Scholarly Paper

Avoiding Disputes in PPP Road Contracts: Quantifying Impacts of Increased Allowable Truck Loads

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Abstract: Dealing with changes is one major concern in long-term public-private partnerships (PPP) concessions, especially during the implementation phase, as some changes might lead to disputes between PPP partners and disrupt the successful execution of the project. In the transport sector, a change in the law regulating truck loading standards inevitably influences the financial stability of road projects procured through PPP. That is, the government's decision of increasing the permissible truck load can lead to an accelerated deterioration of the pavement, and accordingly imposes additional expenditures that are borne by the concessionaire for maintaining the road condition at a satisfactory level, as required by the PPP contract terms. Given the fact that PPP concessions allow for additional compensations to the concessionaires in the case of modifications in the legislative and regulatory conditions, this study proposes two remuneration strategies for consideration by the concerned government to mitigate the adverse implications of increasing truck load limit on the concessionaire's financial status and consequently to avoid the occurrence of disputes with the concessionaire. The work presented herein is twofold, as it quantifies the impact of the change in truck load regulations on two main contract terms: the toll regime and the concession period. Under the first approach, the government would provide direct compensation to the concessionaire through a shadow toll paid per overloaded truck. The value of the shadow toll was found to be largely influenced by the truck class, truck load, pavement structure, climatic conditions and traffic volumes. Moreover, it was found that the highest values of shadow tolls would apply to projects with relatively thin pavements and high traffic volumes. Under the second approach, an extension of the concession period was considered, which allows the concessionaire to recover the increased pavement maintenance costs. It was found that the length of the extended term depends, to a great extent, on the project's characteristics in terms of the pavement structure, climatic conditions, traffic volumes, and more importantly on the toll revenues generated during the extended period. The two proposed alternative compensation techniques were devised and demonstrated through a methodology that involved flexible pavements performance prediction under varying loading conditions, using AASHTOWare Pavement ME. The proposed methodologies represent a framework that helps the two main parties involved in a PPP road project (i.e., the concessionaire and the highway agency) to accurately assess the effect of any increase in truck loading on the pavement performance and to decide on a fair compensation to be offered by the highway agency to the concessionaire, thereby contributing to the avoidance of dispute occurrence. **DOI: 10.1061/JLADAH.LADR-911.**

Introduction

Dealing with changes is listed as one major concern in long-term PPP concessions, especially during the implementation phase, as some changes significantly affect the project's progress, potentially leading to disputes between the government and the concessionaire (Bao et al. 2018). These changes are classified under three major categories: (1) changes in the legislative and regulatory conditions; (2) changes in the economic conditions; and (3) changes required by the government, i.e., modifications of the construction specifications or additional operational requirements (World Bank 2009).

In the case of road concessions, changes in the legislative and regulatory conditions might involve the regulations related to truck loading standards. In fact, the "increased legal load limit" is identified by the World Bank as one performance-related risk in PPP road projects (World Bank and PPIAF 2008). Transportation agencies around the world have shown a recurrent tendency to increase the permissible truck load with the aim of decreasing the cost of goods transported by trucks (National Research Council 1990; MnDOT 2015; Hajek et al. 1998; OBrien et al. 2012; McKinnon 2005; Nykänen and Liimatainen 2014; Liimatainen et al. 2020; Osman et al. 2008; Mousa et al. 2008).

In PPP road projects, bidders prepare their proposals based on the actual traffic characteristics, including truck loading conditions.

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The government's decision of allowing a certain increase in truck load limit results in additional expenditures, borne by the concessionaire, for maintaining the pavement at a satisfactory level of performance, as per the contract terms. In such case, disputes might arise between PPP partners with the concessionaire claiming a compensation from the government for the increased maintenance cost resulting from the change in the truck operating conditions.

Owing to the fact that the diverse legal frameworks regulating PPP contracts in different countries recommend the incorporation of appropriate provisions that allow PPP partners effectively deal with changes encountered throughout the PPP project's life cycle (World Bank 2009; APEC 2014; Soecipto and Verhoest 2018), this study proposes a methodology for quantifying the impact of changes in truck loading regulations on the contract terms, and consequently provides guidelines regarding two possible concessionaire compensation strategies. These strategies respectively affect the toll levels and the length of the concession period, two parameters directly influencing the concessionaire revenues (World Bank 2009). The proposed strategies are formulated as to ensure that fair compensation is provided to the concessionaire and, accordingly, to prevent or help avoid the occurrence of disputes between PPP partners.

