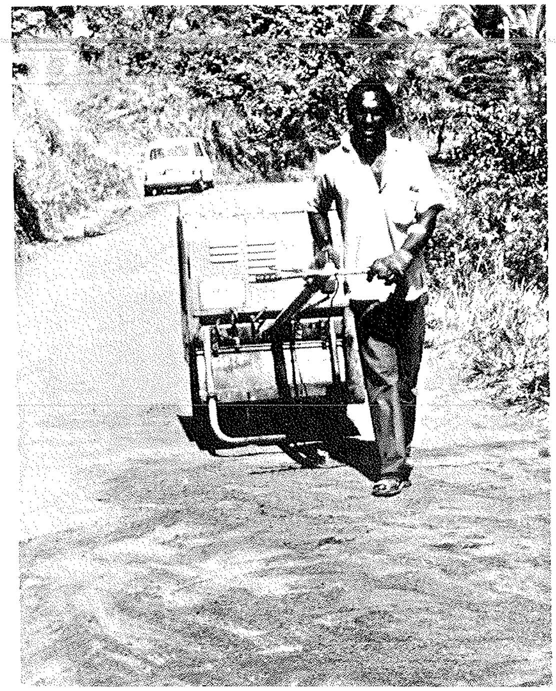

Figure 7.

NOTE: Figure 8 was not included in TRR 702. It was subsequently reproduced in Transportation Research Circular Number 214, January, 1980, as shown below.

Effect of Simple Road Improvement Measures on Vehicle Operating Costs in the Eastern Caribbean
H.Hide and D.Keith

Insert Figure 8 on page 276

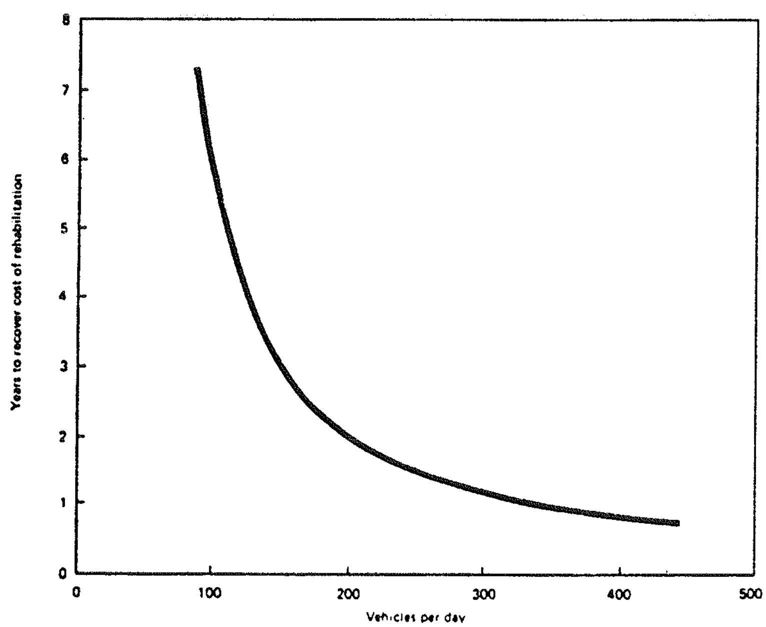

Fig. 8 THE TIME REQUIRED TO RECOVER THE TOTAL COST OF REHABILITATION ON LOW FLOW ROADS

Project Correspondent Pascual A. Caballero, Bureau of Barangay Roads, Ministry of Public Highways, Republic of the Philippines.

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Low-Volume Roads: Second International Conference

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NATIONAL RESEARCH COUNCIL

NATIONAL ACADEMY OF SCIENCES
WASHINGTON, D.C. 1979

Contents

OUTLINE OF A GENERALIZED ROAD ROUGHNESS INDEX FOR WORLDWIDE USE

W. R. Hudson, The University of Texas at Austin

The solution to the problems of providing uniformity in roughness measurements is not an easy one. No perfect answer exists, only a set of intelligent alternatives. It is vital, however, that some type of framework be set up so that coordination can begin. A multifaceted approach is proposed as follows:

1. Develop a Generalized Roughness Index (GRI) which has a sound basis and can provide a pseudo-standard for comparison of all methods.
2. Evaluate the use of an artificial calibration method (such as developed by the Transport and Road Research Laboratory) with a variety of instruments and cases to determine its value, problems, and utility.
3. Apply the concept of a standard rating panel to provide an additional methodology for defining and reproducing the GRI in countries all over the world without the cost of purchasing a stable profilometer, such as the General Motors device.
4. Evaluate the use of rod and level surveys and recommend field equipment to simplify and speed up such surveys for establishing calibration points on a GRI.

It is recommended that a GRI be implemented to test these concepts. Cooperation will be needed among several countries and agencies. Particular attention should be given to coordination of research data from the Kenya, Brazil and India projects, in which the World Bank is involved.

Background

One of the primary operating characteristics of a highway or pavement at any particular time is the level of service that it provides to its users. In turn, the variation of this level of service, or serviceability, with time provides a measure of the road's performance. This performance and the cost and benefit implications thereof are the primary outputs of a pavement management system. User costs are particularly related to road roughness on very rough roads. It was shown by Carey and Irick (5) in 1960 that road surface roughness was the primary variable needed to explain the driver's opinion of the quality of serviceability, or level of service, provided by a road surface, e.g., its desirability for use.

Road roughness can be thought of in many ways. some people talk about smoothness, others, serviceability. The Canadians use riding comfort and there are national committees in the United States to evaluate "riding quality." Still others talk of surface profile. In the European committees of PIARC, the Permanent International Association of Road Congresses, the English term "roughness" has come to be associated with surface texture and skid resistance or hydroplaning. Herein, roughness and smoothness can be defined as opposite ends of the same scale. A general definition of roughness must describe those surface characteristics of a road which affect the riding quality as perceived by the road user. 137

The availability of a roughness scale is important in terms of evaluating a road and its performance, but it is also very important in terms of evaluating vehicle operation and user costs. A common roughness scale for worldwide use regardless of the level of roughness, e.g., gravel surface or paved surface, is highly important.

Surface Roughness

Serviceability, or ride quality, is largely a function of roughness. Studies made at the AASHO Road Test (8) showed that about 95 percent of the information about the serviceability of a road is contributed by the roughness of its surface profile. That is, the correlation coefficients in the present serviceability, or PSI, equation studies improved only about 5 percent when other factors were added to the index (8). Francis Hveem discusses this problem in several papers. He states that "there is no doubt that mankind has long thought of road smoothness or roughness as being synonymous with pleasant or unpleasant." Road surface roughness is not easily described or defined, and the effects of a given degree of roughness vary considerably with the speed and characteristics of the vehicle using the pavement.

Roughness Defined

Road roughness is a phenomenon present in a road surface that is experienced by the operator and passengers of any vehicle travelling over that surface. Surface roughness is a function of the road surface profile and certain parameters of the vehicle, including tires, suspension, body mounts, seats, etc., as well as the sensibilities of the passenger to acceleration and speed. All of these factors undoubtedly affect the phenomenon of roughness. Safety considerations also influence our acceptance of roughness. Hudson and Haas (10) refer to "pavement roughness" as the "distortion of the pavement surface which contributes to an undersirable or uncomfortable ride." This definition refers to the road surface and divorces itself from other considerations. For purposes of this paper, this definition involving surface distortion will suffice in terms of "road roughness."

Components of Roughness

To define completely a roughness function some evaluation of the roughness of the entire surface area of the pavement should be made. However, for practical purposes this roughness can be divided into three components; transverse variations, longitudinal variations, and horizontal variations of pavement alignment. In other words, any functional roadway parameter which imparts accelerations to the vehicle or to the riders must be examined. More particularly of interest are those functions which influence the comfort and safety of the rider and/or the deterioration of the vehicle. Previous studies have shown that longitudinal roughness is probably the major contributing factor to undersirable vehicle forces (8). The next greater offender is transverse roughness (e.g., the roll component transmitted to the vehicle). The horizontal curvature of the roadway, which imparts yaw forces to the vehicle, is considered to be the least offensive and the one which is normally handled by following good highway alignment practices. Since most vehicles (approximately 70 percent) travel in a well-defined wheel path with their right wheel located approximately one meter (2-1/2 to 3-1/2 feet) from the outside lane line we conclude that measurements of longitudinal profile in the two respective wheel paths 1.83 meters (six feet) apart might provide the best sampling of roadway surface roughness. Furthermore, comparison between the two wheel paths can provide some measurement of the cross slope or transverse variations which are also important.

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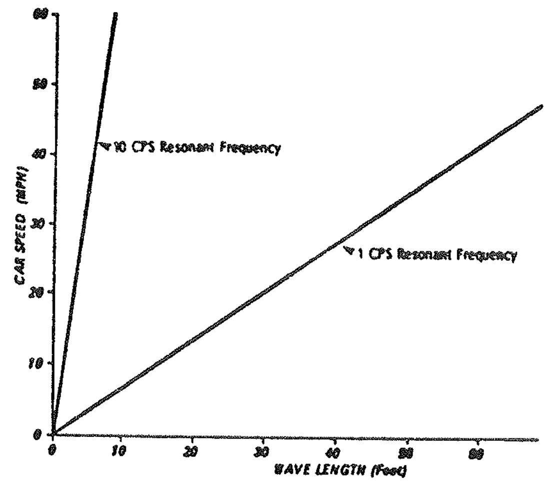
A rider in a vehicle passing over a road surface experiences a ride sensation. This ride sensation is a function of the road profile, the vehicle parameters, and the vehicle speed. A variation of any one of these three variables can make a rough road profile appear smooth or vice versa. Therefore, we might say that, from a passenger's viewpoint, roughness is an unfortunate combination of road profile, vehicle parameters, and speed. Riding characteristics of airplanes are also affected by the properties of the pavements and of the aircraft. Accelerations of sufficient magnitude to critically affect safety of aircraft operations are sometimes obtained over poor pavements.

Although some vehicles have hard suspension and others soft, the vehicle parameters (tires, suspension body mounts, seats, etc.) do not vary sufficiently to make a significant change in passenger comfort. With the limitation of relatively fixed vehicle parameters it is apparent that ride sensation is most dependent upon the car excitation generated by the various combinations of road profile and vehicle speed. Most drivers have experienced the sensation of either slowing down or speeding up to improve their ride on a particular road. This indicates that the road has a wave length content which, when driven over at a particular speed, produces an excitation in the vehicle at one of the vehicles resonant frequencies. The typical passenger car has resonant frequencies at between one and ten cycles per second. The relationship between wavelength, car speed, and car resonant frequency is shown in Figure 1. This relationship indicates that at many speeds there is a road wavelength that will cause an excitation at one of the car resonant frequencies. If the amplitude of that wavelength is large, the car ride will be noticeably affected.

Figure 1. Relationship between resonant frequencies of cars, car speed, and pavement surface wavelength.



In general, most passenger car ride characteristics are very much alike, and for any particular road most cars will be driven at about the same speed. With two of these variables held relatively fixed, the excitations into the car and thus the riding characteristics of the car become primarily a function of the wavelength content of the road profile surface.

Surface Roughness Evaluation

Roughness evaluation has received considerable attention from many highway and airport agencies in North America. Roughness is the primary component of serviceability and a large number of different roughness measures are in current use. This concept of preception by the highway user is important. This definition of roughness excludes surface texture and microtexture of surface aggregates since these are not perceived by the user to affect riding quality. Instead they affect skid resistance and other operational characteristics but will be excluded in this paper. The diameter of the surface stone used in pavement surface treatments which causes "noise," is discernible to the user, has an effect on the user's perception, and is roughness by this definition.

Surface Profile

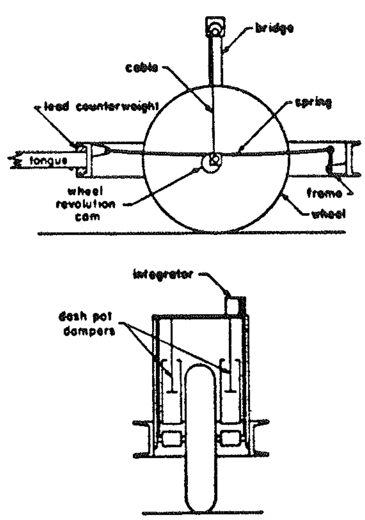
Many authors, such as Darlington (6) and Carey (3), feel that a surface profile is the best way to characterize roughness. In terms of profile, roughness can be defined as "the summation of variations in the surface profile." Profiles in this sense do not include the overall geometry in the road but are limited to wave lingths in the surface that are less than approximately 152.4 meters (500 feet) in length. In Darlington's terms, roughness is "the analysis of the profile or of the random signal known as profile."

Carey in (3) points out four fundamental uses of surface profiles or roughness measurements: as construction quality control tools, to locate abnormal changes in the highway such as drainage or subsurface problems, extreme construction deficiencies, etc., to establish a systemwide basis for allocation of pavement maintenance resources, and to identify pavement serviceability-performance histories.

In summary, a profile is a detailed recording of surface characteristics and roughness or smoothness is a statistic which summarizes these characteristics. Thus, roughness-smoothness is a statistic or number which summarizes the riding quality or surface profile of a road.

How rough is rough? Once the surface characteristics are summarized, it is essential to establish a scale for this statistic or summary value. This can be done in many ways, as pointed out by Darlington (6). Traditionally there are two ways of determining this statistic; mechanical integration and mathematical integration or analysis. The first of these methods is the most common, that is, the use of some mechanical instrument or device, such as the BPR roughometer in Figure 2, to mechanically filter and summarize the data in a specified way. The second method involves recording the profile as faithfully as possible and then analyzing and/or integrating this profile mathematically with some standard mathematical procedure, such as that outlined by Walker and Hudson (31 and 32), Roberts and Hudson (24 and 25), and Darlington (6). The most common methods in current use for mechanical measurement and summary include the BPR Roughometer (15 and 16), the PCA Roadmeter (1 and 2), the Mays Meter (32 and 33), the Chloe Profilometer (4), and the land plane or Profilograph (rolling straight edge) (28).

Figure 2. Schematic Diagram - BPR Roughometer



A number of studies have been made to compare these instruments and a number of references are available, including (6, 11, 16, and 22).

Since so much has been written about the various instruments available, we will not attempt in this short paper to review all these measurement methods in detail. See (14, 16, and 39) for details.

Comparison of Measurement and Summary Techniques

Regardless of the measurement and type of summary techniques used, it is essential that a good reference be established and maintained. It is equally important that accuracy be maintained in summation.

Darlington (6) points out that three basic reference methods have been used historically to measure roughness: the so-called rolling straight edge or land plane, as illustrated in Figure 3, the inertial mass as used in the BPR Roughometer, illustrated in Figure 2, the Mays meter and the PCA meter which the automobile serves as the inertial mass and, finally, an inertial reference profilometer, such as the Surface Dynamics or General Motors Profilometer, where an external reference is provided.

Figure 3. Land plane roughness device sometimes called Profilograph or rolling straight edge.

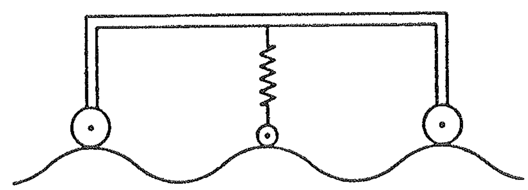


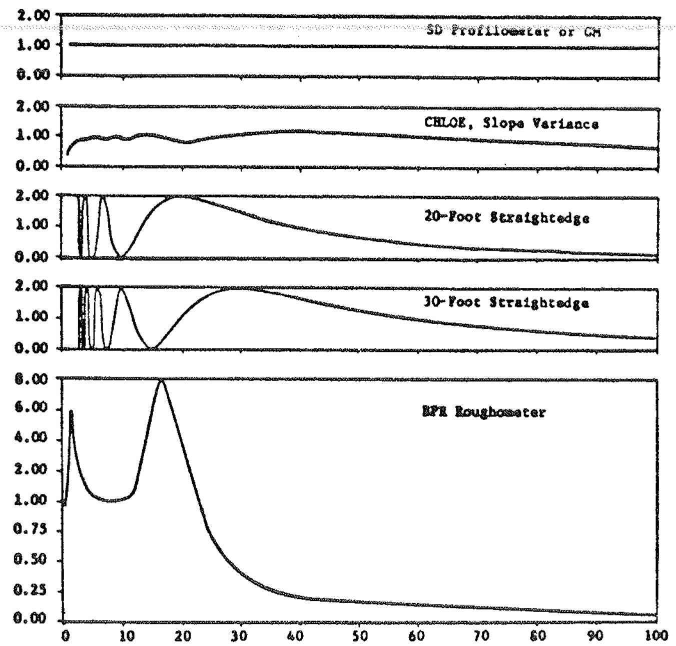
Figure 4 illustrates by means of a Bode plot the transfer function or response of several types of instruments to the input of road roughness. The problem is that the straight edge or land plane device is so erratic in its response that it is relatively useless. This is illustrated in Figure 4, where the effect of roughness wavelengths which are any multiple of the length of the straight edge results in zero output from the device.

Darlington simulated the response of the BPR roughometer (or vibrometer, or seismic reference device) on an analog computer using measured physical characteristics of the instrument. His analysis shows that the roughometer type device yields reasonable results for wave length in the region of approximately 1.22 to 4.26 meters (4 to 14 feet). Wave lengths in the range of 4.26 to 5.48 meters (14 to 18 feet) are badly distorted, and wave lengths beyond 6.70 meters (22 feet) rapidly attenuate to zero response.

The need for compatibility or Generality

As outlined above, diverse measurements of roughness are used around the world. It is not feasible to talk of equality among these measurements since it is not possible to provide compatibility among the various measuring systems if proper consideration is given. This compatibility involves two levels of concern: "External" compatability -- relating to whether the results of one agency's or country's work has quantitative relationship or meaning to those of another agency, and "Internal" Compatibility -- relating to correlating results, achieving repeatability, etc., within an agency.

Figure 4. Theoretical differences between SD Profilometer, Chloe, rolling straight-edges and seismic roughometer



This second aspect of compatibility is well illustrated by the Brazil Project (18) for it is essential that measurements made in all parts of Brazil be compatible with each other even though it is not possible to make all the measurements with a single instrument.

The problem of external compatibility is best illustrated by the fact that results of studies in Kenya can be compared to the findings in Brazil only if there is compatibility between the two sets of roughness data. I feel this can best be accomplished by establishing a "generalized roughness index" which can be used as a compatible base of comparison. This is preferable to selecting any particular measurement system, which itself may be changing and which may not be available to a particular potential using agency.

If a Generalized Roughness Index (GRI) is used, the the matter resolves to one of providing some way of determing the GRI in any particular instance.

In his opening remarks to a National Conference on roughness measurements and correlation in 1972, Mr. W. N. Carey, Jr., Executive Director of the U.S. Transportation Research Board speaks to these problems (3).

> A third use of profile measurements is to establish a systematic statewide basis for allocation of pavement maintenance resources. A word of caution here is in order. In the interest of finding low-cost tools that can be easily available to each highway department district, there is a tendencey to suggest highly simplistic devices. I believe that reliance on these devices may lead to serious mistakes in the development of priorities for maintenance expenditures. . .

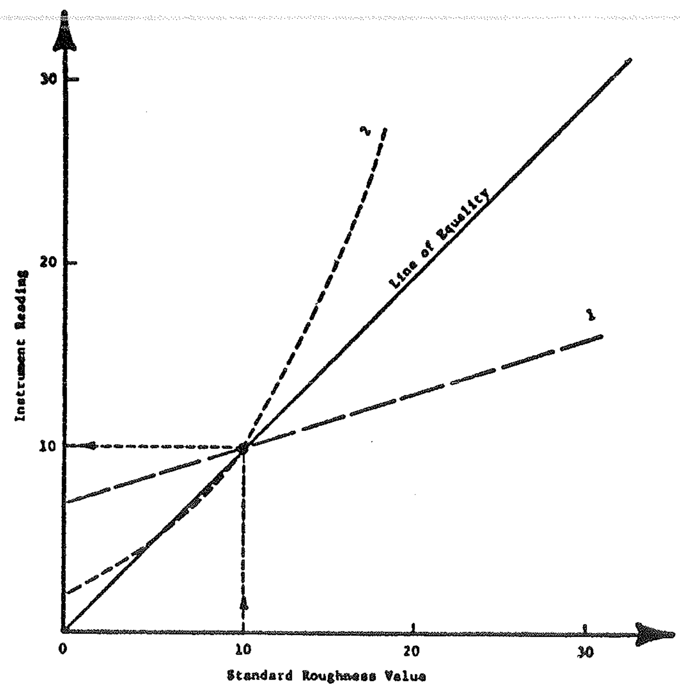
Carey's comment can easily be extended to include low-volume and unpaved road planning in developing countries where roughness can be used not only for allocating maintenance resources but also for ascertaining user and vehicle operating costs. Although the absolute accuracy required for these various purposes may differ in all cases, relative accuracy and compatibility are important.

History of Roughness Calibration and Correlation

The earliest roughness measurements were reported by Hogentogler, as far back as 1923 (42) and early development of the Roughometer was reported in 1926 (19). Even in these early developments the need for calibration was readily recognized. From 1941. when the BPR Roughometer became "standardized," the Bureau of Public Roads (now the Federal Highway Administration) maintained a "standard calibration section" for testing any new or modified BPR Roughometer. It was observed from the beginning that instruments manufactured as nearly alike as possible did not record the same roughness value for the same pavement. The fallacy of a single calibration section is discussed by Hudson and Hain (15).

It is not possible to calibrate a dynamic instrument at a single point over its range and expect the calibration to be satisfactory for use of the instrument over a full range of roughness. This is illustrated in Figure 5 where a standard roughness section with a value of 10 has been set up. We might assume that any other instrument which reads 10 would be calibrated to the standard value. In fact, this assumption is depicted by the solid "line of equality" in the figure. This line assumes that if an instrument reads 10, it is "calibrated" and thus will read 20 when the standard instrument reads 20, 30 when the standard instrument reads 30, etc. Alternatively line No. 1 illustrates a plausible case of a linear relationship where instrument No. 1 is

Figure 5. Single point BPR calibration problems.



calibrated to the standard instrument on the section with value 10. Without additional test points we would not realize that the slope of the calibration line is really different from the assumed line of equality. Dotted line No. 2 illustrates a more complex case of nonlinear relationship which would, of course, also be missed with the single point calibration. Some twenty-four state agencies had BPR Roughometers in use in 1960. Many of these devices have been calibrated by this one-point method and by no other method.

Roughometer Calibration Course - AASHO Road Test

As reported by Hudson and Hain (15) there was a need to use the Roughometer in the AASHO Road Test but it became obvious very early, with the AASHO Profilometer to compare to, that the BPR Roughometer was a variable instrument, difficult to keep in calibration. In our work at the AASHO Road Test we were not only involved in measuring the roughness of all pavements with the AASHO Profilometer and in developing and operating the BPR Roughometer, but also in checking and calibrating at least six roughometers from states such as Michigan, North Dakota, Minnesota, and Wisconsin which brought their instruments to the Road Test for calibration against the AASHO Profilometer for determining serviceability. Basically the method involved the installation of aluminum bars on the surface of a smooth rigid pavement to establish four separate test sections of different but known roughness. The roughometer could then be checked against the standard sections at any required time.

