Evaluating the Impact of Oversize and Overweight Loads on Highways in Different Climate Zones: Texas Case Study

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Number of Words in Text: 4,846
Number of Tables: 3*250 = 750
Number of Figures: 7*250 = 1,750
Total Equivalent Number of Words: 7,346
Abstract

The high volume of oversize and overweight (OS/OW) vehicles is disproportionately increasing the damage to the U.S. highway infrastructure system and reducing the service life of pavement significantly. Thus, transportation agencies should have the capacity to estimate the impact of the damage caused by OS/OW vehicles in order to maintain the safety of the system and to develop effective infrastructure management and rehabilitation strategies. However, the evaluation of pavement damage caused by different OW/OS loading levels requires detailed information about pavement structure and materials, truck traffic characteristics, and regional climatic conditions.

In this paper, we discussed the efforts of an ongoing research project and one of its major tasks is to combine the different paradigms that influence pavement performance into a single evaluation methodology by integrating material, structural, climatic, and traffic information. The proposed methodology is then implemented into three Texas case studies to evaluate the impacts of OS/OW loads on highways under different scenarios and combinations of the related factors. Pavement age and prior maintenance and repair history are identified as two kinds of critical information in the regression process.

Key words: Oversize, Overweight, Permit, Pavement, Climate zones, Texas, PMIS
1. Background

Trucks that carry loads more than standard weight limits (80,000 lbs.) and standard size (8 feet 6 inches wide and 14 feet high) are known as oversize and overweight (OS/OW) vehicles, and trucks with gross vehicle weight (GVW) exceeding 254,000 lbs. or maximum permissible weight on any axle or axle group, or 2,000,000 lbs. with less than 95 ft. of axle spacing is defined as a super heavy load [1]. An OS/OW load can cause damage to highways in a number of ways. For example, an OW/OS load that exceeds the allowable limit can cause the damage to pavement including rutting, pavement edge failure, pavement surface failure, road embankment slope failure and pavement foundation shear failure. In the case of multiple super-heavy loads (e.g., generated by wind turbine farms), the number of equivalent single axle loads (ESALs) exceed the remaining life of the pavement. History has shown that it may only take one vehicle-pass for such failures to occur. In this regard, transportation agencies should have the capacity to estimate the impact of the damage caused by OS/OW vehicles in order to maintain the safety of the system and to develop effective infrastructure management and rehabilitation strategies.

The recent oil and gas booming produces over 546,000 jobs, generates $137.8 billion in economic output, and contributes more than $71.1 billion to the economy of Texas and New Mexico [2]. Accordingly, the number of OS/OW vehicles and the vehicle-miles of travel (VMT) have increased rapidly over the past several years in Texas. The total number of OW/OS permits issued in FY 2014 was 836,259, which has increased 6% and 67% over FY 2013 and FY 2010, respectively [3]. However, development of the well site (i.e., the movement of equipment and materials necessary to construct the pad site and access roads), the drilling process (i.e., hydraulic fracturing), and operations (i.e., saltwater disposal) have brought high-volume and frequent truck trips and resulted in damage to state and county roads that were not designed for such traffic levels. In this regard, coordinated efforts towards efficient planning and routing of the OS/OW loads are becoming increasingly important from the standpoint of both pavement reservation and traffic management.

In this paper, we describe the efforts of an ongoing research project sponsored by a regional University Transportation Center (UTC) in the U.S. Department of Transportation (DOT) Region 6. The project is aimed to develop a web GIS-based routing assistance tool to optimize the OS/OW routes based on the historical and expected heavy traffic levels and pavement conditions. As one of the major project tasks, we made an attempt to evaluate the impact of OS/OW loads to highway pavements by analyzing historical data with respect to the characteristics of OS/OW vehicles (i.e., dimension and weight), their origin and destination, permitted routes, frequency of the routes, pavement condition data, and climatic effects.