Under the first strategy, the government could provide direct compensation in the form of an increase in availability payments. Such an availability-payment increase would be set based on truck class, varying pavement structures, and evidence of damage resulting from overloaded trucks.

Under the second strategy, an extension of the term of the toll road concession would allow the concessionaire to recover its losses, in case the legal system governing the PPP agreement allows for such an arrangement. A methodology is hereafter presented that can allow the parties to assess the appropriate length of an extension for different types of pavement structures. The extension of the concession period was determined based on the increase in the pavement's life-cycle agency cost resulting from the increase in the truck load limit.

Literature Review

Changes in Truck Loading Standards

Transportation agencies impose a maximum permissible truck/axle load to control the deterioration rate of highway pavements and bridges. Regulations related to truck weight have always been controversial. That is, while a high truck load limit increases the cost of pavements' construction and maintenance, it reduces the cost of goods' transport by trucks. These regulations have witnessed periodic adjustments by different transportation agencies, owing to the enhanced pavement design methods and vehicle performance, which allowed for an increase in the permissible truck load. Moreover, it is expected that revisions of truck loading standards be called out recurrently (National Research Council 1990).

In the United States, the Local Road Research Board conducted a review of literature to investigate the effect of such an increase on the environment, traffic safety, and the pavement service life. In general, an increase in axle weight leads to an exponential increase in pavement damage, with an exponent power close to 3 for flexible pavements. For example, the Minnesota state legislature has periodically altered its regulations as to account for possible truck weight limit increase in specific areas of the state (MnDOT 2015). In addition, Hajek et al. (1998) developed a methodology for assessing the pavement cost following the Ontario Ministry of Transportation's initiative to modify truck weights and dimension regulations.

In conjunction with the tendency of several European countries to enhance freight transport productivity through the adjustment of truck loading and configurations' standards, OBrien et al. (2012) investigated the implications of increasing the gross vehicle weight limits on bridges in Ireland. Another study by McKinnon investigated the impact of increasing the maximum truck weight from 32.5 t to 44 t (35% increase), as recommended by the Armitage Committee, on traffic levels, road haulage costs, and pollutants emissions in the United Kingdom (McKinnon 2005).

In view of the modified truck load regulations in Finland, which allowed for a 17%, 19%, 22%, and 46% increase in the weight limits, respectively, for four-axle truck without trailer, five-axle truck without trailer, eight-axle vehicle combination, and nine-axle vehicle combination, research studies were conducted to assess the economic and environmental benefits, in terms of the road haulage costs, fuel consumption, and emissions of road freight transport (Nykänen and Liimatainen 2014; Liimatainen et al. 2020).

Similarly, the Ministry of Transport in Egypt increased load limits for different axle types by 17%–36%, and related research studies were conducted as a result, which aimed to investigate the effect of this change in axle load regulations on the truck equivalence factor (Osman et al. 2008) and on the road agency costs and road user costs (Mousa et al. 2008).

Contract Provisions for Dealing with Changes in PPP Projects

PPP contracts should be designed in a way that recognizes their longevity. One way to enhance a proper PPP contract formulation can be to include clauses that allow for adequate compensation to the operator/concessionaire in the case of changes to the project's characteristics imposed by the government (World Bank 2009).

However, flexibility should be adequately structured in the contract to prevent the adverse implications of contract renegotiation (APEC 2014; Soecipto and Verhoest 2018). In fact, the renegotiation of contract terms must be allowed only in well-defined situations (World Bank 2009).

Under some legal systems, such as that of France, governments, representing the public interest, retain special privileges that allow them to apply unilateral changes to a PPP contract (referred to as an administrative contract under the French legal system) without the approval of the concessionaire. The latter is then provided an automatic compensation in order to maintain the contract's financial equilibrium. This process is referred to as contract adaptation (World Bank 2009).

Briefly, regardless of the PPP contract type, any unfavorable change in the project's characteristics, imposed by the government and affecting the financial status of the concessionaire, requires a compensation to be issued in favor of the concessionaire.