TRRL Pipe Calibration Course

Another artificial calibration technique has been proposed and used by the Transport and Road Research Laboratory in England. This concept appears to have promise for use as a calibrating device or standardization method around the world. A short note on the moethod is presented in (39). Briefly, the method involves the selection of a smooth pavement section approximately 300 meters (985 feet) long as a standard. This smooth section becomes the smoothest section in a series of 6 calibration sections. Subsequently rougher sections are created by adding artificial bumps to the surface of the standard sections by means of pipes with external diamter of 3.413 centimeters (1.34 inches). A total of six levels of roughness are created. Thus, the problem of one-point calibration is alleviated and yet the calibrating agency need find only one smooth, relatively unchanging pavement section. The absolute profile of this basic smooth standard section can likewise be checked with precise rod and levels on a quarterly or semiannual basis as necessary.

Use of a "Standard" Device for Calibration

Probably the most widely used method of calibration and correlation has been the use of some type of so-called standard device. Really this approach should be divided into two types. The first involves the selection of one replicate from the group of similar devices being used and the use of this replica only for calibration purposes so that it presumably does not "wear out." This is the approach that the BPR took with the check section as outlined earlier. I liken this approach to goldplating a crowbar. If you have two dozen crowbars and select one of them because it appears to be more perfect in shape and weight than the others and plate it with gold, what do you have? Still a crowbar, albeit a shiny and expensive one. There is little evidence that this type of "standard" device has been successful in true calibration and correlation.

The second type of standard device involves the use of a master device which is itself calibratible or which has a standard of accuracy which is perhaps a magnitude greater than the other devices for which it is to be the master control. The AASHO Road Test Profilometer was such a device which became a standard against which dozens of Chloe Profilometers and BPR Roughometers were calibrated during and soon after the AASHO Road Test. This approach is discussed below as the Texas Calibration Course.

Use of Hydraulic Shaker Table

The General Motors Profilometer was originally developed for obtaining road profile input which could be fed into a vehicle ride simulator for testing vehicle suspensions at the General Motors Proving Ground (26 and 27). Some authorities feel that a similar approach can be used for inputting standard roughness to a machine in an analytically controlled manner to calibrate other devices. This method involves observing the responses of a measuring device in a laboratory with a servo-controlled hydraulic ram resting under each wheel. Known excitation is applied through the hydraulic rams to the vehicle to determine its response. More specifically, the wheels of the vehicle are vibrated by a shaker table in a manner to simulate operation of the vehicle on each of a set of standard test sections. Road profile data obtained with an instrument such as GM Profilometer are used to drive the shaker table. The profile data tape could be used for any number of successive recalibrations over any period of time and, in that sense, would not change.

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There is, of course, some question about the correspondence between readings obtained by shaker table and roughness measurements obtained in the field. The major source of discrepancy remains in the fact that the vehicle is moving and wheels are rotating while measurements are being made in the field but not while operating on a shaker table. The dynamic vs. static tire conditions are of particular concern. At the present time the National Cooperative Highway Research Program is undertaking a research project which will undoubtedly investigate the shaker table approach to calibration of roughness devices (21). In general, this method does not seem possible for use worldwide since the shaker table is cumbersome and expensive. If a simple version could be devised it could be duplicated and purchased by interested goups but a great deal of research and development is required and we must await the results of the NCHRP study.

Texas Calibration Course

The Center for Highway Research and the Texas State Department of Highways and Public Transportation use the SDP or General Motors Profilometer as a master calibration device for a series of Mays Meters which are used routinely throughout the state. This approach is reported by Walker, Hudson and Williamson (32, 33, and 34). To some degree, a similar approach has been taken by the Michigan Highway Department, as reported by Holbrook and Darlington (12 and 13). The same approach is being taken at the present time in the UNDP Brazil Study (18). A SDP was purchased and is used for measuring a set of calibration sections. These sections are run regularly by eight Mays Meters to insure that their calibration remains stable. A control chart procedure and regular check procedure similar to that outlined by Williamson is followed (32, 33, and 34).

Basically, Texas maintains a group of 25 pavement sections which vary from smooth to rough. Every three months the profiles of all these sections are measured and analyzed with the SDP Profilometer. In this way, a set of pavements with known roughness are always available for use in checking and calibrating any other roughness instrument. Any instrument which appears to be giving erroneous readings is regularly run on several check sections and the values plotted on a standard control chart. If a device is "out-of-control" on three or four sections then it is thoroughly checked, mechanically repaired, and, if necessary, recalibrated.

Rod and Level Surveys

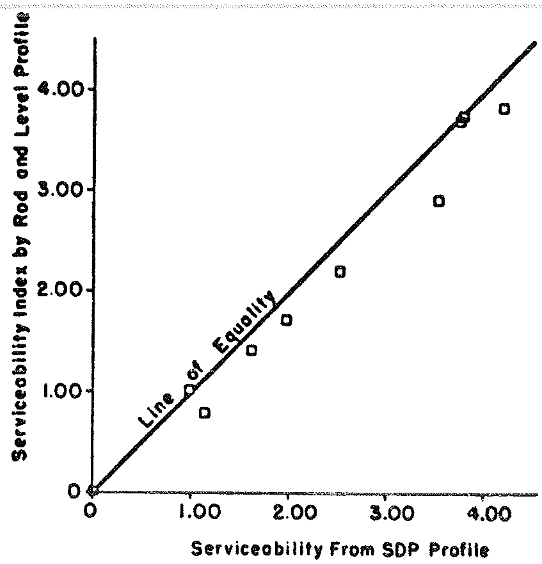
Many people feel that it is possible to establish vehicle roughness calibrations over standard pavement sections by running control rod and level surveys of the calibration sections to see if and how their profiles are changing. There are two basic problems associated with this methodology. First, the response of the vehicle and most roughness measuring instruments to a profile is an integration of everything the measuring instrument sees on the road surface. This is a continuous process and not one involving discrete points such as are used in a rod and level survey. This problem is magnified by the fact that even the best manual leveling techniques make it expensive to make measurements of test sections 300 meters (985 feet) long at spacings closer than about 1/2 meter (1.6 feet). Even in this case a total of 600 measuring points is required each time a calibration section is checked.

Perhaps more difficult than the accuracy and detailed problem outlined above is the need to integrate and/or summarize and anlyze the profile. To date, little has been done in this area. Recently we have investigated the use of second derivations of the profile to yield estimates of vertical accelerations present in the profile. A relationship has, in turn, been developed between vertical accelerations and SI.

Calculations are simple and do not require a large computer facility as is the case with existing profile analyzing methods such as power spectral density, Fourier transform, and digital filtering. Road profile root mean square vertical accelerations have a strong correlation with Mays Meter roughness readings as shown in the study by McKenzie and Srinarawat (40). Figure 6 illustrates a very good agreement in terms of serviceability index from 10 road surface profiles obtained by rod and level method and the Surface Dynamics Profilometer (SDP) (41). This plot also suggests that road profile data from rod and level and SDP are interchangeable and rod and level can be used to provide commonality among road roughness scales presently in use.

Certainly, these discrete rod and level surveys have some practical advantages, particularly in developing countries where labor-intenseive methods are economical. It might be far more practical to obtain detailed, discrete profiles with rod and levels of, say, ten or twelve pavement test sections on a regular basis than to maintain a high-technology, expensive electronic device for continuous profile measurements. Such a method will be practical if data analysis techniques can be developed and automated for easy use of the data.

Figure 6. Comparison of serviceability indices derived from rod and level profile and SDP profile.



Rating Panel Approach - Canadian Good Roads Association

Immediately following the AASHO Road Test, the Canadian Good Roads Association desired to put the findings of the AASHO Road Test into practice. In order to do this, they ran a rather complete survey of the existing roughness of their pavement system. They did not agree totally with the serviceability concept outlined at the AASHO Road Test and they chose to develop a Riding-Comfort Index Scale with values from 1 to 10. This index is basically an evaluation of pavement riding quality or roughness (7, 9, and 10).

After carefully establishing their Riding Comfort Index, a standard procedure was adopted using a small panel of well-trained raters to go from location to location evaluating the riding quality of these pavements and recording this riding quality in a data management system. A great deal of work has been done on rating scales and other subjective evaluations (5, 17, 20, and 24). There are some shortcomings to this approach, but it has the benefits of being practical, relatively inexpensive, and reasonably stable although its precision may be questioned. It certainly fulfills the concept and answers the question, however, raised by Carey in the quote referenced earlier in this paper. This approach deserves further consideration.

Standard Rating Panel

While it is not in present use, I believe that the concept of using a standard panel of pavement riding quality raters to establish a time-and-condition-stable standard roughness scale offers great promise as a practical solution. Yoder and Milhous (37) show in thier studies of rating panels and various instrumentation that rating panels of fifteen persons or more are quite stable in predicting pavement serviceability. Since roughness is so highly correlated with serviceability, there is little doubt that such panels would be equally stable in predicting pavement roughness. Carey and Irick (5) report similar results when comparing panels at the AASHO Road Test, as do Roberts and Hudson (24 and 25).

One major problem exists, what about panels from different cultures? For example, a panel from the United States rides predominately on paved roads. Can it rate accurately on the same scale as a panel from a developing country which rides predominately on gravel roads? How could this dichotomy be solved? Perhaps if as many as three members could be made available to participate in panel ratings in each of the major areas of the world, goegraphic and cultural stability could be evaluated.

This method would never have the precision or detail of physical calibration. However, it might be accurate in terms of insuring that different classes of road roughness are adequately separated.

The following section presents a discussion of the relative merits of these methods for use in establishing a General Roughness Index.

Possible Approaches for Calibration

Evaluation of the concepts for calibration outlined in the last section indicates that three basic methods have strong potential: the use of a shaker table to input artificial roughness in a laboratory, the use of artificial roughness calibration sections, and the use of standard road sections along with a method of evaluating the roughness of these standard calibration sections from time to time.

However, the practical limitations of the problem set forth in this paper apparently preclude any possibility of using a hydraulic shaker table with known roughness inputs to calibrate roughness devices. No such equipment is presently in use for this purpose, even in the United States, and the development and employment of such equipment in the field seems completely infeasible at this point. Therefore, the other two major approaches are discussed in further detail: artificial calibration sections and standard pavement calibration sections.

Artificial Roughness Course

The concept of introducing well defined artificial roughness onto a selected section of smooth pavement in identifiable stages follows the approach of Abaynayaka and TRRL. The approach is certainly feasible since any country in the world could develop at least one smooth, strong section of pavement to serve as the base section. They could then find several pieces of standardized pipe or other material approximately 2 meters (6.6 feet) long to introduce roughness. These two ingredients can be combined in several stages to provide up to six or even more test sections of increasing roughness. The method therefore warrants careful consideration.

The major problems associated with this method are the artificiality of the roughness introduced and the potential of generating resonance or harmonic motion in the measuring vehicle being calibrated. As indicated by the anlysis of Darlington (figure 4), the transfer function of a roughness measuring device is highly dependent upon the wavelength characteristics and amplitude of the roughness in the roadway surface. It yields reasonable readings for wavelengths in the range of 1.22 to 4.28 meters (4 to 14 feet) and it has two resonance frequencies at 0.61 meters (2 feet) and 5.18 meters (17 feet). The response of the instrument to step-inputs might be on the first peak present at very short wavelengths. If some type of resonance is generated in the system, say for roughness level six, then the multiplication amplitude could be even higher. It is entirely possible that the response of an instrument to the roughest calibration section would be, for example, a very large roughness number and yet the instrument might respond different to a very rough gravel road with natural potholes, etc. There is certainly also the possibility that the calibration course can be set up in such a way as to cover the range of interest for most very rough roads and thus to serve adequately as a calibration procedure. The only way to ascertain the answer to this question is to study the problem theoretically and to apply the concept in the field where an alternative method of calibration and checking, such as the SDP or General Motors Profilometer, exists for comparison. This type of comparison check is being made in Brazil and results will be reported soon.

The other problem with this method is that it does not yield to traditional analysis of random data or profiles as outlined by Darlington, Williamson and Walker (6, 36, 30, and 31). It is possible that another type of analysis could be used to evaluate the step function inputs to the roughness profile which will be made by the pipes or artificial bumps. It is desirable that someone follow up on the required analytical approach as a part of the evaluation methodology for this procedure.

Finally, this concept is attractive in the sense that only about six test sections are needed to cover a wide range of roughness and only one basic strong pavement section is needed to provide the base section. Considerable thought, however, needs to be given to the possibility of replication of roughness levels within the artificial calibration course. This could be done by adding two additional roughness levels whose roughness corresponds with a previously selected level, but with new roughness being introduced by an alternate pattern or an alternate means such as a few wider bumps or a rearrangement of the location of the bumps to interrupt regular patterns.

Natural Pavement Calibration Sections

The use of existing pavement sections for calibration of roughness devices is an attractive alternative, but there are problems. The attractiveness seems obvious since the sections are typical of the pavements to be measured in the real world; they contain normal roughness inputs of varying wavelengths and amplitudes over a wide spectrum of conditions. The problems, however, are multifold and must be considered. They include finding sections at extremes of roughness, the changing of roughness with time on a selected test section, the large number of sections usually required, and the considerable time and effort required to check the sections which are normally fairly widely spaced geographically.

Obviously it is not possible to set up a normal pavement section calibration course on which the test pavement roughness will remain constant. All of the pavements are in various degrees of deterioration. Most of them were built smooth but they are in the process of change and experience shows that rough pavements change more rapidly than smooth pavements. It is absolutely essential then that for this approach some method of determining the roughness history of each test section with time be developed. This can be done in at least three ways; by true profiles measured "continuously" with instruments such as the SDP profilometer, true profiles measured at discrete increments with precise rod and level techniques, and repeated evaluation of the roughness of the calibration section by a standard rating panel.

Evaluation of the True Profiles - "Continuous." Of the three listed methods, the most attractive seems to be the use of existing pavement with an evaluation of their true profiles. This technique was chosen for use in the Brazil Project where adequate research funding was available to provide a standard profilometer, in this case the SDP profilometer, for making continuous measurements for calibration.

It seems, however, that this approach is impractical at the present time for use worldwide as a calibration standard. The use of a standard roughometer or other "gold-plated" version of a typical machine carried around the world as a standard device is not realistic as shown by experience at the AASHO Road Test and the work by the Center for Highway Research for the Texas Highway Department.

Evaluation of True Profiles - Discrete. It is possible that analytical techniques can be developed to accurately evaluate a discrete rod and level profile of pavement test sections set up for standardization. Field work is underway by Srinarawat and Hudson to evaluate this approach and to compare the accuracy required and the spacing or detail of the measurement points needed to provide adequate information (41).

If the approach is feasible from an analytical point of view, it is possible that field practice can show what type of level instrument and perhaps even what special level rod could be most useful to speed up the process and make it more practically applicable. The U.S. Air Force, for example, has developed a laser profiling system which works on the same basis as a rod and level but which takes automatic readings using a laser beam for a light source (38).

Another point favoring the rod and level approach is the hand labor which is normally available in many of the developing countries for which a roughness calibration is needed. The rod and level crews could make the necessary measurements on a quarterly or triannual basis with relatively little expense whereas in the United States, for example, such an approach might not be as economical as a profilometer.

Thusfar, work by Srinarawat and Hudson seems to indicate that it is possible to interchange machine and rod-level measurements (41).

Roughness Panel. A third approach to establishing and maintaining standard roughness evaluations of calibration test sections is appealing and should be carefully considered. It involves setting up a standard rating panel and developing a Generalized Roughness Index (GRI) which could be used not only for rating and establishing the roughness level of the calibration sections but as a standardized roughness scale for comparing instruments against each other all over the world without having to select any one particular instrument as the "standard."

This approach is far from thoroughly formulated and a great deal of additional thought will be needed before it can be accepted or rejected. However, it is worthy of consideration. If the method works, its value is readily evident. If adequate accuracy and details can be obtained, calibration sections could be set up and evaluated regularly without the expense and detail required for rod and level surveys.

Likewise, the potential pitfalls to the method are obvious. The method would basically be subjective rather than objective, which we, as engineers, always strongly desire. The potential value of the method lies in the question of whetehr or not we can make the subjective rating process objective by carefully selecting and establishing rating panels and rating procedures using up-to-date modern scaling and psychological techniques to overcome some of the subjectivity of the rating approach.

The basic value and acceptability of ratings for judging pavement quality was well established at the AASHO Road Test by Carey and Irick (5) and subsequently by Yoder and Milhous in the significant NCHRP study (37). As outlined previously herein, the Canadian Good Roads Association has also made an excellent practical application of the rating concept (5 and 35).

Another major problem with the roughness rating approach is possible cultural differences amongst countries. One country, for example, such as the United States, has a population accustomed to riding on paved roads which are basically smooth. On the other hand, other countries such as many of the countries in Africa and Latin America, are accumstomed to riding on unpaved roads. There is considerable concern that this cultural or historic difference, which is also by the way aggravated by traditional types and quality of vehicles used, would greatly affect any relationship developed by a rating scheme, and thus would completely invalidate the concept of relative ratings.

Generalized Roughness Index

After a thorough evaluation of the problem of establishing a common basis for comparing roughness measurements all over the world, and specifically comparing roughness measurements in Kenya, Brazil, and India in terms of using data taken from these three research studies and combining it for use in developing improved joint models, it is recommended that a Generalized Roughness Index or a universal roughness index be developed to serve as a basis for comparison instead of the output of any particular roughness device. On the surface this seems an arbitrary intermediate step; however, experience shows otherwise.

At the present time, no simple, robust roughness measuring and evaluation technique exists which is constant enough to become the appropriate "standard." The SDP profilometer might be considered, but work in adopting and using this instrument in Brazil and in comparing it to the Texas instrument manufactured ten years ago shows considerable difference in hardware and data processing techniques. Many people feel we are on the threshold of developing a non-constact probe to replace the road-following wheel for the SDP device. When this happens, you can be assured that the transfer function of this transducer will be different from that of the road-following wheel. Thus, the "standard" would change again. Many other examples could be cited, but for simplicity let it suffice to say that no real "standard" exists.

An example of a similar situation existed in 1962 concerning specifications and measurement of subgrade strength for pavement design. The American Association of State Highway Officials at that time desired to establish a standard design method which would be useable and used by all or at least a large majority of the State Highway Departments. There were many candidate measuring techniques, such as CBR, Texas Triaxial strength, shear modulus, California R-Value, and others. Majority vote would have selected CBR since it was used by more states than any other method. However, comparison of the CBR between states showed that even this so-called "standard" was far from standard since each state made slight modifications in the empirical test procedure. In the face of this diversity, Mr. T. S. Huff, Chief Highway Design Engineer for the Texas Highway Department and Chairman of the AASHTO Committee, recommended that a "soil support value" with a range from zero to ten be set up as the "standard." Each State Highway Department then related its soil test method to the soil support value rather than to some state test procedure. Nationwide information on standard test materials obtained from the AASHO Road Test was used to establish common points.

At this time, 15 years of experience in using the AASHO Interim Design Guide has shown the wisdom of selecting the what-seemed-at-the-time "arbitrary" Soil Support value.

GRI - A Combined Approach

Examination of alternatives indicates that the practical approach to solving this problem will involve some combination of the factors discussed above. To provide realism in the calibration, it is essential that 10 to 12 real pavement sections be included in a calibration course. These can be evaluated on a semiannual basis by rod and level surveys. A detailed methodology will be published by Srinarawat and Hudson within the next year.

To provide a large number of calibration sections of varying roughness and a calibration technique with some commonality around the world, a TRRL calibration course should be added to the calibration procedure. The methodology currently outlined by Abayanaka and the TRRL should be used until a more definitive consensus procedure is developed. Finally, the overall reasonableness of the scale can be assured at any time using a rating panel to ensure that reasonable roughness ratings are established for uniformity. These ratings should involve panels on at least all three or four major research efforts in the world and should include at least three or four common members in each panel in the initial stages of development. These common members could be employees of the World Bank or other research personnel who are involved in one or more of the world-wide research projects and who could bereficially visit other activities, thus providing the necessary commonality of ratings.

The GRI itself should have a relatively large scale, perhaps 0 to 100 and should be generalized with smoothness of existing new highways falling in the range of 10 to 15 and roughness on some of the roughest roads now perceived falling in the 70 to 80 range. This gives adequate room at both ends of the scale for changes and variations not yet observed and in no way detracts from the use of the Index.

Some readers will undoubtedly be disappointed that a firm Index in full detail is not presented here; however, work over the past 10 years shows that there will be several steps required to solve this problem and we believe this paper is a necessary first step in defining the problem so that an intelligent compromise can be reached.

Summary and Recommendations

Solving the problems of providing uniformity in roughness measurements is not easy. No perfect answer exists, only a set of intelligent alternatives. It is vital, however, that a framework be set up so that coordination and use can begin. I proposed a multifaceted approach.

1. Develop a GRI which has a sound basis and can provide a pseudo-standard for comparison with any roughness scale existing now or to be developed.
2. Evaluate the use of the TRRL artificial calibration method for a variety of roughness devices and cases to determine its value, problems, and utility.
3. Apply the concept of a standard rating panel to provide an additional methodology for defining and reproducing the GRI in countries all over the world without the cost of purchasing an SDP profilometer or similar equipment.
4. Use rod and level surveys and recommend field equipment to simplify and speed up such surveys for establishing calibration points on a GRI.

It is recommended that action be taken to implement a GRI and to test the concepts set forth above. Cooperation will bee needed among several countries and agencies and a leader, such as the World Bank, is needed. Particular attention should be given to coordination of research data from the Kenya, Brazil, and India projects.

Acknowledgments

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ROAD RESEARCH LABORATORY

Department of the Environment

RRL REPORT LR 427

A REVIEW OF RURAL TRAFFIC-COUNTING METHODS IN DEVELOPING COUNTRIES

by

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CONTENTS

A REVIEW OF RURAL TRAFFIC COUNTING METHODS IN DEVELOPING COUNTRIES

ABSTRACT

This Report reviews methods of rural traffic counting currently used in developing countries and examines the accuracy of the resulting flow estimates.

The results of a questionnaire survey among a sample of developing countries suggest that decisions on the duration, frequency, and timing of counts are at present arbitrary. Consequently, estimated daily traffic flows can rarely be expected to lie within ± 30 per cent of the true value averaged over the whole year. Although repeating counts at intervals throughout the year increases the accuracy of traffic estimates, this is achieved only at a disproportionate increase in cost.

It is concluded that for any appreciable increase in the accuracy of rural traffic estimates much more needs to be known about the magnitude and causes of the variations in flow. This requires that automatic traffic counters be used on a wider scale than at present.

1. INTRODUCTION

This Report reviews the methods of rural traffic counting currently used in developing countries. The object of the review was to examine the accuracy of estimates of rural traffic flow resulting from the counting methods, and, if necessary, to make suggestions for their improvement. The Report is the first in a series that is considering the design of traffic survey methods suitable for developing countries.

Information on traffic flow is needed for many purposes, in determining the appropriate standards of layout and design for particular roads, in allotting the resources for maintenance and improvement between the different roads in a network and in making general planning decisions on the development of transport systems. Existing methods of traffic counting provide information that is often inadequate and of doubtful accuracy and this research has been undertaken to establish the most economical methods of survey to produce adequate and reliable data.

Information on the methods in use for counting rural traffic was obtained from a questionnaire circulated to a sample of developing countries in 1970. This was supplemented by information obtained during visits and from technical publications.

