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Sensitivity analysis of the mainline travel lane pavement service life when utilizing part-time shoulder use with full depth paved shoulders

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Abstract

Part-time Shoulder Use (PTSU) is an Active Traffic Management (ATM) strategy that utilizes the shoulder as an additional travel lane during high congestion periods to temporarily increase roadway capacity. This strategy has become increasingly popular on freeways around major metropolitan areas in the United States (U.S.) and Europe. This research focused on freeways near major metropolitan areas where the roadways are structurally sound, but widening roadways has become increasingly expensive to implement. These areas typically utilize full-depth paved shoulders, defined as shoulders built to the same pavement structural profile as the mainline travel lanes and structurally sufficient to carry heavy vehicle loading. As a result of PTSU, the load repetitions on the mainline travel lanes can be reduced for multiple hours during each day by shifting vehicles to the shoulder and this load reduction may indirectly increase the mainline pavement's service life. This research explored the potential benefits of PTSU based on a variety of conditions, including climate conditions, pavement types, and traffic loading levels. The results suggest that across all of these conditions an extension of 10–20% in service life can be expected for both flexible and rigid pavements in the mainline travel lanes.

Keywords: Part-time shoulder use; Full depth paved shoulder; Pavement performance; Service life; Flexible pavement; Rigid pavement

1. Introduction and background

Part-time Shoulder Use (PTSU) is an Active Traffic Management (ATM) strategy that utilizes the shoulder as an additional travel lane during high congestion periods to temporarily increase roadway capacity. There are three types of PTSU: Bus-on-Shoulder (BOS); static; and, dynamic. BOS was the original implementation in the United States (U.S.) in the 1970s [1]. BOS aids transit routes that operate partially on highways around cities and can assist with on-time transit arrivals even during periods of high congestion [2]. Static PTSU is when the shoulder is used as a travel lane at a specific time of the day, typically during the morning and evening commuting periods [2]. For areas where heavy congestion is less predictable, dynamic PTSU activates when the roadway experiences a specific traffic density [2]. The focus of this study is on static PTSU which is becoming more prevalent due to land use changes and decreased funding in major metropolitan areas, such as in the Delaware Valley Region (near Philadelphia, Pennsylvania) which has several PTSU

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projects currently being evaluated in the 2040 long range plan [3–5].

PTSU lanes have been found to handle 1000 to 2000 vehicles per hour per PTSU lane [2,6]. Other studies have found that PTSU lanes carries 15% to 20% of the mainline traffic for six-lane and four-lane highways, respectively [7,8]. Some studies have found a 0.4- to 1-min delay reduction per mile of PTSU [2,9]. Estimates have found that the level of safety typically remains the same within the PTSU segment and a study reported that some safety improvements were observed upstream of the PTSU [8]. Another study found 20% of the post implementation crashes were PTSU related but the overall crashes in the segment were reduced [10].

The objective of this research is to analyze the effects of PTSU on pavement service life on the mainline lanes. While pavement structural integrity is typically evaluated before PTSU is implemented, most studies only make a basic reference to the factor of pavement structural integrity evaluation [8,11]. The use of PTSU is typically paired with full-depth paved shoulders (i.e., shoulders that have the same pavement structural profile as the mainline travel lanes) to ensure the structural integrity of the shoulder with an increased volume of heavy vehicle loading. This study is focused upon roadways with full depth paved shoulders already implemented so the construction cost is not factored into this study and typically the shoulders are repaired at the same time as the mainline lanes which was the reason for the focus upon the mainline lanes.

2. Research approach

The research approach is to conduct an initial study into the possible benefits of PTSU for future projects with a full-depth paved shoulder. During the highly congested periods of the day when PTSU is in effect, some of the traffic loading will be redistributed off of the mainline travel lanes and onto the shoulder which could extend the service life of the pavement on the mainline. The U.S. was divided into four climate zones for analysis. The other parameters include two pavement types, two typical roadway structures, and three traffic volumes. The effects of these factors on pavement performance were predicted using the American Association of State Highway and Transportation Officials (AASHTO) AASHTOWare PavementME Design® software [12]. While this is not a perfect system as certain construction and environmental effects from actual field data, it is a software that provides quality data based upon typical performances with a reliability factor adding a factor of safety to minimize these effects. The standard for performance will be the time until the roadway meets a specified distress threshold, as predicted for each climate zone. If a threshold is exceeded, it signified the need for repair due to a variety of distresses such as fatigue cracking for flexible pavements, faulting for rigid pavements, and the International Roughness Index (IRI) or smoothness rating for both pavement types. The performance of the pavement both before and after PTSU was quantified.

2.1. Study sites

In this study, the sites were found by dividing the U.S. into four distinct climate zones to represent each weather region. The climate zones were selected based on the Federal Highway Administration's (FHWA) Long-Term Pavement Performance (LTPP) program and represent wet-freeze (WF), wet-no freeze (WNF), dry-freeze (DF), and dry-no freeze (DNF) conditions, as shown in Fig. 1 [13]. A U.S. Department of Transportation (USDOT) study on the effects of truck size and weight restrictions in the U.S. was used to model the baseline pavement structures for analysis [14]. The USDOT's Comprehensive Truck Size and Weight (CTSW) study used typical pavement structures from various states to be representative of each climate zone. The pavement sections were taken from: Ohio for WF conditions; Utah for DF conditions; Arizona for DNF conditions; and, Mississippi for flexible pavements in WNF conditions and Georgia for rigid pavements in WNF conditions. The CTSW study established three roadway structures (two interstates and one other National Highway System (NHS) structure) based on the LTPP data for those states [13]. Due to similarities in structural profiles, the two interstate structures were combined for this research resulting in a total of two pavement structures for analysis (i.e., an interstate and an Other NHS roadway). The material types used to model these structures were typical values based upon LTPP information and common local soil types for those states. The design features and other input information are presented in Table 1.

The three traffic volume levels used in the analysis were: the maximum average daily truck traffic (ADTT) for interstates; the average ADTT for interstates; and, the average ADTT for the Other NHS roadway for each climate zone [14]. For this research, these will be referred to as high volume, medium volume, and low volume, respectively. Typical truck type distributions for each climate zone, based upon the representative state DOT distribution, was established for this research and included in Table 2 below. The high volume interstate was modeled as a six-lane highway and the two other volumes were modeled as four-lane highways [15]. The traffic data, both trucks per day (tpd) and truck classifications, are summarized in Table 2. Any additional truck or traffic data was left as default values in PavementME Design.

Distress indices for each zone were needed to determine when the roadways first need repair, as an indicator of pavement service life. There was no region-specific data that was found for the wet climate zones (WF and WNF), and as a result, national averages were used for those two zones [20]. The data for the DF zone was taken from the Utah DOT Pavement Design Manual and the DNF indices were found from an Arizona study that determined base values for a mechanistic-empirical pavement