Concessionaire Payment Options in PPP Projects

In PPP projects, different payment options are adopted to allow the concessionaire to recover its investment plus a reasonable rate of return. These options depend on (1) the type of the payment (availability-based or usage-based), and (2) the funding agent (the government or the facility users) (Soecipto and Verhoest 2018). Availability-based payments are fixed regular subsidies made by the government to the concessionaire based on the provided service (World Bank 2009). Shadow tolls are of the usage-based payment type; however, these tolls are not collected directly from users, but they are rather paid by the government to the concessionaire based on the actual number and characteristics of vehicles using the road (Bain 2009; Heravi and Hajihosseini 2012). Availability-based payments and shadow tolls are popular under the private finance initiative (PFI) procurement policy adopted in the United Kingdom. Conversely, user fees are favored by southern European countries (e.g., France, Italy, Portugal, and Spain) as well as in some developing countries, such as Malaysia, South Africa, Croatia, China, and Brazil (World Bank 2009).

Concession Period Extension

Extending the concession period is one support measure that can be adopted by governments to remunerate the concessionaire for financial losses caused by governmental actions or decisions, or in case of a force majeure such as war or earthquake. The concession contract must clearly define all events that permit the extension of the concession term (World Bank 1999).

The extension of the concession term is a common practice in countries such as Indonesia (World Bank 1999) and Brazil (Guimarães 2014). In other countries, such as Italy and Japan, extending the concession period aims to reduce toll levels without compromising the concessionaire's benefit (World Bank 1999). In France, a significant number of PPP road concessions were extended in favor of the concessionaire, after assuming new obligations required by the government (World Bank 2009).

Furthermore, extending the concession period has been adopted by governments to solve disputes in several scenarios. The tunnel under the Channel between the UK and France, also referred to as the Eurotunnel or Chunnel, is one of the largest PPP infrastructure projects. This mega-PPP project faced several disagreements between the concessionaire and the government, caused by additional expenditures imposed by the government during the construction. This was resolved by awarding a 10-year extension of the concession period in favor of the concessionaire (World Bank 2009).

Problem Statement

The World Bank identifies several types of risks encountered in PPP road projects, among which is the increased legal load limit. This risk is treated as a "change in law," consequently requiring compensation to be provided by the government to the concessionaire (World Bank and PPIAF 2008). However, the literature lacks studies on possible concessionaire compensation strategies to be adopted in such condition. Accordingly, this study addressed the critical scenario of the possible decision by transportation agencies to increase the permissible truck load limit and its resulting implications on road projects procured through the PPP project delivery approach.

The addressed research questions can be formulated as follows. First, how does the increase in the truck legal load limit affect the pavement performance? Second, how does this change in the pavement performance translate in terms of pavement damage and, consequently, pavement maintenance expenditures? Third, what type of compensation can be provided by the government to the concessionaire as a remuneration for the additional maintenance expenditures? And finally, how may it be ensured that a fair assessment of the adopted compensation is made?

Work Objective and Methodology

The objectives of this study can be summarized as follows: (1) to identify the impact of the change in truck-load limit on the contract terms, and (2) to provide techniques for compensating the concessionaire as a means to prevent disputes from arising as a consequence of introducing such changes in truck-loading regulations. As such, it quantifies the impact of an increased truck-load limit on the tariff regime and the concession period. To this end, it is proposed that the concessionaire be compensated for the change in the truck-load regulations either in the form of an increase in availability payments, and more specifically in the form of shadow tolls, or through the extension of the concession period term.

The realization of the stated objectives requires the prediction of the performance of flexible pavements when these are subjected to (1) trucks loaded based on the default loading condition (as assumed during the preparation of the bid), and (2) overloaded trucks (after the change in the truck loading regulations is authorized). To this effect, the study considered the cases where governments increase the axle load limit for all truck types by 10%, 20%, or 30%.

The AASHTOWare Mechanistic–Empirical Pavement Design software (referred to as Pavement ME) served as the platform to model the performance of various flexible pavements under different truck loading conditions. Pavement ME requires detailed input parameters and predicts the performance of the modeled flexible pavement in terms of pavement distresses such as the international roughness index (IRI), rutting, fatigue, and thermal cracking (MDOT 2015).