To the best knowledge of the authors, extensive studies have been made nationwide to develop load-zoning procedure and methods for evaluating load restrictions ([4], [5]). These studies, however, did not lead to applicable methods that can be used to evaluate the impact of super-heavy loads and to determine new design criteria and strategies for maintenance. There are no documented guidelines and recommendations that provide practical guidance on appropriate parameters (e.g., thickness and maximum repetition) and preservation techniques specifically
developed for accommodation of the OS/OW loads. To this end, this paper has at least three major contributions: 1) finding the impacts of different levels of OW/OS loads to highways different climate zones; 2) quantifying the parameters of the deterioration models for pavements under such circumstances for determining new design criteria and strategies for accommodating the OW/OS loads; and 3) the proposed approach is particularly valuable for the states with the GIS-based pavement management system that are looking for a workable solution to assess their mass historical OS-OW routing data, and evaluate the OS/OW loading impacts to their infrastructures.

The rest of this paper is organized as follows: In Section 2, we discuss the consolidation of the related data on pavement condition, the OS/OW loading, and climatic data from multiple well-established data sources. In Section 3, we describe the detailed regression procedures for modeling pavement performance. In Section 4, we design three case studies to evaluate the impact of OS/OW loads on highways in different scenarios and combinations of various factors. Section 5 concludes this paper with our major findings.

2. Data Consolidation: Pavilion Data, OW/OS Routing Data, and Climatic Data

The evaluation of pavement damage caused by the OS/OW operation requires detailed information about pavement structures and materials, maintenance and repair (M&R) histories, OS/OW traffic characteristics, and regional climatic conditions. In the next sub-sections, we will discuss how to consolidate these related data from multiple well-established data sources.

2.1 Pavement Management Information System (PMIS) in Texas

The Texas Department of Transportation (TxDOT) maintains a vast network of highway pavements and has more paved lane-miles than any other state in the U.S. – 192,150 lane-miles to be exact. Effectively managing the required maintenance in order to preserve pavement assets with a limited budget has always been a challenge for Texas. Sufficient funds must be available to reconstruct and maintain pavements in the lane-miles that are nearing the end of the useful life. In addition, Texas’ role as a leading exporter, the continued growth of NAFTA traffic through state gateways, and the increased volume of shipping containers in the Gulf of Mexico due to the 2014 expansion of Panama Canal all combine to produce significant mobility needs between now and 2030 [6]. The programs that closely monitor the pavement network and effectively plan maintenance and rehabilitation (M&R) activities (with the corresponding budget limits) have becoming increasingly important to TxDOT. As a result, TxDOT has long been a proponent of pavement management systems (PMS) since their inception and implemented a comprehensive inventory and condition database for the entire state of Texas in the early 1990s [7]. The resulting database, termed Pavement Management Information System (PMIS) is still in use today and is updated annually with new data [8].

TxDOT divides each highway into a number of sections with an average length of 0.5 mile for pavement management and data collection purposes. Totally, more than 190,000 data collection sections are contained in PMIS, which are identified (or referenced) by a unique address - a combination of district name, county name, highway name, and beginning and end reference mile markers. In the PMIS database, pavement condition data are stored according to pavement...
type and its own distress types. For example, asphalt pavement has seven distress types (shallow rutting, deep rutting, patching, failures, block cracking, alligator cracking, and longitudinal cracking). The percentage of the area or length of the section which is affected by each distress type is recorded as the density of that distress (Q). Q values can be converted to distress scores and additional information about this condition assessment method can be found in [8]. The Condition Score is a composite pavement performance index defined by TxDOT based on the combination of the Ride Score and the Distress Score. In a word, PMIS contains a wealth of pavement performance data that can be analyzed and used to develop empirical performance prediction models.

In this study, we use PMIS as the major source for collecting the pavement data of the highways of interest. A request of PMIS dataset was initiated in March, 2015 by the research team and was received from the TxDOT Lubbock District one month later. The dataset contains more than 2 million records that cover the whole state-network pavement data from 2004 to 2014.

