Impact of User Delay on Pavement Life-Cycle Cost

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GLOSSARY OF ABBREVIATIONS

AADT - Annual Average Daily Traffic
FHWA - U.S. Federal Highway Administration
HMA - Hot Mix Asphalt
ICP - Interlocking Concrete Pavement
ICPI - Interlocking Concrete Pavement Institute
LCC - Life-Cycle Cost
VOC - Vehicle Operating Cost

Executive Summary

In the pavement engineering world, it is customary to use the term *user costs,* rather than the term *user benefits*, when referring to the costs incurred by the motorists travelling on roads. A motorist, or a user, traveling on a road always incurs costs associated with the travel. If a change is made that reduces the costs incurred by the user, the incremental reduction in the user costs is called the user benefit. Consequently, when user costs are addressed, they are actually determining the incremental user benefits.

This report is concerned with the differences in user costs associated with maintenance and rehabilitation of a hot mix asphalt pavement (HMA) and an interlocking concrete pavement (ICP). This report only considers maintenance and rehabilitation (M & R) costs incurred during the service life of the roadway. While initial construction of a roadway may also incur some user costs, it has been assumed that the roadways included in the analysis were constructed as “green field” projects.

A simple user delay cost model was developed to compare HMA and ICP roadway pavements. M & R activities planned for HMA and ICP pavements and traffic information were taken from a recent ICPI Life-Cycle Cost Comparison Tools Development study. The duration of the maintenance and rehabilitation work was estimated based on Applied Research Associates, Inc. (ARA) experience. The M & R actions and costs with their year of implementation represent the total needed to maintain the pavement at a suitable level of service over a 50-year life. Other assumptions include the length of construction zones for various M & R activities, change in vehicle speed travelling through the work zones and value of time for passenger and heavy vehicle/bus drivers.

The total present cost of M & R delays for HMA surfaced roadway was estimated at $57,009 with a net present worth of $15,886. The corresponding cost for the ICP surfaced roadway was $54,350 with a net present worth of $18,528, 14 percent higher than the HMA with a difference ($2,642). However, the total cost of delays is very small compared to the total life-cycle costs, i.e., initial construction plus subsequent M & R rehabilitation costs which average about $820,000 for HMA and ICP. Specifically, the cost of user delays represents about 1.7 percent of the total present worth of M & R costs.

1. Introduction

It is customary to use the term *user costs,* rather than the term *user benefits*, when referring to the costs incurred by the motorists travelling on roads. A motorist is considered a user, traveling on a road always incurs costs associated with travel. If a change is made that reduces the costs incurred by the user, the incremental reduction in the user costs is called the user benefit. Consequently, when user costs are addressed, they are actually determining the incremental user benefits.

This report is focused on the differences in user costs of a hot mix asphalt pavement (HMA) and an interlocking concrete pavement (ICP). This report only considers maintenance and rehabilitation or M & R costs incurred during the service life of the roadway. While initial construction of a roadway may also incur some user costs, it has been assumed that the roadways included in the analysis have been constructed as "green field" projects.

1.1 Application of Road User Costs

In the past, road user costs were not included in the economic evaluation of alternative designs of pavement investments because user costs were considered to be indirect or "soft" costs. However, over the past 10 years, many agencies include road user costs in evaluating the cost-effectiveness of competing investment alternatives. The importance of road user costs is especially relevant on higher traffic volume roads where the potential for delays is large and contractors must meet specific requirements to minimize user delays due to M & R operations. These requirements may include, for example, night work only or use of detours to minimize the delay impacts of M & R activities on the travelling public and to maximize safety for construction workers. The cost of these requirements is part of the contract bid price and is thus included in construction costs. Consequently, a part of the "soft" road user costs is transformed into agency costs.

1.2 Types of User Costs

User costs belong to the category of indirect costs that may be considered when comparing factors and consequences from alternative pavement investments. The indirect costs include the following items:

- Construction zone delay costs;
- Vehicle operating costs;
- Collision costs; and
- Environmental costs.

1.2.1 Construction Zone Delay Costs

Construction zone delay costs are incurred as the result of additional travel time spent by motorists driving through construction zones or detours as the result of scheduled M & R activities. These activities for the two pavement types studied differ in type, duration, and frequency. Although the majority of agencies are not using time delay costs to obtain bids for construction work explicitly, time delay costs are included in construction costs and for M & R of roadways by including contact provisions intended to minimize user costs. These provisions typically include requirements for keeping a specified number of lanes open and completing construction by set dates. The expected difference in time delay costs for the two pavement types was quantified in this study.

