

ROAD USER COSTS
AND THE INFLUENCE OF PAVEMENT TYPE
- A PERSPECTIVE

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EXECUTIVE SUMMARY

The costs incurred by motorists while operating vehicles on highway facilities are referred to as Road User Costs. These costs include Vehicle Operating Costs, Accident Costs and Travel-Time Delay Costs. There is a growing interest among researchers and various state transportation agencies to quantify the contribution of road user costs in total Life Cycle Cost (LCC) analysis of pavements. There also is a need to evaluate the relationship between high impact road user costs and pavement type and condition. Knowledge about these areas will provide important information necessary for making better decisions regarding highway rehabilitation and construction, and an appropriate selection of pavement materials.

This report provides a review of recent user cost developments, and the philosophies and approaches to the computation of various components of user costs in relation to different types of pavements. The three main components of user costs, Vehicle Operating Costs, Accident Costs, and Travel-Time Costs are addressed separately and factors contributing to each of these are discussed. A summary of all such factors contributing to road user costs is furnished. The available research literature is synthesized to provide an indication of the state-of-the-art of research in this area. The applicability of the results of such research to current benefit-cost analysis procedures also is discussed.

The results of the study include a subjective assessment of the contribution of each major user cost factor to total user cost. A user cost component impact matrix is developed based on the literature study and a qualitative analysis performed by experts at the Texas Transportation Institute. Specific conclusions and recommendations are drawn from this information.

The major conclusions of the research are summarized as follows:

- * General relationships between user costs and pavement type and pavement condition have not been studied to any significant extent.

- * Current research results are not easily incorporated into existing benefit-cost and life cycle cost analysis procedures and programs.
- * Theory and limited research findings suggest that concrete pavements reduce fuel consumption costs compared to asphalt pavements.
- * Reduction of rehabilitation time can correspondingly reduce user costs over the life of the pavement.

Based on these major conclusions, recommendations for specific research in the area of user costs are offered, especially in relation to the influence of pavement type. Conclusive work in the areas suggested could have a significant impact on the selection of pavement type for a range of pavement construction/rehabilitation projects. The highest priority research area is:

- * Examine fuel consumption costs as related to pavement type and condition.

Other research areas that need immediate attention are:

- * Examine travel-time delay costs encountered during maintenance/repair activities for various types of pavements.
- * Examine truck tire wear costs as related to pavement type and condition.
- * Identify innovative rehabilitation techniques that will reduce rehabilitation time and therefore, reduce work zone delay costs.

Background evidence, conclusions, and recommended research areas are discussed in depth in this report.

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Chapter 1

INTRODUCTION

The costs incurred by motorists while operating vehicles on a highway are referred to as Road User Costs. These costs constitute a major component of pavement life cycle costs. User costs typically include Vehicle Operating Costs, Travel-Time Delay Costs, Accident Costs and costs incurred by road users due to deferral of maintenance of a highway. This report reviews recent user cost developments and the philosophies and approaches to the computation of various components of user costs in relation to different types of pavements. Various factors contributing to each user cost component are identified. Pertinent literature was obtained through the Transportation Research Information Services (TRIS), Highway Research Information Service (HRIS), and the Texas Transportation Institute.

The primary purpose of this research is to identify various road user cost components considered in a life cycle cost analysis and to review their impact on total user cost as related to the choice of a particular pavement type. The principal study objectives are:

1. Review recent developments in the evaluation of user costs;
2. Assess the impact of individual user cost components on total user cost; and
3. Evaluate the influence of pavement type and pavement condition on various components of user costs as described in current research.

Conclusions are drawn and recommendations are provided for conducting further research based on a synthesis of the existing literature and opinions of experts at the Texas Transportation Institute.

The study focuses on recent investigations by researchers in the developed nations. The methodology used to perform the literature evaluation is described in Chapter 2. Chapter 3 provides a brief discussion of current life cycle cost analysis techniques and the manner in which user costs are incorporated into this analysis. A synthesis of current approaches to evaluating

road user costs is presented in Chapter 4. Chapter 5 describes the impact that user cost components have on total user costs in relation pavement type and condition. This chapter offers several areas for further research and a time table for conducting the proposed research. The last chapter summarizes the study results by citing both general and specific conclusions and key recommendations.

Chapter 2

RESEARCH METHODOLOGY

This chapter describes the methodology for conducting the literature review in the area of user cost analysis. It explains the approach used in performing the literature search, examining articles, and drawing conclusions.

2.1 Literature Search

The procedure followed to obtain articles and papers relevant to the area being investigated included the following steps:

1. Obtain a list of articles in the same and/or relevant area by performing a keyword search. Some important keywords are: pavements, pavement management, pavement economics, cost analysis, benefit-cost analysis, life cycle cost, user cost, delay, fuel consumption, vehicle operating cost, accident cost, travel-time, running cost, congestion cost and so on. At this stage the list included approximately 750 articles, research documents, Transportation Research Board (TRB) publications.
2. Short-list the articles based on their titles. Approximately 80 percent reduction occurred in this manner. The initial short-listing had to be carried out by titles due to the large volume of literature received from the keyword search.
3. Obtain the remaining 20 percent of the articles in their original, photocopied, microfiche, or abstract form. This was possible through the various literature databases listed below.
4. Short-list the articles obtained in step 3 further for more pertinent ones. Approximately 140 articles, most of them in the form of abstracts, were reviewed to obtain those that specifically pinpointed the area to be investigated.

5. Use the remaining articles (approximately 45) for review purposes. Each of these articles is then summarized in the annotated bibliography.
6. Use the bibliographies of selected articles to expand the database. This way those articles not accessed by the initial keyword search, if any, are covered.

A major source of various research abstracts is the Transportation Research Information Services (TRIS). TRIS is a computer-based research information storage and retrieval system maintained and operated by the Transportation Research Board (TRB). It is a conceptual umbrella file for a conglomerate of subfiles covering various modes and aspects of transportation. Consisting of more than 250,000 abstracts of published works and summaries of research projects in progress, TRIS enables its users to be connected with the most complete transportation research database available. There are three principal active subfiles of TRIS:

1. Highway Research Information Service (HRIS) - Sponsored by the state highway and transportation departments and the Federal Highway Administration, USDOT
2. Urban Mass Transportation Research Information Service (UMTRIS) - Sponsored by the Urban Mass Transportation Administration, USDOT
3. Transportation Library Subfile (TLIB) - Supplied by the Northwestern University Transportation Library and The Institute of Transportation Studies Library, University of California, Berkeley

All the information was obtained by on-line retrieval from these databases through DIALOG Information Services, Inc.

Other sources of articles and research abstracts were:

1. NOTIS, Texas A&M library database
2. Texas Transportation Institute (TTI) library
3. Personal libraries of researchers at TTI

Articles and reports not available at the Texas A&M University library or the Texas Transportation Institute library were obtained from outside sources through the Inter Library

Services at Texas A&M. The literature search was conducted with the assistance of research librarians at TTI.

2.2 Literature Review

The review procedure was as follows:

1. Study the article for
 - data gathering technique
 - statistical validation of data
 - regression equations developed
 - economic analysis techniques adopted for decision making
 - comparative analysis by different pavement types and/or pavement condition.
2. Write a summary of the article, to be included in the annotated bibliography
3. Synthesize the information gathered from all the articles to determine the significant factors contributing to user cost, and their effect on pavement type selection.

After reviewing the available literature, an analysis of the various user cost components currently being researched was conducted in the following manner:

1. Identify different approaches, if any, adopted by various researchers to evaluate each user cost component and to quantify its effect on total user cost.
2. Discuss the strengths and weaknesses of the aforesaid approaches from the point of view of a correct representation of the actual socioeconomic costs incurred. Discuss specific conclusions drawn by researchers in this regard.
3. Identify the relationships developed, if any, between pavement type and pavement condition and various user cost components examined.

The results of this analysis are discussed in Chapter 4. References are made only to major research efforts which adopted characteristically different approaches to the study of a particular component. Other research work using similar approaches is included in the annotated bibliography.

The annotated bibliography includes summaries of research efforts which study various components of user costs. A reference list of related work is also provided by author and title. The reference list and the annotated bibliography are presented in the form of "most recent first", so that the reader can readily determine the most recent date when a particular component was investigated.

While the primary purpose of the literature review was to examine the research related to user costs, it also was relevant to briefly review total life cycle cost methodologies. This was necessary to better understand how user costs are applied in the context of total life cycle cost analysis. The next chapter provides a brief overview of different life cycle cost approaches.

Chapter 3

LIFE CYCLE COSTS

The most effective utilization of available resources is a major concern of any State Agency when required to make a decision among several alternatives for new construction and rehabilitation of a highway system or network. A common methodology used by State Agencies to evaluate competing alternatives is Life Cycle Cost (LCC) analysis. This chapter briefly describes different methods that can be adopted for performing a life cycle cost analysis. It also discusses the role of road user costs in this analysis.

A wide variety of techniques have been used in the past for evaluating the most beneficial alternative for highway construction/rehabilitation. Life cycle cost analysis has been the key

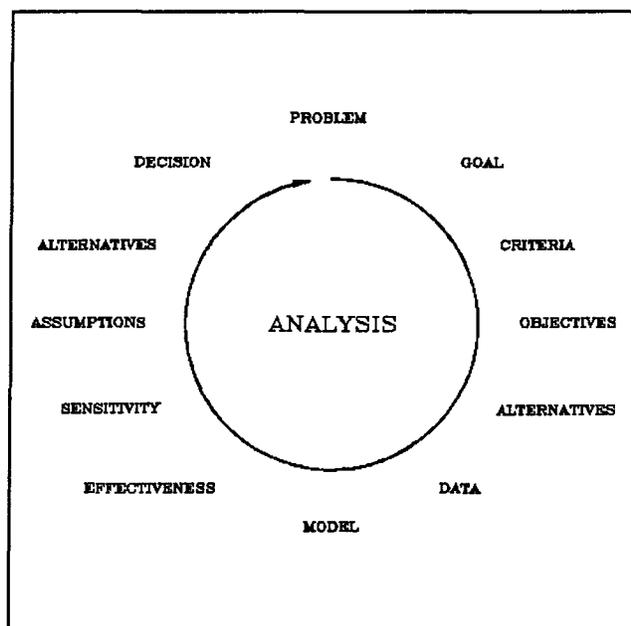
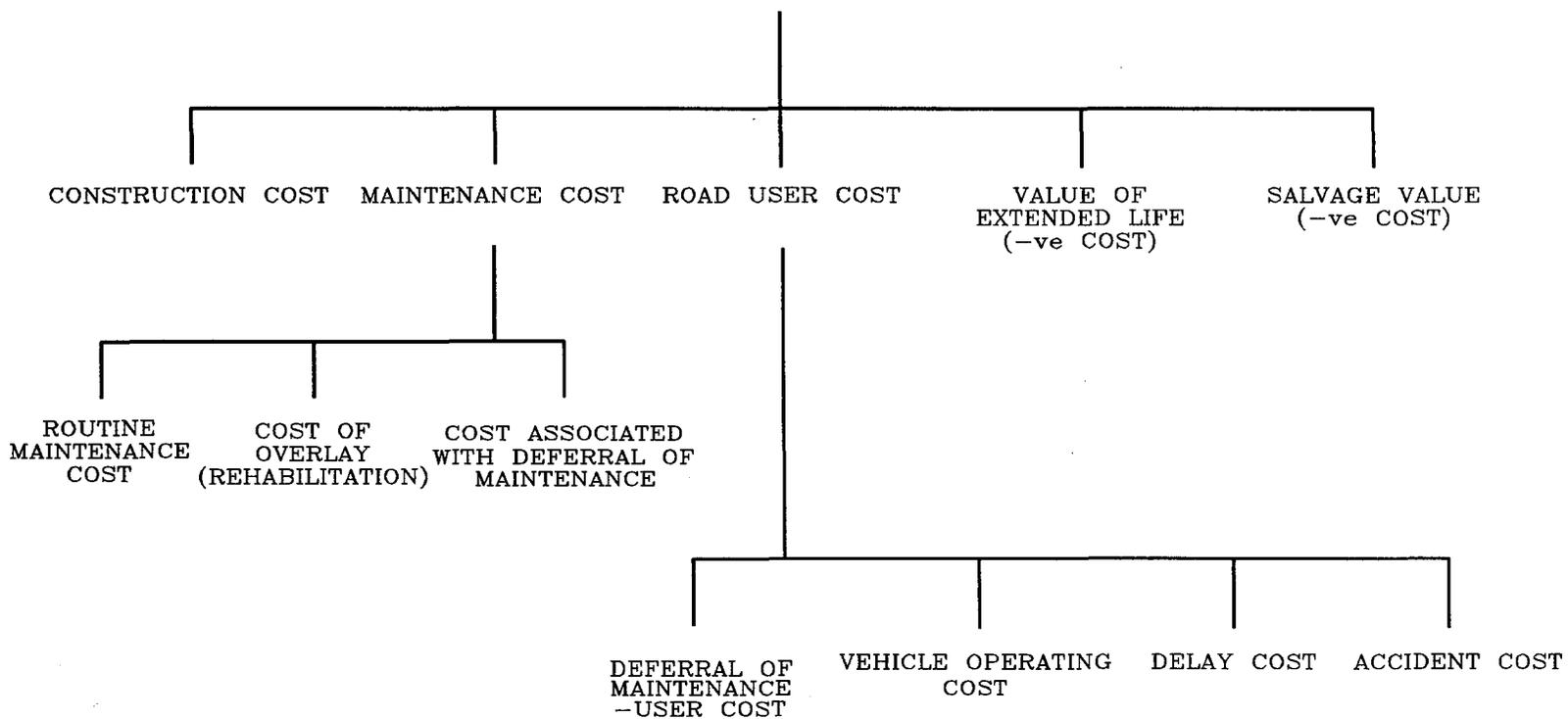