2.2 The Map of OS/OW Routes in Texas

The characteristics of OS/OW vehicles such as dimensions and weights, origins and destinations (or the O-D matrix), permitted routes, and frequency of the routes are another kind of critical information. In this study, we used the OS/OW map from a previous research project in Texas. As part of that project, the researchers developed a highly efficient GIS-mapping approach and converted a massive data set of OS-OW permit routes into a GIS format. The following procedures proposed by them can be summarized as follows [9]:

- Clean and standardize the original route descriptions in TxDOT OS/OW permit data;
- Prepare a navigable route network based on a Texas DOT on-system roadway layer;
- Create a route intersection layer (referred to as the “junction layer”) that contained all intersections, origins, and destinations involved in the original route descriptions;
- Map the route descriptions into separate ESRI shapefiles on the basis of the route layer and junction layer;
- Further process the resulting Shapefiles for future GIS route analysis

Figure 1 shows the most common roadways assigned to OS/OW loads in Texas.

2.3 Climate Zones in Texas

Temperature and moisture affect pavement performance, and hence its capacity to accommodate the OS/OW load. For example, the OS/OW load may cause pavement damage when it is transported at a time when the pavement is in a weakened state (e.g., soft asphalt concrete surface at high temperature and/or weak pavement soil foundation due to high moisture state). In this regard, we grouped pavement sections to represent the best-case and worst-case scenarios of these climatic characteristics, as follows:

- Zone 1: This zone represents dry-cold climate;
- Zone 2: This zone represents dry-warm climate;
- Zone 3: This zone represents wet-cold climate;
Zone 4: This zone represents wet-warm climate;

Each county in Texas is assigned to one of the above zones and these zones are depicted in the color-coded map shown in Figure 2:

Figure 1: Route frequency by total number of OS/OW loads on Texas Road Network [9]

Figure 2: Texas Climate Zone Map (Source: TxDOT)
3. Methodology: Modeling Pavement Performance Under Multiple Factors

In this study, we use Pavement Condition Score (PCS) as the primary pavement performance index, which is a 1 – 100 index (with 100 representing no or minimal distress and roughness) defined by TxDOT in the PMIS. PCS considers pavement’s Distress Score (DS) and roughness (measured in International Roughness Index or IRI). These two indices can also be found in the PMIS database. According to PCS, roads can be grouped into five classes: Very Good (90-100), Good (70-89), Fair (50-69), Poor (35-49), and Very Poor (1-34) [8]. A well-accepted sigmoidal function was used to regress pavement performance models under the combined effects of the aforementioned factors ([10], [11], [16]):

\[
PCS = 100 \times (1 - e^{-\left(\frac{a}{AGE}\right)^b})
\]

Where: PCS = Pavement Condition Score defined by TxDOT
Age = Pavement Age
\(a\) and \(b\) are two coefficients that represent the effects of the considered factors

It should be noted that the proposed model is not intended as a mechanistic explanation of the distress progression in pavements, but a most accurate regression possible with the available data.

Pavement age, construction and M&R histories are critical for the accuracy of the regression models, and, ultimately, for the confidence in these models. In a perfect dataset, PCS of all sections in the network should stay constant or decrease with time. Otherwise, it should increase upon receiving a repair action. However, such a perfect data set does not exist, since pavement condition data are noisy and contain errors (either human or systematic errors). In addition, even though the M&R data may be available, it is not easily accessible or ready for integration. M&R data are usually gathered by construction personnel and are stored in construction databases (separate from PMS database) [12]. Integrating these data has always been a major challenge for TxDOT [12]. Thus, it is very difficult to integrate construction and repair history with condition data from these databases. To deal with noisy pavement condition data and integrate them with prior M&R histories, we used a method called “proximity-based outlier detection” to group neighboring roadway sections that have similar historical performance patterns (i.e., condition-versus-age patterns) [12]. These proximity-based sections are likely to have similar characteristics (i.e., structure, climate, subgrade, traffic loading) and construction and repair histories. A group of these adjacent sections can be defined as a cluster.

The algorithm of clustering neighboring pavement sections is discussed briefly here and more detail can be referred to the work of Saliminejad and Gharaibeh [12, 14]. In a cluster of pavement sections, the cluster’s homogeneity can be measured by the tightness of its probability density function (PDF), for example, the multivariate Gaussian PDF in Equation 2.

\[
f(x | \mu, \sigma^2) = \frac{1}{\sigma \sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}}
\]
Where: \( f(x) \) is the probability density function and \( x = \text{PCS} \) in this case;
\( \mu \) is mean of the PCS vectors for all pavement sections in the cluster; \( \sigma \) is standard deviation and \( \sigma^2 \) is variance; \( e \) is Euler’s number ( \( e \approx 2.71828 \)).