1.2.2 Vehicle Operating Costs

Vehicle operating costs (VOC) include costs of owning, operating, and maintaining a vehicle including fuel, oil, tire, maintenance and repair, and depreciation costs. VOC depend on pavement smoothness and traffic flow. For the comparison of the two pavement types, it can be assumed that the flow conditions will be similar because both types will have the same traffic on the same alignment. While smoothness can be a major factor for high traffic volume highways, it is of less importance in the municipal urban environment where roadways need to accommodate elevation difference due to crossing streets, commercial and residential driveways and have surface roadway "furniture" such as utility access covers and catch basins, etc. As such, vehicle operating costs were not specifically included in this study.

1.2.3 Collision Costs

Differences in the occurrence of fatal collisions, injury collisions, and property damage only collisions may arise because the two pavement types may not have identical characteristics. These characteristics can include pavement friction during the analysis period and under a variety of pavement conditions (e.g., dry, wet, and icy), visibility of traffic control lines, visibility of geometric features under adverse weather conditions, level of illumination at night, and perhaps other characteristics such as the likelihood of ice forming on the pavement surface. Differences in collision rates between the two pavement types have not been quantified in this study because there are insufficient data to do so, and if such differences exist, they are likely marginal. In addition, we have not encountered any study where such quantification has been done.

1.2.4 Environmental Costs

Environmental costs include the cost of air, noise, and water pollution.

Air pollution – For the purposes of this study, air pollution costs concern differences in air pollution costs, such as costs of greenhouse gas emissions, associated with different pavement types. While there have been several studies evaluating the effect of pavement characteristics on fuel consumption, all have been related to highway pavements [1,2,3]. We are not aware of any relevant studies related to ICP. Therefore, air pollution costs were not quantified in this study.

Noise pollution – Differences in the pavement texture may result in sound level (decibel) differences emitted by vehicles and tires. These differences may impact people on adjacent properties. There are numerous sources for noise pollution in the urban environment and slower moving traffic tends to reduce noise from moving vehicles. While noise from pavers can be controlled by chamfer size and joint spacing, noise pollution issues were not quantified in this study.

Water pollution – Since both pavements generate stormwater runoff, there are likely no significant differences in water pollution caused by the same traffic operating on the two pavement types. Consequently, water pollution costs were not quantified in this study.

2. Quantification of Construction Delay Costs

Accurate quantification of the additional travel time and VOC due to the changes in traffic flow caused by work zones is a very complex task. A vehicle traveling through a construction zone may need to decelerate from an approach speed (normal operating speed) to a queuing speed, decrease speed in a work zone, and then upon existing the work zone, accelerate to the normal operating speed. An example of a speed diagram for a vehicle travelling through a work zone is illustrated in Figure 2-1. The figure shows a speed profile that results in a queuing delay, but without stop-and-go conditions.

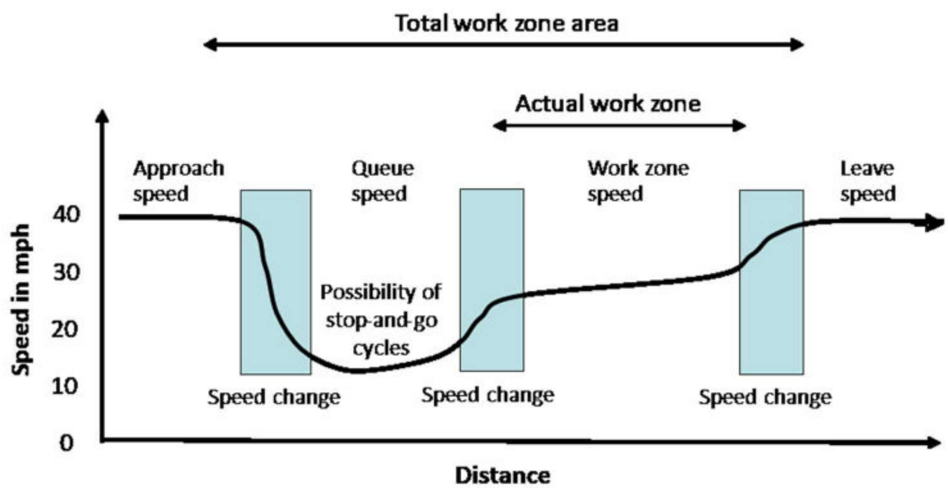

Figure 2-1. Change of Vehicle Speed in Work Zones.