The efficiency of the traffic counting methods was tested using continuous traffic measurements conducted by the Road Research Laboratory at 38 sites in Kenya. Comparative data were also obtained from two sites in Nigeria and 30 of the sites used in the United Kingdom 50-point census for 1969[1].

The Report first considers methods of traffic counting currently in use in developing countries. Next a brief discription is given of the Kenya experiment followed by an outline of the method of calculating errors in traffic counts.

Sample testing is then described and the results presented and discussed.

2. METHODS FOR COUNTING RURAL TRAFFIC IN DEVELOPING COUNTRIES

Appendix 1 summarises the information on methods for counting rural traffic in fourteen developing countries located in South America, Africa, the Middle East and the Far East. The information was correct at the time of the survey, but, as some countries are making changes in their traffic census methods, it may no longer be so in certain cases. Notwithstanding this, conclusions drawn from the results are probably still broadly correct. The aspects of particular interest to this study are the duration, frequency, and timing of counts.

2.1 Duration of counting

The duration of counting is standardised in about half the countries sampled. It ranges from a single 8-hour count (Turkey) to a continuous count for 15 days (Ethiopia), although the latter is exceptional, being for special counts only. The most common period is 12 hours (6am - 6pm or 7am - 7pm) repeated for 5 or 7 days. The complex 8-hour count each day for three weeks, that is proposed for some stations in Thailand, can be regarded as an effective 24-hour count for 7 days.

2.2 Frequency of counting

For 'national' censuses (counts made annually over the entire country) the frequency of counting varies considerably from country to country. One country states that the frequency of counting is irregular, two countries state once a year, four countries state twice a year, three countries state three times a year, and one country states four times a year. Where the frequency is more than once a year, it is usually related to the number of major climatic seasons.

2.3 Timing of counts

The timing of counts is not generally standardised, although for 'national' censuses some countries specify broad wet and dry (or harvest) seasons when counts will, or will not, be made. Thus, in respect of their timing, traffic counts in developing countries can be considered as random samples. The period for counting, however many hours and days it comprises, is effectively a random selection in that any period in the year other than a few containing obviously unusual activities, such as Easter or Christmas, can be chosen. Even when, as in some of the national censuses, certain months or periods are specified, sampling is still essentially random since there is no evidence that the period chosen is selected on the basis of a known pattern of seasonal variation. Also, experience has shown that in practice these periods are, regrettably, rarely adhered to.

In some developing countries, the purpose of traffic counts is not always clear. It might be to provide estimates of average daily traffic in the specified week, month, or year, or merely the average flow during the observation hours.

2.4 The quantity to be estimated

Although it is rarely explicitly stated, rural traffic counts usually attempt to measure average rather than peak usage. The commonest measure of average usage is the amount of daily traffic. However, the word 'daily' sometimes refers to a period of less than 24 hours. In the United Kingdom[2] rural traffic counts are taken to obtain the 16-hour (6am - 10pm), seven-day, average flow occurring in August. All current counting systems based on 'm-hour days' (where m $\leq$24) suffer from a number of drawbacks. Since m varies so much between countries this suggests that the particular value chosen is arbitrary. Certainly it is not normally possible or meaningful to assign limits of error to the traffic estimates that result. Further, the 'm-hour' days are not natural periods of human activity such as the day, week or month. Thus, variations in traffic-flow characteristics, which can only add to estimation errors, are to be expected, e.g. the distribution of traffic through the hours of the day will vary with route characteristics: the distribution on a major trunk route carrying a large proportion of goods vehicles is unlikely to be the same as that on a farm-to-market road.

In the USA, the term 'daily' traffic has its normal meaning: the flow of vehicles passing a given location in 24 consecutive hours. The basis of American traffic observations is the quantity 'Average Annual Daily Traffic' (abbreviated to ADT), which is defined as the 'Annual average number of vehicles during 24 consecutive hours that pass a particular point on the road over the period 365 days'[3]. This term would seem to have a number of advantages not shared by the various 'm-hour' days. It is unambiguous, readily understandable, and corresponds with a natural period of human activity. Thus it eliminates those problems associated with variations in the hourly distribution of traffic in different locations. However, the most important advantage of the ADT concept is that it enables statistical methods to be applied to the problem of rural traffic counting. Generally, it would seem to be the most logical basis for traffic observations and is the one used in this analysis. 153

3. KENYA STUDY OF RURAL TRAFFIC FLOW

The objectives of the Kenya study were to provide the data necessary for a quantitative evaluation of current traffic count methods, and to allow various new counting strategies to be tested. The study can be separated into two stages:

(i) the measurement of the total pattern of traffic variation for a full year and the relation of this, if possible, to the level of flow, the type of road, and the economic and climatic characteristics of the region around each site: and

(ii) the statistical evaluation, using the results from (i), of optimum methods of counting traffic.

Observations were made from March 1968 to July 1970 using Fischer and Porter hourly recording counters at 26 sites, and from September 1968 to November 1970 using SYX-RRL non-recording counters - which were read daily by observers - at 12 sites. The sites were chosen to be representative of the general range of flow levels, road types, and climatic conditions found in Kenya.

4. ERRORS IN ESTIMATES OF ADT FROM SAMPLE COUNTS

Only where continuous counts are made under perfect conditions can a true ADT or total year's flow be computed with the expectation of its being absolutely accurate. It follows that any count of less than one-year's duration must be regarded as a sample, and the estimate of ADT or total years's flow made from it will be subject to error. The error of estimation is simply the difference between the estimated ADT and the true ADT. If the mean and the standard deviation of these errors are calculated, then probability analysis can be applied to determine, for a given level of confidence, how accurate an estimate of ADT is provided by a particular sample period or sampling procedure.

The method of error determination used in the analysis followed the above principles. For a given duration of counting, repeated samples were drawn from the actual flows recorded at each site in one complete year. From each estimated daily flow (ADT_E), the true value (ADT_T) was subtracted to give the error of estimate. The resulting errors were divided by ADT_T and multiplied by 100 to give the proportional error of estimate in percentage terms. This was done so that errors obtained at sites with different flow levels would be on a comparable basis.

Thus:

$$\text{proportional error of estimate} = 100 \left(\frac{ADT_E - ADT_T}{ADT_T} \right) \text{ per cent}$$

Finally the standard deviation and the coefficient of variation of the percentage errors were calculated.

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4.1 Sample testing

The errors resulting from the following ADT sampling procedures were determined:

1. Random samples of 1, 2, 3, 4, 5, weekdays and 7 consecutive days for all possible periods in the year except those including a Public Holiday.

2. As in 1 for periods of 1, 2, 4, and 6 whole weeks.

3. Random samples of 1, 2, 3, 5 weekdays and 7 consecutive days repeated at regular intervals of three, four, and six months. To provide samples of a reasonable size it was necessary to group the sites by flow level as follows:

Group 1	(ADT < 75 vehs/day)
Group 2	(ADT 76-200 ")
Group 3	(ADT 201-600 ")
Group 4	(ADT 601-1000 ")
Group 5	(ADT > 1001 ")

4.2 Desirable accuracy of estimates of traffic flow

To judge the results of the sample tests objectively, it is necessary to decide what level of accuracy estimates of traffic should attain. Specifically we must state within what range of error we wish our estimates of ADT to lie, and how certain we need to be that the estimates lie within the stated range. In the USA[3], the accepted standard is that there should be only a 1 in 20 chance (5 per cent level of probability) that the error of estimate will exceed ± 10 per cent at any sample count site carrying over 500 vehicles/day. For roads with lower flows, errors of up to ± 20 per cent are acceptable.

It might be felt that developing countries cannot afford such high standards as the USA, since, the more precise estimates must be, the greater the cost of obtaining them, However, it is considered that accuracy standards in developing countries should be similar to those quoted, and in fact should tend towards the higher of the two, even for roads with low traffic flows.

Whereas the use in the USA of lower accuracy standards of traffic counting for roads with low traffic flows is justified to some extent by the relative unimportance of such roads in the USA, the main aim of road improvements in most developing countries is progressively to upgrade earth and gravel roads to bituminous-surfaced roads, i.e. stage construction[4], when the level of traffic demands it. A reasonable standard of traffic estimation is therefore required even for roads with low traffic flows.

Lowering the confidence limits at which estimates are judged does not seem to be worthwhile since the results rapidly lose any real significance.

Until precise studies are completed of the cost-effectiveness of various methods of traffic counting and the sensitivity of the highway planning process to errors in traffic estimates, it will not be possible to specify desirable accuracy limits for developing countries. The USA standards will, however, serve as a criterion by which to judge the performance of estimating procedures elsewhere.

4.3 Practical limits to sample duration

The final point to be discussed before the results are examined is whether there are likely to be any practical limits to the duration of counting in developing countries. In this connection, the most critical consideration is whether counts will be made manually or by machines.

Experience of conditions in developing countries suggests that the great majority of counts will continue to be made manually. The use of automatic counters is at present uncommon and they are only gradually being introduced, mainly for the measurement of seasonal variation and long-term traffic trends. The more widespread use of automatic counters for general counting seems unlikely for some time to come since they are expensive to buy. Also, they require skilled supervision and maintenance if accurate results are to be obtained, and the necessary skills take time to acquire. Lastly, manual methods have the advantage of giving classified counts of traffic flow, and they may also be politically desirable because of the generally acute unemployment problems.

If manual methods of counting are used, then a one-week's continuous count is about the practicable maximum. Apart from the probable loss of accuracy caused by the boredom of the enumerators, longer counts at each point would reduce the coverage of the road system that was possible. In practice, many counts, although spanning seven days, will probably be for less than 24 hours on some, and possibly all, days. Night-time counts are unpopular and difficult to supervise effectively, especially in distant rural locations.

Cost-effectiveness considerations also indicate the need to keep the duration of counting as short as possible. Since wages are the main element, the cost of traffic counting can be assumed to increase in direct proportion to its duration. However, simple sampling theory suggests that the accuracy of the resulting ADT estimates is likely to increase in proportion to the square root (approximately) of the duration of counting, i.e. other things being equal, a count for four days will only double the accuracy of ADT estimation in comparison with that obtained from a single day's count, whereas the cost will have risen by a factor of four.

5. RESULTS

All estimate errors given in the results are at the 5 per cent level of confidence. Lower confidence limits 10 per cent (1 in 10 chance) or 20 per cent (1 in 5 chance), can be calculated by multiplying the results by 0.84 or 0.65 respectively.

5.1 Traffic variability and ADT

In the early stages of the analysis, it became apparent that the results were strongly influenced by the ADT at each sample site, so this effect was investigated first. The relationship between traffic variability and flow level is illustrated in Figure 1 which shows the coefficient of variation of daily flows (V) over a complete year, plotted against ADT.

From the Kenya data alone, it is clear that the coefficient of variation is inversely related to ADT - the curve has been fitted by inspection as a rough guide. A simple regression analysis based on the relationship,

$$V = \gamma \, (ADT)^{-\lambda},$$

where γ and λ are constants, showed that ADT accounts for approximately 55 per cent of the total variation in V. The implication is that, in Kenya at least, the main factor governing the variability of traffic is the average level of flow, and not the function of the road or the type of traffic it carries.

Excluding the most extreme of United Kingdom results, Figure 1 shows that traffic variability increases rapidly below flows of approximately 1000 vehicles per day. Partly this is a consequence of the law of small numbers: when the total flow is low a unit change has a proportionately bigger effect than when the total is large. Also, in practice, variation is inherently greater at low flows because the traffic stream is composed of fewer individual trip motivations, i.e. a flow of 20 vehicles per day on a given road may be motivated entirely by the travel demands of a small government administrative centre, a school, or a single agricultural enterprise. Any change in its activities, such as school holidays, or crop harvesting, can produce very large relative volume changes. Conversely, on roads carrying 500 or more vehicles per day, the trips are usually motivated by a wide range of activities whose operational variations tend to be mutually balancing. When the travel demand for one is high another will be low and vice-versa. Between these two extremes there is a gradual transition and one would expect a steady decrease in variation with increasing flow of traffic.

The increase in traffic variability below flows of approximately 1000 vehicles per day is significant because in many developing countries the majority of the rural road system carries daily flows less than this. In Jamaica (1964), Zambia (1964), and Kenya (1970), the percentages of the rural road system carrying less than 1000 vehicles per day were 95, 98 and 95 respectively [5]. Thus in developing countries rural traffic estimation is especially difficult because of the inherent variability of daily travel.

Generally the United Kingdom results do not exhibit any close relationship between traffic variability and flow level. Surprisingly, over a third of the United Kingdom results are characterised by a very much higher variability than equivalent sites in Kenya. It seems that the effects of climate in the United Kingdom, particularly snow, are much more disruptive than those in Kenya. Also, because the climatic contrast between winter and summer in the UK is very marked, sites located close to tourist or holiday centres are likely to experience larger relative changes in flow level than equivalent sites in Kenya. Inspection of the locations of sites in the United Kingdom showed that those sites with exceptionally high variability were located either close to tourist-holiday resorts or in areas likely to experience inclement weather.

5.2. Errors from random continuous counts of different durations

Table 1 gives the errors for ADT estimates obtained from random continuous counts of different durations. Generally, the errors in estimates fall as both the duration of counting and the ADT increase. There are, however, considerable variations between sites in the rates at which the errors decrease with respect to both the duration of counting and the ADT. Because of the magnitude of the variations, they are unlikely to be accidental and are probably related to site location and the function of the roads. To make the trends clearer, sites have been grouped into the five flow levels used for repeated sampling and the results averaged. Figure 2 shows that the errors in estimates fall rapidly as the duration of counting and the ADT are increased, but there is a marked decrease in the rate of fall when the duration of counting exceeds a week. This suggests that rural travel is dominated by weekly, rather than by daily or monthly activities. Another significant feature is the sharp fall in errors in estimates when the duration of counting is extended from five weekdays to one full week. As might be expected, the latter effect is more pronounced at the higher flow levels i.e. on roads that serve regional and district centres with distinctive weekend activities. Clearly, variations in flow at the weekend contribute significantly to total variability, and so if circumstances arise that allow only a count of 4 or 5 days this period should span the weekend rather than only weekdays. It should be recalled at this point that the suggested maximum practicable duration for a continuous manual count is one week (see 4.3). Figure 2 shows that large errors are associated with counts of only a few days' duration. The lowest flow-level group has errors in estimates ranging from ± 35 per cent for a one-week count to ± 62 per cent for a count of a single day. On roads carrying 1000 vehicles per day or less, errors in estimates are at best approximately ± 20 per cent for a one-week count and ± 30 per cent for a one-day count. 157

Clearly then, no practicable duration of random counting is likely to provide ADT estimates of an acceptable accuracy for the great majority of roads in developing countries.

5.3. Repeated random samples

Table 2 gives the errors for ADT estimates obtained from repeated random counts of different durations. The figures in brackets show the errors in estimates for continuous counts of equivalent durations. Inspection of the results suggests that the errors in estimates of repeated random counts are related to those obtained from single random counts. If a random count of duration d gives an error equal to $\pm x$, then repeating the count will reduce the error to $\pm \frac{0.94x}{\sqrt{n}}$, $(n > 1)$ where n is the number of repetitions (i.e. the errors from repeated counts are approximately proportional to the inverse of the square root of the overall duration of counting).

As might be expected, repeated counts give more accurate estimates of ADT than continuous counts of the same duration and the advantage increases with the number of repetitions. Also, repeating a count twice reduces the errors in estimates to approximately 22 per cent of their continuous count value, and repeating four times results in a 40 per cent reduction. However, only at the highest flow levels and for counts repeated four times do the errors in estimates approach the desirable standard of ± 10 per cent. Below traffic flows of 600 vehicles per day, repeating counts 3 or 4 times generally results in errors in estimates of between ± 10 and ± 20 per cent.

Because of organisational difficulties, repeated counts are unlikely to be regarded as a practical proposition for most data requirements, although they may be of use for one-off studies. Also they cannot generally be expected to produce estimates of a desirable accuracy.

5.4 Sampling errors for individual months

It seemed likely that random samples drawn from particular months might show errors considerably different from those drawn throughout the year. If a wet season falls consistently in a particular month and normal travel is likely to be interrupted by rain, then samples from that period can be expected to have higher-than-average errors. Conversely, other months, between seasons and away from Public Holidays, could have virtually constant near-average flows, and consequently very low sampling errors. To test this possibility, random samples were drawn separately from each month and the error in ADT estimate calculated as before. The results for one whole week are shown in Table 3.

There is considerable variation in errors in estimates from month to month. At any site, the ratio of the largest to the smallest monthly error has a range from approximately 2 to an exceptional 27. Generally, the ratio is in the range 3-12. Even at moderately high flow levels of 400-600 vehicles ADT, the maximum monthly error for one-week random counts can reach 48 per cent. In contrast, even at ADT's of less than 40 vehicles the minimum error in any month does not exceed 10 per cent. Generally, if the month, or months, could be predicted during which sampling errors were likely to be a minimum, then relatively short counts could produce ADT estimates of a high accuracy. Table 4 shows that counts for as few as three consecutive days have errors of 20 per cent or less if the observations are conducted during the month of minimum sampling error.

6. DISCUSSION

The magnitude of the errors clearly indicates the need for improvements in the methods of measuring traffic flow in developing countries. In considering how this might be done, it seems useful to examine the basis of methods of counting rural traffic in some developed countries.

6.1 Rural traffic counting in the United Kingdom

As mentioned in Section 2.4, rural road planning and design in the United Kingdom are based upon the average daily flow (7-day average, 6am-10pm) measured in August. Average factors are used to adjust any observations taken in other months to their August equivalent. August conditions are used as the basis for counting because average monthly travel demands have consistently been found to be at their highest then [1]. Although the method has worked satisfactorily in the United Kingdom, because it is based upon a 16-hour observation period it shares all the criticisms previously levelled at the other 'm-hour' counting systems. Furthermore, although the idea of conducting all counts during a single period of peak activity is attractive, the method does not seem suitable for use in a developing country, because it presumes that seasonal variations in traffic flow are the same everywhere, and remain so, year after year. Geographical considerations suggest that, in the mainly tropical or sub-tropical developing countries, the climatic variations, and hence most of the likely traffic flow variations, are neither as simple nor as consistent as those experienced in the developed countries.

This suggestion is given some confirmation by Figures 3(a) and 3(b) which show the monthly patterns of flow variation recorded at 21 of the Kenya sites. No simple pattern emerges: the seasonal variation of traffic is highly variable both at individual sites and between sites. The causes of the monthly flow variations at each site and whether they recur are still being studied, but it is clear that the method of standardising traffic counts in the United Kingdom could not be used in Kenya, as there is not a single month when flows are near maximum at all sites at the same time.[

6.2 Rural traffic counting in the USA

As explained in Section 2.4, the object of rural traffic counts in the USA is to estimate ADT. When sample counts are made, usually for one or two consecutive days only, the results are adjusted to give ADT estimates, within the accuracy limits described in 4.2, by factors derived from a relatively small number of continuous counting stations called control stations. This procedure is based upon the fact that seasonal patterns of variation have been found to persist from year to year[3] on the same road sections and are similar:

(i) for long consecutive lengths of major road (ADT >500 vehicles) all of which are not necessarily on the same route;

and (ii) for all minor roads (ADT <500 vehicles) within a given economic (geographic) region.

Thus the seasonal patterns of traffic variation on all sections of road can be represented by those obtained from either 'route control stations' or 'area control stations'.

This system would seem to be the more promising of the two described as far as developing countries are concerned, but it would not be easy to implement. The present sophistication of traffic counting in the USA has been achieved only after many years of recording traffic flows. What is apparent is that the use of automatic traffic counters will be a necessary pre-requisite of any significant improvement in the accuracy of current traffic estimates in developing countries.

6.3 Use of automatic traffic counters in developing countries

When first introduced into developing countries, automatic counters should be operated continuously at fixed locations. These should be chosen to represent the major traffic routes and geographic areas; the method of doing this is described in a recent Report[5]. As well as monitoring long-term trends, the counter results will enable a study to be made of the magnitude, frequency, and causes of the day-to-day and month-to-month, fluctuations in flow. A clear understanding of these will enable methods of counting traffic to be designed along the lines indicated, so that ADT estimates of a prescribed accuracy can be made. After one or two years, additional counters could be obtained and a start made on the grouping of road sections according to their seasonal variation characteristics. In the USA seasonal variation counts are made for only one week in every month at a given location; with efficient organisation, a single counter can therefore cover four sites per year.

In the initial stages of such a system, there is no need for expensive makes of traffic counter to be used. The simple SYX-RRL Nos. 4A or 4B accumulating counter would be adequate and it costs approximately one-tenth as much as a recording counter. A recent report by the Road Research Laboratory describes the operation and maintenance of the SYX-RRL counters under tropical conditions[6].

7. CONCLUSIONS

1. Traffic counts in developing countries should seek to provide estimates of the Annual Average Daily Traffic (ADT) on a road.

2. If made manually neither simple random traffic counts nor replicated random counts of any practicable duration can provide estimates of ADT within desirable limits on the majority of roads in developing countries.

3. Any appreciable improvement in estimates of traffic flow in developing countries will require the use of automatic traffic counters operated continuously at fixed locations.