The optimal clustering scenario can be determined by searching the scenario that maximizes the overall probability of pavement sections belonging to clusters. In mathematical terms, the probability that a highway consists of a clustering scheme (\( g_1 \) to \( g_k \)), given that the condition data for \( n \) sections in this highway are \( \text{PCS}^1 \) to \( \text{PCS}^n \), can be computed as follows:

\[
P(g_1,\ldots,g_k | \text{PCS}^1,\ldots,\text{PCS}^n) \propto \prod_{i=1}^{n} P(\text{PCS}^i | g_1,\ldots,g_k) \prod_{j=1}^{k} P(g_j) \tag{3}
\]

Where: \( P(g_j) \) is the probability of having an M&R project with the length equal to \( g_j \);
\( P(\text{PCS}^i | g_1,\ldots,g_k) \) is the probability of having a condition data vector of \( \text{PCS}^i \) for section \( i \), given the clustering scheme \( g_1,\ldots,g_k \).

Among all possible clustering scenarios, the one gives the highest probability (calculated by Equation 3) is selected as the optimum clustering scenario. A genetic algorithm (GA) is used to solve this clustering problem because of its computational efficiency in finding a near-optimal solution for the fitness function (i.e., equation 3) and its lack of sensitivity to initial values [15]. Finally, each highway corridor in the network can be segmented into homogeneous clusters consisting of the pavement sections with similar construction and repair actions.

After clustering pavement sections, it is necessary to estimate pavement age based on performance data and historical M&R information. Year of M&R treatment can be estimated based on the magnitude of increase in PCS and the year in which this increase occurred. For example, considering a pavement section, its PCS was 100 at 2010 and then gradually decreased to 35 in 2013. Then the value of PCS has suddenly increased from 35 to 100 in 2014. Thus, it can be assumed that this pavement section received a major rehabilitation in 2013 (making its age in 2013 is 4 years and in 2010 is 0 years). Once condition-versus-age patterns are determined, the pavement performance curve can be regressed and the related coefficients (i.e., parameters \( a \) and \( b \) in Equation 1) can be determined finally.

4. **Case Study: The Impact of OS/OW loads on highways in Texas Different Climate Zones (HIGH LOW DEFINITION)**

As discussed previously, to evaluate the impact of OS/OW loads on highways in different climate zones, multiple factors need to be considered, i.e., pavement characteristics, climate, subgrade quality, OS/OW traffic loading levels, maintenance and rehabilitation histories. Thus, in this section, we designed three case studies to evaluate pavement performance in different OS/OW scenarios and combinations of the related factors. In Case Study 1, we only considered
the highways with the same OS/OW loading level, but in different climate zones. In Case Study 2, we put our focus on the highways in one climate zone only (i.e., Zone 2 in this case) and studied their performance at various OS/OW traffic levels. In Case Study 3, we made a further analysis on the reduction of pavement service life for the highways selected in Case Study 2. Noted that pavement age and the M&R history are two key variables in the whole regression process. The regression procedures are illustrated in Figure 3 for the purpose of better understanding. The details of three case studies are being elaborated in the following subsections.

Figure 3: The detailed evaluation procedures implemented in the case studies

4.1 Case Study 1: The impact of OS/OW vehicles on highways in different climate zones

In this case study, we designed two scenarios: the high OS/OW traffic scenario and the low OS/OW traffic scenario. In each scenario, based on the Texas OS/OW vehicles routing map (Figure 1), we selected four highways (one for each climate zone) as the objects of regression analysis. Next, we applied the proposed pavement performance regression methodology with the associated pavement condition data, and then obtained the regression curves for the selected highways. It should be noted that, for the comparative purpose, we selected highways in the same road class (i.e., the US Highway), wherever possible, if the data permits. Results and findings from the two scenarios will be discussed in detail as follows.
The High OS/OW Traffic Scenario