There are several computer programs to facilitate the quantification of user delay costs. Notable programs include, PEAT [4], HDM IV [5], MicroBENCOST [6] and QUEWZ [7]. Some of these programs require complex input data and calibration while others are not sensitive enough for this study. Also, regardless of the program used, the estimated road user costs are mainly influenced by assumptions regarding traffic volumes during lane closures and assumptions taken on the value of travel time. For this reason, the quantification of maintenance and rehabilitation activity delay costs was carried out using an MS Excel-based model employing a number of simplifying assumptions. This approach is transparent and facilitates sensitivity analysis.

2.1.1 Primary Assumptions

The example calculation of user delay costs assumes a municipal 2-lane minor collector roadway with a bus route.

Type of Maintenance and Rehabilitation Activities

M & R activities planned for the HMA and ICP pavements were taken from a recent ICPI Life-Cycle Cost Comparison Tools Development study [8]. The duration of the maintenance and rehabilitation work was estimated based on ARA experience and is summarized in

Table 2-1 for the HMA pavement and in Table 2-2 for the ICP. The M & R actions with their year of implementation and costs represent the total needed to maintain the pavement at a suitable level of service for a life of 50 years.

Table 2-1. Pavement Maintenance and Rehabilitation Action Plan - HMA

Years after initial construction	Description of pavement layer, Amount (Quantity)	Amount	Quantity per 2-lane mile	Duration of Work (hours)
10	Rout and seal, ft/mile (ft)	1300	1,300	3.4
10	Spot repairs, mill 1.5 in/patch 1.5 in, % area (ft^2)	2	2,534	2.5
15	Spot repairs, mill 1.5 in/patch 1.5 in, % area (ft^2)	10	12,672	12.3
20	Mill HMA, in (ton)	1.5	1,199	6.0
20	Resurface with HMA Surface, in (ton)	1.5	1,208	7.6
25	Rout and seal, ft/mile (ft)	2600	2,600	6.8
30	Spot repairs, mill 1.5 in/patch 1.5 in, % area (ft^2)	5	6,336	6.2
35	Mill HMA, in (ton)	1.5	1,199	6.0
35	Full depth asphalt base repair, % area (ft^2)	10	12,672	40.9
35	Resurface with HMA Surface, in (ton)	1.5	1,208	7.6
40	Rout and seal, ft/mile (ft)	2600	2,600	6.8
43	Spot repairs, mill 1.5 in/patch 1.5 in, % area (ft^2)	5	6,336	6.2
48	Mill HMA, in (ton)	3.5	2,797	10.2
48	Resurface with HMA Binder, in (ton)	2	1,573	7.9
48	Resurface with HMA Surface, in (ton)	1.5	1,208	7.6

Table 2-2. Pavement Maintenance and Rehabilitation Action Plan - ICP

Years after initial construction	Description of pavement layer, Amount (Quantity)	Amount	Quantity per 2-lane mile	Duration of Work (hours)
8	Replace cracked pavers, % area (ft^2)	2	2,534	20
18	Replace worn/rutted pavers wheelpath, %area (ft^2)	5	6,336	30
28	Replace cracked pavers, % area (ft^2)	2	2,534	20
38	Replace worn/rutted pavers wheelpath, %area (ft^2)	5	6,336	30
48	Replace cracked pavers, % area (ft^2)	3	3,802	30

Traffic Flow Characteristics

Basic Characteristics of Traffic Flow

- Current (2020) AADT: 10,000 vehicles;
- Percentage of heavy vehicle and bus traffic: 10 percent. It is assumed that the percentage of heavy vehicle and bus traffic will remain the same throughout the analysis period;
- Traffic growth factor: 1 percent annual linear growth;
- AADT in the last year of the analysis period (2070): 16,446 vehicles; and
- AADT is total traffic flow in both directions.