Figure 1.
Systems Analysis Diagram¹⁹

methodology used in most of these analyses. The Systems Analysis Diagram¹⁹ shown in Figure 1 outlines a conceptual procedure depicting the steps involved in a life cycle cost analysis. Life cycle costs depend on the projected performance life of the various identified alternatives. For each of the alternatives, various cost components are considered, as shown in Figure 2. In addition to these components, the length of the analysis period, interest rates, inflation and so on have to be included. All these components need to be integrated into a procedure that will ensure the lowest life cycle cost for a

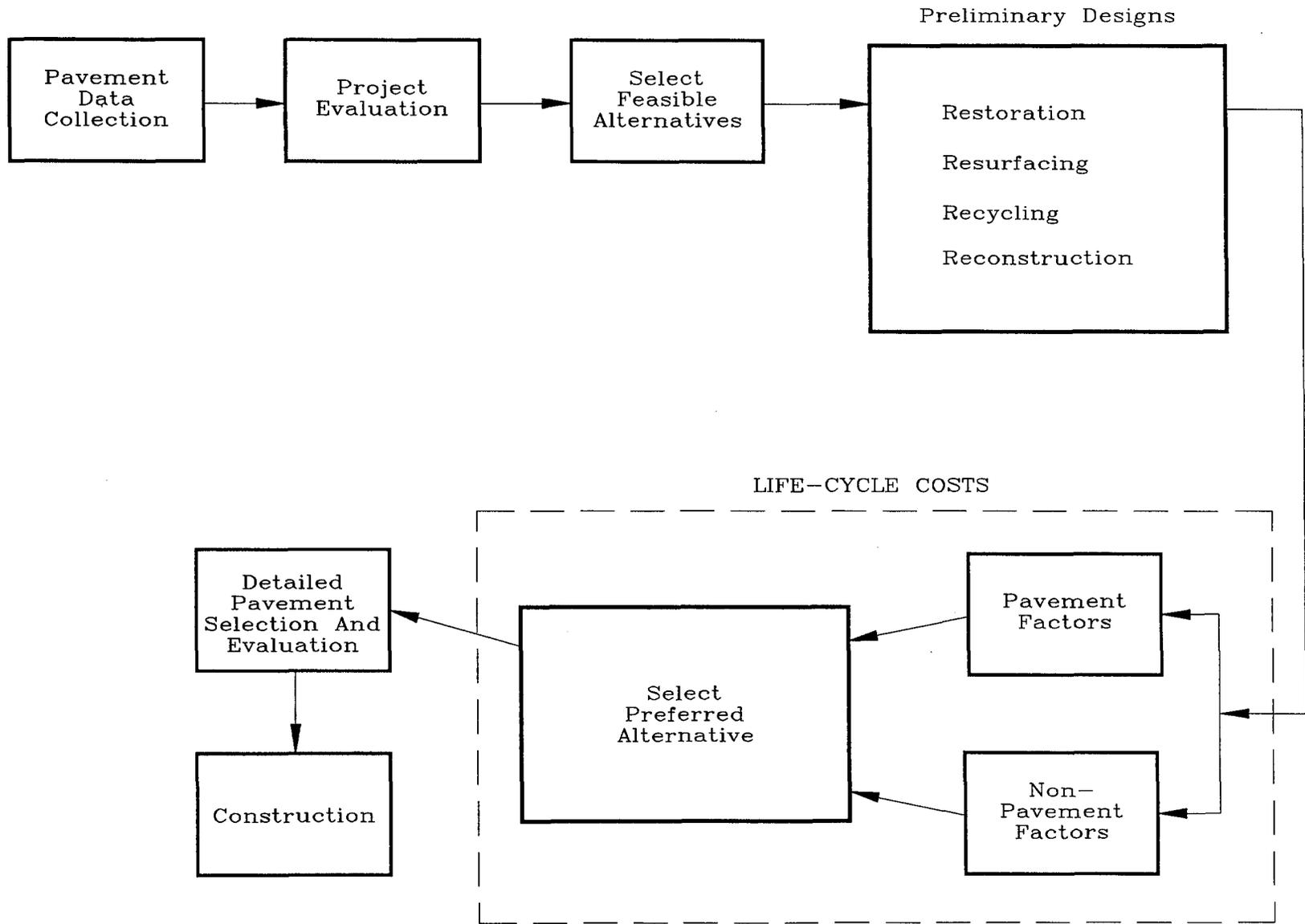
given alternative. Figure 3 shows a more specific step-by-step "Pavement Rehabilitation Process" which can be used to select a preferred alternative. Voigt and Knutson devised this procedure

TOTAL LIFE CYCLE COST



8

Figure 2. Components of Life Cycle Cost



6

Figure 3. Pavement Rehabilitation Process⁵

to perform a "4R analysis", where the four Rs represent Resurfacing, Restoration, Recycling and Reconstruction⁵.

The term Life Cycle Cost (LCC) analysis has been defined in several ways in the past. An appropriate definition of LCC can be, "a technique that discounts future costs according to a specified interest rate, allowing cost comparisons of different strategies and alternatives on the basis of present worth or equivalent uniform annual costs⁴". The LCC analysis is performed over an analysis period which is generally defined in terms of service life, economic life, or analysis life. Service life estimates the actual total usage of the facility. It is the time span from installation of a facility to retirement from service. The economic life is the life in which a project is economically profitable or until the service provided by the project can be provided by another facility at lower cost. The economic life may be less than the service life. Shortage of capital often extends a project service life beyond the end of its economic life. Analysis life may not be the same as economic or service life of a project, but it represents a realistic estimate to be used in economic analysis such that returns on the initial investment are obtained within that length of time. Estimation of the analysis period used in an economic analysis should be sensitive to the uncertainties associated with changes in technology over this time. The Highway Engineering Handbook³⁶ recommends the analysis life should not exceed 40 years. This estimate, however, was made in 1960, and a more refined estimate based on a similar concept may be necessary for economic analyses performed in the 1990s.

The interest rate used to discount future costs to present dollar value is an important factor in the LCC analysis. The results of a LCC analysis are found to be extremely sensitive to the discount rate used. A discount rate which is too low will raise the present value of benefits and result in socially undesirable projects being selected. On the other hand, a rate which is too high will tend to favor projects which have a shorter payback period, with small benefit flows over a longer period of time. In general, an inappropriate discount rate will result in misallocation of resources between public and private investments. There appears to be a lack of consensus on the correct method to determine a proper discount rate. As a result, a sensitivity analysis is often performed to determine how sensitive the project selection decision is to

different discount rates. The AASHTO Red Book²⁹ recommends a discount rate of four to five percent for transportation projects.

Several methods are available for performing the economic analysis of rehabilitation or reconstruction alternatives. They are:

1. Benefit-Cost Ratio Method
2. Break-Even Analysis
3. Payback Period
4. Capitalized Cost
5. Present Worth Method
6. Annualized Method (Equivalent Uniform Annual Cost)
7. Rate of Return Method

All the methods cited above are used in economic analyses performed to date. A brief description of each of these methods is given in NCHRP 122¹⁹. The Annualized Method, which is sometimes referred to as the Equivalent Uniform Annual Cost Method, can be considered advantageous over other economic analysis methods especially when comparisons are made between alternatives with different analysis periods⁴.

Researchers have attempted to justify several other approaches in order to arrive at a procedure for decision-making among available alternatives. One such approach is the "Cost Effective Method of Analysis"¹⁰. It is based on the concept of maximizing the benefit-cost ratio. The Cost Effective Method of Analysis has an advantage over benefit-cost analysis particularly in case of rehabilitation programs which involve options that alter the pavement type. It mandates the inclusion and quantification of the benefits provided by each rehabilitation option considered in addition to their cost. Examples of some benefits that may be considered in this analysis are:

1. Improvement in distress condition
2. Improvement in ride quality (serviceability)
3. User cost reduction

4. Structural capacity improvement
5. Lowest cost of improvement per user

It is the objective of administrators to maximize all of the above benefits at minimum cost, thus making the most cost effective use of available funds. However, this cannot be accomplished objectively without incorporating each benefit category cited above into the economic analysis. Based on their study, Novac and Kuo¹⁰ have concluded that the Cost Effective Method of analysis is more reliable than the Life Cycle Cost (LCC) analysis method, since it performs the analysis based on benefit-cost ratio instead of LCC. The authors further argue that life cycle costing can be used to justify any desired alternative simply by manipulating the inherent assumptions. The validity of this claim is evident from a comparison of life cycle cost analysis performed by researchers in two separate research efforts^{5,14}. In both the cases, initial cost of construction and annual maintenance cost for asphalt and concrete pavements are considered to perform LCC analysis. A sensitivity analysis using different real interest rates is performed and conflicting conclusions are drawn as regards the suitability of two different pavement materials. An excellent discussion of comparative economic analysis of asphalt and concrete pavements is provided by Robert Roy and Gordon Ray, in the form of a critique to the paper written by Sandler et al²⁰. Little material is available on Cost Effective Method of analysis, however, Smith, Shahin and Darter¹³ have made a notable project level use of this technique. Further research is required to confirm the applicability of the Cost Effective Method of analysis to pavement selection procedures currently adopted by State Agencies.

Another approach to life cycle cost analysis, particularly for rehabilitation/overlay strategies, is the "Decision Support Model"⁶. The Decision Support Program (DSP) in this model requires detailed information about the existing pavement. It consists of the existing pavement material, the pavement serviceability index (PSI), the overlay material, the percentage of area to be patched, cost of patching, cost of routine maintenance, and so on. Based on the input provided, the model generates useful information such as the PSI after overlay, maintenance costs after overlay, and user costs after overlay. The DSP also helps the decision maker analyze this information and make the optimal selection. A slightly different approach is adopted by

Wong and Markow²⁴, keeping in view the changing character of state and federal highway programs, which emphasized maintenance and rehabilitation in lieu of new construction. Central to their study was the use of a simulation model of highway performance and costs that considered variations in several parameters of the problem. Two different economic objectives were investigated: one based on equity (to allocate highway maintenance expenditures) and the second based on efficiency (considers total social costs).

The level of pavement performance associated with each probable alternative needs to be considered while evaluating life cycle costs. Fwa and Sinha¹ have stressed the importance of pavement performance considerations from the point of view of highway agencies and road users. Two approaches to quantify costs are suggested in this paper to incorporate pavement performance consideration into the LCC evaluation. The first approach makes use of a quantitative performance measure for comparing different overall pavement performances in the various strategies considered. The second approach relies on establishing quantitative values of user benefits for different pavement serviceability levels.

Four important conclusions can be drawn from a review of the approaches discussed:

1. There is little agreement in regard to which method of economic analysis is most appropriate for comparing alternatives. The cost effective method of analysis mentioned above needs to be studied further from the point of view of its advantages over life cycle cost analysis by way of specific applications.
2. User costs have not been accounted for by many researchers while discussing life cycle cost analysis.
3. There is a clear disagreement among researchers^{5,14} on whether rigid pavements or flexible pavements fare better in a LCC analysis.
4. Pavement performance considerations from the point of view of the highway agency and road users should be included in a life cycle cost analysis.

The next chapter specifically reviews recent developments in road user cost components and their relationship to pavement type and condition.

Chapter 4

ROAD USER COSTS: A SYNTHESIS OF CURRENT APPROACHES

There is substantial evidence in the research conducted on road user costs that their contribution to the life cycle cost of pavements is significant. However, transportation agencies have frequently excluded road user costs in their economic analyses until recently. Most economic analyses performed to date have accounted for construction costs, maintenance costs, and in some cases, the value of extended life²⁶, and salvage value.

Available research indicates that of the three main components of total life cycle cost of a highway, that is, construction costs, maintenance costs and road user costs, road user costs contribute the most to total life cycle cost. In research conducted by the World Bank⁹ for developing the HDM III model, it is stated that road user costs of vehicle operation and travel time are by far the largest component and can amount to 90 percent for two lane highways serving a few thousand vehicles per day or more. In 1979, the French DOT estimated that the annual balance of energy spent on road transportation was less than 10 percent for construction and maintenance, and more than 90 percent consumed by road users²⁹. In a discussion on cost-benefit analysis of highway appraisals, Pearman and Button have pointed out the importance attached to road user costs by the British Department of Transportation¹⁸. They stated that apart from costs directly related to the construction process, the only consequences of a road scheme which can be estimated with sufficient precision for inclusion in a benefit-cost analysis are the savings in time, vehicle operating costs and accident cost savings. The AASHTO manual on User Benefit Analysis of Highway and Bus-Transit Improvements³⁰ (1977), better known as the Red Book, also has stressed the importance of "an efficient transportation investment plan for the affected communities and the economy as a whole", and hence the inclusion of road user costs in any highway and transit improvement analysis. Considerable research has been conducted in the United States and abroad on road user costs and approaches to quantify them,

for inclusion in economic analyses. However, there are certain areas which need to be further investigated, and it is the primary purpose of this study to identify these areas and propose the necessary research.