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TABLE 1

Errors in ADT estimates from random counts of varying duration (per cent)

ADT (vehicles)	Number of Weekdays					Number of Weeks			
	1	2	3	4	5	1	2	4	6
25	70.6	58.8	50.2	48.0	41.4	36.3	34.1	33.9	34.9
26	69.0	57.0	55.1	51.7	53.1	31.2	28.4	23.3	19.4
26	80.6	69.4	63.7	61.2	58.8	50.2	44.7	38.0	33.1
32	83.9	71.7	66.2	66.6	65.8	54.7	55.7	60.0	63.3
44	41.7	31.8	27.2	26.8	25.1	22.5	19.2	16.8	17.4
56	37.4	30.4	27.2	27.4	25.5	22.9	19.4	14.9	9.2
63	52.9	43.7	40.8	37.0	35.5	30.0	28.4	26.8	23.3
88	44.1	40.8	39.8	34.9	30.6	26.5	22.5	20.4	16.1
93	51.0	45.3	42.9	40.8	43.7	33.1	32.9	31.6	30.2
106	45.7	38.6	34.7	31.8	28.4	24.1	20.8	19.0	18.8
120	41.6	34.3	25.5	25.9	29.4	22.3	20.2	17.4	14.5
152	39.0	33.9	36.3	31.4	27.0	34.5	30.6	22.5	7.4
156	36.8	32.1	30.0	28.4	25.5	18.8	14.1	10.1	6.3
250	50.8	47.0	44.5	43.5	41.4	39.8	34.7	34.5	32.5
355	35.7	28.4	27.2	26.8	30.2	13.1	12.3	11.8	10.2
357	41.7	37.2	32.7	30.8	30.4	36.6	32.7	19.0	8.2
438	37.2	36.1	34.9	36.8	34.9	22.1	17.6	14.1	5.5
494	38.4	30.8	27.6	25.5	25.1	18.0	17.4	17.8	16.7
501	36.8	33.7	33.1	32.9	31.8	29.4	27.6	21.6	16.5

TABLE 1 (continued)

ADT (vehicles)	1	2	3	4	5	1	2	4	6
622	25.3	20.4	17.2	17.2	17.2	17.4	13.9	9.6	7.8
632	40.0	35.3	32.9	29.4	27.4	24.9	23.3	22.1	21.4
650	32.3	34.3	36.4	34.5	32.7	22.7	17.2	9.8	7.0
675	25.7	23.9	23.5	22.0	20.2	21.2	17.4	11.2	7.8
676	30.4	31.8	34.3	31.8	32.5	20.8	19.0	16.8	16.7
788	26.6	20.6	19.8	19.2	16.3	19.0	16.5	14.9	14.5
792	39.2	44.1	45.7	45.9	41.0	24.5	22.3	16.3	16.3
825	20.8	19.0	18.6	16.8	17.6	19.0	16.8	13.7	12.7
1109	24.5	21.8	19.4	17.8	15.3	16.1	14.3	14.7	14.5
1185	31.4	30.2	30.4	30.2	28.6	18.2	17.0	17.0	17.2
1250	35.3	28.0	26.7	22.0	21.2	15.3	13.5	11.0	9.6
1373	34.3	40.4	43.1	41.2	36.1	16.5	13.7	9.8	8.8
1751	30.0	27.2	26.5	25.1	22.2	18.0	17.0	17.8	17.4
1766	26.8	29.8	31.2	31.4	26.1	12.9	11.2	8.6	7.1
2846	31.2	29.0	28.4	29.0	27.0	16.3	12.7	7.8	6.9

TABLE 2

Errors in ADT estimates from repeated random counts of varying duration (per cent)

Flow level (vehicles/day)	Repetitions	Duration of counting: Number of weekdays 1	2	3	5	1 week
< 75	1	62.3	51.7	47.2	43.5	35.5
	2	46.6 (51.7)	36.4	31.4	28.8	23.5 (32.9)
	3	33.5 (47.2)	28.0	25.5	23.5	17.6
	4	25.9 (45.5)	24.3	22.1	20.4	16.1 (30.6)
75-200	1	43.1	37.4	34.9	30.8	26.6
	2	28.0 (37.4)	22.9	24.5	21.2	17.6 (23.5)
	3	23.7 (34.9)	18.6	17.4	15.7	14.3
	4	18.6 (32.1)	17.2	15.9	13.9	12.5 (20.2)
201-600	1	40.2	35.5	33.3	32.3	26.5
	2	32.7 (35.5)	27.8	25.1	21.6	17.6 (23.7)
	3	22.7 (33.3)	22.3	18.0	17.4	14.3
	4	21.8 (32.7)	20.2	15.7	15.1	12.5 (19.8)
601-1000	1	30.0	28.6	28.6	25.7	21.2
	2	19.2 (28.6)	15.5	17.6	17.0	13.9 (18.4)
	3	16.3 (28.6)	15.5	15.9	13.9	11.4
	4	14.3 (27.0)	11.2	12.3	12.2	10.0 (14.3)
>1000	1	30.6	29.4	29.4	25.3	16.3
	2	17.8 (29.4)	18.4	16.8	14.7	13.3 (14.3)
	3	15.7 (29.4)	15.7	14.9	12.9	11.8
	4	14.3 (29.0)	11.0	11.8	11.2	7.6 (12.3)

Figures in brackets are for continuous counts of an equivalent duration.

TABLE 3
Errors in ADT estimates from random counts of 1 week in different months (per cent)

ADT (Vehicles)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Yearly Average
25	48.8	15.9	27.4	13.3	10.0	27.0	7.0	23.9	21.4	17.4	27.2	26.1	36.3
26	31.8	22.5	8.4	23.1	33.3	18.0	64.3	22.3	25.1	38.4	34.7	35.5	50.2
32	13.9	40.6	39.8	28.6	23.3	11.8	9.6	14.1	14.5	14.1	18.8	12.9	54.7
44	10.8	4.9	16.1	15.9	11.4	21.8	9.8	12.0	13.1	7.0	18.4	5.7	21.8
88	6.9	12.0	25.3	14.7	36.1	11.8	11.0	21.6	14.1	15.5	17.6	23.9	26.5
93	10.0	8.8	12.9	5.5	18.8	6.1	9.0	10.8	31.0	26.6	20.8	45.7	33.1
106	23.9	22.5	34.3	12.3	17.8	6.3	7.6	16.3	14.5	20.8	30.0	15.3	24.1
156	18.2	6.7	10.0	31.4	28.0	5.5	12.0	6.3	20.2	5.9	11.8	9.8	18.8
250	11.0	8.4	8.0	17.4	8.6	18.8	9.2	5.7	18.0	19.6	45.5	18.4	39.8
349	6.7	9.6	9.6	5.9	5.5	7.0	5.5	7.4	9.2	8.2	9.2	8.0	13.1
357	9.2	5.3	8.2	11.0	78.0	4.3	9.2	23.5	4.3	2.9	10.2	17.6	36.6
438	10.8	4.7	13.9	5.3	9.4	4.7	5.1	3.5	10.0	10.4	7.8	28.6	22.1
494	6.7	9.0	28.6	12.5	8.4	6.9	6.5	7.6	6.9	16.5	9.8	14.1	18.0
501	13.7	3.3	8.6	19.8	11.2	5.1	8.8	11.6	9.2	7.4	10.4	48.0	29.4
622	9.0	3.9	38.8	4.3	7.4	12.2	4.3	15.9	10.6	20.0	17.6	6.7	17.4
632	8.6	6.9	8.0	13.5	5.1	21.2	8.4	18.4	25.5	25.9	7.0	9.6	24.9
675	17.6	10.8	6.1	5.5	6.3	14.7	8.0	3.7	13.1	14.5	5.7	15.9	16.7
676	7.6	4.1	6.3	3.7	8.0	2.4	17.2	17.4	9.0	4.3	19.0	15.3	20.8
788	15.5	2.4	6.3	3.7	9.2	6.7	12.9	6.9	5.9	6.5	8.2	30.4	19.0
792	6.1	10.2	9.2	5.3	11.8	6.1	21.8	8.0	11.0	35.5	7.6	8.4	24.5
825	9.0	8.6	7.4	7.4	9.0	3.7	6.9	5.5	6.5	10.2	8.4	20.0	19.0
1109	8.6	2.0	8.4	3.3	4.5	3.3	7.0	18.0	8.2	4.7	7.0	22.0	16.1
1185	3.9	8.6	8.2	4.3	7.8	8.6	7.2	8.2	17.2	6.1	26.6	10.0	18.2
1250	11.0	5.3	4.7	11.0	12.7	7.6	8.6	7.8	14.3	6.5	5.5	15.9	15.3
1751	17.2	10.8	4.3	3.1	11.4	4.9	9.0	5.9	8.8	10.0	5.9	19.2	18.0
2846	8.0	3.7	11.0	2.9	11.0	7.8	7.6	13.9	12.5	22.7	26.3	6.3	16.3

TABLE 4
Errors in ADT estimates from random counts of 3 consecutive weekdays in different months (per cent)

ADT (vehicles)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Yearly Average
25	82.3	17.0	33.3	23.1	19.2	21.2	21.4	39.6	22.5	17.4	29.0	64.7	50.2
26	42.7	37.6	17.4	31.0	54.5	36.1	103.7	38.4	23.5	38.6	35.1	38.0	63.7
32	31.8	54.1	71.0	52.7	31.0	22.7	20.0	21.4	31.4	33.1	31.9	30.0	66.2
44	17.2	10.2	20.2	18.8	14.3	32.9	14.9	19.0	23.5	19.0	34.5	18.6	27.2
88	13.9	25.1	37.2	33.5	54.9	23.1	15.3	28.0	19.2	42.7	20.6	19.0	40.2
93	13.5	16.7	17.6	15.1	30.6	13.1	14.7	14.1	33.3	41.9	35.9	49.2	42.9
106	22.0	32.1	51.5	17.2	30.6	16.7	16.1	18.8	16.7	17.8	40.2	29.0	34.7
156	21.0	6.7	9.8	54.1	42.3	12.0	19.4	14.1	19.6	12.9	17.4	10.0	30.0
250	28.8	25.1	11.4	14.9	19.6	30.2	13.3	10.6	25.5	25.1	65.8	42.9	44.5
349	8.6	14.5	13.3	8.8	9.0	11.2	10.2	14.3	13.7	15.9	13.5	15.3	27.2
357	12.3	9.2	13.1	33.5	69.6	4.9	11.8	31.4	6.7	6.7	20.4	17.0	32.7
438	18.8	13.5	16.1	6.9	7.8	6.1	7.4	8.0	14.1	20.6	11.4	53.9	34.9
494	7.6	13.3	29.4	11.0	7.8	12.9	13.9	14.5	12.7	24.1	18.8	32.9	27.6
501	11.8	5.9	10.2	23.5	14.7	5.9	12.7	18.4	15.7	12.9	8.2	53.7	33.1
622	12.3	10,0	28.4	9.6	16.8	6.5	8.6	24.9	15.1	14.5	20.8	17.2	17.2
632	10.8	12.5	11.0	19.2	6.3	23.3	10.8	18.8	29.4	38.6	13.7	15.3	32.9
675	20.4	7.8	6.1	18.2	10.6	22.9	13.7	5.1	18.8	16.5	8.2	25.7	25.1
676	4.9	4.5	9.2	6.7	8.2	3.9	22.7	31.0	8.2	4.3	20.0	29.8	34.3
788	15.1	5.5	6.7	12.0	18.0	12.9	13.5	7.8	7.2	18.6	11.6	28.8	19.8
792	9.0	12.3	9.6	13.9	11.4	10.0	25.9	11.8	12.2	35.5	9.2	22.0	45.9
825	15.3	8.4	12.3	9.8	8.6	6.9	10.4	5.3	13.1	12.2	10.4	11.4	17.6
1109	6.9	6.3	12.2	10.2	4.3	9.6	8.2	28.2	10.0	10.8	7.4	32.9	19.4
1185	7.2	8.2	4.9	12.9	6.9	7.8	10.6	14.1	18.8	7.0	25.5	32.7	30.4
1250	9.8	8.6	5.3	31.8	20.2	11.2	11.4	9.4	15.7	11.4	7.4	35.9	26.6
1751	19.0	13.7	5.1	17.0	10.4	8.2	14.9	9.0	11.4	16.3	6.3	28.4	26.5
2846	20.0	6.3	13.3	10.2	8.6	13.1	10.4	9.8	14.3	22.3	31.8	16.5	28.4

8. APPENDIX I

Questionnaire on national procedures for survey of rural traffic flow

COUNTRY	NATIONAL CENSUSES				GENERAL COUNTS			AUTOMATIC COUNTERS	
	Is there any form of national traffic census operating?	For how many hours and days are observations made during a survey?	How many surveys are made a year?	Are all classes of road covered?	For how many hours and days are observations made?	Is there any specific period, or periods, of the year when observations are made?	Does the Government set standards for traffic observations?	Are automatic traffic counters in use?	For what purpose?
COLOMBIA	Yes	24 hours a day for 7 days.	1	Only roads maintained by national Government (about 7 sites per year).	24 hours a day for 7 days mainly.	No.	Yes.	Yes.	As continuous counters at fixed locations.
CYPRUS	Yes	7 days continuously on some trunk roads; 92 hours spread over 5 days on others. 84 hours spread over 5 days on tourist and village roads, but varies from year to year.	3	Yes	Varies	Varied from place to place to coincide with local crop-harvesting period.	Yes	No	
ETHOPIA	Yes	24 hours a day for 5 days.	3 Jan-April dry season; June-August wet season; Sept.-Dec. intermediate season.	All-weather roads built and maintained by the Imperial Highway Authority whether primary, secondary or feeder roads.	24 hours for 7 to 15 days.	No	Yes	No	

APPENDIX I - continued (1)

COUNTRY	NATIONAL CENSUSES				GENERAL COUNTS			AUTOMATIC COUNTERS	
	Is there any form of national traffic census operating?	For how many hours and days are observations made during a survey?	How many surveys are made a year?	Are all classes of road covered?	For how many hours and days are observations made?	Is there any specific period, or periods, of the year when observations are made?	Does the Government set standards for traffic observations?	Are automatic traffic counters in use?	For what purpose?
GHANA	Yes	7 days 12 hours (6 a.m.-6p.m.) manually and 24 hours by automatic counter.	3 or 4 times a year.	Only primary and secondary roads.	16-or 24-hour counts for 1 week.	No.	No.	Yes.	As continuous counters at fixed locations.
IRAN	No	(one is proposed for 1971)			3 days 1st day: midnight-8 a.m. 2nd day: 8 a.m.-4 p.m. 3rd day: 4 p.m.-midnight.	Up to 2 times a year in each season	No.	To a limited extent.	
KENYA	Yes	12 hours (6 a.m.-6 p.m.) for 5 days in a week and 24 hours on the remaining 2 days.	4 February, May, August, November.	Yes	12 hours (6 a.m.-6 p.m.) for 7 days.	Wet weather and main annual social events avoided.	Yes	No	
LESOTHO	Yes	12 hours a day for 7 days	Irregular	Mostly main roads.	12-hour 1 day counts.	No	No	No	
MALAWI	Yes	1 day 12 hours manual and 24 hours automatic counter.	2 Wet and dry season.	Main and secondary roads only.				Yes	For short counts of one day's duration.

APPENDIX I - continued (2)

COUNTRY	NATIONAL CENSUSES				GENERAL COUNTS			AUTOMATIC COUNTERS	
	Is there any form of national traffic census operating?	For how many hours and days are observations made during a survey?	How many surveys are made a year?	Are all classes of road covered?	For how many hours and days are observations made?	Is there any specific period, or periods, of the year when observations are made?	Does the Government set standards for traffic observations?	Are automatic traffic counters in use?	For what purpose?
MAURITIUS	No				12 hours (6 a.m.-6 p.m.) for 7 days.	During sugar crop period July to December.	No	No	
TANZANIA	Yes	72 hours	2	Yes	72 hours	No	No	No	
THAILAND	Yes	New standards being introduced. All roads to be covered. Most counts 2 times a year, April and October, 8-hour counts (8 a.m.-4 p.m.) for 5 week-days. At a few sites 4 times a year January, April, July, October, 8-hour counts spanning 24 hours for a total duration of 3 weeks; i.e. an effective one-week count.			1 day 8 hours manual (8 a.m.-4 p.m.) and 24 hours by automatic counter.	No		Yes	In the past for short counts of one day's duration but permanent sites are to be set up.
TURKEY	Yes	Variable, majority are 1-day 8-hour counts. Some are for 24 hours 1 or 2 days.	8-hour counts usually 3 times a year but some just once or twice 24-hour counts repeated up to 15 times a year.	Only those which are the responsibility of the national highways department.				Only in urban areas.	
UGANDA	Yes	24 hours a day for 7 days.	2	Only roads which are the responsibility of the Ministry of Works.	24 hours a day for 7 days.	No	Yes	Yes	For short counts of 7 days duration.

APPENDIX I - continued (3)

COUNTRY	NATIONAL CENSUSES				GENERAL COUNTS			AUTOMATIC COUNTERS	
	Is there any form of national traffic census operating?	For how many hours and days are observations made during a survey?	How many surveys are made a year?	Are all classes of road covered?	For how many hours and days are observations made?	Is there any specific period, or periods, of the year when observations are made?	Does the Government set standards for traffic observations?	Are automatic traffic counters in use?	For what purpose?
ZAMBIA	Yes	12 hours for 5 days in a week and 24 hours on the remaining 2 days.	Once a year in June.	Yes	Varies from 12 hours up to 7 days.	Dry season May-October	Yes	To a limited extent.	For short counts of 30 days duration.

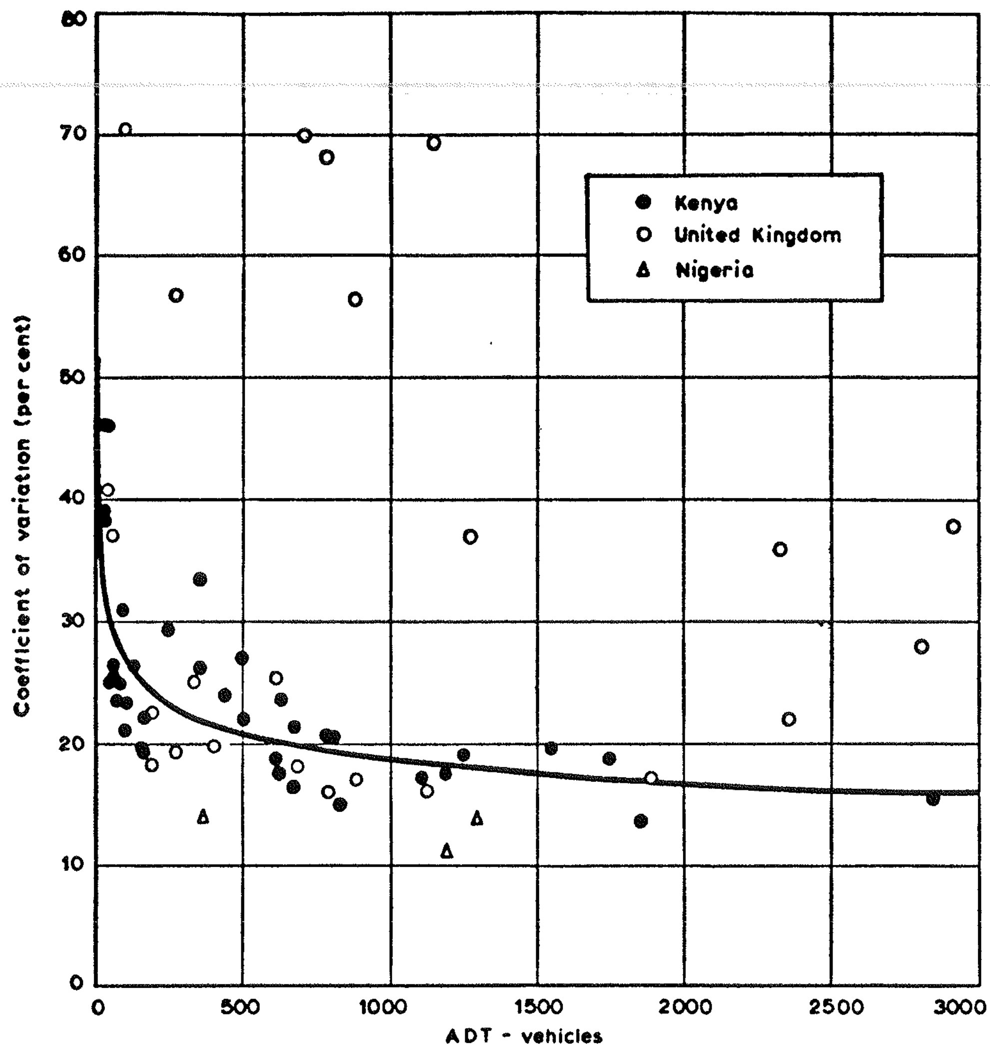

Fig.1. RELATIONSHIP BETWEEN DAILY VARIABILITY AND FLOW LEVEL

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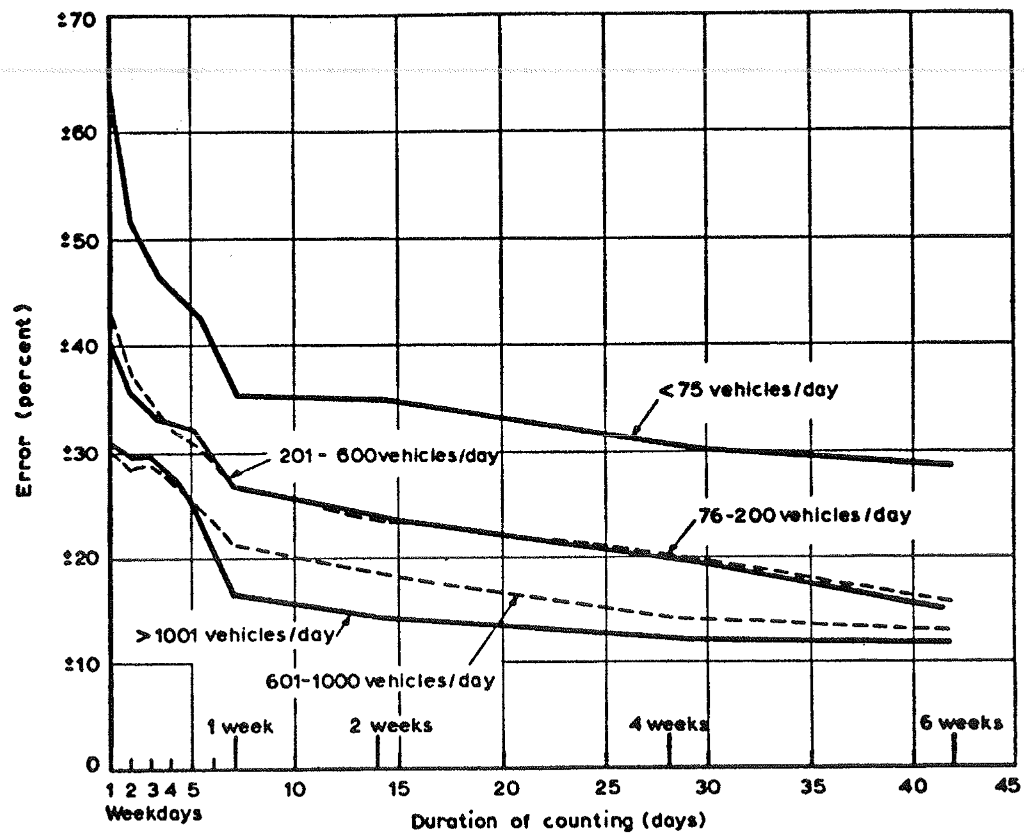

Fig.2. ERRORS IN ADT ESTIMATES FROM RANDOM COUNTS OF VARYING DURATION

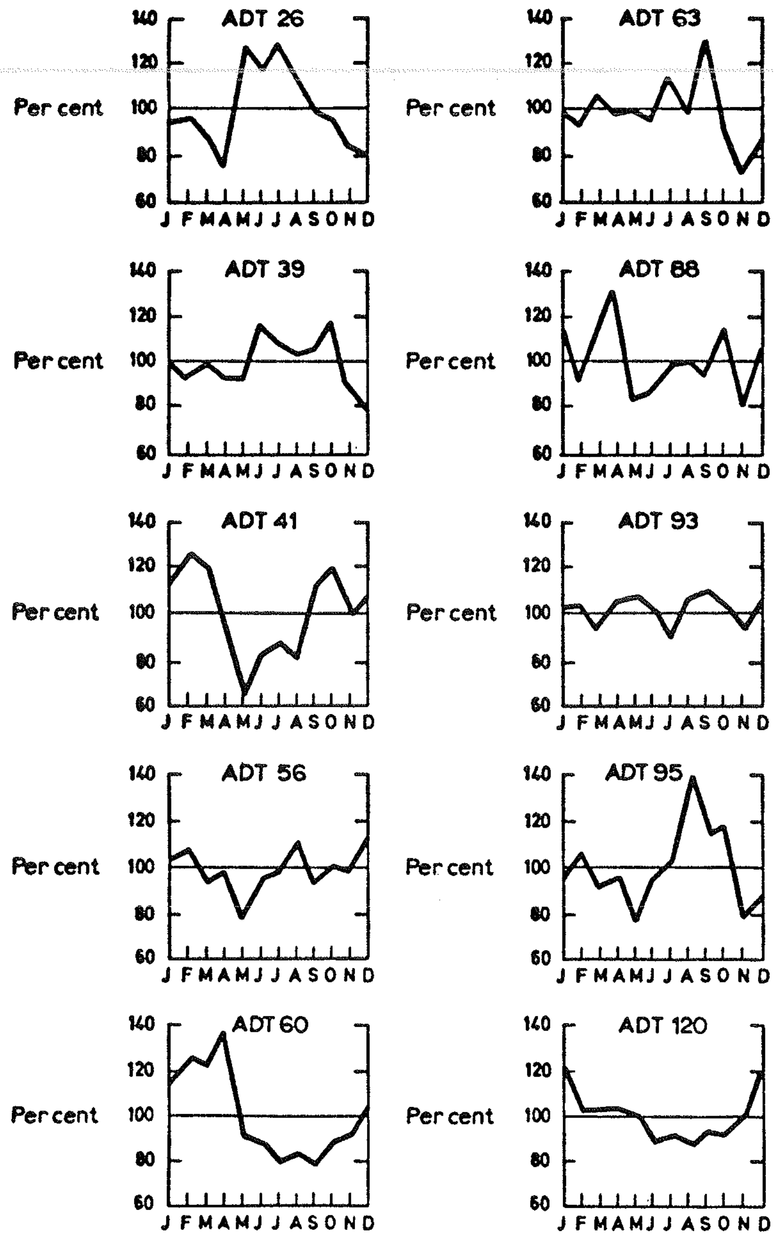

Fig. 3 (a) MONTH-TO-MONTH VARIATIONS IN AVERAGE TRAFFIC FLOW ON WEEKDAYS - KENYA (ADT 26-120)