Considering the first concessionaire compensation strategy, the value of the shadow toll was determined for each truck class as a percentage of the toll charged to the truck driver, based on the increased damage caused by the overloaded truck. Pavement ME was used to model the performance of a reference flexible pavement subject to different truck class–truck load combinations. The considered truck loading conditions were (1) default, (2) 10% overloaded, (3) 20% overloaded, and (4) 30% overloaded. Based on the predicted distresses, a damage factor was defined and calculated for each truck class–truck load combination. Finally, the shadow toll was quantified based on the increase in the damage factor caused by the corresponding increase in the truck load. These steps were repeated for various (1) flexible pavement structures, (2) climatic conditions, and (3) traffic characteristics to investigate the sensitivity of the results to the road project's characteristics.

The assessment of the required extension of the concession period also relied on the modeling of the performance of a reference flexible pavement considering the aforementioned four loading conditions using Pavement ME. Based on the predicted distresses, the first rehabilitation was scheduled for each loading condition, in accordance with fixed performance thresholds. Considering that the performed rehabilitation was an asphalt-concrete overlay of the existing flexible pavement, Pavement ME was used again to model the performance of the overlay subject the four-truck loading condition. Accordingly, a full schedule of pavement rehabilitation activities needed for each truck loading condition was established. RealCost (USDOT 2010) was used to perform the life-cycle cost analysis (LCCA) of the reference pavement subject to (1) trucks loaded based on the default loading condition, (2) 10% overloaded trucks, (3) 20% overloaded trucks, and (4) 30% overloaded trucks. Finally, the length of the extension of the concession term was determined as to allow the concessionaire to recover the additional maintenance costs imposed by the increased truck load limit. These steps were similarly repeated for various (1) flexible pavement structures, (2) climatic conditions, and (3) traffic characteristics to investigate the sensitivity of the results to the road project's characteristics.

Modeling the Performance of Flexible Pavements under Different Truck Loading Conditions

In this section, the input parameters required for conducting the Pavement ME simulations are provided.

Pavement ME Input Parameters

The two compensation techniques proposed in this study were applied to various flexible pavement structures, starting with the reference pavement structure. The choice of the input parameters was based on data collected from the literature. Thin and thick flexible pavements were considered for the analysis [152.4 mm (6 in.) and 203.2 mm (8 in.) asphalt-concrete (AC) layer thickness] (Chatti et al. 2004; Attia and Ahmed 2014; Al-Qadi et al. 2021), along with two truck traffic levels [annual average daily truck traffic (AADTT) of 2,000 and 4,000] (Attia and Ahmed 2014; Salama et al. 2006), three different climatic conditions (Virginia, Montana, and Texas) representing moderate, cold, and hot climates with a mean annual air temperature of 53.8°F, 46.7°F, and 70.5°F, respectively (Al-Qadi et al. 2021), and three base layer thicknesses (Wu and Harvey 2008). Furthermore, strong and weak material properties for the three pavement layers (asphalt-concrete layer, base layer, and subgrade) were included in the study (Al-Qadi et al. 2021), and two operational speeds (60 mi/h and 25 mi/h), with the 25 mi/h corresponding to the deceleration areas before reaching toll booths.

Table 1 provides the main input parameters for the Pavement ME Pavement runs. The data in bold correspond to the reference pavement structure.

In addition to the input parameters provided in Table 1, Pavement ME requires traffic data related to truck loading and vehicle class distribution. Those will be addressed in details in the subsequent sections.

Modeling the Load Increase in Pavement ME

Truck loading in Pavement ME is modeled using an axle load spectra approach. The software provides the default axle load distributions (ALD) as calibrated based on LTPP test sections from around the US and Canada. The percentages of single axles carrying a load ranging from 1,360.77 to 18,597.28 kg (3,000 to 41,000 pounds), at 453.59 kg (1,000-pound) intervals, are required for each truck type (Classes 4 to 13) for every month of the year. The same inputs requirements are needed for tandem, tridem, and quad axles with loads ranging from 2,721.55 to 37,194.57 kg (6,000 to 82,000 pounds) at 907.18 kg (2,000-pound) intervals for the tandem axles and from 5,443.10 to 46,266.42 kg (12,000 to 102,000 pounds) at 1,360.77 kg (3,000-pound) intervals for tridem and quad axles (MDOT 2015).