Road user costs can be classified into the following four main categories as shown in Figure 4:

1. Vehicle Operating Costs
2. Travel-Time Delay Costs
3. Accident Costs
4. User Costs associated with the deferral of maintenance

Each of the main categories is further divided into their major subcomponents as depicted in Figure 4. Zuieback and Bailey¹² also included discomfort costs as another contributor to road user costs. However, it is difficult to quantify discomfort costs for inclusion in an economic analysis. In category four above, significant research has not been conducted to quantify the incremental increase in user costs due to deferral of maintenance of a pavement. The following subsections will address each of the first three user cost categories, based on the research completed in these areas to date.

4.1 Vehicle Operating Costs

Vehicle operating costs are the largest cost component of road user costs in developing countries, whereas in the developed nations, travel-time costs assume an equally dominant role¹¹. Claffey³⁴ has pointed out seven physical features of road design which affect vehicle operating costs. They are: profile, alignment, surface characteristics, intersections-at-grade, access-exit points, road shoulder widths, and length. Variations in these design features influence different types of vehicle operating costs as delineated in Figure 4. They are:

1. Fuel Consumption Cost
2. Lubricant or Engine Oil Consumption Cost
3. Tire Wear Cost
4. Maintenance and Repair Cost
5. Depreciation and Interest Cost
6. Miscellaneous Costs

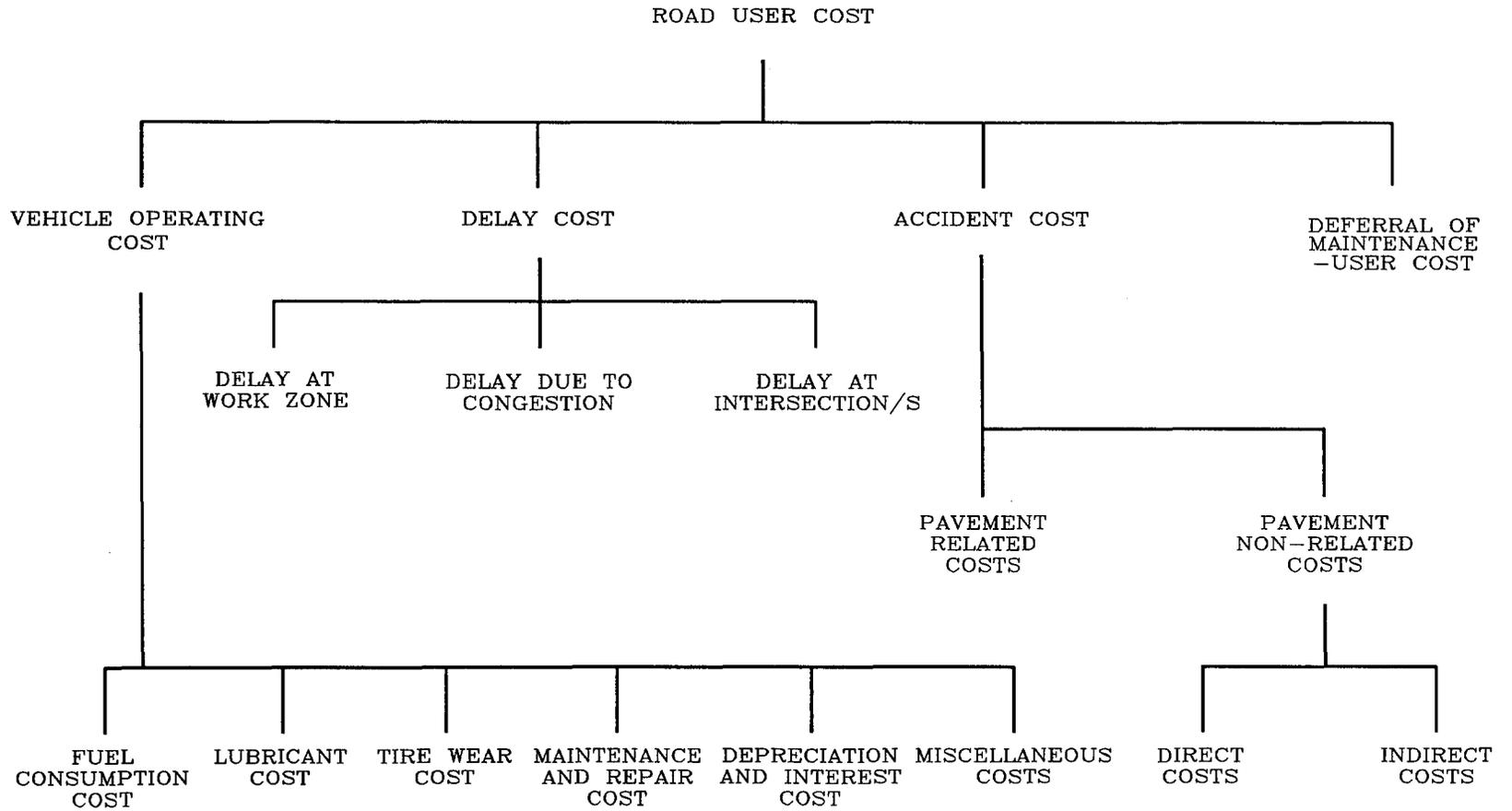


Figure 4. Components of Road User Cost

The Red Book³⁰ cites idling cost as another component of vehicle operating costs. The HDM III model¹¹ accounts for two other components: (1) Overheads, and (2) Cargo holding costs. However, the components shown in Figure 4 can be considered as a satisfactory representation of overall vehicle operating costs. These components will be addressed individually.

4.1.1 Fuel Consumption Cost

Fuel consumption cost is considered the largest contributor to vehicle operating costs. The importance of this component has been recognized by researchers in the past²¹. Based on a study conducted by the U.S. Environmental Protection Agency³³ in 1973, for a passenger vehicle moving at 40 mph, compared to a smooth concrete roadway surface, a patched asphalt surface may reduce gas mileage by 15 percent, a gravel road by 35 percent, a sandy surface by 45 percent, and a dirt road by 15 to 35 percent. In a sensitivity analysis conducted in the World Bank study on vehicle speeds and operating costs in 1987⁹, fuel consumption costs were observed to vary over a wide range. The contribution of fuel consumption cost to the total vehicle operating cost ranged from 17 percent to 42 percent for various vehicle classes and road surface conditions. The road surface conditions are defined in terms of the gradient, the horizontal curvature, and the roughness for a particular section of roadway.

Two different approaches have been employed by researchers to estimate fuel consumption costs. One of these approaches² uses basic equations of motion to derive a formulation for fuel consumption in which speed, and the coefficients for rolling, air, and gradient resistance are the independent variables. The advantage of this approach is that new technology in tires or vehicle design can be incorporated by revising estimates for the various coefficients without having to undertake a major experiment. The second approach, adopted in a study conducted by Zaniewski²⁵ *et al.*, employs multiple regression techniques to model measured consumption as a function of vehicle and road variables. This type of analysis has a limited application value, since the results could only be valid for the test vehicle and cannot be transferred to other vehicle types. Changes in technology will also necessitate a new experiment. Another major shortcoming of this approach is that it does not refer to any objective measure of road surface condition. Recent research in this area (refer annotated bibliography) has focused

on the relationship of road surface condition and fuel consumption. Rolling resistance loss and suspension loss have been identified as the main contributors to fuel consumption of a vehicle.

There is some theoretical evidence that concrete pavements, due to very small pavement deflection, reduce rolling resistance compared to flexible pavements thus saving on fuel consumption. There also exists some research literature in favor of concrete pavements as regards to fuel consumption. However, any conclusive work that determines the relationship between pavement type and fuel consumption has not been performed.

4.1.2 Oil Consumption Cost (Lubricant Cost)

Oil consumption of a vehicle is affected by the dust producing characteristics of road surfaces. The more dusty the surface, the greater the frequency of engine oil changes³⁴. Empirical equations have been developed in the HDM III¹¹ model, which relate oil consumption to road roughness as measured by the Transportation Road Research Laboratory Towed Fifth Wheel Bump Integrator (Hide, *et al.*, 1975). This component is generally a very small part of overall vehicle operating costs.

4.1.3 Tire Wear Cost

This is an important component of road user costs for heavy goods vehicles. Tire wear was observed to account for 23 percent of the average running cost of a typical heavy truck operating on paved roads in rolling terrain in Brazil (GEIPOT, 1982, Volume 5). Current knowledge of tire mechanics recognizes two principal modes of tire wear: Carcass wear; and Tread wear.

In the World Bank study⁹, mathematical models are formulated for predicting tire wear as a function of vehicle and road characteristics. A detailed discussion of tire wear costs is given in a report prepared by Follete³². The underlying theory behind the approach adopted in this report is that the degree of tire wear can be explained in terms of slip energy, which is a product of the tractive force and the "interface slip velocity" at the tire/road interface. A similar approach incorporating the energy conservation principles was also used by Sullivan³¹. However,

these studies did not relate pavement type and condition to tire wear.

4.1.4 Vehicle Maintenance and Repair

Vehicle maintenance and repair costs relate to vehicle usage-related stresses which subject the vehicle parts to wear and subsequent failure. The degree of these stresses depends on road roughness and road geometry. The stresses associated with road roughness cause wear of the steering and suspension system and failure of the parts such as springs and brackets. The stresses associated with road geometry are in the form of forces imposed on the engine, the gear box, clutch, rear axle, and the brakes while overcoming resistance to movement of the vehicle. Repeated application of these forces cause wear and failure of vehicle components that bear against these forces.

Vehicle maintenance has been further subdivided into two categories:

1. Maintenance parts; and
2. Maintenance labor

Vehicle maintenance, depreciation, and interest are important interrelated components of total cost of vehicle ownership and operation. Maintenance parts and labor typically constitute 15 to 35 percent, and depreciation and interest - 15 to 25 percent of total vehicle operating costs excluding overheads. Together they account for approximately the same proportion as fuel and tire consumption combined⁹. Simple models correlating spare parts and mechanics' labor with road characteristics were developed by Chesher and Harrison (1985).

4.1.5 Depreciation and Interest Cost

Research conducted for developing the HDM III model¹¹ indicates that depreciation costs constitute a significant portion of vehicle operating costs, varying from 9 percent to 50 percent for various classes of vehicles. A model is formulated⁹ to establish the relationship between vehicle depreciation and vehicle utilization. Vehicle depreciation is expressed as a function of the average vehicle service life in years, and the average annual vehicle utilization in kilometers of travel per year. The interest cost is expressed as a fraction of the price of a new vehicle of the same class.

In a separate research effort by Bennett and Dunn³, two distinct approaches were used for quantifying depreciation. The first is based on accounting practices, and the second is based on resale prices of motor vehicles. Equations are developed for predicting the rate of depreciation as a function of age and utilization for passenger cars, light commercial vehicles, and medium and heavy commercial vehicles. It is recommended that 70 percent of passenger car depreciation be allocated to time, and 30 percent to use. For all other vehicles, 85 percent of depreciation should be allocated to time and 15 percent to use.

In yet another study conducted by Butler²² (1984), vehicle depreciation consists of time and use components. A service life model was proposed, which contained these two components. By assuming that the major influence on the value of the use component was caused by adverse driving conditions, a procedure was proposed to predict the use component as a function of road geometry and road roughness. Vehicle utilization or use was related to road roughness in another study in Brazil²⁸. However, any specific conclusion towards establishing a relationship between pavement type and depreciation costs was not obtained.

4.1.6 Miscellaneous Costs

These costs take into account factors not captured by road roughness, such as:

1. moisture
2. depth of loose material, and
3. reduced passability due to gravel loss

Equations are developed in the HDM III model¹¹ to quantify the effects of these factors.

4.2 Travel-Time Delay Costs

Delay costs are a major contributor to road user costs in the developed nations¹¹. The travel-time delay of vehicles on a highway depends on the ambient traffic conditions. Under very light traffic conditions, a motor vehicle is able to travel at a speed that is regulated mainly by speed limits and other design attributes of the facility. These consist of the volume/capacity (v/c) ratio, roadway type, pavement condition, gradient, curves and the like. The vehicle's travel can be steady and largely uninterrupted by speed changes. As traffic volumes on a given facility

increase, the speed of the vehicle is determined in part, by other traffic on the facility. The higher the volume of traffic relative to capacity, the slower is the running speed of the traffic stream. At some point, however, there are so many vehicles trying to use the roadway that flow (volume) of vehicles on the facility is actually reduced, the v/c ratio falls, and severe traffic interactions force vehicles to come to complete stops for periods of time before moving forward again. This breakdown and queuing of traffic is level of service F, as defined by the Highway Capacity Manual³⁵.

Level of service F relative to vehicles travelling over a highway section describes a forced flow condition in which the highway acts as storage for vehicles backing up from a downstream bottleneck. In other words, physical lines of waiting vehicles (i.e., queues) occur upstream of the bottleneck section. Such bottlenecks may result from irregularly occurring situations such as stalled vehicles or traffic accidents, or from regularly occurring traffic demand that exceeds capacity for a given bottleneck section of the roadway. In either case, however, the net effect is that demand for highway service exceeds the roadway's capacity to furnish it.

The costs to the highway motorist are greatly increased when there is queuing, and elimination of such conditions will provide large cost savings to the user. The decision to perform queuing analysis can be based on the need to justify a construction/rehabilitation project, or the need to understand driving conditions. Once the volume and capacity of a road section are known, average running speed can be estimated directly for different highway design speeds. The AASHTO Red Book³⁰ has outlined a procedure to estimate average running speeds. These relationships of v/c ratios and speed were derived from curves for hourly operating speed for corresponding highway types in the Highway Capacity Manual³⁵.