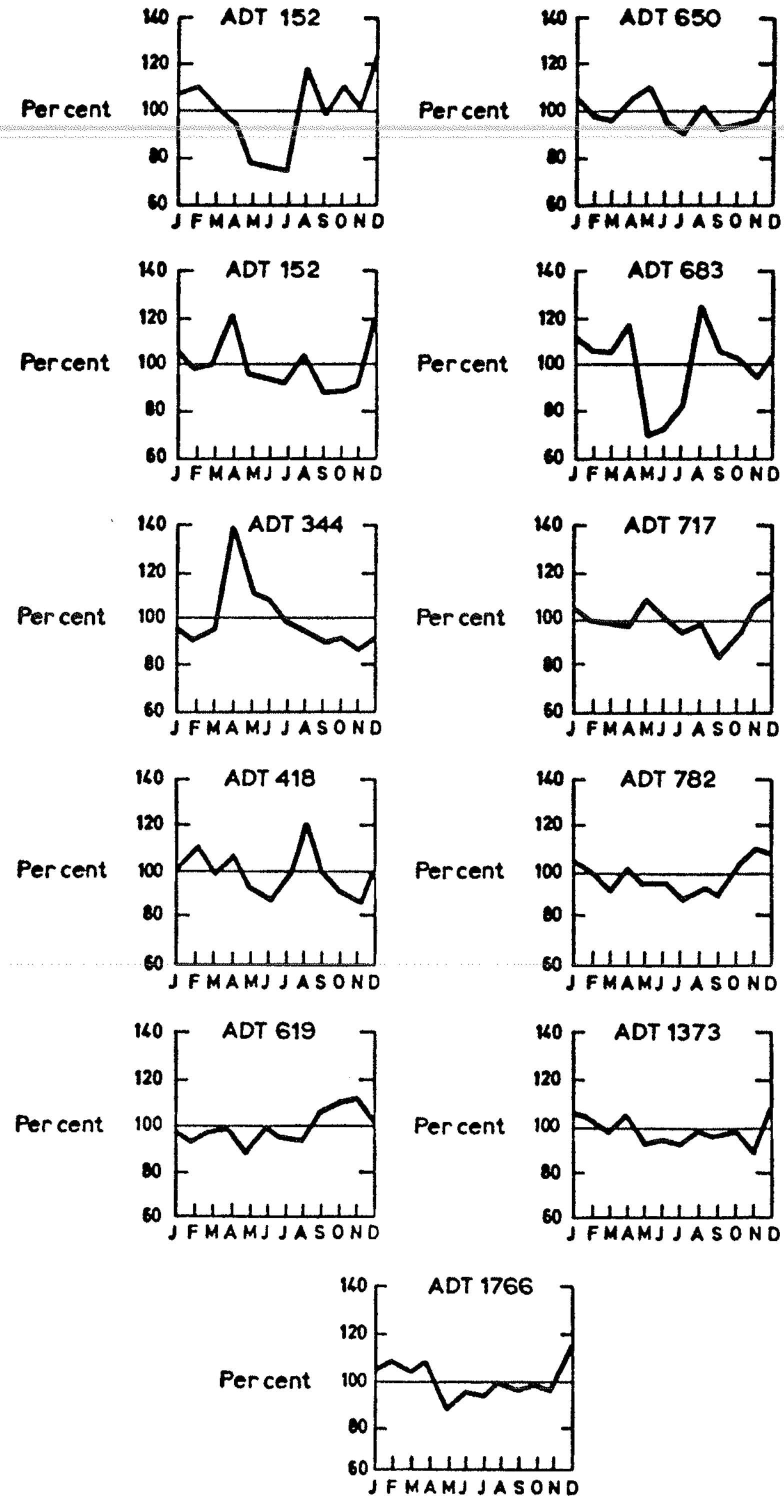

Fig. 3 (b) MONTH TO MONTH VARIATIONS IN AVERAGE TRAFFIC FLOW ON WEEKDAY - KENYA
(ADT 152-1766)

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TRANSPORT and ROAD RESEARCH LABORATORY

Department of the Environment

TRRL REPORT LR 516

THE SENSITIVITY TO TRAFFIC ESTIMATES OF ROAD PLANNING IN DEVELOPING COUNTRIES

by

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1973

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THE SENSITIVITY TO TRAFFIC ESTIMATES OF ROAD PLANNING IN DEVELOPING COUNTRIES

ABSTRACT

This Report gives an analysis of the sensitivity to traffic estimates of rural road planning decisions in developing countries. Consideration was given to decisions concerning the annual amounts spent on maintaining each section of road, the economic justification of road improvements, and the selection of road design standards and hence construction costs.

The Report shows how each of these decisions is sensitive to the traffic parameters used in making them. Many of the traffic parameters are shown to be subject to large errors due to the estimating methods currently in use. This is particularly the case with estimates of induced traffic likely to result from road improvements and the forecasts made of all future traffic for planning and designing road improvements.

The analysis stresses the need for improvements in traffic estimation methods and for further research into the fundamental characteristics of rural road traffic in developing countries.

1. INTRODUCTION

This Report analyses the sensitivity to traffic estimates of decisions about rural road planning in developing countries. The analysis was undertaken because a recent study of counting methods in developing countries showed that estimates of rural traffic flow were subject to considerable error[1]. It therefore seemed prudent to consider the effect of any errors in the traffic estimates generally used in reaching planning decisions. Errors in estimates of traffic parameters can be ignored provided highway planning decisions are not seriously affected. However, if it can be shown that uncertainty in traffic estimates have a considerable effect on the costly decisions which are made this would justify both improvements to counting methods and increasing the money spent on traffic estimation.

1.1 Definition of sensitivity

All decisions in maintaining, planning and constructing a road need estimates of traffic parameters. Some decisions require estimates of only a single parameter, others of several. Each of these estimates is usually treated in analyses as if it was certain to occur, yet many of them are subject to considerable uncertainty. If a small change in the estimate of one parameter will alter the decision under consideration, then the decision is said to be sensitive to changes in the estimates of that parameter. On the other hand, if one particular parameter can be varied over a wide range of values without affecting the decision, then the decision is said not to be sensitive to uncertainties regarding that particular parameter. For example, in the

United Kingdom[2], roads are built in discrete numbers of lanes each of which is able to accommodate a range of traffic volumes. For rural roads these are as follows:*

	2-lane	0- 9 000	passenger car units/day (pcu)
	3-lane	9 000-15 000	passenger car units/day (pcu)
Dual	2-lane	15 000-33 000	passenger car units/day (pcu)
Dual	3-lane	33 000-50 000	passenger car units/day (pcu)
Dual	4-lane	50 000-60 000	passenger car units/day (pcu)

In deciding capacity requirements for future road networks there would be no need to refine traffic estimates to a greater accuracy than the nearest 1000 pcu if the predicted value for the design year was in the middle of one of these ranges, say, 5000, 12 000 or 24 000 pcu, etc. However, if the predicted traffic flow was close to one of the transition levels in the relationship between the number of lanes and road capacity, then a considerable degree of sophistication in traffic estimation procedures would be justified to determine with confidence the required number of lanes and hence the cost of providing them.

1.2 Scope of the study

The term 'planning' has so far been used to describe all the decisions made in maintaining and improving a road system. Analysis was limited to the main decisions, i.e. those concerned with the annual amounts to be spent on maintaining each section of road, the economic justification of road improvements, and the selection of road design standards and hence construction costs. A further restriction on the scope of the analysis was that decisions concerning traffic capacity were not considered. Congestion is uncommon on the rural roads of most developing countries and consequently few countries have yet defined capacity standards.

As will be seen from the following examples, the methods by which decisions in different countries are made differ considerably. Although this is partly a reflection of the rapid changes in highway practice in developing countries, it would nonetheless be possible to criticise some of the methods used on the basis of generally accepted engineering and economic principles. This has not been done as it is considered outside the scope of this study. Differences in principle are discussed and their effect on the sensitivity of decisions indicated, but it is the sensitivity of decisions as they are now made, not as they ought to be made, which are of interest. To this end the examples used were selected to give a fair cross-section of current practice in developing countries.

2. THE SENSITIVITY OF ANNUAL MAINTENANCE COST ESTIMATES

If the effects of topography and climate on road maintenance needs are regarded as fixed for a given section of road, then the two most important factors affecting maintenance costs are the type of surface and the traffic volume carried. However, the form of the relationship between road maintenance costs and traffic volumes has not been finally established. Some countries use a different fixed cost per kilometre for earth, gravel, and bituminous surfaced roads, but this practice is not common. Most developing countries decide their maintenance expenditures by using a relationship of the form:

Total maintenance cost per year (TMC) = $a + bQ$

where Q is the flow in vehicles per day and a and b are constants. Examples are shown in Table 1.

---

* They are currently being revised, but serve to illustrate the point.

TABLE 1

The relationship between maintenance costs and traffic flow in various countries

Country and Year	Type of road surface		
	Earth	Gravel	Bitumen
Kenya: 1969 (pounds/mile)	95 + 1.37Q		Fixed cost per mile
Niger: 1963 (francs/km)		40 000 + 1620Q	98 320 + 320Q
Nigeria[3]: 1967 (pounds/mile)	150 + Q		340 + 0.2Q
Tanzania: 1969 (shillings/mile)	2930 + 22Q	2500 + 48Q	9353 + 3.74Q
Venezuela[4]: 1960 (Bolivars/km)	1550 + 54Q	5200 + 18Q	10 400 + Q
Zambia[5]: 1964 (pounds/mile)	36 + 1.7Q	96 + 1.4Q	242 + 0.065Q

The ratio of the percentage change in maintenance cost to the percentage change in flow level is defined as the sensitivity ratio. If the sensitivity ratio is 1.0, it means that a 100 per cent error in the estimated traffic flow produces a 100 per cent error in the allocated maintenance cost. Conversely, a sensitivity ratio of zero means that the allocated maintenance cost is independent of the estimated traffic flow. Inspection of the form of the relationships in Table 1 shows that the sensitivity ratio is constant for any particular road surface in a given country. The actual values are given in Table 2.

TABLE 2

Sensitivity ratios for the maintenance cost relationships given in Table 1

<table>
<tr><th rowspan="2">Country and Year</th><th colspan="3">Type of road surface</th></tr>
<tr><th>Earth</th><th>Gravel</th><th>Bitumen</th></tr>
<tr><td>Kenya: 1969</td><td colspan="2">0.59</td><td></td></tr>
<tr><td>Niger: 1963</td><td></td><td>0.80</td><td>0.25</td></tr>
<tr><td>Nigeria: 1967</td><td colspan="2">0.40</td><td>0.06</td></tr>
<tr><td>Tanzania: 1969</td><td>0.43</td><td>0.66</td><td>0.04</td></tr>
<tr><td>Venezuela: 1960</td><td>0.78</td><td>0.26</td><td>0.01</td></tr>
<tr><td>Zambia: 1964</td><td>0.82</td><td>0.59</td><td>0.03</td></tr>
</table>

It can be seen that the ratios vary from as little as 0.01 to a maximum 0.82. Generally those for earth surfaced roads are the highest, followed by those for gravel surfaced roads, with, as might be expected, bituminous surfaced roads having the lowest ratios.

3. THE SENSITIVITY OF CRITERIA USED FOR THE ECONOMIC JUSTIFICATION OF ROAD IMPROVEMENTS

The methods used for the economic justification of road improvements differ in the various developing countries, but in all, once a criterion has been selected, projects are judged on whether or not their value will exceed some agreed minimum. If there are several projects then they are ranked and accepted for improvement in rank order until the total cost reaches the limit of available funds.

A common criterion used for the selection of proposed road improvements is the Internal Rate of Return (IRR). This is only one of a number of criteria in general use, but it has been preferred by the World Bank for its own analyses[6] and is the one used here. Although doubts have recently been expressed about the suitability of the IRR for assessing public investments[7], since each project in the analysis was considered separately and none of the projects assumed a complex cost or benefit stream over the design life of the road, the conclusions of the following analysis would not have been altered if either Cost-Benefit Ratio or Net Present Value criterion had been used instead.

Initially the sensitivity of the IRR to changes in the estimated present daily traffic and traffic growth were tested. These are the main traffic parameters which have to be estimated for each road that is assessed. In practice each is estimated separately so it is necessary to show their separate effect. Rather than devise hypothetical road projects, ten - described in Appendix 1 - were selected from those recently constructed in developing countries. Where it was apparent that some of the ten projects were likely to give similar results, calculations were restricted to those which inspection suggested would give either the typical or the extreme values of the sensitivity ratio. In fact, it soon became obvious that the same few projects, because of the naivety or sophistication of their overall assumptions, would provide the range of values. The results which follow probably contain the likely values for all projects.

3.1 Present daily traffic

For each project the IRR was calculated using the assumption as given. Then, keeping all other factors constant, the estimated present level of traffic was varied by ± 20, ± 40, ± 60, ± 80 and + 100 per cent and the IRR calculated. Fig. 1 illustrates the range of values obtained. Minor variations in the slopes of the individual graphs are caused by discontinuities in the project assumptions. To simplify them linear regression lines were fitted and in each case the correlation coefficient exceeded 0.98. From the regression lines a mean sensitivity ratio of 0.70 was calculated. This clearly shows that the IRR is generally very sensitive to errors in estimates of present daily traffic, although the spread of the graph lines indicates that project sensitivity is considerably influenced by the mix of the other assumptions.

3.2 Traffic growth

The sensitivity of the traffic growth assumptions used in each project was tested in the same manner as the present daily traffic estimates. Fig. 2 shows the relationships obtained. In each case linear regression lines gave regression coefficients above 0.99. The sensitivity ratios are very scattered ranging from 0.20 to 0.71 with a mean of approximately 0.43. This is not really surprising as Appendix 1 shows that assumptions about traffic growth vary considerably among projects. 181

It is interesting that the mean sensitivity ratio for errors in estimates of traffic growth is lower than that found for the errors in estimates of present daily traffic. The probable explanation for this is that the discounting with time of the benefits from road improvements reduces the effect of distant uncertainties.

Because of the magnitude and range of the sensitivity ratios in the last two tests, the sensitivity of the justification for road improvements was examined in more detail. The effect on the IRR of three other aspects seemed particularly worth studying. They were:

(i) present traffic composition;

(ii) estimates of induced traffic; and

(iii) assumed changes in traffic composition.

3.3 Present traffic composition

For assessing the justification for road improvements in developing countries, traffic is usually separated into 'light' (cars and vans) and 'heavy' (lorries and buses) vehicles. Although more complex classifications are made for some purposes, they are rarely used in the calculation of either costs or benefits. The principal effect of errors in estimating present traffic composition is on vehicle operating cost savings, since operating costs per km are usually assumed to be higher for heavy than for light vehicles. Thus the IRR for a project with a high proportion of heavy vehicles is likely to be much more sensitive to errors in estimates of traffic composition than one in which the proportion of heavy vehicles is low.

The results in Fig. 3 suggest that this is so. Below about 30 per cent heavy vehicles, the IRR is relatively insensitive to errors in estimates of percentage composition with sensitivity ratios of less than 0.20. However, with 60 per cent heavy vehicles, sensitivity ratios increase to approximately a half. The extreme values for Project 10 occur when the percentage of heavy vehicles exceeds 80, which is unlikely to be common in practice.

3.4 Induced traffic

Very few of the reports considered in this analysis explain what is meant by induced traffic. Usually the term implies the extra flow of vehicles on an improved facility over-and-above that which would have been expected from normal trends. Alternatively, on an entirely new facility, it is taken to be the extra volume of traffic over-and-above that which would have been expected to divert from existing routes. Neither of these is strictly correct; the traffic on a new road or the extra traffic on an improved road can be broken down into:

(i) that traffic 'diverted' to the new facility, finding it more convenient or attractive than the former route of travel;

(ii) that traffic which has made a change in 'mode', e.g. from rail or air to road;

(iii) that traffic which is entirely new and never existed before, and is assumed to be the effect of making certain areas more accessible to larger numbers of people.

Strictly the term induced traffic should be reserved for (iii)[8]. It is unfortunate that the three components are frequently lumped together. One result of this practice is a tendency to ascribe to each unit of induced traffic the same benefits as each unit of existing traffic; this is incorrect. (All but one of the projects used in the analysis made this mistake). The benefits to each unit of induced traffic should be taken as one-half of those of each unit of existing traffic[9]. Even if benefit calculations are correct, errors in estimating induced traffic can be expected to have a considerable effect on the IRR since the changes in flow are often assumed to occur immediately after the road is improved. The extra benefits that result are thus relatively unaffected by the practice of discounting all the benefits to their present value.

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Assumptions concerning induced traffic can be classified into one of two types:

(i) Immediate increase assumption. This assumes that there is an immediate, once and for all, increase in traffic as soon as the new facility is opened, after which traffic continues to grow as before. (See, for example, Project 2, Appendix 1).

(ii) Limited time assumption. This assumes that for a number of years after the improvement - usually two or, more rarely, three years - traffic will grow at a faster rate than was established before the improvement. After the limited time period has elapsed traffic is usually assumed to grow at the pre-improvement rate. (See, for example, Project 10, Appendix 1). This type of assumption is open to several criticisms, but these are not considered here for the reason given in 1.2.

Using one Project (2) in which the benefits to induced traffic were incorrectly taken as equal to those of existing traffic, and one project (3) in which the benefits to induced traffic were correctly calculated as half those of existing traffic, the induced traffic assumptions were tested as follows:

(i) immediate increase of 20, 40, 50, 80 and 100 per cent;

(ii) increase for 2 years of 10, 20, 30, 40 and 50 per cent per year;

(iii) increase for 3 years of 10, 20, 30, 40 and 50 per cent per year.

In each case sensitivity was measured relative to the value of the IRR with no induced traffic. This method of testing was adopted since considerable uncertainty surrounds present methods of estimating induced traffic. None of the reports used in the analysis produced or quoted any evidence to support the amount of induced traffic used. In these circumstances, it seems fair to measure the sensitivity of the IRR relative to what it would be if it were assumed that there was no induced traffic. The results are shown in Fig. 4.

As might be expected in each case the sensitivity ratio is higher for Project 2 which makes incorrect assumptions about the benefits to induced traffic. Although the immediate increase assumption gives the lowest sensitivity ratios, they are still large at between 0.37 and 0.52. However, the sensitivity ratios when induced traffic is assumed to occur over two and three years range from 0.74 to 1.68. The magnitude of these values gives cause for concern at the present lack of knowledge concerning induced traffic in developing countries. The estimation of induced traffic is clearly in urgent need of research.

3.5 Changes in traffic composition

One of the projects used for this analysis assumes that the proportion of heavy vehicles will increase and one that it will fall, but most, explicitly or implicitly, assume that the proportion will remain constant with time. This seems unrealistic for, unless there are artificial restraints on the personal ownership of vehicles, it can be expected that on rural roads in developing countries the proportion of heavy vehicles will fall with time.

In the early stages of development, when a country is being opened up by road communications, personal ownership of vehicles is uncommon and the ubiquitous bus or multi-purpose lorry provides the main means of transport. Also, the low standard of many roads deters all but the most ruggedly constructed vehicles and the most determined of operators - usually the commercial lorry and bus operators. At a later stage of economic development the low standard roads are improved, and increased ownership and use of light vehicles is made possible: hence the proportion of heavy vehicles steadily falls. 183

Vehicle registration statistics from a sample of developing countries suggest that many developing countries have passed or are passing through the stage described above (see Fig. 5). The number of heavy vehicles has been expressed as a percentage of the total stock of vehicles. Generally, the proportion of heavy vehicles declines with time and in some cases (Afghanistan, Brunei, Ghana, Laos, Sarawak) this is quite marked. Some of the countries in Fig. 5(d), however, show a sensibly constant proportion of heavy vehicles with time, and, in the case of Nepal, an increasing trend is apparent. The latter is hardly surprising as the rugged terrain has, until recently, limited the development of roads. These trends are, of course, only true nationally, and on individual rural roads there will be considerable variation from them. Nonetheless, they do strongly suggest that only on roads opening up new land and in the early stages of development is the proportion of heavy vehicles likely to increase or remain constant with time: the results from a recent study of the composition of rural traffic flows in Kenya indicated a similar tendency[10].

From the foregoing discussion, it seems that a reasonable measure of the sensitivity of the IRR to assumptions about changes in traffic composition is obtained by comparing the value of the IRR assuming a constant proportion of heavy vehicles with that assuming that the proportion of heavy vehicles declines by various amounts over the design life of each project. Fig. 6 gives the results.

With one exception, the assumption of a constant instead of a declining proportion of heavy vehicles with time will result in an increased IRR. (The negative sign of the results for Project 1 is caused by the somewhat unlikely assumption that the absolute operating costs of light vehicles exceed those of heavy vehicles.) It can be seen that, as was the case with present traffic composition, (section 3.3) the sensitivity of the IRR is determined by the initial proportion of heavy vehicles. Below approximately 50 per cent heavy vehicles, sensitivity ratios are relatively low, being less than 0.1. Only when the proportion of heavy vehicles exceeds 50 per cent, do sensitivity ratios reach moderate values of 0.16 and 0.31.

NOTE: Section 4 has been deleted because it does not deal with the subject of this publication.

5. DISCUSSION

There are two objectives in making a sensitivity analysis of a planning decision: first, to determine the effect on the final decision of changing the value of each of the variables involved in reaching it; secondly, to calculate the probability that the estimated values of the variables which cause significant changes in the results will occur.