In the present study, Pavement ME was used to predict the response of a pavement for four scenarios: all trucks are loaded based on the default axle load distribution predefined in the software, and truck Classes 5 to 13 are overloaded by 10%, 20%, and 30%. Class 4 trucks (buses) are not assumed to be overloaded in any of the four scenarios given the limited number of passengers that can ride a bus at one given time. The truck overload was modeled by shifting the default axle load distribution for each truck class (5 to 13) and for each axle type (single, tandem, tridem, and quad) in order to obtain approximately a 10%, 20%, or 30% higher average axle load.

The default single axle load distribution for Class 9 trucks and the shifted axle load distributions for the 10%, 20%, and 30% overloaded Class 9 trucks are shown in Fig. 1. The same was done for the single, tandem, tridem, and quad axle load for truck Classes 5 to 13.

Table 1. Pavement ME input parameters

Input	Value/characteristic
Pavement type	New asphalt-concrete pavement
Design life (years)	20
AADTT	**2,000**–4,000
Operational speed	**96.56 km/h (60 mph)**–40.23 km/h (25 mph)
AC layer thickness	**152.4 mm (6 in.)**, 203.2 mm (8 in.)
PG grade	**PG 64-22**, PG 70-16
Base layer thickness	**254 mm (10 in.)**, 127 mm (5 in.), 381 mm (15 in.)
Base type	**A-1-a**, A-2-4
Subgrade type	**A-1-a**, A-2-6
Climate station	**Roanoke, Virginia** Great Falls, Montana San Antonio, Texas

Note: Values shown in bold represent the base case.

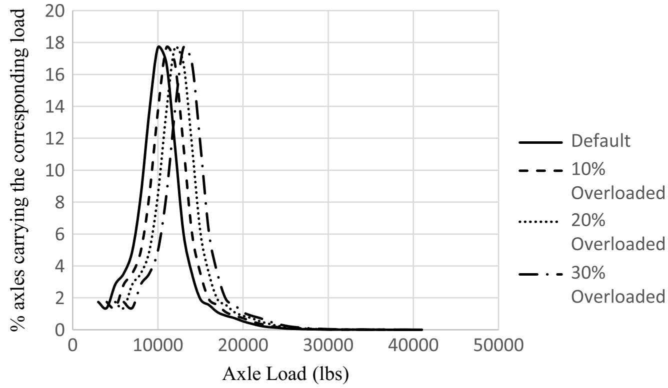

Fig. 1. Single axle load distribution for Class 9 trucks for different loading conditions.

Concessionaire Compensation through a Shadow Toll Paid by the Government

Toll levels, charged from the toll road users, depend on several factors, including the vehicle classification in terms of the type, weight, and number of axles (USDOT 2014; Hensher 1991). In the case of the availability of public funds, the government might remunerate the concessionaire for increasing the maximum allowable truck load limit by paying a shadow toll for each overloaded truck, in addition to the toll collected from the truck user. This section provides a methodology for determining the value of the shadow toll per truck as a percentage of the toll charged to the same truck type.

Pavement Performance Modeling under Different Truck Class–Truck Load Combinations

The methodology for determining the shadow toll per truck type as a percentage of the toll charged to truck user is presented in Fig. 2. The shadow toll was determined for each truck type individually; thus, each truck class (5 to 13) was considered separately in the Pavement ME runs. Alternatively stated, for assessing the shadow toll relative to class n trucks ($n = 5$ to 13), the vehicle class distribution was considered to include 100% class n trucks. Furthermore, for each class i trucks, four loading conditions were modeled: (1) trucks are loaded based on the default axle load distribution predefined in Pavement ME, and (2) trucks are then overloaded by 10%, 20%, and 30%. The axle load distributions for 10%, 20%, and 30%