Central to the evaluation of delay costs is the quantification of cost of travel-time. A dollar value is assigned to the travel-time delay measured in any of the three delay cost subcomponents described above. The most recent effort to estimate the value of travel-time was by Chui and McFarland (1986)¹⁵. Their estimate of dollar value of travel-time has been used in subsequent research to evaluate delay costs for various categories. However, the assumptions

made by Chui and McFarland, while assigning a dollar value to travel-time, may not be valid for conditions prevalent in the case of different delay cost components. Delay costs are categorized into the following three components:

1. Delay at work zone
2. Delay due to congestion
3. Delay at intersections

4.2.1 Delay at Work Zone

Work zone delay is the increase in travel time due to restraints imposed on the traffic by the presence of an active work zone. The work zone may be any construction/rehabilitation activity which forces either diversion of the traffic or a reduction in the number of lanes available to traffic flow. The duration for which the traffic has to be diverted from the work zone depends on the rehabilitation strategy being adopted. Thus, delay cost at work zones is a direct function of the type of rehabilitation/repair activity. Memmott and Dudek²³ in 1982 developed a model (QUEWZ) to estimate delay costs at work zones. The major characteristics of the model are:

1. Two types of lane closure strategies are assumed. The first type is closure of one or more lanes in one direction of travel. The second type is a crossover, where one side of the roadway is closed and two-lane, two-way traffic is maintained on the other side of the roadway.
2. Hourly traffic volumes are used rather than Average Daily Traffic (ADT). This allows for a much more accurate estimate of average speeds, and the estimated queue when demand exceeds capacity.
3. A typical hourly speed-volume relationship is assumed in the model but can be changed by the user as part of the input data.
4. Vehicle capacity through the work zone is not a constant parameter but can be exogenously input by the user.

5. Relatively small amount of data are required to run QUEWZ.
6. The output from QUEWZ includes vehicle capacity and average speed through the work zone, hourly road user costs, daily user costs, and if a queue develops, the average length of queue each hour.

The model takes into account all possible components of delay cost at a work zone. These include: cost of travel-time, with or without a queue; additional operating cost of speed change cycle, with or without a queue; and vehicle running cost, with or without a queue. Models for alternative traffic control strategies like closing entrance ramps, temporary use of shoulder as an operating lane, diverting traffic to the frontage road, and splitting traffic during middle lane closures need to be developed.

The contribution of work zone delay costs to the life cycle cost of a pavement has been overlooked in the past. All previous research efforts in this area are directed towards the study of user costs associated with solitary work zone activities. This, however, may lead to inappropriate conclusions since it does not reflect the frequency of occurrence of work zones or repair activities over the life of a pavement. The number of repair activities over the life of a pavement is related to the pavement type. Thus, previous research work has not considered the effect of pavement type on work zone delay costs.

4.2.2 Delay due to Congestion

An assessment of the cost of congestion on freeways and major street operating conditions was performed in seven Texas cities and 22 other urban areas in the U.S. for the period 1982 to 1986⁷. The cost of congestion is attributed to travel-time delay cost, increased fuel consumption cost, and increased auto insurance premiums. The travel-time delay costs depend on average speed, which is a function of the v/c ratio, roadway type, pavement condition, roadway gradient, and curvatures. Congestion can be defined by the level of service F , as discussed earlier. It is apparent that pavement type or condition does not have any significant impact on cost of congestion.

4.2.3 Delay at Intersections

The cost imposed on the user due to delay at intersections consists of three components:

1. Cost of travel time, that is the additional time spent at stoppages;
2. Idling costs; and
3. Cost of additional fuel consumption imposed due to speed change cycles before and after passing through the intersection.

The AASHTO Red Book³⁰ presents a discussion of intersection delay costs, effect of signalization, and a procedure to evaluate the intersection delay costs. However, it needs to be updated for the various cost escalations since the time it was developed. The intersection delay costs do not appear to have any significant relationship with pavement type or condition.

4.3 Accident Costs

In evaluating accident costs, human life valuation is the most difficult component to quantify with a sufficient degree of precision. It is particularly important in case of accidents involving loss of human life. Three different approaches have been discussed in the past to quantify the value of human life. These are: (1) Willingness to Pay; (2) Cost of Human Capital; and (3) Implied value of Life. Atkins²⁷ discusses these approaches in detail. He has favored the "human capital" approach for evaluating accident costs.

Rollins and McFarland¹⁷ in 1985 used the "willingness to pay" approach to evaluate accident costs. It is a measure of society's valuation of road safety. It incorporates the concept of consumer's surplus in addition to market price evaluations. A major criticism of this approach is that as the degree of risk, or the probability of accident increases, the willingness to pay increases rapidly, sometimes indicating an infinite value of life²⁷. Thus, the valuation scale in this case is non-linear. There exists a further problem that theoretical relationships (and, also for example, accident reduction projects) are based on objective probabilities generally drawn from frequency distributions, while the actual perception and behavior of individuals with respect to risk is based on subjective assessments of probability.

The human capital approach is based on the concept of the value of life equated with individual productivity in the form of a discounted stream of future earnings. The income stream consists of that portion occurring between the time of accidental death and normal life expectancy. The main shortcoming of the human capital approach is that it does not include any measure of consumer's surplus over and above the income measure, as does the willingness to pay approach. Thus, it yields a value which only represents the minimum estimate of what society should be willing to pay to save an average life. Additional values such as costs of pain, suffering and grief are considered non-economic, and they are not incorporated into national economic measures, although they clearly affect socioeconomic welfare in a way which should, in principle, be quantifiable. Another problem with the human capital approach is the misleading effect of age and life cycle characteristics. For example, in net income calculations, children and the elderly can be shown to have a negative present worth. Such measures are inappropriate and can lead to absurd interpretations of social preferences, and hence need to be properly taken into consideration. The third approach, the "implied value of life" has not been used for accident cost evaluation. Its major drawback is that it may reflect past nonrational or inconsistent public decisions.

Accidents costs are categorized into direct costs and indirect costs. Direct costs include:

1. Damage to vehicle
2. Damage to other property
3. Medical expenses
4. Cost of loss of vehicle use
5. Value of time lost
6. Legal and court costs
7. Miscellaneous direct costs, and
8. Funeral costs (if fatality involved)

Indirect costs include:

1. Production and consumption loss for injured person
2. Losses to injured person's home, family, and to community
3. Cost of accident investigation
4. Insurance administration cost

Two different injury scales, the A-B-C & Property Damage Only (PDO) and the Maximum Abbreviated Injury Scale (MAIS), are available to categorize accidents into different severity levels. However, benefit-cost analyses often are based on a State's accident data, which typically consist of the number of accidents per year at various accident locations, with injury severities coded by the A-B-C and PDO scale, rather than by the MAIS¹⁶.

Another classification of accident costs can be made into pavement related costs and pavement non-related costs. However, the relationship between roadway characteristics, measured in terms of Pavement Serviceability Index or any other measure, and frequency of occurrence of accidents has not been investigated in the research performed to date.

4.4 Summary of User Cost Components

Figure 5 describes all the components of road user costs and the various subcomponents that contribute to each of these costs. A discussion of the individual impact of all the user cost components on the total user cost is given in the following chapter.

The user cost subcomponents described in Figure 5 represent a summary of past research efforts covered in this study. However, there is a void in the research literature in following two areas:

1. **Deferral of Maintenance - User Cost**

This component includes costs incurred by the user due to deferral of pavement maintenance beyond the service life. It is expected that user costs will increase at a much higher rate in the deferred maintenance stage due to reduced pavement serviceability. This accelerated increase in user costs may be different for different pavement types.

2. Pavement Related Accident Costs

This component is included with the intention of accounting for accident costs which may be directly related to pavement type. No conclusive work, however, has been performed in this area to date.

Problem statements are developed for certain significant areas in Chapter 5, which cover the above two problem areas, and also other problems where further investigations are required in order to obtain definitive results regarding the variation in user costs as related to different pavement types and conditions.

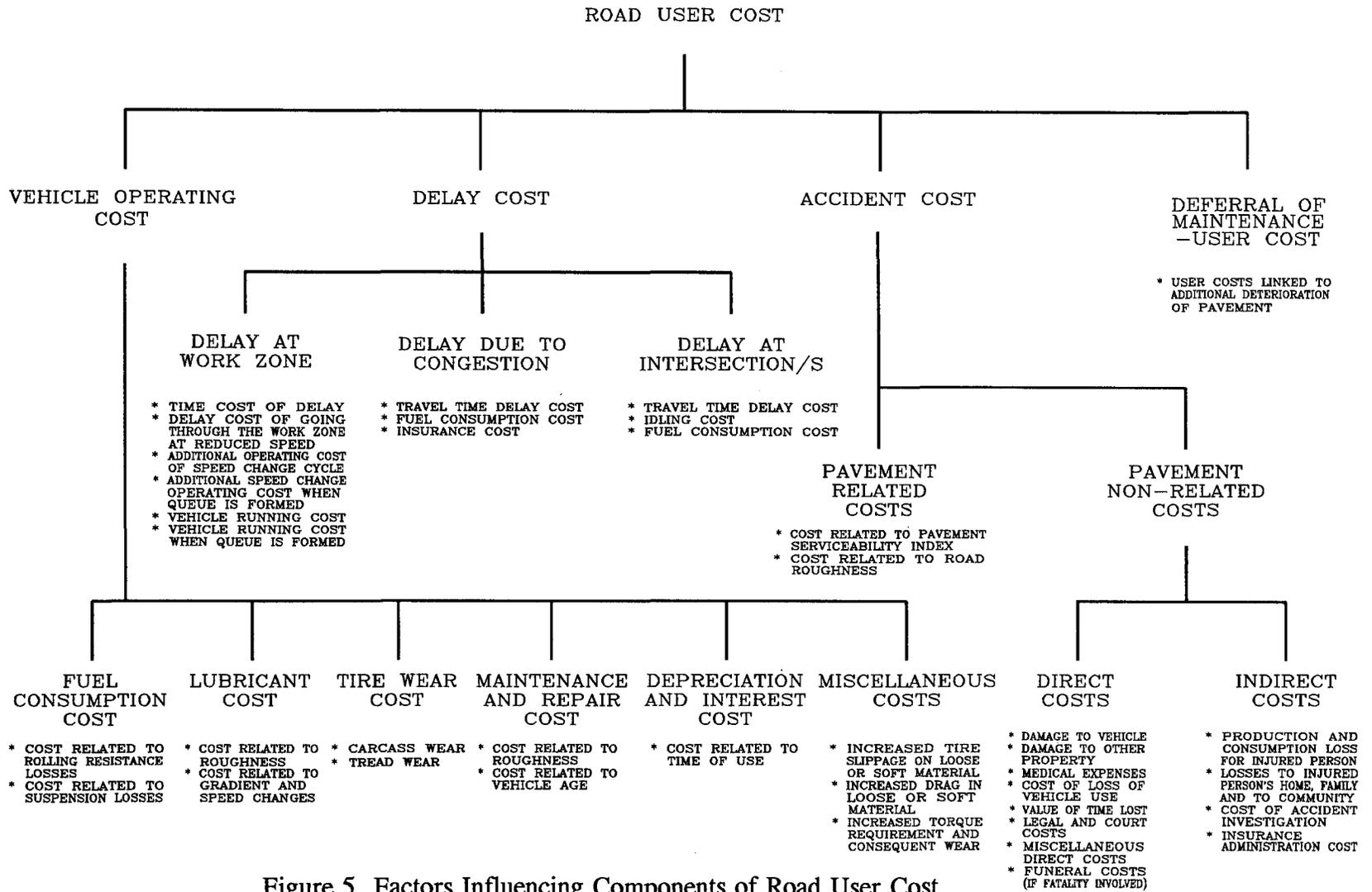


Figure 5. Factors Influencing Components of Road User Cost

Chapter 5

ROAD USER COST COMPONENTS: INDIVIDUAL IMPACT ON TOTAL USER COST

It is extremely difficult to perform an objective assessment of the impact of each component of road user costs on total user cost within the scope of this study. Also, due to the wide range of vehicle classes being used, such an assessment needs to be separately performed for each vehicle class involved. This would require an extensive research effort that incorporates the study of each user cost component for every operating vehicle class. Hence, this research evaluates the contribution of each road user cost component to total user cost by pavement type based on a subjective assessment process.

5.1 Assessment Methodology and Results

A subjective assessment of the contribution of each user cost component to total user cost is provided in the form of a matrix as shown in Figure 6. The matrix was developed based on conclusions drawn from the literature review performed for this purpose, and the judgement of experts in this area at the Texas Transportation Institute. An evaluation of the contribution of overall user costs to the total life cycle cost of a pavement, however, remains to be accomplished. Each column in this matrix represents a critical user cost component. Three indicators that affect each of these components relative to total user cost are given in the top three rows of the first column. These indicators are:

1. Impact on User Cost:

This indicates the degree to which each user cost variable affects the total user cost. The effect is expressed on a scale of high-medium-low. It is observed that fuel consumption cost, delay due to congestion, and costs incurred due to deferred maintenance are considered to be the major contributors to user costs.

2. Sensitivity to pavement type:

The sensitivity of various components of road user cost to the pavement material is indicated in this section of the matrix. The sensitivity is expressed in terms of high-medium-low. It is evident from research in this area to date, that there is disagreement among researchers regarding the effect of pavement type on fuel consumption. More specific research directed at studying fuel consumption in relation to various pavement types needs to be undertaken. Tire wear cost and delay at work zones are found to be extremely sensitive to the pavement type.