The analysis has been concerned with the first of these objectives, and it has been shown that each of the decisions considered is sensitive to the traffic data needed to make them. It is much more difficult to calculate the likelihood that estimates of a given traffic parameter will be subject to a specified error. A recent study[1] has provided confidence limits for estimates of present daily traffic from traffic counts of varying duration. Evidence was also presented in the results on the confidence limits of estimates of the present proportion of different types of vehicles. However, the other traffic parameters considered are based on forecasts and very few studies of the accuracy of these have been made - as far as is known, none in the developing countries. On the evidence of the methods being used (see Appendix 1), it must be concluded that most forecasts of rural traffic in developing countries are subject to considerable error: as indicated above a figure of ± 50 per cent is a likely minimum confidence interval.

This Report emphasises the need to evaluate the consequence of decision errors, although no attempt to quantify them has been made. The consequences of improving or not improving a road, or of over-designing or under-designing it are difficult to predict. If an investment is made in a road before conditions warrant, then the opportunity is foregone of investing that money, possibly more profitably, elsewhere. Equally, if an investment is made in a road after conditions warrant, then the benefits that would have accrued if the investment had been made at the optimum time will be foregone in favour of other, and possibly lesser, benefits elsewhere. (Similar reasoning can be applied to the under-designing or over-designing of a road.) The magnitude of the effects of either of these actions obviously varies with circumstances, but economically they are both undesirable and the causes of them should be eliminated if possible.

The results clearly show that improved traffic estimates could, in many cases, greatly increase the certainty of planning decisions. This is especially notable in the case of estimates of induced traffic.

6. CONCLUSIONS

1. All of the three planning decisions considered are sensitive to errors in estimating the traffic parameters used in making them.

2. Accurate estimates of present daily traffic are of fundamental importance both to current decisions and to decisions relying upon forecasts.

3. The very large sensitivity ratios associated with estimates of induced traffic used in the economic assessment of road improvements indicates the need for urgent research on the socio-economic changes induced by road improvements in developing countries.

4. The results stress the need for improvements in traffic estimation methods and for further research into the fundamental characteristics of rural road traffic in developing countries.

7. ACKNOWLEDGEMENT

The work described in this Report forms part of the research programme of the Overseas Unit (Unit Leader: Dr. E.D. Tingle)

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9. APPENDIX I

PROJECT CHARACTERISTICS AND ASSUMPTIONS USED IN TESTING THE SENSITIVITY OF THE ECONOMIC JUSTIFICATION OF ROAD IMPROVEMENTS

Project number	Design life (years)	Construction cost (£'s 1000)	Length of project (km)	Type of improvement	Terrain and soil type	ADT (vehicles)	Traffic growth assumptions	Benefit calculations
1	30	396	55	Earth-gravel to bitumen.	Flat to rolling over sandy silt with pockets of silty clay.	220	1. Separate growth rates assumed for cars: 10 per cent for five years, 8 per cent for five years, 6 per cent for five years, 4 per cent for five years, and 2 per cent for ten years; and for trucks: 10 per cent for five years, 12 per cent for five years, 10 per cent for another five years, and 5 per cent for fifteen years. 2. Although not specifically mentioned the proportion of heavy vehicles is increasing with time from 45.5 per cent.	1. Separate operating cost savings assumed for light and heavy vehicles with the former exceeding the latter. 2. Maintenance costs are assumed to be independent of the traffic flow. 3. Induced benefits mentioned but not quantified.
2	20	880	111	Slightly improved gravel and improved gravel to bitumen.	Flat through rolling to mountainous over shallow soils overlying granite.	403	1. All vehicles assumed to increase by 25 per cent for one year and 8.5 per cent for the remaining nineteen years. 2. The proportion of heavy vehicles is assumed to remain constant with time at 34 per cent.	1. Separate operating cost savings assumed for light and heavy vehicles. 2. Fixed maintenance saving independent of traffic flow. 3. Induced benefits discussed but not included.

APPENDIX I - Continued

Project number	Design life (years)	Construction cost (£'s 1000)	Length of project (km)	Type of improvement	Terrain and soil type	ADT (vehicles)	Traffic growth assumptions	Benefit calculations
3	20	260	36	Improved track to gravel.	Mountainous over dark red clays with red humic top soils.	237	1. All vehicles assumed to increase by 14 per cent for two years, then by 9 per cent until the ADT reaches 600 vehicles, and then by 3 per cent till the design life is reached. 2. The proportion of heavy vehicles is assumed to remain constant with time at 14 per cent.	1. Separate operating cost savings assumed for light and heavy vehicles. 2. Fixed maintenance saving independent of traffic flow, based on route shortening. 3. Simple before-and-after calculation of benefits.
4	20	1317	140	Unimproved gravel to bitumen.	Rolling to mountainous over volcanic deposits covered with black cotton soil.	330	1. All vehicles assumed to increase by 25 per cent for one year and 4.5 per cent for the remaining nineteen years. 2. The proportion of heavy vehicles is assumed to remain constant with time at 20 per cent.	1. Separate operating cost savings assumed for light and heavy vehicles. 2. Fixed maintenance saving independent of traffic flow. 3. Induced benefits discussed but not included.
5	20	826	40	Improved track to bitumen.	Flat through rolling to mountainous over volcanic ashes and pumice	245	1. All vehicles assumed to increase by 19 per cent for two years, then by 6 per cent until the ADT reaches 600 vehicles, and then by 3 per cent till the design life is reached. 2. The proportion of heavy vehicles is assumed to remain constant with time at 34 per cent.	1. Separate operating cost savings assumed for light and heavy vehicles. 2. Fixed maintenance saving independent of traffic flow. 3. Simple before-and-after calculation of benefits.

APPENDIX I - Continued

Project number	Design life (years)	Construction cost (£'s 1000)	Length of project (km)	Type of improvement	Terrain and soil type	ADT (vehicles)	Traffic growth assumptions	Benefit calculations
6	20	2051	149	Single lane bitumen and gravel to 2-lane bitumen.	Rolling to mountainous over residual soils from weathered gneiss of the basement complex.	Five road sections 1042 1161 653 256 274	1. All vehicles assumed to increase by 10 per cent for ten years, then by 8 per cent for five years, and 7 per cent for five years. 2. The proportion of heavy vehicles is assumed to remain constant with time.	1. Separate operating cost savings for light and heavy vehicles. 2. Gravel and single lane bitumen maintenance costs assumed proportional to traffic flow. Two-lane bitumen maintenance cost fixed per kilometre.
7	33	1365	203	Gravel to bitumen	Flat to rolling over non-calcareous black soils.	104	1. Very complex growth assumptions for four separate vehicle classes. Trucks and pickups assumed to increase by 3.1 and 4.0 per cent respectively over fifteen years, and then both by 3 per cent for nineteen years. Buses and cars are both assumed to increase by 5.1 per cent for five years, then by 5.9 and 6.3 per cent respectively for ten years, and finally both by 3 per cent for nineteen years. 2. The above assumptions result in the proportion of heavy vehicles declining slightly with time.	1. Separate operating cost savings for light and heavy vehicles. 2. Maintenance saving proportional to traffic flow assessed on before-and-after basis. 3. Induced benefits mentioned but not quantified.

APPENDIX I - Continued

Project number	Design life (years)	Construction cost (£'s 1000)	Length of project (km)	Type of improvement	Terrain and soil type	ADT (vehicles)	Traffic growth assumptions	Benefit calculations
8	15	197	13	Gravel to bitumen.	Flat over alluvial gravels.	242	1. Complex assumptions discussed resulting in the use of a standard 'vehicle unit' and a simple constant growth rate of 6 per cent. 2. The proportion of heavy vehicles is implicitly assumed to remain constant with time.	1. Complex operating costs calculated for standard vehicle to allow for the deterioration of the road without improvement. 2. Fixed maintenance cost on existing road assumed, but cost assumed to vary slightly with flow on improved bitumen road. 3. Induced benefits in terms of increased agricultural production and that foregone if the road were not improved form the main justification for the project.
9	22	2020	111	Gravel to bitumen.	Flat to rolling over sand with underlying granite.	275	1. All vehicles assumed to increase by 10 per cent for one year and 9 per cent for the remaining twenty-one years. 2. The proportion of heavy vehicles is assumed to remain constant with time at 27.4 per cent.	1. An average operating cost figure is used for both light and heavy vehicles. 2. Maintenance costs are assumed to be independent of the traffic flow; £280 per km for gravel and £310 per km for bitumen. 3. No induced benefits considered.
10	20	1295	96	Gravel to bitumen.	Flat to rolling over red loam and gravels.	115	1. All vehicles assumed to increase by 10 per cent for the first two years, and 7 per cent for the remaining eighteen years. 2. The proportion of heavy vehicles is assumed to fall from 60 per cent at the time of construction to 40 per cent at the end of the design life.	1. Separate operating cost savings assumed for light and heavy vehicles. 2. Maintenance costs are assumed to be in direct proportion to traffic flow and lower at all flows on bitumen roads than on gravel or earth surfaced roads. 3. No induced benefits considered. 4. Benefits are calculated on a before-and-after improvement basis rather than a with-and-without basis.

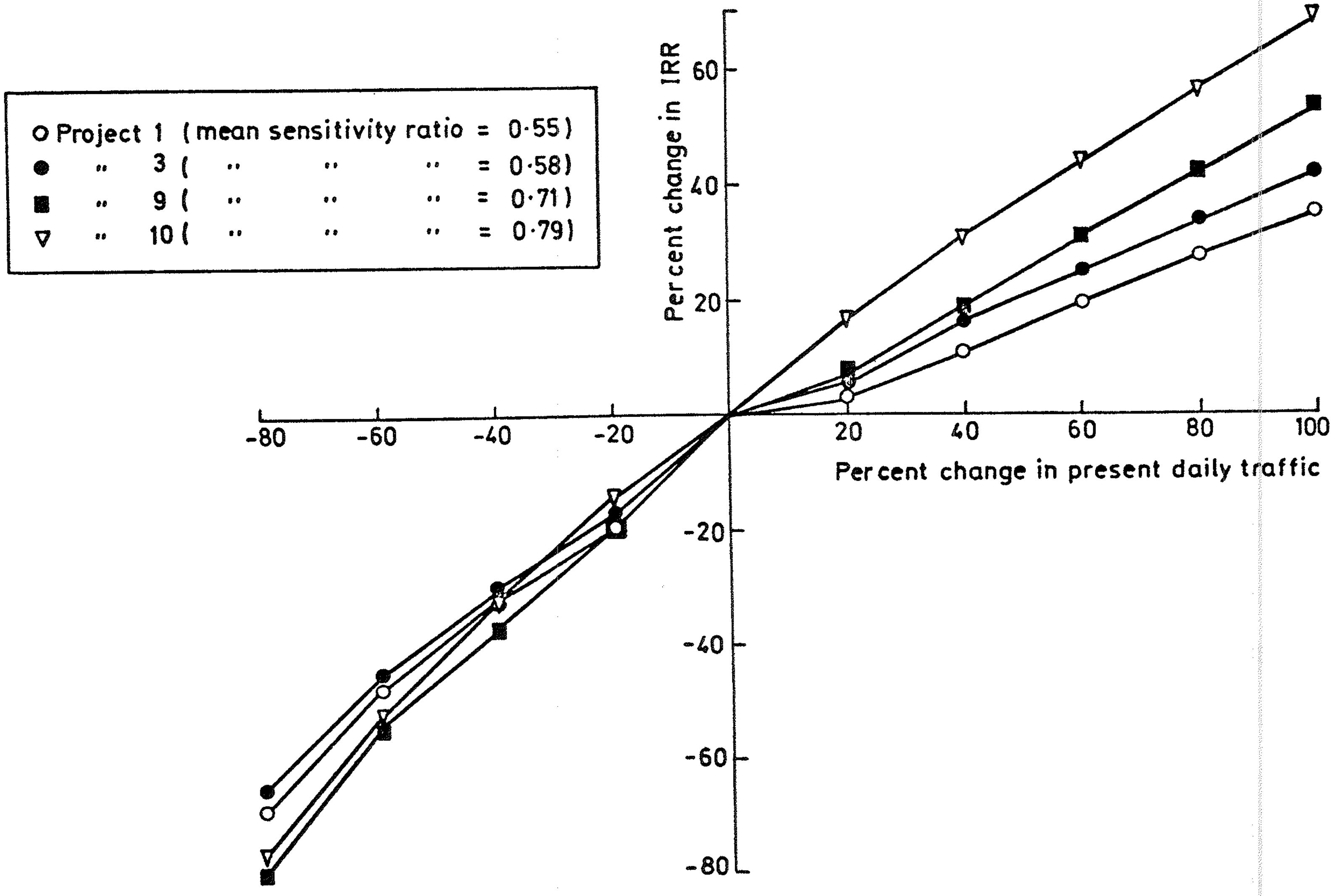

Fig. 1. SENSITIVITY OF THE IRR TO ESTIMATES OF PRESENT DAILY TRAFFIC

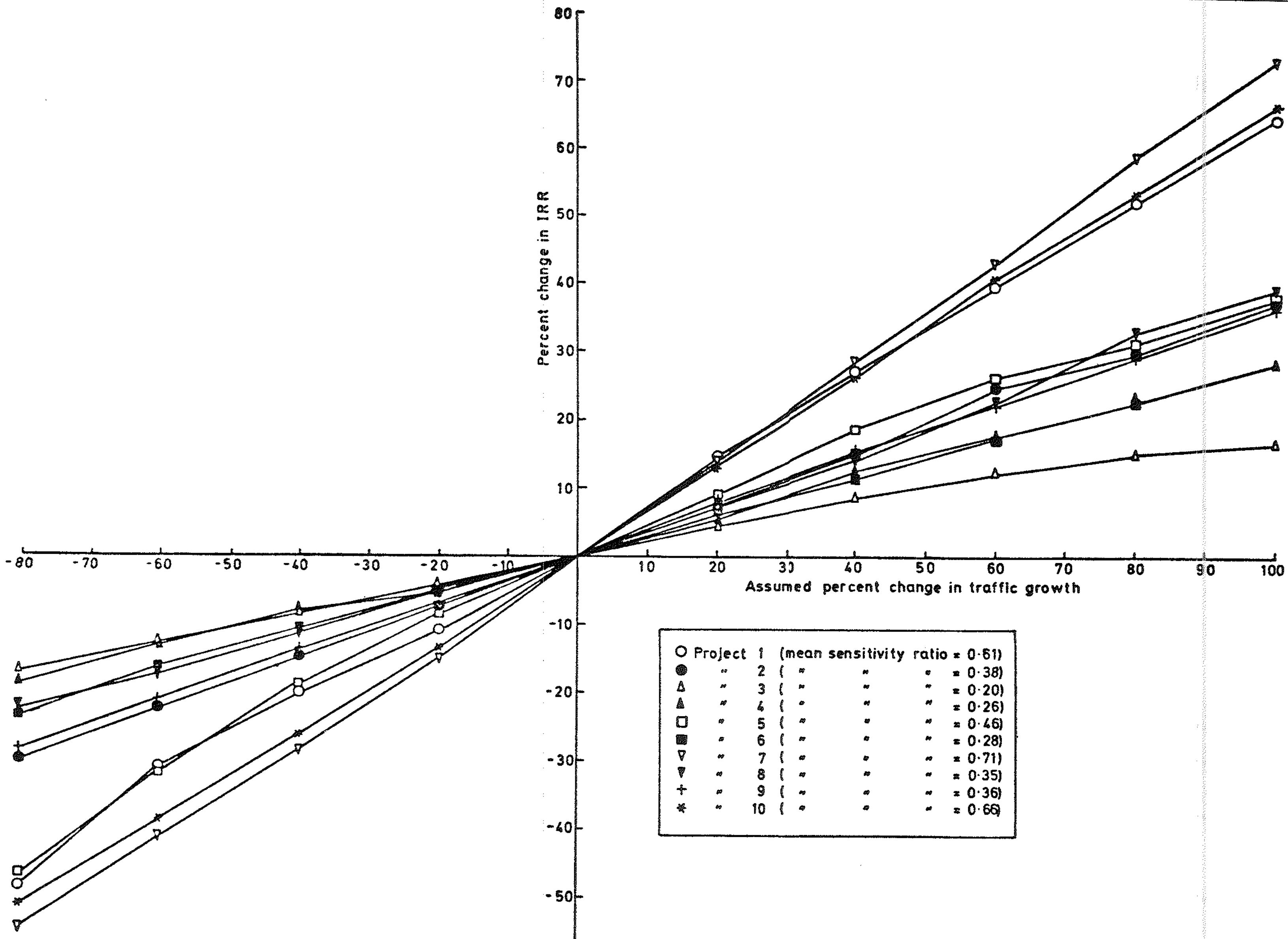

Fig. 2. SENSITIVITY OF THE IRR TO ESTIMATES OF TRAFFIC GROWTH

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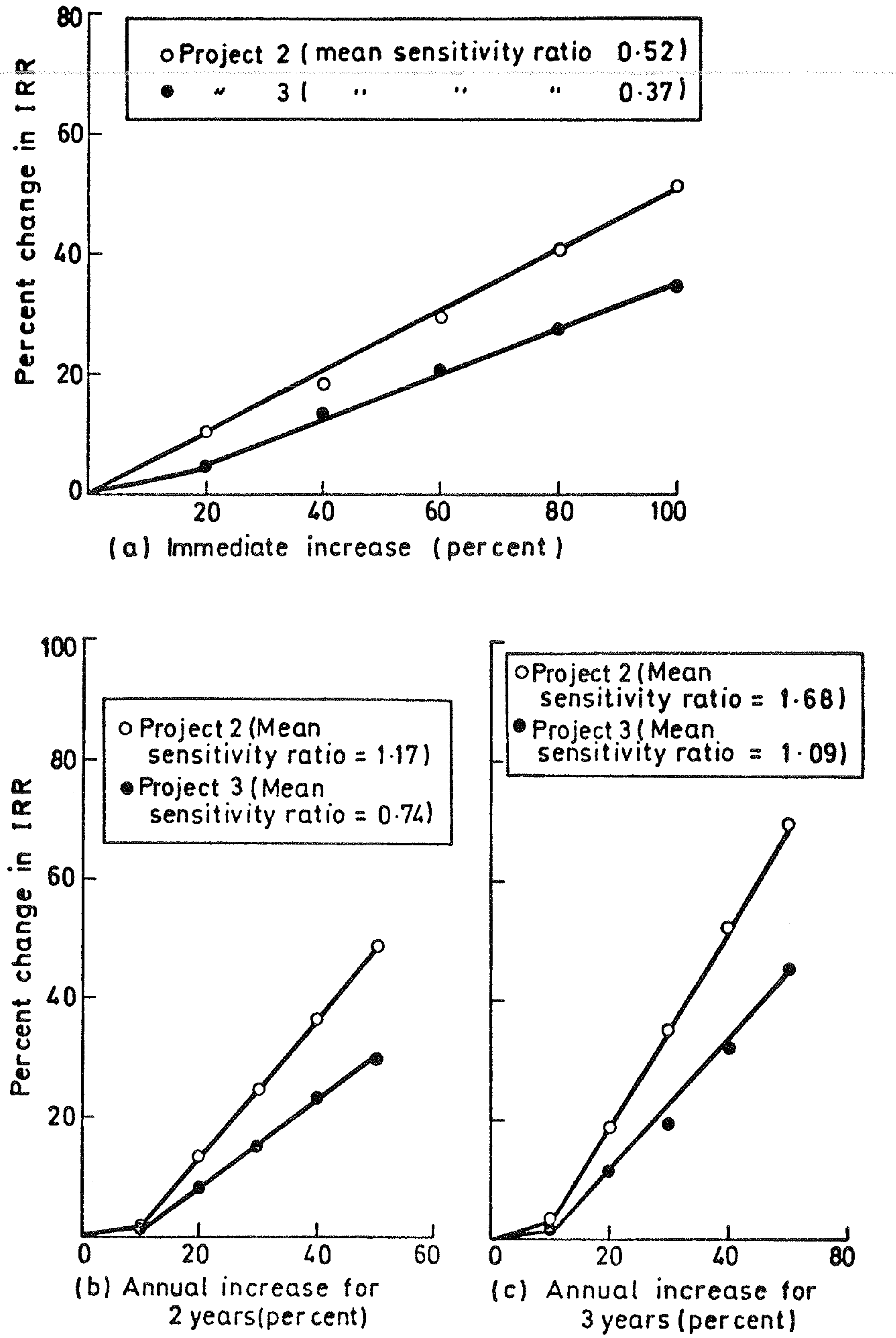