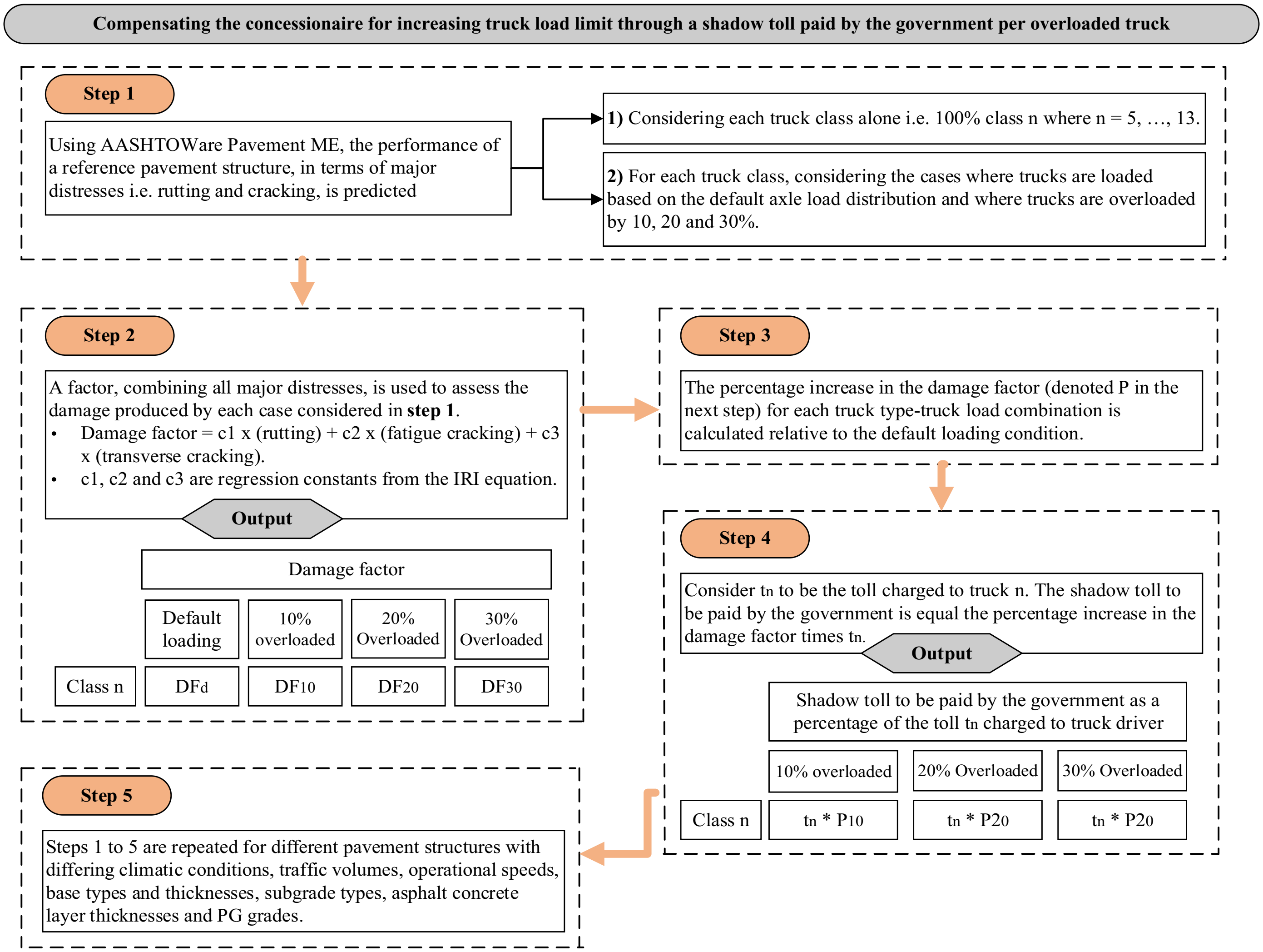

Fig. 2. Methodology for determining the shadow toll paid by the government for compensating the concessionaire.

Fig. 3. Predicted IRI for the reference pavement structure subject to Class 9 trucks under different loading conditions.

Fig. 4. Predicted total rutting for the reference pavement structure subject to Class 9 trucks under different loading conditions.

overloaded trucks were established, for class n trucks, as explained in the previous section.

These simulations were repeated for different pavement structures with varying climatic conditions, material properties, layers thicknesses, and traffic volumes. In total, for each considered pavement structure, 36 simulations were conducted: nine different truck classes (Classes 5 to 13), with four loading conditions (default axle load distribution, 10%, 20%, and 30% overloaded) for each truck class.