3. Sensitivity to pavement condition:

As the physical condition of a pavement (expressed by the Pavement Serviceability Index) deteriorates, the cost incurred by the motorist using the pavement increases. The rate at which this increase in user cost occurs is different for different components of user cost. In other words, the sensitivity of various user cost components to change in the pavement condition is not the same. The variation in this sensitivity is expressed using a scale of high-medium-low, as delineated in Figure 6.

The bottom two rows of the matrix indicate a subjective assessment of the amount of existing research work in various user cost areas and the estimated cost of performing research in those areas, expressed by "Extent of research" and "Research cost estimate" respectively.

1. Extent of research:

A subjective opinion concerning the extent of investigations in various user cost areas is furnished. The literature review performed for this project and the opinions of experts at the Texas Transportation Institute formed the basis for the assessment. The extent of research indicates which user cost components have not been investigated to date, and also those that have a potential for further research. It may be noted that the matrix excludes user cost components like : discomfort costs due to noise generation, radiation, and air pollution; costs associated with lighting; and costs incurred due to skidding, which also have not been studied to date. The extent of research work performed to date is expressed in terms of substantial-fair-none.

2. Research cost estimate:

An approximate estimate of the expected research expenditure is provided for each user cost component. A scale of high-moderate-low is used. The estimated dollar value range is as follows:

High	:	\$160,000 to \$220,000
Moderate	:	\$120,000 to \$160,000
Low	:	\$60,000 to \$120,000

The individual user cost component impact matrix is given on the following page.

	USER COST ITEMS COST IMPACT	VEHICLE OPERATING COSTS					DELAY COSTS			ACCIDENT COSTS		COST INCURRED DUE TO DEFERRAL OF MAINTENANCE
		FUEL CONSUMPTION COST	LUBRICANT COST	TIRE WEAR COST	MAINTENANCE AND REPAIR COST	DEPRECIATION AND INTEREST COST	MISCELLANEOUS COSTS	DELAY AT WORK ZONE	DELAY DUE TO CONGESTION	DELAY AT INTERSECTION/S	DIRECT COSTS	
IMPACT ON USER COST	HIGH	X						X				X
	MEDIUM				X	X	X		X		X	
	LOW		X	X			X			X		
1 SENSITIVITY TO PAVEMENT TYPE	HIGH			X			X					
	MEDIUM	X ⁵	X									X
	LOW	X			X	X	X	X	X	X	X	
2 SENSITIVITY TO PAVEMENT CONDITION	HIGH			X			X					X
	MEDIUM	X	X		X			X		X	X	
	LOW					X	X		X			
3 EXTENT OF RESEARCH	SUBSTANTIAL	X							X	X		
	FAIR		X	X	X	X	X	X			X	
	NONE						X					X
4 RESEARCH COST ESTIMATE	HIGH	X						X	X			
	MODERATE		X	X	X							
	LOW					X	X	X		X	X	X

1 Sensitivity of the User Cost variable to pavement type; that is, Portland Cement Concrete (PCC) pavement or Hot Mix Asphalt Concrete (HMAC) pavement.
2 Sensitivity of the User Cost variable to pavement condition expressed in terms of Pavement Serviceability Index (PSI).
3 The amount of research work performed to date, to investigate the User Cost variable being considered.
4 Approximate research cost estimate, High: \$160,000 - \$220,000; Moderate: \$120,000 - \$160,000; Low: \$60,000 - \$120,000.
5 The extent of the effect of pavement type on fuel consumption cost has not been conclusively determined.

Figure 6. User Cost Component Impact Matrix

5.2 Research Problem Areas

Recommended research opportunities in six critical areas are outlined in the following pages in the form of problem statements developed for each of these areas. These problem statements were selected on the basis of their potential medium to high impact on user cost and the potential impact of pavement type and condition. Each problem statement is rank ordered according to its potential for immediate contribution. Each problem statement is described in the following manner:

A. PROBLEM TITLE

The problem title indicates the problem area being addressed in one sentence.

B. PROBLEM STATEMENT

The problem statement describes the problem area in more detail. It also outlines the scope of the problem area to be investigated.

C. RESEARCH PROPOSED

The specific investigations required within the scope of the problem area outlined in the problem statement are described.

D. IMPLEMENTATION

The implementation statement discusses the applicability of the results derived from conducting the research outlined above. The issue of immediate availability of results for subsequent application is also addressed.

E. ESTIMATED COST

A range of estimated research expenditures on the problem area being considered is provided.

1. **PROBLEM TITLE:**

Fuel consumption related to pavement type and condition

PROBLEM STATEMENT:

Fuel consumption cost of vehicles has been considered a major contributor to vehicle operating costs, and hence, user costs. It is influenced by road design, engine speed and output, and traffic conditions. There is a lack of consensus among researchers concerning the effect of pavement type and condition on fuel consumption. Fuel consumption over the entire life of a pavement also has not been investigated.

RESEARCH PROPOSED:

As a first step towards finding a solution to the above problem, it is proposed that a limited field test be conducted to determine if there is a relationship between fuel consumption cost of vehicles and pavement type and condition. This would involve a 3-S2 truck on a combination of different pavement types and conditions. The proposed research should also include an economic feasibility study to determine the most cost effective pavement type and material in terms of fuel consumption cost.

IMPLEMENTATION:

The results of this study will provide information for making adjustments to estimated fuel consumption by pavement type. The results will be formulated for direct use in existing benefit-cost and life cycle cost procedures and programs. One important use will be in the MicroBENCOST program being developed by TTI under National Highway Cooperative Research Project 7-12. This program will become the dominant economic analysis tool for a wide range of highway improvement projects. The results of this study will provide the adjustments by pavement type to be incorporated directly into the MicroBENCOST program. Once a pavement type adjustment is included in this program, the significant influence of pavement type for various improvement strategies can be evaluated, as part of the planning and project development process.

ESTIMATED COST:

\$ 160,000 to \$ 220,000

2. PROBLEM TITLE:

Delay cost at work zones on various types of pavements

PROBLEM STATEMENT:

Travel-time delay costs are imposed on the road user due to the diversion of traffic in the presence of a work zone. These costs constitute a significant portion of the total delay costs. A work zone is comprised of any rehabilitation/construction activity which necessitates temporary diversion of traffic. In the existing literature on this area, delay costs are calculated for solitary work zone conditions, without considering the overall impact of all such conditions during the life of the pavement, on total life cycle cost of the pavement. This consideration is especially important for delay costs since the number of rehabilitation/construction activities during the life span of a pavement are different for different types of pavements.

RESEARCH PROPOSED:

It is proposed that an investigation be carried out to identify the relationship between pavement type and the corresponding work zone delay costs. The research will be based on past data pertaining to work zone activities on the pavement types to be studied.

IMPLEMENTATION:

The results of this study will provide improved estimates of delay costs at work zones, as related to pavement type. The results will provide estimates of both the work zone costs of a single rehabilitation, as well as estimates over the life of pavement. This information can be used directly in existing life cycle cost comparisons of pavement types. It is anticipated that the results will be available for immediate implementation in making these cost calculations.

ESTIMATED COST:

\$ 60,000 to \$ 120,000

3. PROBLEM TITLE:

Truck tire wear cost related to pavement type and condition

PROBLEM STATEMENT:

In order to reduce the operating costs of heavy vehicles by improving road surface characteristics, it is important to quantify the effect of surface characteristics on tire cost. There is general agreement that tire wear cost is a significant contributor to operating costs of heavy vehicles.

RESEARCH PROPOSED:

It is proposed that an investigation be carried out to understand the mechanism of tire wear on various types and conditions of pavements. A tire model developed by TTI may be used for this purpose. The proposed research will also identify the impact the rate of pavement deterioration has, on the rate of tire wear.

IMPLEMENTATION:

The results of this study will provide improved estimates of the impacts of pavement type and condition on truck tire wear. This will provide valuable additional information to be used in conjunction with the fuel consumption estimates in Problem Statement 1. These estimates of tire wear will be useful in improving the truck cost estimates in benefit-cost and other life cycle cost procedures. It is anticipated that the results will be available for immediate implementation.

ESTIMATED COST:

\$ 120,000 to \$ 160,000

4. PROBLEM TITLE:

Accident costs pertaining to pavement type

PROBLEM STATEMENT:

Accident costs impose an avoidable burden on road users and the national economy. All the existing research literature in this area has addressed this issue from the safety perspective. A relationship between pavement type and accident rates needs to be established.

RESEARCH PROPOSED:

It is proposed that an investigation be conducted to identify the relationship between pavement characteristics and accident rates and costs. Historical accident data available from the National Accident Sampling System (NASS), National Crash Severity Survey (NCSS), National Center for Health Statistics, National Electronic Injury Severity Survey (NEISS), and the Federal Highway Administration may be used for this purpose.

IMPLEMENTATION:

The results of this study will provide estimates of accident costs as related to pavement type. This will fill a void in the existing data that has not been previously examined in any detail. Since previous work in this area is very limited, it is not known at this time if the results of the study would be ready for immediate implementation. One special problem using accident statistics is the relatively low frequency of fatal accidents, subdivided into several categories. However, given previous work by TTI in estimating accident rates and costs, it is anticipated that this problem can be overcome, and a statistically valid estimate of the relationship between accident costs and pavement type can be established.

ESTIMATED COST:

\$ 60,000 to \$ 120,000

5. PROBLEM TITLE:

Quantification of incremental increase in road user costs due to the deferral of maintenance and assessing the sensitivity of this user cost escalation to pavement type.

PROBLEM STATEMENT:

Deferral of maintenance beyond the serviceable life of a pavement results in an accelerated increase in user costs. A relationship between pavement serviceability and corresponding user costs needs to be established. It will aid the investment decisions by effecting a cost trade-off between excessive user costs and the cost of a major rehabilitation activity.

RESEARCH PROPOSED:

It is proposed that an investigation be carried out to establish a relationship between the rate of pavement deterioration and the corresponding increase in user costs. The proposed research should also include a study of sensitivity of the incremental increase in user costs over different pavement materials.

IMPLEMENTATION:

The results of this study will provide estimates of user costs related to deferral of maintenance activity, with special emphasis on pavement type. This study should be considered preliminary in nature, since deferred maintenance has received almost no attention in previous research. It is anticipated that some part of the study will give direction for further work in the area. However, there is one part of the study which may be available for immediate implementation. The study will attempt to establish the relative impacts of pavement type. Therefore, while the total effect may not be estimated, the incremental effect of pavement type may be available for inclusion in existing procedures and programs.

ESTIMATED COST:

\$ 60,000 to \$ 120,000

6. PROBLEM TITLE:

Travel-time delay costs due to congestion

PROBLEM STATEMENT:

Cost of travel-time delay caused due to congestion is a major component of road user costs in urbanized areas. There is no conclusive evidence regarding the impact of pavement type on congestion cost and that of congestion cost on road user costs.

RESEARCH PROPOSED:

It is proposed that travel-time delay costs be investigated to quantify their contribution to road user costs and the life cycle cost of pavements. The proposed research also should include study of the effect of increased noise level, fuel consumption, and other discomfort costs caused by queuing, as a result of congestion. The relationship of all these costs to pavement type will also be investigated.

IMPLEMENTATION:

The results of this study will provide estimates of travel-time delay due to congestion. This is an especially important area, but preliminary work on establishing the relationship between traffic flow and facility demand needs to be completed before the work on this study can be completed. This preliminary work is being performed on several projects in this country and other countries. The results of these other projects will be used to make estimates of delay for this study. The results will be available for immediate implementation in the various benefit-cost procedures and programs used to estimate user impacts in congested urban areas, and pavement selection criteria based on these.

ESTIMATED COST:

\$ 160,000 to \$ 220,000

5.3 Schedule of Proposed Research

The following schedule of research is prepared in terms of the relative urgency of performing research in the six problem areas. The contribution of each of these components to total user cost is another important consideration. The problem areas have been prioritized from this point of view. Availability of funds is considered a major impediment to performing the research over a shorter period. However, it may be possible to conduct the research activity over a shorter duration so that the results can be available earlier.

PROBLEM STATEMENT	YR.									
	1	2	3	4	5	6	7	8	9	10
# 1 - Fuel Consumption	■	■	■	■						
# 2 - Delay at Work Zone			■	■						
# 3 - Truck Tire Wear				■	■	■				
# 4 - Accident Costs						■	■			
# 5 - Deferral of Maint.								■	■	
# 6 - Congestion-Delay							■	■	■	■

Figure 7. Schedule of Research

Chapter 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 General Conclusions

After conducting an extensive study of the existing literature in the area of user costs, it is evident that there is a void in the research work pertaining to the relationship between pavement type and corresponding user costs. The variation in pavement condition over the life of a roadway and its impact on user costs also has not been adequately investigated to date. Most past research is based on isolated case studies, with very little attention given to the effect of pavement type and condition, as determined by the pavement surface characteristics, on road user costs. The need to correlate each of the user cost variables to a standard measure of road surface characteristics has been overlooked. Another drawback of some previous work in this area is that the results are not in a form that can be directly used in the existing benefit-cost and life cycle cost analysis procedures and programs. More definitive research work in these areas could have a significant influence on the selection of pavement type for various improvement strategies as part of the planning and development process of a project. There could be tremendous potential for realizing significant savings by incorporating these conditions into the planning and implementation stages of infrastructure rehabilitation and reconstruction.

Another potential area for improvement involves rehabilitation strategies and techniques. Examination of specific rehabilitation techniques was outside the scope of the study. However, this issue is particularly critical in the case of work zones^{1*}. The length of time a work zone is set up and traffic is delayed can have a significant impact on user costs. This can, in turn, affect the estimated life cycle cost of both new and reconstructed pavements. If improved construction techniques can reduce the amount of time to complete rehabilitations, significant motorist savings

^{1*} "Work Zone" is a term widely used to refer to any major repair or rehabilitation activity on a road section, which requires temporary diversion of traffic.

can be realized over the life of the pavement.