Fig. 4 . SENSITIVITY OF THE IRR TO VARIOUS ASSUMED VALUES OF INDUCED TRAFFIC

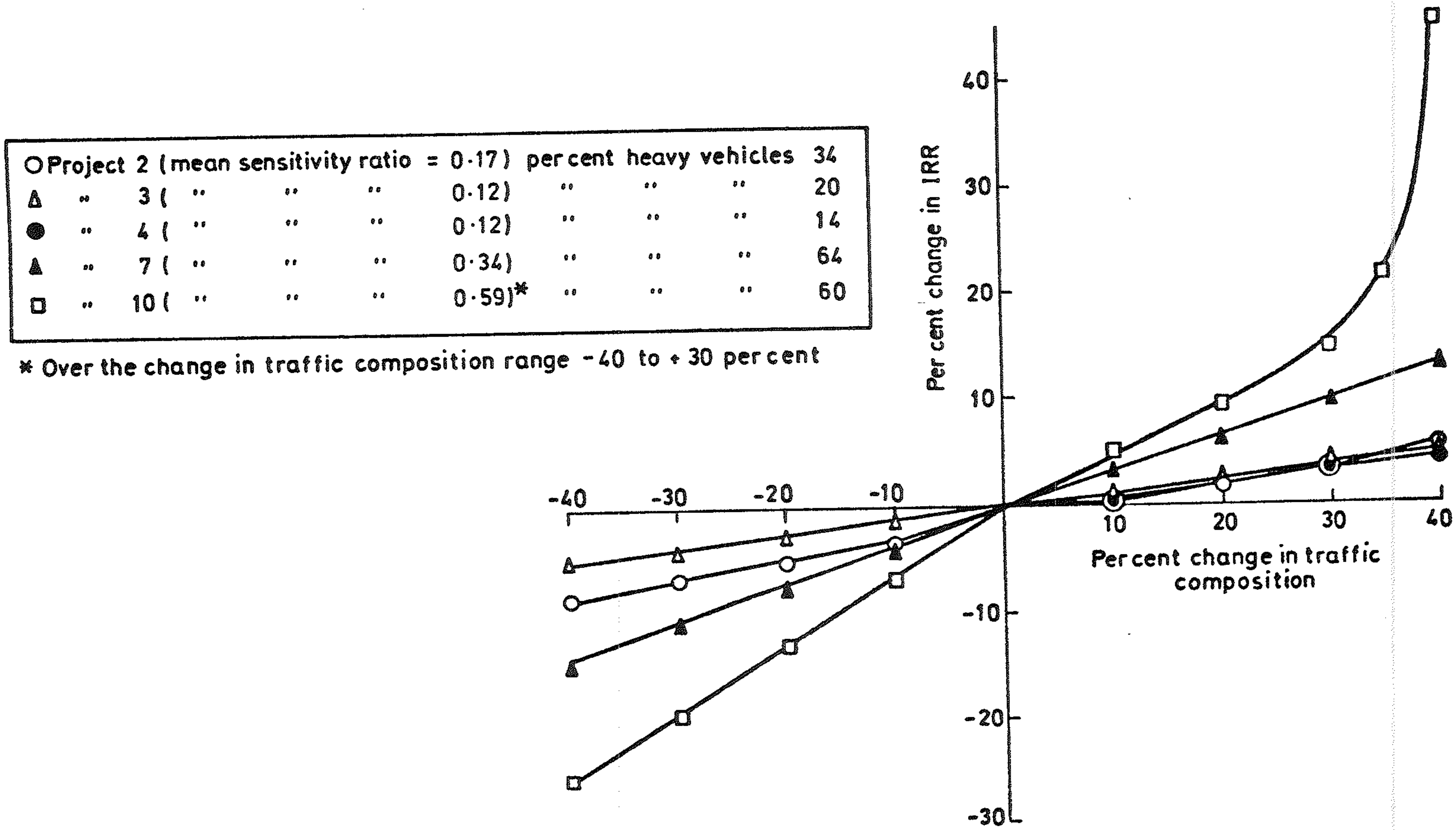

Fig. 3. SENSITIVITY OF THE IRR TO ESTIMATES OF PRESENT TRAFFIC COMPOSITION

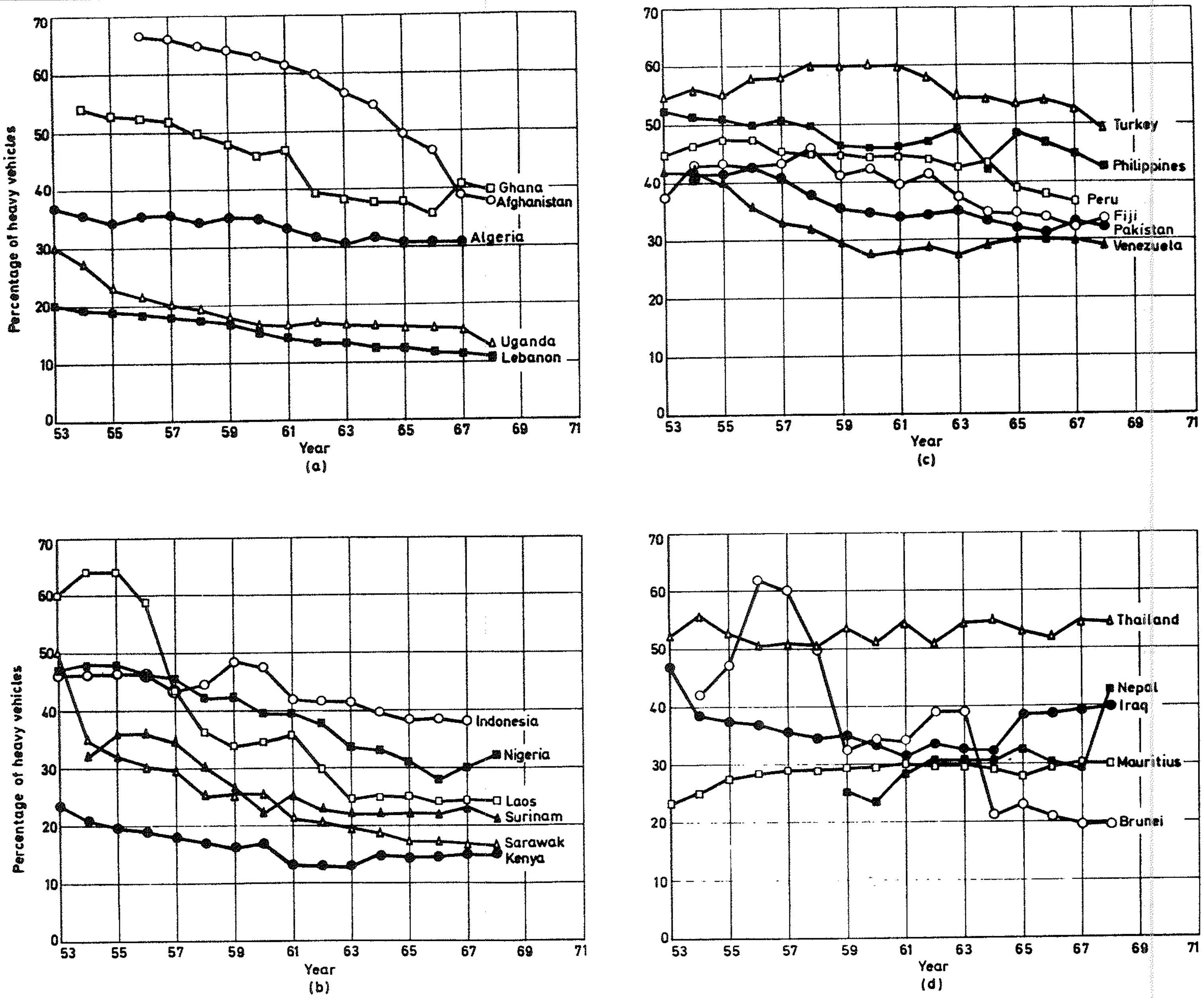

Fig. 5 . TRENDS IN HEAVY VEHICLES AS A PROPORTION OF THE TOTAL VEHICLE YEAR STOCK

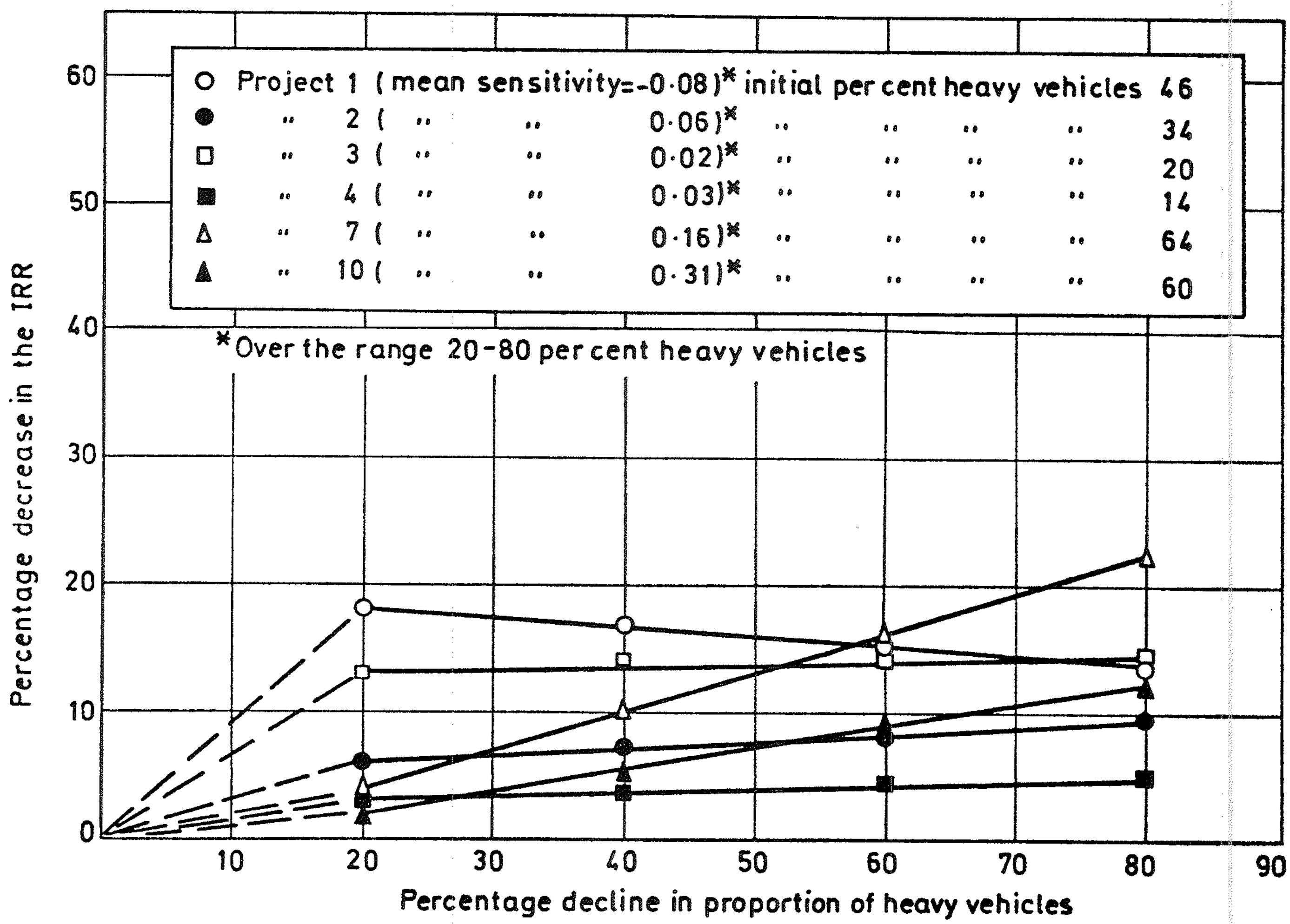

Fig. 6 . SENSITIVITY OF THE IRR TO CHANGES IN TRAFFIC COMPOSITION

Bibliography

The following bibliography contains two sets of references. The first set consists of a reference for each selected text that appeared in the preceding part of this compendium. The second set consists of references to additional publications that either were cited in the selected texts or are closely associated with material that was presented in the overview and selected texts. Each reference has five parts that are explained and illustrated below.

(a) Reference number: This number gives the position of the reference within this particular bibliography. It is used in the compendium index but should ***not*** be used when ordering publications.

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La siguiente bibliografía contiene dos series de referencias. La primera serie consiste en una referencia para cada texto seleccionado que apareció en la parte anterior de este compendio. La segunda serie consiste en referencias a publicaciones adicionales que fueron mencionadas en los textos seleccionados o que se asocian íntimamente con el material que se presentó en la vista general y los textos seleccionados. Cada referencia tiene cinco partes que se explican y se ilustran abajo.

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(e) Analyse : ce paragraphe est une analyse du texte dont le titre est cité dans la partie (b).

Illustration (from Comp. 1) **Ilustración** (del Comp. 1) **Illustration** (du Recueil 1)

(a) Reference number
(a) Número de referencia → Reference 5
(a) Numéro de la référence

(b) Title
(b) Título → A REVIEW OF HIGHWAY DESIGN PRACTICES IN DEVELOPING COUNTRIES
(b) Titre

(c) Bibliographic data
(c) Datos bibliográficos → Cron, Frederick W. Washington, DC: International Bank for Reconstruction and Development; 1975 May. 57 p.
(c) Données bibliographiques

(d) Availability information
(d) Disponibilidad de la información → Order from: International Bank for Reconstruction and Development, 1818 H Street, N.W., Washington, DC 20433.
(d) Disponibilité des documents

(e) Abstract
(e) Resumen → The design standards of some 150 highway projects financed by the International Bank for Reconstruction and Development between 1960 and 1970 are reviewed, and areas of agreement between the standards of the 63 countries studied are identified; practical highway standards based on these areas of agreement are sketched for the guidance of planners in developing countries. The roads discussed here, fall into three functional categories: a small group of expressways, freeways and toll roads carrying large volumes of traffic; a very large group of 2-lane highways carrying a wide range of traffic volumes serving both local and long distance traffic; and a smaller group of low-traffic tertiary or special purpose roads existing primarily for land service. Comments are made on the problem of classifying highway standards, and on the comparison of standards. Conclusions regarding standards for the capacity- related elements of design and standards for the velocity-related elements of design (radius of curvature, stopping sight distance, passing sight distance) are discussed, as well as the horizontal and vertical clearances for bridges. The standard live loadings for bridges, the structural capacity of pavements and legal load limits are covered, and conclusions relating to pavement design, design standards for 2-lane highways, incremental development of highways, and levels of service are presented.
(e) Analyse

The order should include all information given in parts (b) and (c) above.

El pedido deberá incluir toda la información dada en las partes (b) y (c).

L'ordre de commande doit inclure toutes les informations données dans les parties (b) et (c).

SELECTED TEXT REFERENCES

Reference 1
ECONOMIC AND FINANCE COMMITTEE REPORT

Permanent International Association of Road Congresses. Paris, France; 1979; 61 p. (XVIth World Road Congress, Vienna, September 16–21, 1979).

Order from: Permanent International Association of Road Congresses, Secretariat, British National Committee, St. Christopher House, Southwark Street, London SE1 0TE.

This report presents four papers. The first paper, Indirect Effects of New Road Links on Urban Living Conditions, describes a study that proposes a process of analysis and quantification of the inconvenience caused to the community by the destruction of buildings or open spaces of high value, as well as the effects of dislocation. The second paper, The Economic Issues of Highway Maintenance (Selected Text No. 1), links the level of maintenance to traffic volume by economically balancing the extra costs associated with improvement in service against the extra benefits. The approach described in the paper is designed to determine the correct level of expenditure for maintenance, the standards to be achieved, and an appropriate assessment method. The third paper is titled, Choice in Road Investment and Its Execution in Developing Countries, By Reference, to Costs in Hard Currency, Employment and the Standard of Technology in the Country. The fourth paper consists of three parts: general aspects of operations in highway exploitation, applying calculations of viability to the operations of highway exploitation, and methods of calculation of the viability of operations in highway exploitation. Illustrative examples based on experiences in France are included.

Reference 2
HIGHWAY AND BRIDGE MAINTENANCE: OPERATIONS, COSTS, AND MODELING. 6 REPORTS.

Highway Research Board, Washington DC; 1973; 62 p. (Prepared for the 52nd Annual Meeting; Highway Research Record Number 451).

Order from: Transportation Research Board, Publications Office, 2101 Constitution Avenue, N.W., Washington, DC 20418.

The first report in this publication addresses the problem of inventorying the road system and maintaining low-volume tracks in the Sudan. The survey of Sudan roads attempted to obtain information on soils, drainage, aggregate availability, and vehicle operating costs. The report emphasizes the survey procedure, the related problems, and the evaluation of the technique. The report also discusses maintenance techniques for extending the useful life of existing tracks into the rainy season and providing all-season vehicular transport to central and northern Sudan. The second report Maintenance Costing Method for Low-Volume Roads (Selected Text No. 2) discusses the importance of maintenance as it applies to low-volume roads in developing countries. The decision to pave versus the use of local aggregate to surface roads is discussed, and a method of estimating maintenance and costs as developed for a transportation system planning activity in the Sudan is presented. The report notes that the total cost of the economy in areas of limited road systems varies with the mileage of roads of a particular surface type to be maintained. The third report describes a procedure for simulation modeling of highway maintenance operations. A mowing model was developed that facilitates decision making related to mowing operations; the program developed for the model is a utility program that can be extended to other highway maintenance operations. Three other reports describe the evaluation of equipment utilization and management within the Virginia Department of Highways, an instrument for detecting delamination in concrete bridge decks, and the detection of bridge deck deterioration.

Reference 3
MAIN ROAD MAINTENANCE COSTS

Ministry of Public Works, Transport and Urban Development, Republic of Upper Volta; 1977; 14 p. (Pan African Conference on Highway Maintenance and Rehabilitation, Ghana, November 1977).

Order from: Transport and Road Research Laboratory, Overseas Unit, Crowthorne, Berkshire, RG11 6AU, U.K.

The paper describes earth road and asphalt-surfaced road maintenance procedures in the Upper Volta and includes detailed costs for manual maintenance including the filling of road surface depressions and potholes, clearing of ditches and removal of undergrowth from the right of way, resurfacing, major reshaping, minor reshaping, and special anti-corrugation maintenance. Information is given on the staff required per unit of work, together with details of the equipment needed for both manual and mechanized maintenance and the materials to be used in the operation. Costs are given in each case, leading to the calculation of unit costs and total costs for each type of work. This paper represents the first step in the process of the economic evaluation of maintenance procedures.

Reference 4
EVALUATING THE ECONOMIC PRIORITY OF HIGHWAY MAINTENANCE

Harral, C.G.; Fossberg, P.E.; Watanatada, Thawat. Washington, DC: International Bank for Reconstruction and Development, Transportation Department; 1977; 71 p. and annexes. (Pan African Conference on Maintenance and Rehabilitation, Ghana, November, 1977).

Order from: Transport and Road Research Laboratory, Overseas Unit, Crowthorne, Berkshire RG11 6AU, U.K.

The method for determining the economic impact of different levels of the maintenance effort is described, as well as the Highway Design and Maintenance Standards Model (HDM) (see Reference 22), which was used in the study. The method is based on the theory that economic benefits of highway maintenance expenditures are comprised of three basic components: reductions in user costs, reductions in future maintenance and rehabilitation costs required to provide the same level of service if preventive maintenance is done in a timely manner, and reduction or prevention of the economic loss due to road closures. The effect of the original surface design, material types, volume and axle-load configuration of traffic and climate are all evaluated against the incremental maintenance levels through an assessment of road deterioration. Three case studies are presented that describe the determination of (a) the most economic grading and regravelling policies for unpaved roads, (b) optimum timing (and traffic volume) at which to pave an unpaved road, and (c) the most economic pavement design, maintenance and rehabilitation strategies over a 20-year life cycle of a heavily trafficked paved highway. The study confirms that the economic returns are very high for levels of maintenance well above those currently practiced in most developing countries.

Reference 5
ENGINEERING ECONOMICS OF THE MAINTENANCE OF EARTH AND GRAVEL ROADS

Faiz, Asif; Staffini, Edgardo. Low-Volume Roads: Second International Conference. Washington, DC: Transportation Research Board; 1979; pp. 260–268 (Transportation Research Record 702).

Order from: Transportation Research Board, Publications Office, 2101 Constitution Avenue, N.W., Washington, DC 20418.

This paper presents a methodology for the economic evaluation of maintenance programs for unpaved roads with low traffic volumes (under 250 vpd), a situation commonly encountered in rural areas in developing countries. The technique, drawing heavily on the road deterioration and user cost relationships developed in the IBRD/TRRL Kenya Road Transport Cost Study (see References 17 and 18), involves a dynamic model that relates vehicle operating costs to traffic-induced road deterioration. The proposed methodology requires a two-step procedure: first, to determine economically optimal and technically appropriate maintenance strategies; and second, to apply these strategies to assess the economic value of the global road maintenance program. The incremental economic analysis used in the methodology permits the differentiation of benefits in the form of vehicle operating cost savings between routine periodic maintenance. The use of the evaluation technique is demonstrated by application to a road maintenance program. Although the proposed method requires the use of multiple regression analysis and elementary calculus, graphical methods can be used as an alternative.

Reference 6
EFFECT OF SIMPLE ROAD IMPROVEMENT MEASURES ON VEHICLE OPERATING COSTS IN THE EASTERN CARIBBEAN

Hide, H.; Keith, D. Low Volume Roads: Second International Conference. Washington, DC: Transportation Research Board; 1979; pp. 269–276 (Transportation Research Record 702).

Order from: Transportation Research Board, Publications Office, 2101 Constitution Avenue, N.W.; Washington, DC 20418.

The paper describes the effect on vehicle operating costs of a simple labor-intensive method of rehabilitating and maintaining badly deteriorated bitumen-surfaced roads in the Eastern Caribbean. The techniques developed for the rehabilitation and maintenance of the roads are described, and the equipment, materials, and manpower required are listed. The rehabilitation and maintenance system is a simple one restricted to providing adequate drainage, filling the potholes in the road, and providing a minimum seal over the whole road surface. The reduction in vehicle operating costs resulting from the improvement in the riding quality of the road surface is shown to be sufficient to recover the rehabilitation costs in a very short time even at flows as low as 100 vehicles per day. The majority of the roads included in this scheme are of low strength, have low geometric standards, and have traffic flows ranging from 50 to 1500 vehicles per day. All the roads have been trafficked for at least one year since being rehabilitated and some for two years. During this time little or no damage to the surface has taken place.

Reference 7
OUTLINE OF A GENERALIZED ROAD ROUGHNESS INDEX FOR WORLDWIDE USE

Hudson, W.R. Low-Volume Roads: Second International Conference. Washington, DC: Transportation Research Board; 1979; pp. 249–259 (Transportation Research Record 702).

Order from: Transportation Research Board, Publications Office, 2101 Constitution Avenue, N.W., Washington, DC 20418.

The solution to the problem of providing uniformity in roughness measurements requires a multifaceted approach. The approach outlined in the paper is as follows: (1) develop a Generalized Roughness Index (GRI) that has a sound basis and can provide a pseudo-standard for comparison of all methods; (2) evaluate the use of an artificial calibration method (such as developed by the Transport and Road Research Laboratory) with a variety of instruments and cases to determine its value, problems, and utility; (3) apply the concept of a standard rating panel to provide an additional methodology for defining and reproducing the GRI in countries all over the world without the cost of purchasing a stable profilometer, such as the General Motors device; (4) evaluate the use of rod and level surveys and recommend field equipment to simplify and speed up such surveys for establishing calibration points on a GRI. It is recommended that a GRI be implemented to test these concepts. Cooperation will be needed among several countries and agencies. Particular attention should be given to coordination of research data from the Kenya, Brazil, and India projects in which the World Bank is involved.

Reference 8
A REVIEW OF RURAL TRAFFIC COUNTING METHODS IN DEVELOPING COUNTRIES

Howe, J.D.G.F. Great Britain Road Research Laboratory, Tropical Section; 1972. 10 p. plus tables and graphs (Road Research Laboratory RRL Report LR 427).

Order from: Transport and Road Research Laboratory, Crowthorne, Berkshire RG 11 6AU, U.K.

This report reviews methods of rural traffic counting currently used in developing countries and examines the accuracy of the resulting flow estimates. The results of a questionnaire survey among a sample of developing countries suggest that decisions on the duration, frequency, and timing of counts are at present arbitrary. Consequently, estimated daily traffic flows can rarely be expected to lie within ±30 percent of the true value averaged over the whole year. Although repeating counts at intervals throughout the year increases the accuracy of traffic estimates, this is achieved only at a disproportionate increase in cost. It is concluded that for any appreciable increase in the accuracy of rural traffic estimates much more needs to be known about the magnitude and causes of the variations in flow. This requires that automatic traffic counters be used on a wider scale than at present.

Reference 9
THE SENSITIVITY TO TRAFFIC ESTIMATES OF ROAD PLANNING IN DEVELOPING COUNTRIES

Howe, J.D.G.F. Great Britain Transport and Road Research Laboratory, Overseas Unit; 1973; 15 p. plus graphs (TRRL Report LR 516).

Order from: Transport and Road Research Laboratory, Crowthorne, Berkshire, RG11 6AU, U.K.

This report analyzes the sensitivity to traffic estimates of rural road planning decisions in developing countries. Consideration was given to decisions concerning the annual amounts spent on maintaining each section of road, the economic justification of road improvements, and the selection of road design standards and hence construction costs. The report shows how each of these decisions is sensitive to the traffic parameters used in making them. Many of the traffic parameters are shown to be subject to large errors due to the estimating methods currently in use. This is particularly the case with estimates of induced traffic likely to result from road improvements and the forecasts made of all future traffic for planning and designing road improvements. The analysis stresses the need for improvements in traffic estimation methods and for further research into the fundamental characteristics of rural traffic in developing countries.

ADDITIONAL REFERENCES

Reference 10
CONSEQUENCES OF DEFERRED MAINTENANCE

Transportation Research Board, Washington, DC: 1979; 24 p. (National Cooperative Highway Research Program Synthesis of Highway Practice 58).

Order from: Transportation Research Board, Publications Office, 2101 Constitution Avenue, N.W., Washington, DC 20418.