In this scenario, we selected one highway in each climate zone, which are: US287L (Zone1), US287L (Zone2), US90R (Zone3), US77L (Zone4). Noted the selected roads are in the same class to ensure that they have similar pavement characteristics (materials and structures, for example) at the maximum extent. Their pavement performance curves were regressed, as shown in Figure 4. The regression coefficients are summarized in Table 1. Based on our observations from Figure 4, we have some interesting findings:

- In a short-term period (i.e., pavement age is less than two years), the PCS of the selected highways dropped drastically (i.e., in the worst case, the PCS of US 287 reduced from 100 to 85 in less than two years). The reasons are two-fold: the high level of OS/OW loads and none or minimal repair interventions scheduled in the early age of pavement. The reduction speed of pavement performance in the four climate zones (as measured by PCS) shows the following trend:

  Zone 1 > Zone 3 > Zone 4 > Zone 2

- In a long-term period (i.e., pavement age is more than five years), the reduction speed of pavement performance in the four climate zones shows a different trend:

  Zone 3 > Zone 4 > Zone 1 > Zone 2

It is reasonable to observe these different trends since we take the prior M&R history as a critical variable in the regression process. Thus, the regression curves reflect the combined effects of pavement aging, OS/OW traffic loads, and M&R interventions.

![Figure 4: PCS of the roads in the high OS/OW traffic scenario in Case Study 1](image-url)
The Low OS/OW Traffic Scenario

In this scenario, similarly, we still selected one road in each climate zone, which are US70L (Zone1), US62L (Zone2), US90L (Zone 3), FM2686K (Zone4). It should be noted that in Zone 4, we had to choose an FM class road due to the limited data. Their pavement performance curves were regressed, as shown in Figure 5. The regression coefficients are also summarized in Table 1. We have the following interesting findings as observed from Figure 5:

- In a short-term period (i.e., pavement age is less than four years in this case), the reduction speed of pavement performance (as measured by PCS) shows the following trend:

  $$\text{Zone 4} > \text{Zone 3} > \text{Zone 2} > \text{Zone 1}$$

  This trend is consistent with our logical understanding about the climatic effects on pavement: without implementing any M&R interventions at the early age of pavement, pavements in cold and dry weather have a better performance than those in warm and wet weather.

- In a long-term period (i.e., pavement age is more than five years in this case), the roads present various trends in pavement performance reduction. It is reasonable since M&R actions will be implemented on pavement as time goes and our regression models take the prior M&R history as the critical variable. In other words, the observed trends present the combined effects of M&R actions and climatic effects on the pavement later age behavior.

- It should be noted that the performance of roads in this scenario has dropped much more than the roads in the first scenario in the whole service life (20 years in this case). It is reasonable since we consider the effects of prior M&R activities in our regression models. Normally, the DOTs pay more attentions on the roads with high OS/OW traffic loads and implement more frequent M&R actions. In this regard, the pavement performance of these roads can be maintained well and their PCS are usually kept at a higher level during the whole service life. Especially, the Texas Transportation Commission’s stated goal is to reach 90 percent “good” or better pavement conditions, which means the PCS of a road need to be at least “70” or up.

<table>
<thead>
<tr>
<th>Case Study 1</th>
<th>The high OS/OW loading scenario</th>
<th>Climate Zone</th>
<th>Selected Road</th>
<th>Road Section</th>
<th>Parameter a</th>
<th>Parameter b</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Zone1 US287L</td>
<td>Zone1 US287L</td>
<td>122-278</td>
<td>15673.0012</td>
<td>0.0651</td>
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<tr>
<td></td>
<td>Zone2 US287L</td>
<td>Zone2 US287L</td>
<td>278-394</td>
<td>5254.8034</td>
<td>0.0939</td>
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<tr>
<td></td>
<td>Zone3 US90R</td>
<td>Zone3 US90R</td>
<td>692-922</td>
<td>35.0825</td>
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<tr>
<td></td>
<td>Zone4 US77L</td>
<td>Zone4 US77L</td>
<td>710-814</td>
<td>50.6585</td>
<td>0.2057</td>
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</tr>
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<table>
<thead>
<tr>
<th>Case Study 1</th>
<th>The low OS/OW loading scenario</th>
<th>Climate Zone</th>
<th>Selected Road</th>
<th>Road Section</th>
<th>Parameter a</th>
<th>Parameter b</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Zone1 US70L</td>
<td>Zone1 US70L</td>
<td>226-480</td>
<td>8.4662</td>
<td>0.9087</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Zone2 US62L</td>
<td>Zone2 US62L</td>
<td>24-136</td>
<td>6.8977</td>
<td>0.9450</td>
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</tr>
<tr>
<td></td>
<td>Zone3 US90L</td>
<td>Zone3 US90L</td>
<td>422-484</td>
<td>7.4720</td>
<td>0.7123</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Zone4 FM2686K</td>
<td>Zone4 FM2686K</td>
<td>474-492</td>
<td>6.4260</td>
<td>0.6912</td>
<td></td>
</tr>
</tbody>
</table>
4.2 Case Study 2: The impact of OS/OW vehicles on highways in the same climate zone