6.2 Highest Priority Conclusion

There is an urgent need to establish the influence of pavement type on fuel consumption. Previous work by Zaniewski²⁴ found that concrete pavements provided approximately 20 percent reduction in fuel consumption for large trucks (3S-2), as compared to asphalt pavements with the same pavement roughness. However, these estimates were based largely on a World Bank study in Brazil, with roads in much poorer condition than those found in the U.S. For this reason the results have not been accepted by other experts in the area for use in life cycle cost estimates of pavement rehabilitation. There are, however, theoretical reasons indicating there should be a difference by pavement type. As vehicles pass over a pavement, there is less pavement deflection with concrete pavements, which in turn reduces rolling resistance, one of the principal factors affecting fuel consumption. If even a portion of the 20 percent truck fuel savings can be captured by changing pavement type, the savings could be substantial, especially when measured over the life of the pavement.

6.3 Other Conclusions

Several specific conclusions in the three major user cost areas, which should be considered while deciding a course of action, are discussed in the next sections.

6.3.1 Vehicle Operating Costs

Vehicle Operating Costs (VOC) have been studied to a considerable extent in the past. It has been established that fuel consumption cost and depreciation cost are the two major components of VOCs. These two components contribute up to 60 percent of the total VOC. Tire wear costs are significant only in the case of heavy vehicles and may range from 10 to 20 percent of total VOC depending on the roughness condition of the pavement.

Lubricant cost is almost a negligible component of vehicle operating costs. It is generally between 1 to 2 percent of the total VOC. Maintenance and repair cost varies over a wide range depending on the usage-related stresses the vehicle is subjected to, which is a function of road

roughness and geometry. Miscellaneous costs also vary to a large extent dependant on pavement specific conditions.

Based on the literature research conducted in the area of vehicle operating costs, it is concluded that there is minimal research evidence concerning the relationship between fuel consumption costs and pavement type and condition. Another area that needs further investigation is truck tire wear costs, which constitutes a significant portion of vehicle operating costs for heavy vehicles. In the existing literature, there is no conclusive procedure outlined for quantifying tire wear cost for heavy vehicles.

6.3.2 Accident Costs

It was found that no significant attempt has been made to study the influence of pavement related factors on accident costs. Accident rates and costs may be related to the Pavement Serviceability Index, and road roughness. An attempt was made to relate accident rates and costs to PSI by McFarland (1972). However, more extensive work is required in this area. The traffic delay caused by accidents also has not been considered in the work performed to date.

6.3.3 Delay Costs

Three important observations were made while studying the available literature on the delay cost component of total user costs. They are:

(1) While assigning a dollar value to travel time, the value obtained by Chui and McFarland in the Texas Transportation Institute study report 396-2F has been universally used in most research. It seems improper to associate a generalized time-cost value to all the delay categories mentioned below:

1. Delay due to congestion
2. Delay due to diversion of traffic at a work zone
3. Delay due to deferral of repair/ maintenance

Separate estimates for the value of travel time need to be made while calculating delay costs, depending upon the delay category being considered.

(2) There is a void in the research pertaining to the impact of "deferral of repair/

maintenance" on road users (category c above). Past studies in this area have concentrated on the additional costs imposed on State agencies due to deferral of repair work with no regard to the corresponding impact on user costs.

(3) In a solitary attempt to measure work zone delay in the past, the effect of travel-time delay cost on life cycle cost of pavement was not addressed⁷. This work did not include the important aspect of "frequency of occurrence" of work zone activities during the life of different types of pavements. This may lead to inappropriate conclusions for alternative pavement selection strategies. The number of repair activities over the life of a particular pavement is related to the pavement type. Hence, it is important that conclusions based on LCC analysis be used for pavement selection, rather than those based on individual cost components. Another area not addressed in the study was the effect of different rehabilitation strategies, techniques and materials on the duration of rehabilitation activities. The pavement rehabilitation strategy being adopted at a work zone directly affects the travel-time delay. It determines the duration for which the work zone will remain active.

6.4 Recommendations

Further research in the problem areas outlined in the previous chapter needs to be undertaken to aid highway agencies in arriving at judicious policy decisions regarding pavement type selection. Two factors considered extremely important while attempting to perform any further research are:

1. Establishing a definitive relationship between the user cost variable being studied and pavement type and condition.
2. Immediate applicability of the results to the existing benefit-cost and life cycle cost analysis procedures.

The highest priority recommendation is to study the impact of pavement type on fuel consumption. This problem area is summarized as follows:

Fuel consumption related to pavement type

Proposed research in this area is intended to investigate the relationships between fuel consumption costs and the pavement type and condition. An economic feasibility study to determine the most cost effective pavement type will also be a part of this research.

Other problem statements developed in the previous chapter will aid researchers investigate the problem areas listed below. The importance of immediate applicability of the results is stressed in the implementation of each problem statement. The problem areas identified are listed in descending order of priority, and include:

Delay at work zones on various types of pavements

Delay costs incurred due to work zone or repair activities should be studied from the life cycle cost perspective. This will take into consideration the important aspect of frequency of routine maintenance and repair for the type of pavement being investigated.

Truck tire wear cost related to pavement type and condition

Tire wear costs constitute a major component of vehicle operating costs for heavy vehicles. Hence it is proposed that investigations pertaining to truck tire wear be undertaken to quantify the effect of road surface characteristics on tire wear cost.

Accident costs pertaining to pavement type

Accidents have been investigated in the past from the safety perspective. It is proposed to study accidents and quantify accident costs by correlating them to pavement type.

Quantification of incremental increase in road user costs due to deferral of maintenance and assessing the sensitivity of user cost escalation to pavement material

Research in this area will attempt to quantify the accelerated increase in user costs when maintenance is deferred beyond the serviceable life of a pavement. It is expected to aid the investment decisions by identifying a cost trade-off between excessive user costs and the cost of rehabilitation.

Travel-time delay costs due to congestion

It is proposed that travel-time delay costs be investigated to quantify their contribution to road user costs and the life cycle cost of pavements. The relationship between occurrence of congestion and pavement type, if any, will also be investigated.

Because of the strong relationship between rehabilitation time and work zone delay, it is recommended that research also be conducted to identify innovative rehabilitation technologies which would reduce rehabilitation construction time through the application of improved construction processes, methods, and materials. Reducing rehabilitation construction time would subsequently decrease work zone related delays during the rehabilitation period, thereby reducing user costs due to such delays. The benefit in terms of lowering user costs is potentially substantial.

The research areas proposed in this study have the potential to provide important information in making better decisions regarding highway rehabilitation and reconstruction. This, in turn, will result in more cost-effective use of transportation expenditures, a better transportation system, more efficient movement of goods, and improved economic activity. The results should also substantially reduce the conflicts and uncertainties over the role of pavement type in that process. In the past many poorly substantiated claims have been made regarding the impact of pavement type. The overall goal is to determine which of those are valid and what impact they have on motorist costs.

Chapter 7
APPENDIX

A. ANNOTATED BIBLIOGRAPHIES OF ARTICLES REVIEWED

Abstracts of the research literature reviewed while conducting the literature research are provided in this section. Useful information concerning the agencies and sources of publication for each research report are also included for the benefit of the reader. The articles/research reports are listed in the order of "most recent first". The original research reports were obtained from various sources referred to earlier in Chapter 2.

A discussion of the user cost areas covered in this section is provided in Chapters 4 and 5. They include an interpretation of the outcomes of all these research efforts, based on which recommendations are proposed in Chapter 6, for undertaking more conclusive research work in the key areas.

1. VEHICLE OPERATING COSTS

1. **TITLE :** Fuel Consumption of Vehicles as Affected by Road-Surface Characteristics

AUTHORS : Hedric W. du Plessis, Alex T. Visser and Peter C. Curtayne

AGENCY : Division of Roads and Transport Technology, CSIR

P.O. Box 395, Pretoria 0001, South Africa

REPORT NO. :

SOURCE OF PUBLICATION : American Society for Testing and Materials,

Philadelphia (ASTM STP 1031, 1990)

DATE : 1990

NO. OF PAGES : pp. 480-496

APPLICABLE CATEGORY: Fuel Consumption

SUMMARY :

This paper discusses two approaches that have been employed for estimating fuel consumption of vehicles. An equation is then formulated, incorporating the important variables associated with fuel consumption.

One of the aforesaid approaches uses the basic equations of motion to derive a formulation for fuel consumption in which speed, and the coefficients for rolling, air, and gradient resistance are the independent variables. The advantage of this approach is that new technology in tires or vehicle design can be incorporated by revising estimates for the various coefficients without having to undertake a major experiment.

The second approach employs multiple regression techniques to model measured consumption as a function of vehicle and road variables. This type of analysis has a limited application value, since the results are only valid for the test vehicle and cannot be transferred to other vehicle types. Changes in technology will also necessitate a completely new experiment. This approach also has another major shortcoming in that it does not refer to any objective measure of road-surface condition.

The objectives of this study were to determine the effects of road roughness and other road-surface characteristics on fuel consumption. Regression equations are developed for the rolling resistance coefficient, for various types of vehicles. The rolling resistance, which is a function of road roughness, texture depth, and tire pressure, is found to be the major component contributing to fuel consumption.

In summary, the authors also recommend that the effect of the number of wheels on rolling resistance, and the difference in rolling resistance between cross-ply and radial-ply tires be investigated.

2. **TITLE :** Road Macro- and Megatexture Influence on Fuel Consumption

AUTHOR : Ulf S. I. Sandberg

AGENCY : Swedish Road and Traffic Research Institute
S-581 01 Linkoping, Sweden

REPORT NO. :

SOURCE OF PUBLICATION : American Society for testing and Materials,
Philadelphia (ASTM STP 1031, 1990)

DATE : 1990 **NO. OF PAGES :** pp. 460-479

APPLICABLE CATEGORY: Fuel Consumption

SUMMARY :

Four types of losses are assumed to affect fuel consumption of a car: (a) engine, fan, exhaust, and transmission losses, (b) aerodynamic drag losses, (c) rolling resistance losses, and (d) suspension losses. In this paper, effects of losses in (c) and (d) above, on fuel consumption have been investigated. Due to the difficulties associated with pure rolling resistance measurement, the experiments were conducted on a "typical" car (Volvo 242), which limits the applicability of results.

The following questions which are of vital importance for estimation of road surface effects on fuel economy are addressed in this report:

- (1) How much may the existing range of road surface macro- and megatexture influence fuel consumption?
- (2) Is the contribution to fuel consumption significant in relation to macro- and megatexture?
- (3) Which wavelengths of the road texture/unevenness are most important for creating energy losses during car driving?

Several variables contributing to fuel consumption were combined, by performing a multiple regression analysis. The R^2 values range from 0.68 to 0.77 for various speeds. It is concluded that macrotexture may influence fuel consumption up to 7 or 8 percent. Megatexture seems to have a high influence on fuel consumption at medium speeds, but it reduces at higher speeds.

3. TITLE : The Influence of Pavement Evenness and Macrotexture
on Fuel Consumption

AUTHORS : Robert Laganier and Jean Lucas

AGENCY : Civil engineers, LCPC, BP19, Bougenais 44340, France

REPORT NO. :

SOURCE OF PUBLICATION : American Society for Testing and Materials,
Philadelphia (ASTM STP 1031, 1990)

DATE : 1990 **NO. OF PAGES :** pp. 454-459

APPLICABLE CATEGORY: Fuel Consumption

SUMMARY :

Three tests were conducted to estimate the influence of evenness and macrotexture of paved roads on fuel consumption of vehicles:

- (a) laboratory simulation of roughness on a vibration bench,
- (b) road test track comparisons of surfacings having extreme macrostructure but the same (good) degree of evenness, and
- (c) analysis of direct fuel consumption measurements on a sampling of actual roads having various evenness and macrotexture levels.

Pavements have been characterized by (1) evenness as determined by a longitudinal profile analyzer, and (2) macro-texture as measured by a minitexture meter. The effects have been expressed as extra fuel consumption, as compared to a completely smooth and even pavement. Both evenness and macrotexture have shown a measurable extra fuel consumption.

In conclusion, it has been pointed out that other causes of excess consumption, related to road alignment, traffic control, and driving habits also need to be considered while estimating fuel consumption.

4. TITLE : Road-Surface Influence on Tire Rolling Resistance

AUTHOR : Guy Descornet

AGENCY : IRSIA (Institut pour l'encouragement de la Recherche Scientifique dans l'Industrie et l'Agriculture, Brussels, Belgium)

REPORT NO. :

SOURCE OF PUBLICATION : American Society for Testing of Materials,
Philadelphia (ASTM STP 1031, 1990)

DATE : 1990 **NO. OF PAGES :** pp. 401-415

APPLICABLE CATEGORY: Fuel Consumption

SUMMARY :

In 1979, the French DOT estimated that the annual balance of energy spent in road transport was divided up less than 10 percent at the construction and maintenance stages, and more than 90 percent consumed by the users. Among the latter, fuel consumption was found to be an important component. A major factor contributing to vehicular fuel consumption is rolling resistance.

This paper presents a unique apparatus and procedure for measurement of rolling resistance. A "quarter car" trailer has been designed and built at the Belgian Research Center for measuring the rolling resistance of a reference tire on the road. It has been used for investigating the influence of road surface characteristics on rolling resistance. A regression equation has been developed for obtaining the coefficient of rolling resistance. The coefficient of rolling resistance is then corrected for temperature effects and the effect of rolling resistance on fuel consumption is analyzed.