This synthesis, which will be useful to maintenance engineers and highway administrators, presents information on the economic, energy, esthetic, and safety impacts of deferring maintenance on highway facilities. New management concepts are evolving and factors important to highway administrators in formulating maintenance strategies are noted. Recent studies have attempted to quantify maintenance needs, develop maintenance strategies, and set priorities. Maintenance service levels must be defined and practical field measurement systems designed to identify and quantify deferred maintenance. A distinction can be made between (a) deferring physical maintenance that is cumulative and ultimately must be done if the facility is to be restored to good condition and (b) deferring, reducing, or eliminating maintenance activities that affect primarily esthetic or functional characteristics of the highway. An area that requires research is that of maintenance vs. reconstruction and, specifically, the costs and benefits of various levels of maintenance. Four different rehabilitation strategies for pavement evaluation in Utah are discussed. An example of a maintenance impact assessment procedure applied to structures was provided by a Minnesota study. Impacts on drainage, services, energy, and design are also discussed.

Reference 11
RECORDING AND REPORTING METHODS FOR HIGHWAY MAINTENANCE EXPENDITURES

Transportation Research Board, Washington, DC: 1977. 35 p. (National Cooperative Highway Research Program Synthesis of Highway Practice 46).

Order from: Transportation Research Board, Publications Office, 2101 Constitution Avenue, N.W., Washington, DC 20418.

A maintenance management information system is described that provides basic information needed by operating managers for routine decisions and by top management for program control and improvement. The system should contain data recorded at the field level and reports generated by computer, that assemble and analyze the data. The types of reports generated should fit the end use of the report at a particular management level. The systems used by 11 states were studied and two types of recording systems were identified: the single recording system which uses one procedure for reporting both maintenance and management information and payroll and accounting information, and the parallel recording system, which uses separate reports for this information. Their respective advantages and disadvantages are noted. Recording of work location (by milepost or highway segment) would allow maintenance data to be correlated with other data systems including condition surveys, skid studies, photologging, etc. The recording of time (in man-hours), equipment, and material quantities are also discussed. Among the recommendations are (a) a recording and reporting system must provide for internal management needs; (b) the system should furnish maintenance information to the pavement management and other management systems; (c) the recording system must stress accuracy; (d) reports for district and central offices must be made monthly; (e) a standing committee on maintenance standards or maintenance management should exist in every state.

Reference 12
MAINTENANCE SYSTEMS: ESTIMATING MAINTENANCE COSTS, SOLID-WASTE DISPOSAL SYSTEMS, MAINTENANCE STATION LOCATIONS, MANAGER TRAINING, AND EQUIPMENT MANAGEMENT. 7 REPORTS.

Highway Research Board, Washington, DC; 1972; 51 p. (prepared for the 51st Annual Meeting; Highway Research Record Number 391).

Order from: University Microfilms International, 311 North Zeeb Road, Ann Arbor, Michigan 48106.

The reports presented in this record focus on the application of systems logic to the selection of maintenance policy and are concerned with minimizing the cost of transportation while maximizing the use of the maintenance dollar, determining current and future equipment needs, and developing a regional approach to the problem of solid-waste disposal at recreational facilities and along highways. The first report, Predicting Maintenance Cost for Use in Trade-Off Analysis, suggests that it is erroneous to measure highway maintenance costs without reference to other factors and that maintenance costs are directly related to design and operation of highways. A maintenance cost model is described. It is part of a total-cost model that has potential for use in predicting maintenance costs. The second paper presents an analysis of solid-waste disposal methods. The problems of storing, collecting, transporting, and disposing of refuse in rural areas are examined, and a mathematical model example is included. The use of optimization models to determine where maintenance stations can most economically be located is discussed in the third report. A sanding and plowing model is given, and it is suggested that this technique could be applied successfully to other maintenance functions. Two abridged reports discuss the general applicability of systems logic to maintenance programs and the training program for highway maintenance managers. A detailed study of equipment management is presented in the seventh report. The eighth report, Repair Shop Work Reporting Procedure, notes that employee morale and productivity were improved by applying performance standards to repair shop activities.

Reference 13
MAINTENANCE PLANNING AND SUPERVISION. 32 REPORTS.

Highway Research Board, Washington, DC; 1971; 229 p. (Highway Research Record Number 347).

Order from: University Microfilms International, 300 North Zeeb Road, Ann Arbor, Michigan 48106.

This record reports a maintenance management workshop that discussed problems and solutions to problems encountered in implementing and utilizing management reporting systems, maintenance levels, performance standards, organizational structures, and training. Among the aspects that were highlighted in the reports was the fact that reporting systems must be flexible enough to accommodate the changing input and output needs of management. The management system must be conceived as a team effort. An outstanding problem is the turn-around time needed to process the data into a meaningful report. The methodology of setting and evaluating roadway service levels is discussed. The legal ramifications of formalized maintenance levels that affect safety were discussed. The relationship of maintenance levels as a variable to other fixed components of a maintenance management system is described. The skillful use of interdisciplinary experts, a statistical approach to the method of measuring the quality of highway maintenance, and the development of quality standards are also covered. A British method to measure productivity is described, and it is noted that program budgeting in maintenance can be made into a practical management process if performance standards are used. A project is being developed by the Highway Research Board [NCHRP Project 19-2(4)] based on the use of a unique card system for controlling allocations of resources in conjunction with the use of a work order form to control expenditures. The impact of improved communications on hierarchical organizational structures is examined, and programs in Louisiana, Wisconsin, and Pennsylvania are described.

Reference 14
PERFORMANCE BUDGETING SYSTEM FOR HIGHWAY MAINTENANCE MANAGEMENT

Highway Research Board, Washington, DC; 1972; 213 p (National Cooperative Highway Research Program Report 131).

Order from: Transportation Research Board, Publications Office, 2101 Constitution Avenue, N.W., Washington, DC 20418.

A complete model system for highway maintenance budgeting and management is described. The model consists of the following interrelated elements: maintenance program development, budget preparation and evaluation; fiscal authorizations, work programs authorization and operations control, and fiscal control. The model system presents basic concepts, procedures, and relationships within which there are numerous options for selection of specific criteria and standards and alternatives as to techniques and procedures. The model system was developed in accordance with five basic criteria: establishment of maintenance levels; definition of work load; determination of resource requirements; procedures for management planning, evaluation, and control; records and reports to serve the budget system; and simplicity and economy of installation and operation. This report provides background information on current practices and developments in performance budgeting techniques and an evaluation of the state of the art. The report also provides a comprehensive explanation of the concepts and processes of the model performance budgeting system, as well as an explanation of the application of the model system to a highway agency, including procedures for development and implementation, problems likely to be encountered, and potential benefits to be derived.

Reference 15
QUANTIFICATION OF ROAD USER SAVINGS

De Weille, Jan. Washington, DC: International Bank for Reconstruction and Development; 1966; 93 p. (World Bank Staff Occasional Papers Number Two).

Order from: International Bank for Reconstruction and Development, 1818 H Street, N.W., Washington, DC 20433.

This paper attempts to give a generally accepted and more homogeneous approach to the problem of calculating vehicle operating costs. The study deals with road user savings resulting from an improvement in the quality of a road. The difference between road user costs if the road construction were undertaken and those if it were not undertaken constitute road user savings for each vehicle concerned. Total road user savings resulting from the road improvement are calculated by applying estimates of the number of vehicles of different categories. The technical relationships relevant for the ultimate determination of unit road user savings focus largely on the type of vehicle, the type of road surface, and the running speed of the vehicle. Attention is also given to the rise and fall and the curvature of the road. Representative types of vehicles were selected for the study and operating costs were broken into the following: fuel consumption, engine oil consumption, tire wear, depreciation and interest, maintenance, and occupant's (or driver's) time. "Indicative" prices were established for the various cost items. Basic tables present physical or technical relationships determining road user costs under various conditions, as well as the "indicative" prices. These data are then combined in an overall view of road user costs and savings as they relate to the state of the road and the assumptions made as to speed. The limitations inherent in the study, the role of speed and its influence on several aspects of the study, as well as qualifications that attach to the study results, are discussed (see Reference 21).

Reference 16
TECHNIQUES FOR MEASURING VEHICLE OPERATING COST AND ROAD DETERIORATION PARAMETERS IN DEVELOPING COUNTRIES

Abaynayaka, S.W. Low-Volume Roads. Transportation Research Board, Washington, DC; 1975; pp. 302–310. (Special Report 160).

Order from: Transportation Research Board, Publications Office, 2101 Constitution Avenue, N.W., Washington, DC 20418.

Field investigations into the behavior and operating characteristics of traffic and the behavior and deterioration patterns of the road require the use of instruments to make and record measurements for analysis. This paper describes some available techniques for measuring vehicle operating cost and road deterioration parameters with suggestions for simplifying the measurement technique in the light of the technological resources, manpower, and facilities available in developing countries. An instrumented vehicle that rapidly measures the permanent features of the road in terms of horizontal and vertical curvature and road width is described, and methods of measuring the variable features resulting from traffic and the changing pavement condition are discussed.

Reference 17
THE KENYA ROAD TRANSPORT COST STUDY: RESEARCH ON VEHICLE OPERATING COSTS

Hide, H.; Abaynayaka, S.W.; Sayer, I.; Wyatt, R.J. Great Britain Transport and Road Research Laboratory, Overseas Unit; 1975. 70 p. plus charts. (TRRL Laboratory Report 672).

Order from: Transport and Road Research Laboratory, Crowthorne, Berkshire RG11 6 AU, U.K.

This report describes an investigation undertaken in Kenya to examine the effects of various road, vehicle, and environmental parameters on some components of vehicle operating costs. The investigation was undertaken jointly with the International Bank for Reconstruction and Development. The field work was carried out in two parts -- an experimental study of vehicle speed and fuel consumption and a road user survey. The two studies are reported in separate sections, and the results are combined to produce a set of relationships for estimating the effects of road geometry, surface condition, and vehicle age on the components of vehicle operating cost. All components are defined in either quantity or nondimensional terms, and the actual cost is obtained by applying the appropriate unit cost prevailing at a particular time. The relationships derived from this study have been incorporated in the Road Transport Investment Model. (See Reference 5.)

Reference 18
THE KENYA ROAD TRANSPORT COST STUDY: RESEARCH ON ROAD DETERIORATION

Hodges, J.W.; Rolt, J.; Jones, T.E. Great Britain Transport and Road Research Laboratory, Overseas Unit; 1975; 56 p. (TRRL Laboratory Report 673).

Order from: Transport and Road Research Laboratory, Crowthorne, Berkshire RG11 6AU, U.K.

This report describes a study of the performance of paved and unpaved roads that was undertaken in Kenya as part of a larger study designed to provide suitable relationships for use in a computer model capable of estimating the construction costs, maintenance costs, and road user costs throughout the life of a road in a developing country. The paved-road sample consisted of 39 sections located on surface-dressed roads with cement-stabilized bases and 10 sections located on asphaltic concrete roads with crushed stone bases. The unpaved-road sample consisted of 38 test sections located on properly engineered gravel roads (lateritic, quartzitic, volcanic, and coral) and eight sections on earth roads. The deterioration of the surface of the paved roads was quantified in terms of surface roughness, amount of cracking, and depth of ruts. These parameters together with the transient deflections and the CBR and the moisture content of the various pavement layers were monitored for a period of up to four years. The deterioration of unpaved roads was quantified in terms of surface roughness, depth of ruts, depth of loose surface material, and the thickness of the gravel layer. These parameters were monitored for a period of two years. The deterioration of the roads was related to the traffic loading, the original design and construction standard of the roads, the maintenance policy in use, and the environmental conditions.

Reference 19
A ROAD TRANSPORT INVESTMENT MODEL FOR DEVELOPING COUNTRIES

Robinson, R.; Hide, H.; Hodges, J.W.; Rolt, J.; Abaynayaka, S.W. Great Britain Road Research Laboratory, Overseas Unit; 1975; 63 p. plus charts. (TRRL Laboratory Report 674).

Order from: Transport and Road Research Laboratory, Crowthorne, Berkshire RG11 6AU, U.K.

The report describes the development of a model that can be used to aid investment decisions within the roads sector in developing countries. The Report is aimed at senior administrators, engineers and planners and at those responsible for developing improved techniques for road investment appraisal. The model calculates the construction cost of a road and predicts the condition of the road as time passes and vehicles travel along it. Having predicted the condition of the road, the model estimates the costs of road maintenance and the cost of operation of the vehicles for each year. All these costs are then discounted back to the base year and summed over the life of the road to obtain the total cost. All estimates are made in terms of physical quantities and costs are obtained by applying unit rates to these. The model is very flexible and can be used to study the economics of varying stage construction alternatives such as upgrading an earth road to a gravel or paved road at any time during the design life. The report describes the construction, road deterioration, road user cost and road maintenance sub-models and then looks at a case study of a road in Kenya.

Reference 20
TABLES FOR ESTIMATING VEHICLE OPERATING COSTS ON RURAL ROADS IN DEVELOPING COUNTRIES

Abaynayaka, S.W.; Hide, H.; Morosiuk, G.; Robinson, R. Great Britain Transport and Road Research Laboratory, Overseas Unit; 1976; 59 p. (TRRL Laboratory Report 723).

Order from: Transport and Road Research Laboratory, Crowthorne, Berkshire RG11 6AU, U.K.

Tables are provided for estimating vehicle operating costs by component on free-flowing low volume rural roads in developing countries. They provide a convenient and easy reference manual for road appraisal and investment studies. The components evaluated are fuel and oil consumption, maintenance parts and labor charges, tire wear, depreciation, crew costs, and standing charges. They are estimated on a quantity or non-dimensional basis so that costs can be determined for any monetary system or environment by applying the appropriate set of unit rates. Operating costs may be estimated for different road geometries, surface condition, and altitude and for vehicles of different types with different prices, ages, loads, and engine power. The tables are based on research carried out in Kenya by the Overseas Unit of TRRL in collaboration with the International Bank for Reconstruction and Development. Examples are given for paved, gravel, and earth road surfaces.

Reference 21
AN IMPROVED DATA BASE FOR ESTIMATING VEHICLE OPERATING COSTS IN DEVELOPING COUNTRIES

Hide, H. Great Britain Transport and Road Research Laboratory, Overseas Unit; 1976; 25 p. (TRRL Supplementary Report 223 UC).

Order from: Transport and Road Research Laboratory, Crowthorne, Berkshire RG11 6AU, U.K.

This report describes an investigation undertaken by the Transport and Road Research Laboratory in cooperation with the International Bank for Reconstruction and Development (IBRD) in Washington to compare the data base of the vehicle operating cost relationship derived in the joint TRRL/IBRD Kenya road transport cost study with that of the World Bank Staff Occasional Paper No. 2 "Quantification of Road User Savings". (See References 15, 17, 18.)

Reference 22
HIGHWAY DESIGN AND MAINTENANCE STANDARDS MODEL: MODEL DESCRIPTION AND USERS MANUAL

International Bank for Reconstruction and Development. Washington, DC; June 1979. Variable paging.

Order from International Bank for Reconstruction and Development, Transportation, Water and Telecommunications Department, 1818 H Street, N.W., Washington, DC 20433.

The Highway Design and Maintenance (HDM) model predicts the costs of different highway design and maintenance options, including different time-staging strategies, either for a given road project or a specific alignment or for groups of links of an entire highway network. It can quickly estimate the total costs for large numbers of alternative project designs and maintenance policies on a year-by-year basis for up to 30 years and thus be used to search for the alternative with the lowest total cost. The model can evaluate, in the same computer run, up to 20 different road links, each with up to 10 segments with different design standards and environmental conditions. Each link can have a different traffic volume. Up to eight different maintenance policies can be implemented on each segment of the road. Each link or segment can be upgraded at anytime in the life-cycle of the project. The model provides the results of economic analysis for the comparison of two alternatives or groups of alternatives. Vehicle speeds and operating costs and road deterioration and maintenance costs are internally estimated by the model as a function of the road design and maintenance standards, traffic, and environmental conditions. Within the model framework and the limitations of the underlying empirical relationships, the model can be employed in a variety of applications ranging from project-level pre-feasibility and feasibility studies to highway sector resource-allocation planning. The model, which is coded in Fortran IV, requires basic software features available in most major Fortran IV computers. This manual provides a detailed account of the underlying empirical relationships and computational procedures employed in the model. A detailed description is also provided of the preparation of input data and the different kinds of reports generated by the model on economic analysis results, financial expenditures, road user costs, road surface conditions, and maintenance quantities performed and costs. (See Reference 4.)

Reference 23
ROAD NOTE 40; A GUIDE TO THE MEASUREMENT OF AXLE LOADS IN DEVELOPING COUNTRIES USING A PORTABLE WEIGHBRIDGE

Great Britain Transport and Road Research Laboratory, Crowthorne, U.K. 1978; 19 p. plus photographs.

Order from: Her Majesty's Stationary Office, 49 High Holborn, London WC1V 6HB, U.K.

This note gives guidelines for using the Overseas Unit Weighbridge for carrying out axle-load surveys on paved roads in developing countries and incorporates the results of experience gained in axle-load surveys in many parts of the world. The equipment consists of an aluminum alloy weighing platform, reading unit, and a 12-volt car battery. The complete system has a measuring range of 0–10 000 kg and, under field conditions of use, has an overall accuracy of + or - 2 percent of full scale. The equipment is not adversely affected by high temperatures or humidities. This note discusses the selection of the survey site, the installation of the equipment, and the various steps of the survey including traffic counting and axle weighing. A computer program to analyze the results is described.

Reference 24
ROAD NOTE 31: A GUIDE TO STRUCTURAL DESIGN OF BITUMEN-SURFACED ROADS IN TROPICAL AND SUBTROPICAL COUNTRIES

Great Britain Transport and Road Research Laboratory. Crowthorne, U.K.; 1977; 26 p. (Third Edition).

Order from: Her Majesty's Stationary Office, 49 High Holborn, London WC1V 6 HB, U.K.

This guide covers design requirements of most non-urban roads in developing countries. Traffic is defined in terms of the cumulative equivalent number of 8200-kg (18 000-lb) axles to be carried during the design life of the roads. Thus, this guide may be used to design pavements for traffic flows with widely different axle-load distributions and gives the designer greater flexibility in selecting the design life of the pavement. The guide emphasizes the importance of detailed consideration of the influence of tropical climates on moisture conditions in road subgrades, and the desirability of adopting a stage construction approach to road building where traffic growth rates are high, or long-term predictions are uncertain. The details are given of the three main steps to be followed in designing a new road pavement: estimating the amount of traffic (and its axle-load distribution) that will use the road over the selected design life; assessing the strength of the subgrade soil over which the road is built; and taking into consideration the influence of subgrade moisture and the stage-construction approach in selecting the most economical combination of pavement materials and layer thickness that will be sufficient to provide satisfactory service over the design life of the pavement. A French translation of this publication is available.

Index

The following index is an alphabetical list of subject terms, names of people, and names of organizations that appear in one or another of the previous parts of this compendium, i.e., in the overview, selected texts, or bibliography. The subject terms listed are those that are most basic to the understanding of the topic of the compendium.

Subject terms that are not proper nouns are shown in lower case. Personal names that are listed generally represent the authors of selected texts and other references given in the bibliography, but they also represent people who are otherwise identified with the compendium subjects. Personal names are listed as surname followed by initials. Organizations listed are those that have produced information on the topic of the compendium and that continue to be a source of information on the topic. For this reason, postal addresses are given for each organization listed.

Numbers that follow a subject term, personal name, or organization name are the page numbers of this compendium on which the term

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Indice

El siguiente índice es una lista alfabética del vocablo del tema, nombres de personas, y nombres de organizaciones que aparecen en una u otra de las partes previas de este compendio, es decir, en la vista general, textos seleccionados, o bibliografía. Los vocablos del tema que aparecen en el índice son aquellos que son necesarios para el entendimiento de la materia del compendio.

Los vocablos del tema que no son nombres propios aparecen en letras minúsculas. Los nombres personales que aparecen representan los autores de los textos seleccionados y otras referencias dadas en la bibliografía, pero tambien pueden representar a personas que de otra manera están conectadas a los temas del compendio. Los nombres personales aparecen con el apellido seguido por las iniciales. Las organizaciones nombradas son las que han producido información sobre la materia del compendio y que siguen siendo fuentes de información sobre la materia. Por esta razón se dan las direcciones postales de cada organización que aparece en el índice.

Los numeros que siguen a un vocablo del tema, nombre personal, o nombre de organizacion son los numeros de página del compendio donde el vocablo o nombre aparecen. Los números romanos se refieren a las páginas en la vista general, los numeros arábigos se refieren a paginas en los textos seleccionados, y los números de referencia (por ejemplo, Ref. 5) indican referencias en la bibliografía.

Algunos vocablos del tema y nombres de organizaciones estan seguidos por la palabra ***see.*** En tales casos los numeros de pagina del com-

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Index

Cet index se compose d'une liste alphabétique de mots-clés, noms d'auteurs, et noms d'organisations qui paraissent dans une section ou une autre de ce recueil, c'est à dire dans l'exposé, les textes choisis, ou la bibliographie. Les mots-clés sont ceux qui sont le plus élémentaires à la compréhension de ce recueil.

Les mots-clés qui ne sont pas des noms propres sont imprimés en minuscules. Les noms propres cités sont les noms des auteurs des textes choisis ou de textes de référence cites dans la bibliographie, ou alors les noms d'experts en la matière de ce recueil. Le nom de famille est suivi des initiales des prénoms. Les organisations citées sont celles qui ont fait des recherches sur le sujet de ce recueil et qui continueront à être une source de documentation. Les adresses de toutes ces organisations sont incluses.

Le numéro qui suit chaque mot-clé, nom d'auteur, ou nom d'organisation est le numéro de la page où ce nom ou mot-clé parait. Les numéros or name appears. Roman numerals refer to pages in the overview, Arabic numerals refer to pages in the selected texts, and reference numbers (e.g., Ref. 5) refer to references in the bibliography.

Some subject terms and organization names are followed by the word ***see.*** In such cases, the compendium page numbers should be sought under the alternative term or name that follows the word ***see.*** Some subject terms and organization names are followed by the words ***see also.*** In such cases, relevant references should be sought among the page numbers listed under the terms that follow the words ***see also.***

The foregoing explanation is illustrated below.

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pendio se encontrarán bajo el término o nombre alternativo que sigue a la palabra ***see.*** Algunos vocablos del tema y nombres de organizaciones están seguidos por las palabras ***see also.*** En tales casos las referencias pertinentes se encontrarán entre los números de página indicados bajo los términos que siguen a las palabras ***see also.***

La explicación anterior está subsiguientemente ilustrada.

écrits en chiffres romains se rapportent aux pages de l'exposé et les numéros écrits en chiffres arabes se rapportent aux pages des textes choisis. Les numéros de référence (par exemple, Ref. 5) indiquent les numéros des références de la bibliographie.

Certains mots-clés et noms d'organisations sont suivis du terme ***see.*** Dans ces cas, le numéro des pages du recueil se trouvera après le mot-clé ou le nom d'organisation qui suit le terme ***see.*** D'autres mots-clés ou noms d'organisations sont suivis des mots ***see also.*** Dans ce cas, leurs références se trouveront citées après les mots-clés qui suivent la notation ***see also.***

Ces explications sont illustrées ci-dessous.

Illustration (from Comp. 1) **Ilustración** (del Comp. 1) **Illustration** (du Recueil 1)