In this case study, we put our focus on Zone 2 only and studied the roads with different levels of OS/OW loads in the same climate zone. We divided the OS/OW loading into three levels: High, Medium and Low. Next, we selected one road at each level, which are: US287L (High), US180L (Medium), US62L (Low). Noted the selected roads are in the same class to ensure that they have similar pavement characteristics (materials and structures, for example) at the maximum extent. The performance curves of these roads were regressed and illustrated in Figure 6. The regression coefficients are summarized in Table 2. We have some interesting findings as follows:

- In a short-term period (i.e., pavement age is less than four years in this case), the pavement performance drops only due to the level of OS/OW loading. The trend clearly shows that: the more OS/OW vehicles, the more damage to the road. The reduction speed has the following trend:

  \[ \text{High OS/OW Loading} > \text{Medium OS/OW Loading} > \text{Low OS/OW Loading} \]

- In a long-term period (i.e., pavement age is more than four years in this case), the reduction speed presents an opposite trend:

  \[ \text{High OS/OW Loading} < \text{Medium OS/OW Loading} < \text{Low OS/OW Loading} \]

- It is reasonable since we consider the prior M&R history as the key factor in our regression model. It is obviously that the road that transport high volumes of OS/OW
vehicles is usually implemented more frequent M&R actions than the one with low
OS/OW loading. Thus, US 287 has maintained a high-level pavement condition
throughout its whole service life (for example, its PCS is higher than 80 at the end of it
service life, as observed from the regression curve in Figure). Correspondingly, the
pavement performance of US 62 has dropped drastically during its whole service life (i.e.,
its PCS is less than 25 at the end).

Table 2: The regression coefficients for Case Study 2

<table>
<thead>
<tr>
<th>OS/OW</th>
<th>Selected Road</th>
<th>Road Section</th>
<th>Parameter a</th>
<th>Parameter b</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>US287L</td>
<td>278-394</td>
<td>5254.8</td>
<td>0.0939</td>
</tr>
<tr>
<td>Medium</td>
<td>US180L</td>
<td>506-554</td>
<td>17.0104</td>
<td>0.3595</td>
</tr>
<tr>
<td>Low</td>
<td>US62L</td>
<td>24-136</td>
<td>5.4550</td>
<td>0.1089</td>
</tr>
</tbody>
</table>

Figure 6: PCS of the roads with different OS/OW loading levels in Case Study 2

4.3 Case Study 3: The pavement service life reduction at various OS/OW Loading levels

In this case study, we made a further analysis to investigate the pavement service life reduction
at various OS/OW loading levels. Noted that the OS/OW load level on a highway is measured by
accumulative ESALs. In this case, we divided the OS/OW loading into four levels:

- Extreme OS/OW Loading: greater than 1,000,000 ESALs per year
- High OS/OW Loading: between 200,000 and 1,000,000 ESALs per year
- Medium OS/OW Loading: between 20,000 and 200,000 ESALs per year
- Low OS/OW Loading: less than 20,000 ESALs per year
Correspondingly, we selected four highways based on the Texas OS/OW vehicle routing map, which are: US 377 (Low), US 62 (Medium), US 87 (High) and US 180 (Extreme). Letting $\Delta \text{Life} \%$ denote the road service reduction percentage. For example, $\Delta \text{Life} \%$ is equal to 0% for a new road (or the road service life is 100% at this point). As time goes by, the accumulative ESALs on this road will be increased, and so will the reduction of service life ($\Delta \text{Life} \%$). We chose a basic exponential function to regress the relationship between the pavement service life reduction versus pavement age, as shown in Equation 4:

$$\Delta \text{Life} \% = a \times (\text{Accumulative ESAL})^b + c$$  \hspace{1cm} (4)

Where: $a$, $b$ and $c$ are regression coefficients that we need to find.