By means of the aforesaid apparatus, measurements of rolling resistance on paved roads in relation to their surface characteristics have demonstrated that the latter have an influence amounting to a 47 percent excess rolling resistance on the worst road surface, compared with the best, everything else being equal. The corresponding range of potential fuel savings through proper road maintenance and improved paving techniques is estimated at 9 percent.

In summary, it is stated that better accuracy and consistency regarding road surface influence on user cost and traffic noise can be gained by taking megatexture into proper account.

The fuel consumption data was collected by means of vehicles instrumented to measure the rate of fuel consumption and cumulative fuel consumption as a function of speed and acceleration profile. Coast-down testing was carried out for these vehicles previously, to determine the relationship between total vehicle resistance force and pavement conditions. Rolling resistance was found to be the major contributor to fuel consumption.

The results indicate that pavement roughness can affect vehicle resistance by approximately 4 percent for small vehicles tested and as much as 8 percent for the medium size vehicles tested. However, pavement texture depth was found to be relatively insignificant.

6. TITLE : Vehicle Speeds and Operating Costs
AUTHORS : Thawat Watanatada, Ashok M. Dhareshwar, and
Paulo Roberto S. Rezende Lima
AGENCY : The World Bank
REPORT NO. :
SOURCE OF PUBLICATION : The Johns Hopkins University Press
DATE : December 1987 **NO. OF PAGES :** 460
APPLICABLE CATEGORY: Vehicle Operating Costs
SUMMARY :

Three types of speed prediction models are developed in order to determine vehicle speed to be used in evaluating fuel consumption. A Unit Fuel Consumption function has been formulated for fuel consumption prediction purposes.

The data for estimating the unit fuel consumption function were obtained from an experiment using 11 test vehicles. Sixty thousand (60,000) runs under a number of different conditions were conducted. For each run, the unit fuel consumption, engine speed, and vehicle power are computed. The vehicle power is expressed as a function of gradient of the test section and the rolling resistance.

The estimation results based on an ordinary least squares regression are presented. The R^2 value is in the range of 0.92 - 0.98. Following important observations are made in this study:

- (1) Speed change cycles are not in themselves the cause of excess fuel consumption;
- (2) For the same power output, it is always more economical to operate the internal combustion engine at low speed and high torque than vice versa;
- (3) The effect of roughness on fuel consumption is stronger for a loaded than for an unloaded truck.

For the transferability of the Unit Fuel Consumption to various classes of

vehicles, a multiplicative adjustment factor, termed as "relative energy-efficiency factor" has been defined. However, it is stated that the ideal course of action for obtaining reliable estimates of the UFC function for a particular vehicle class would be recalibration.

7. **TITLE:** An Investigation of the Relationship Between Motor Vehicle Operating Cost and Levels of Service Using Internal Energy Methods

AUTHORS: Frank Maxfield Croft, Jr.

AGENCY: Clemson University

REPORT NO.:

SOURCE OF PUBLICATION: University Microfilms International, Ann Arbor, Michigan, 1986

DATE: May 1984 **NO. OF PAGES:** 110

APPLICABLE CATEGORY: Vehicle Operating Costs

SUMMARY:

This study discusses the possibility of treating acceleration noise as a parameter for quantifying vehicle operating costs. The author states that travel time is not the best indicator of operating conditions on a highway unless delays are exceedingly long or frequent. Acceleration noise is recommended as a parameter which is sensitive to the three basic elements of traffic stream, namely: the driver, the road and the vehicle. Acceleration noise is defined as the standard deviation of individual accelerations and decelerations of a vehicle travelling over a section of highway.

The primary objectives of this study were (1) to demonstrate that acceleration noise can be used as a quantitative measure of the quality of traffic flow on an urban freeway, (2) to demonstrate that vehicle operating costs are related to the parameter acceleration noise, and (3) to determine the effect that level of service has on the parameter acceleration noise. The results of this study support the premise that acceleration noise, the internal energy component of the traffic stream, is a quantitative measure of the quality of traffic flow.

Traffic flow data were collected from sections of Interstate 65 in Louisville, Kentucky, using a "floating car" equipped with a Greenshields Traffic Analyzer. The traffic analyzer data were later reduced using an interactive computer program to yield

values of acceleration noise. The relationship between acceleration noise and the traffic flow parameters of speed, volume and density were analyzed using scatter diagrams and plots of the mean values of each parameter for each level of service. The results showed the relationships to be significant and the values of R^2 indicated a high degree of correlation. The relationship between operating cost and traffic flow parameters of speed, volume, and density were analyzed in a similar manner. The results showed the relationships between the variables not to be significant and the values of R^2 indicated little correlation between these parameters. As a result of this study, it was concluded that acceleration noise due to traffic interaction is a quantitative measure of traffic flow quality. The relationship between operating cost and acceleration noise was determined to be quadratic in nature.

8. **TITLE:** Effect of Pavement Type and Condition on Vehicle Operating Costs

AUTHORS: Christo J. Bester

AGENCY: National Institute for Transportation and Road Research, Council for Scientific Research, Pretoria, Republic of South Africa

REPORT NO.:

SOURCE OF PUBLICATION: Transportation Research Record, 1000

DATE: 1984 **NO. OF PAGES:** pp. 28-32

APPLICABLE CATEGORY: Fuel Consumption

SUMMARY:

A procedure for determining the rolling resistance of vehicles, which is then related to the type and condition of pavement, is described in this report. From the rolling resistance, fuel consumption of the test vehicles is then predicted by means of the relationship between the energy requirements and fuel usage of a vehicle.

The combined effect of air and rolling resistance is determined by using a coasting vehicle, that is a vehicle running freely, with the engine disengaged. The speed of the vehicles during coasting was determined at 10-second intervals. From these speeds, the deceleration over the interval and the average speed during the interval are calculated. Linear regression analyses have been performed for both directions of each test section.

Eight different road sections, two of asphaltic concrete pavement, one of portland cement concrete pavement, four with surface treatments and one unpaved, were used to determine the effect of road roughness on rolling resistance of vehicles. The roughness of each section was determined by using a Linear Displacement Integrator (LDI) developed by the National Institute for Transport and Road Research. From the tests, formulas are developed, to determine the savings in fuel consumption, that will result from improving the condition of pavements, either by new construction or rehabilitation.

An important conclusion is that pavement type has a small effect on the rolling resistance, and therefore, on the fuel consumption of vehicles.

9. **TITLE :** Vehicle Operating Costs, Fuel Consumption,
and Pavement Type and Condition Factors
AUTHORS : J.P. Zaniewski, B.C. Butler, G. Cunningham,
G.E. Elkins, M.S. Paggi, R. Machemehl
AGENCY : Federal Highway Administration
REPORT NO. : FHWA/PL/82/001
SOURCE OF PUBLICATION : Texas Research and Development Foundation, 2602
Dellana Lane, Austin, TX 78746
DATE : June 1982 **NO. OF PAGES :** 375
APPLICABLE CATEGORY: Vehicle Operating Costs
SUMMARY :

This report presents updated vehicle operating cost tables which may be used by a highway agency for estimation of vehicle operating costs as a function of operational and roadway variables.

Fuel consumption of eight vehicles was measured on test sections selected to be homogenous with respect to grade, surface type, and roughness. Constant speed tests were performed in 10 mph increments from 10 mph to 70 mph. Eight vehicles representing 7 vehicle classes were used. For the "loaded" trucks, a load typical for the model of truck being tested was selected.

Test sections were selected to be homogenous with respect to grade, surface type, and roughness. A total of 12 test sections were used. Testing was conducted on asphalt and concrete pavements with a range in serviceability of 1.8-4.2 and on concrete and surface-treated pavements. Fuel consumption data was obtained for idling, acceleration, and deceleration, considering the effects of speed, grade, pavement type and roughness. Equations for fuel consumption have been developed by a visual inspection of plotted data.

It was observed that concrete pavements provided up to 20 percent reduction in fuel consumption for large trucks (3S-2) as compared to asphalt pavements with the same pavement roughness.

10. **TITLE:** Depreciation of Motor Vehicles in New Zealand
AUTHORS: Christopher R. Bennett and Roger C.M. Dunn
AGENCY: Department of Civil Engineering, The University of Auckland, New Zealand
REPORT NO.:
SOURCE OF PUBLICATION: Transportation Research Record 1262
DATE: 1990 **NO. OF PAGES:** pp. 12-20
APPLICABLE CATEGORY: Depreciation
SUMMARY:

This paper discusses the depreciation costs of vehicles in New Zealand. Equations are developed for predicting the rate of depreciation as a function of age and utilization for passenger cars, light commercial vehicles, and medium and heavy commercial vehicles. These are based on data collected from newspapers and the Dealer's Guide.

The stability of depreciation over time was investigated by performing the analysis on data from 17 months earlier. It was found that depreciation is unstable with respect to time, leading to the recommendation that a simpler technique be adopted for calculating depreciation costs. Capital recovery, a straight line depreciation technique that considers the effect of time on capital is recommended. The depreciation equations were used to investigate the allocation of depreciation between time and vehicle use. It has been established that the majority of depreciation costs are due to time, not vehicle use.

11. **TITLE:** Vehicle Depreciation and Interest Costs: Some Evidence From Brazil

AUTHORS: Andrew Chesher, Robert Harrison, Joffre D. Swait

AGENCY:

REPORT NO.:

SOURCE OF PUBLICATION: Transport and Road Research Laboratory

DATE: 1980 **NO. OF PAGES:** pp. 2137-2157

APPLICABLE CATEGORY: Depreciation and Interest Costs

SUMMARY:

Depreciation and interest costs and their relationship to highway standards are the subject of this paper. Depreciation per annum is calculated as a function of vehicle age using data pertaining to used vehicle prices.

Relationships between vehicle values and vehicle age and between vehicle utilization, vehicle age, and highway characteristics have been developed from one of the largest bodies of vehicle user survey data ever obtained. The relationships between utilization and highway characteristics, and the vehicle value relationships provide a method of obtaining equations relating depreciation and interest charges to highway characteristics. When combined with equations for other user cost elements on a per kilometer basis, they provide the key to obtaining per annum equations which are the fundamental relationships for cost benefit analyses of highway improvement projects.

2. ACCIDENT COSTS

1. **TITLE :** The Cost of Vehicle Damage resulting from Road Accidents

AUTHORS : Marie C. Taylor

AGENCY : Transport and Road Research Laboratory

REPORT NO. : 256

SOURCE OF PUBLICATION : TRRL, Berkshire, UK

DATE : 1990 **NO. OF PAGES :** 12

SUMMARY :

This paper presents the results of an investigation carried out by sending a questionnaire to car drivers in Great Britain. Two thousand (2,000) car drivers aged 23 or above, and 1,000 car drivers age 22 years or less were chosen for this purpose. The results are based on 3810 of 5381 reported accidents.

An accident is defined as "any incident which involved injury to the driver or another person, damage to any vehicle involved, or damage to property". Accident costs are derived as the expense *actually incurred*, following the accident. The degree of damage is categorized into 1) None, 2) Slight, 3) Serious, and 4) Write off.

An important feature of this study is that it takes into account the discrepancy between "reported" and "not reported" accidents. A study conducted in 1988 (Turnbridge et. al.) indicated that 1 in 5 accidents involving injury to occupants is not reported. Sixteen percent of injury accidents in the present study had not been reported to the police.

The factors considered in evaluating damage costs are :

- (1) Driver's age
- (2) Extent of damage
- (3) Injury severity

- (4) Report to Police
- (5) Insurance claims
- (6) Place of repair
- (7) Vehicle type
- (8) Involvement of other vehicle (if any)
- (9) Damage to other vehicle

2. **TITLE :** Accident Costs for Highway Safety Decisionmaking
AUTHORS : Brenda C. Kragh, Ted R. Miller, and Kenneth A. Reinert
AGENCY : Federal Highway Administration, Office of Safety and
Traffic Operations Research and Development

REPORT NO. :

SOURCE OF PUBLICATION : Public Roads, Vol. 50, No. 1

DATE : 1986 **NO. OF PAGES :** pp. 15-20

SUMMARY :

This report reviews different accident cost numbers and methodological approaches used to develop, present and explain updated accident cost numbers. The components of accident costs and factors influencing these costs also are discussed. Accident costs are broken up into direct and indirect costs.

Direct costs include :

- 1) Property damage cost
- 2) Emergency medical and transportation service costs
- 3) Medical treatment costs - emergency room, hospitalization, doctor/surgeon, follow-on care, home modification and so on.
- 4) Legal and court costs

Indirect costs include :

- 1) Costs experienced by social mechanism
- 2) Human capital
- 3) Cost of psychological deterioration
- 4) Value of life and safety

Two different approaches can be used to determine indirect accident costs. (1) Human capital approach or (2) Willingness-to-pay approach. The Willingness-to-pay approach has been recommended in this report, for obtaining economically sound accident cost number required for making responsible decisions. No recommendations are made as regards to the suitability of a particular accident classification system. The A-B-C & PDO classification and the MAIS classification are currently in use.

3. **TITLE :** Costs of Motor Vehicle Accidents and Injuries
AUTHORS : John B. Rollins, William F. McFarland
AGENCY : Federal Highway Administration
REPORT NO. :
SOURCE OF PUBLICATION : Transportation Research Record 1068
DATE : 1986 **NO. OF PAGES :** 7
SUMMARY :

This paper presents findings of the 1983 accident cost study by the National Highway Traffic Safety Administration in a form suitable to be used by State Agencies for accident cost evaluation.