Traffic Flow During Lane Closures

It is assumed that all scheduled construction work is to be completed during off-peak hours, mostly at night time. The following assumptions were used:

- The number of vehicles affected by the closure per hour of closure: 50 percent of the daily average hourly flow (traffic flow is the same in each hour). Therefore, for 10,000 vehicles per day, the average hourly traffic per lane affected during the closure is 208 vehicles (10,000 ÷ by 24 hours ÷ by 2 lanes).
- Truck percentage during closure: 10 percent.

Work Zones Delays

- Maximum length of the actual work window: 6 hours;
- Costs are for a 1 mile length of road section;
- Length of work zone for maintenance activities is 625 ft;
- Length of work zone for rehabilitation activities is 1,250 ft;
- Normal operating speed of vehicles (approach speed): 40 mph;
- Expected average speed of vehicles in the work zone: 20 mph;
- Value of travel time: Cars: $20.00 per hour, commercial vehicles $50.00 per hour;

Economic Parameters

- Discount rate is 4 percent; and
- Length of analysis period is 50 years.

2.1.2 Calculation of Construction Delay Costs

The calculation of construction delay costs for the two pavement types is summarized in

Table 2-3 for HMA and in Table 2-4 for ICP.

Table 2-3. Construction Delay Costs - HMA

Year	Activity	AADT	Cars	Trucks/ Buses	Delayed Cars	Delayed Trucks	Work Duration (hours)	Time to Pass (hours)	Cost of Delay ($)	Present Worth Cost of Delay ($)
10	Rout and Seal	11,046	10,046	1,000	105	10	2.1	0.06668	1,185	801
10	Spot Repairs	11,046	10,046	1,000	209	21	1.5	0.06668	871	589
15	Spot Repairs	11,610	10,610	1,000	1,000	83	7.5	0.06668	2,188	1,215
20	Mill HMA	12,202	11,202	1,000	933	83	3.8	0.13336	2,284	1,042
20	HMA Surface	12,202	11,202	1,000	1,400	125	4.7	0.13336	2,893	1,320
25	Rout and Seal	12,824	11,824	1,000	185	16	4.2	0.06668	2,706	1,015
30	Spot Repairs	13,478	12,478	1,000	520	42	3.8	0.06668	2,580	796
35	Mill HMA	14,166	13,166	1,000	1,646	125	3.8	0.13336	2,612	662
35	Base Repairs	14,166	13,166	1,000	1,097	83	25.0	0.06668	17,802	4,511
35	HMA Surface	14,166	13,166	1,000	1,646	125	4.7	0.13336	3,308	838
40	Rout and Seal	14,889	13,889	1,000	217	16	4.2	0.06668	3,096	645
43	Spot Repairs	15,340	14,340	1,000	597	42	3.8	0.06668	2,901	537
48	Mill HMA	16,122	15,122	1,000	1,890	125	6.1	0.13336	4,994	760
48	HMA Surface	16,122	15,122	1,000	1,890	125	4.6	0.13336	3,868	589
48	HMA Binder	16,122	15,122	1,000	1,890	125	6	0.13336	3,721	566
								Total Cost	**$ 57,009**	**$ 15,886**

Table 2-4. Construction Delay Costs - ICP

Year	Activity	AADT	Cars	Trucks/ Buses	Delayed Cars	Delayed Trucks	Work Duration (hours)	Time to Pass (hours)	Cost of Delay ($)	Present Worth Cost of Delay ($)
8	Cracked Pavers	10,829	9,829	1,000	410	42	12.5	0.06668	6,851	5,006
18	Worn Pavers	11,961	10,961	1,000	1,370	125	18.4	0.13336	11,220	5,539
28	Cracked Pavers	13,213	12,213	1,000	509	42	12.5	0.06668	8,175	2,726
38	Worn Pavers	14,595	13,595	1,000	1,699	125	18.4	0.13336	13,415	3,022
48	Cracked Pavers	16,122	15,122	1,000	945	63	18.8	0.06668	14,688	2,235
Total Cost									**$ 54,350**	**$ 18,528**

3. Conclusions

The total present cost of M & R delays for HMA surfaced roadway was estimated at $57,009 with a net present worth of $15,886. The corresponding cost for the ICP surfaced roadway was $54,350 with a net present worth of $18,528, 14 percent higher than the HMA with a difference ($2,642). However, the total cost of delays is very small compared to the total life-cycle costs, i.e., initial construction plus subsequent M & R rehabilitation costs which average about $820,000 for HMA and ICP. Specifically, the cost of user delays represents about 1.7 percent of the total present worth of M & R costs.

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