Next, the regression road life reduction curves were regressed for the selected roads, as illustrated in Figure 7. The regression coefficients are summarized in Table 3.

![Figure 7: The service life reduction of the roads with different OS/OW loading levels in Case Study 3 (Measured by $\Delta$PCS %)](image)

The regression curves in Figure 7 present a clear trend of the pavement service life reduction under various levels of OS/OW loading:

$$\Delta \text{Life} \% (\text{Extreme}) > \Delta \text{Life} \% (\text{High}) > \Delta \text{Life} \% (\text{Medium}) > \Delta \text{Life} \% (\text{Low})$$

The observed trend is consistent with our logical expectation: the more OS/OW loads, the more pavement damage, and hence the more reduction of pavement service life. More specifically, in this case, when the accumulative ESAL is 10 million, the service life reduction is 35%, 26%, 22%, and 18% for the roads with extreme, high, medium and low OS/OW loads, respectively.
Table 3: The regression coefficients for Case Study 3

<table>
<thead>
<tr>
<th>ESAL</th>
<th>Parameter a</th>
<th>Parameter b</th>
<th>Parameter c</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extreme</td>
<td>9.599</td>
<td>0.6074</td>
<td>-3.581</td>
</tr>
<tr>
<td>High</td>
<td>5.043</td>
<td>0.7781</td>
<td>-3.581</td>
</tr>
<tr>
<td>Medium</td>
<td>3.6671</td>
<td>0.8390</td>
<td>-3.581</td>
</tr>
<tr>
<td>Low</td>
<td>2.422</td>
<td>0.9694</td>
<td>-6.206</td>
</tr>
</tbody>
</table>

5. Conclusions

In this paper, we presented the work of an ongoing research project which is aimed to develop a web GIS-based routing assistance tool to optimize the OS/OW routes based on the historical and expected heavy traffic level and pavement condition. We put our focus on discussing one of the major tasks of this project: evaluating the impact of OS/OW loads to highway pavements by analyzing historical data with respect to the characteristics of OS/OW vehicles (i.e., dimension and weight), their origin and destination, permitted routes, frequency of the routes, pavement condition data, and climatic effects.

To accomplish this task, firstly, we consolidated various datasets from multiple well-known databases or previous research projects to obtain the related pavement data and the OS/OW loading data. Secondly, to represent the most accurate regression possible with the available data, we used a well-accepted sigmoidal function to develop pavement performance models under the combined effects of the aforementioned factors. In the regression modeling process, pavement age and the prior M&R history are redeemed as two critical parameters. In the regressing process, to deal with noisy pavement condition data and integrate them with prior M&R histories, we used a method called “proximity-based outlier detection” to group neighboring roadway sections that have similar historical performance patterns (i.e., condition-versus-age patterns).

Lastly, we designed three case studies to evaluate highway pavement performance in different OS/OW scenarios and combinations of the related factors. In the first case study, we investigated the impacts of OS/OW vehicles on highways in different climate zones. In the second case study, we studied the pavement performance at different levels of OS/OW loads in the same climate zone. In the third case study, we made a further analysis to investigate the pavement service life reduction at various OS/OW loading levels. The regression curves, the regression coefficients, and the related findings were summarized and elaborated in each case study. These pavement performance regression models have laid a basis for other tasks of this ongoing project, i.e., developing an optimal routing algorithm to significantly reduce road damage from OS/OW vehicles.
Acknowledgement

This research is supported by the funding from Southern Plain Transportation Center (SPTC) (Project No. SPTC 14.1-45). The authors appreciate all their financial supports.
References