Accident data from five states are used in deriving the accident costs. Data from the National Crash Severity Study (NCSS) and the National Accident Sampling System (NASS) are used to relate percentage distributions of injury severities by the MAIS and A-B-C scales.

Two major shortcomings of the 1983 study which have been accounted for in this work are:

- 1) In the previous study, costs were presented in terms of a Maximum Abbreviated Injury Scale (MAIS) whereas benefit cost analyses often are based on injury severities coded by the A-B-C and PDO scale.
- 2) Costs in the previous study were expressed on a per victim and per vehicle basis whereas a state's accident data generally consists of the number of accidents per year, each accident being scaled on the A-B-C & PDO scale.

4. **TITLE :** Costs of Motor Vehicle Accidents in Texas
AUTHORS : John B. Rollins, William F. McFarland
AGENCY : Texas State Department of Highways and Public Transportation
REPORT NO. : FHWA/ TX-85/ 67 + 396-1
SOURCE OF PUBLICATION : Texas Transportation Institute
DATE : May 1985 **NO. OF PAGES :** 156
SUMMARY :

An extensive report on the evaluation of accident costs is provided. Accident statistics used in developing accident costs were obtained from Texas traffic accident data and roadway inventory records for 1981 and 1982. These statistics were developed by following cross-classifications previously determined to be meaningful in benefit-cost evaluations of highway projects :

- Area (rural, urban)
- Severity (fatal, injury, PDO)
- Multiple-vehicle, single vehicle
- Intersection, Non-intersection
- Accident type
- Road type (Controlled access, other divided, undivided)

Statistics were obtained on the basis of these cross-classifications for night accidents and wet weather accidents in order to allow more precise evaluation of countermeasures specifically directed at either of these two subsets of accidents.

Following accident statistics are calculated for the indicated sets of accidents and by the indicated cross-classifications:

- accident frequencies and proportions by severity
- numbers of passenger cars, single unit trucks and combination truck per accident
- numbers of fatalities and injuries (by A-B-C severities) per fatal accident and per injury accident

Various cost components considered are:

(1) Direct Costs -

- 1) Cost of damage to vehicle and other property
- 2) Medical expenses
- 3) Cost of loss of vehicle use
- 4) Value of time lost
- 5) Legal and court costs
- 6) Miscellaneous direct costs
- 7) Funeral costs (if fatality involved)

(2) Indirect Costs -

- 1) Production and consumption loss for the injured person
- 2) Losses to injured person's home, family, and to community at large
- 3) Costs of accident investigation
- 4) Insurance administration costs

Consumer price indices (CPI) are used to assign a dollar value to the direct cost elements. A detailed procedure is outlined, to derive indirect costs. The "willingness to pay" approach is used.

5. TITLE : A framework for costing accidents and accident types

AUTHORS : D. C. Andreassend

AGENCY : Australian Road Research Board

REPORT NO. :

SOURCE OF PUBLICATION : A.R.R.B., P.O. Box 156 (Bag 4), Nunawading,
Vic 3131, Australia

DATE : 1985 **NO. OF PAGES :** 5

SUMMARY :

A framework is developed for applying unit casualty class costs and unit accident-type damage repair costs to accidents of various types and severity levels. Here, "casualty class" is used to refer to a person, while "severity level" is used to refer to an accident. This approach takes into account the difference between persons and accidents in the process of applying costs.

A two-dimensional matrix consisting of accident severity level in rows and casualty class in columns is developed to read out unit costs for a particular accident type. This approach provides a convenient way for weighing the reduction of specific accident types and corresponding cost of those accident types against the countermeasure, when one intends to use a benefit-cost assessment for decision making.

(Note : The evaluation of actual unit cost of a casualty class is not the subject of this paper; rather it is the application of unit casualty and damage costs to the costs of accidents of various severity levels.)

6. **TITLE :** The Economic Cost to Society of Motor Vehicle Accidents

AUTHORS :

AGENCY : USDOT

REPORT NO. : DOT HS806 342

SOURCE OF PUBLICATION : USDOT

DATE : January 1983 **NO. OF PAGES :** 267

SUMMARY :

This report examines all possible costs resulting from motor vehicle accidents. The purpose of presenting these costs is to place in perspective, the tragic losses resulting from motor vehicle crashes, and to provide information for the use of government and public sector officials at all levels in structuring programs to combat these needless losses.

Although this report recognizes the broader aspects of societal costs, it considers only the economic cost aspects. Because of their sheer number, Property Damage Only accidents were found to be the largest source of losses. The second largest contributor was fatal accidents.

The appendices present the government costs related to motor vehicle crashes, and a sensitivity analysis of the results using different estimates of incidence and different discount rates. One important shortcoming of this report is that it uses the Abbreviated Injury Scale, which is extremely inconvenient to develop costs from it. This is primarily because AIS does not focus on outcome of the injury.

Five databases were used :

- (1) National Accident Sampling System (NASS)
- (2) National Crash Severity Survey (NCSS)
- (3) National Center for Health Statistics
- (4) National Electronic Injury Severity Survey (NEISS)
- (5) Federal Highway Administration

7. **TITLE :** Economic and Social Costs of Road Accidents in Australia

AUTHORS : A. S. Atkins

AGENCY : Office of Road Safety, DOT Australia

SOURCE OF PUBLICATION : University of Melbourne

DATE : 1981 **NO. OF PAGES :** 128

SUMMARY :

This study reviews the scope of previous work on the valuation of accident costs to reflect a comprehensive concept of social cost and welfare. The following approaches that are being used in evaluating accidents, are discussed in detail :

- 1) Willingness-to-pay (eg. for reduction in risk)
- 2) Human capital (or the "lost future income" approach)
- 3) Implied value of life approach

A general conclusion is that if road safety, in the form of accident reduction, is considered partly to be a merit good^{2*}, then the human capital approach to valuation of life is favored. This approach should be supplemented by more appropriate estimates of non-market valuations consistent with the concept of national welfare, which is to be maximized in any evaluation model. The accident cost framework proposed in this study focuses on a cost matrix developed by Faigin (1976). It consists of eleven rows with each defining a cost category and an injury scale in seven columns.

The data sources for this study include accident statistics from governmental agencies, and specific studies conducted to obtain costs in the aforesaid eleven categories.

^{2*} "merit good" implies a commodity not sought by individual preference but desired by the community as a whole, in apparent contradiction of individual choice; for example, restrictions on helmets, seat belts, alcohol consumption, and so on.

3. DELAY COSTS

1. **TITLE :** Roadway Congestion in Major Urbanized Areas
AUTHORS : James W. Hanks,Jr. and Timothy J. Lomax
AGENCY : Texas State Department of Highways and Public Transportation, Austin
REPORT NO. : FHWA/TX-90-1131-3
SOURCE OF PUBLICATION : Texas Transportation Institute
DATE : 1990 **NO. OF PAGES :** 148
APPLICABLE CATEGORY : Delay due to Congestion
SUMMARY :

The report contains roadway information for 39 urbanized areas representing a geographic cross-section throughout the country. The database used for this research contains vehicle travel, urbanized area information, facility mileage, and vehicle travel per lane mile information from 1982 to 1988. A primary information source was Federal Highway Administration's Highway Performance Monitoring System.

Roadway congestion index values for various urbanized areas are developed to serve as indicators of relative mobility level. Provision of additional freeway and principal arterial street lane-miles is considered an alternative to alleviate congestion. Number of lane miles required to achieve an RCI value of 1.0 are calculated for various urbanized areas.

Five specific variables are identified and used in congestion cost estimates:

- 1) Daily vehicle miles of travel
- 2) Insurance rates
- 3) Fuel costs
- 4) Registered vehicles
- 5) Population

Three cost components are related with congestion: (1) Delay cost, (2) Fuel cost, and (3) Insurance cost.

2. **TITLE :** MEDITER, A Model for the assessment of Rehabilitation Delay Cost
in ERASME

AUTHORS : Daniel Renault and Frederic Allez

AGENCY : C.E.T.E. Mediterranee, France

REPORT NO. :

SOURCE OF PUBLICATION : Transportation Research Record 1268

DATE : 1990 **NO. OF PAGES :** pp. 1-7

APPLICABLE CATEGORY : Deferral of maintenance

SUMMARY :

This model mixes mechanistic and empirical results, thus improving the quality of pavement condition prediction than that given by purely empirical methods.

The model includes two functions :

- (1) Forecasting evolution of key flexible pavement distress in case of a rehabilitation or reconstruction delay, using the flexible pavement distress prediction (FPDP) model, and
- (2) Assessing maintenance cost increases caused by a rehabilitation or reconstruction delay (for which maintenance includes surface dressings, pothole patching, rehabilitation and reconstruction).

The rehabilitation delay costs are broken down into four parts :

- 1) User costs linked to road deterioration (which are not evaluated by MEDITER, a section level tool)
- 2) Patching costs on severely cracked areas and potholes
- 3) Road shape correction costs caused by rutting
- 4) Rehabilitation cost increases because of loss of strength of pavement structure (which is directly linked to increase in deflection)

This model does not take into account user costs in its economic comparisons.

3. **TITLE :** The Value of Travel Time : New Estimates Developed Using
A Speed-Choice Model

AUTHORS : Margaret K. Chui and William F. McFarland

AGENCY : Texas State Department of Highways and Public Transportation, Austin

REPORT NO. : FHWA/TX- 86/33 + 396-2F

SOURCE OF PUBLICATION : Texas Transportation Institute

DATE : May 1986 **NO. OF PAGES :** 57

APPLICABLE CATEGORY : General estimate of Travel Time

SUMMARY :

Vehicle Operating Costs, Accident Costs, and Time Costs are considered. The value of travel time of each individual is obtained in terms of the square of his/her chosen speed, the distance travelled, and the derivatives of his/her driving cost components other than time costs.

Primary data source included a telephone interview of 500 randomly selected people in Texas. Answers that fell beyond "four standard deviations from the mean" were discarded. Data on Vehicle Operating Costs and on Accident Rates were obtained from existing literature sources. The "willingness to pay" approach has been used to assign a dollar value to travel time.

The main purpose of this study was to develop estimates of the value of travel time for use in the Highway Economic Evaluation Model (HEEM).

4. **TITLE :** A Model to calculate Delay Savings for Highway Improvement Projects
AUTHORS : Jeffery L. Memmott and Jesse L. Buffington
AGENCY : Texas State Department of Highways and Public Transportation, Austin
REPORT NO. : FHWA/TX-84/25 +327-1
SOURCE OF PUBLICATION : Texas Transportation Institute
DATE : October 1983 **NO. OF PAGES :** 115
APPLICABLE CATEGORY : Deferral of Maintenance (User Cost)
SUMMARY :

The calculation of delay savings in the model is based on the projected Average Daily Traffic (ADT), which can be given in the input data or calculated within the program. ADT is then converted to hourly traffic volume. Delay cost, in dollars, is calculated and the difference between the proposed facility and the existing facility is given as Delay Savings.

This study examines the traffic growth on several highways throughout Texas, as a function of several variables, including adjacent lane development, highway type, location, capacity changes, and median treatments. A total of 187 count stations over a ten year period were used to estimate coefficients in a linear regression model.

Hourly delay is calculated as: $DLY = L (V) / SP$

where,

L = length of project in miles

SP = average speed

Dollar cost of delay is calculated as

$$CDLY = DLY [(1-PT) VT_C + (PT) VT_T]$$

where, PT = proportion of trucks

VT_C = value of time, cars (\$/hr.)

VT_T = value of time, trucks (\$/hr.)

The model does not incorporate effect of traffic diversion on change in delay savings.

5. **TITLE :** A Model to calculate the Road User Costs at Work Zones (QUEWZ)
AUTHORS : Jeffery L. Memmott and Conrad L. Dudek
AGENCY : Texas State Department of Highways and Public Transportation, Austin
REPORT NO. : FHWA/ TX-83/ 20 +292-1
SOURCE OF PUBLICATION : Texas Transportation Institute
DATE : September 1982 **NO. OF PAGES :** 120
APPLICABLE CATEGORY : Delay due to Traffic Diversion
SUMMARY :

User costs resulting from restricted capacity through a work zone are considered to include delay or travel time costs, vehicle running costs, speed change cycle costs, and accident costs. Accident costs have not been accounted for in this model due to lack of data on changes in accident rate through a typical work zone.

Two types of lane closure strategies are considered :

- (1) One or more lanes closed in one direction of traffic
- (2) Cross-over; one or more lanes closed in each direction of traffic.

The model uses hourly traffic volumes rather than ADT. This allows for a much more accurate estimate of average speeds and the estimated queue when demand exceeds capacity. Dollar values of operating costs have been taken from the Red Book, and the values of time from the HEEM program.

The total hourly user cost (THC) in each direction is given by,

$$\text{THC} = \text{CQUE} + \text{CDWZ} + \text{CDSC} + \text{CSPC} + \text{CSPQ} + \text{OC} + \text{OCQ}$$

where,

CQUE = time cost of delay

CDWZ = delay cost of going through the work zone at reduced speed

CDSC = time cost of speed change cycle

CSPC = additional operating cost of speed change cycle

CSPQ = additional speed change operating cost when queue is formed
OC = vehicle running cost
OCQ = vehicle running costs when queue is formed

Alternative traffic control strategies like closing entrance ramps, temporary use of shoulder as an operating lane, diverting traffic to the frontage road, and splitting traffic during middle lane closures, are not considered.

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