An example of the predicted performance of the reference pavement structure, in terms of the IRI, total rutting, AC rutting, bottom-up cracking, top-down cracking, and total cracking subject to Class 9 trucks under the four considered loading scenarios are shown in Figs. 3–8, respectively. The percent total cracking was calculated by converting the predicted top-down cracking from feet per mile to percentage and then adding the obtained percent top-down cracking to the predicted percent bottom-up cracking. Note that for the considered climatic station (Virginia), no thermal cracking was observed from the software runs.

Fig. 5. Predicted AC rutting for the reference pavement structure subject to Class 9 trucks under different loading conditions.

Fig. 6. Predicted bottom-up cracking for the reference pavement structure subject to Class 9 trucks under different loading conditions.

Fig. 7. Predicted top-down cracking for the reference pavement structure subject to Class 9 trucks under different loading conditions.

Fig. 8. Total cracking for the reference pavement structure subject to Class 9 trucks under different loading conditions.

Damage Factor Definition and Calculation

The shadow toll to be paid by the government was expressed as a percentage of the toll charged to truck drivers, based on the damage caused by different truck types under different loading conditions. As a first trial, the toll values were determined based solely on the predicted IRI, which includes, among other factors, different distresses such as total rutting, fatigue, and thermal cracking, as shown in Eq. (1) (Robbins et al. 2017)

$$\mathrm{IRI} = \mathrm{IRI}_0 + c_1(RD) + c_2(FC_{\mathrm{total}}) + c_3(TC) + c_4(SF) \tag{1}$$

where IRI = International Roughness Index (in./mi); IRI_0 = initial IRI after construction (in./mi); RD = average rut depth (in.); FC_{total} = total area of load related cracking, combined of alligator (bottom-up), longitudinal (top-down), and reflection cracking in the wheel-path, (percent of wheel-path area); TC = length of transverse cracking, including the reflection of transverse cracks in existing hot mix asphalt (HMA) pavements (ft/mile); $c_1 = 40$, $c_2 = 0.4$, $c_3 = 0.008$, and $c_4 = 0.015$ are nationally calibrated regression constant; and SF = site factor, which is a function of frost, swell, and pavement age.

Several simulations of different pavement structures subject to different truck classes and loading conditions showed that despite the significant changes observed in pavement distresses (such as rutting and cracking) among the different operating conditions, the change in IRI in all cases was minimal. Additional investigations revealed that the IRI values were heavily impacted by the site factor, which is constant regardless of the truck type and loading. Therefore, the predicted IRI did not reflect the actual effect of varying traffic characteristics on the pavement performance, expressed in terms of rutting and fatigue cracking.

Accordingly, a damage factor [Eq. (2)] that includes all pavement distresses, inspired from the IRI equation, was adopted to assess the pavement damage caused by different truck types with different loading conditions

$$\text{Damage factor} = c1 \times (\text{total rutting}) + c2 \times (\text{total fatigue cracking}) + c3 \times (\text{thermal cracking}) \tag{2}$$

Alternatively stated, for establishing the damage factor equation, the initial IRI (IRI_0) and the site factor, which are constant regardless of the considered operating condition, were omitted and the distresses included in the damage factor equation are those predicted by Pavement ME after 20 years.

Taking Class 9 trucks as an example, the predicted distresses at 20 years respectively for the default loading and for 10%, 20%, and 30% overloaded trucks were as follows: total rutting was 0.46, 0.49, 0.51, and 0.54 in., and total fatigue cracking was 38.87%, 42.50%, 46.19%, and 50.12%. No thermal cracking was observed. The damage factor for the default loading condition is therefore $40(0.46) + 0.4(38.87) + 0.008(0) = 33.9$.

Considering the reference pavement structures subject to different truck types under different loading conditions, 36 damage factors were determined for each truck class–truck load combination, provided in Table 2. The percent increase in the damage factors relative to the default loading case are also determined in Table 3.

The shadow toll to be paid by the government to remunerate the concessionaire for increasing truck load limit should be proportional to the increase in the damage caused by overloaded trucks. Consider i to be the toll charged to class i trucks (i = 5 to 13) under the default loading condition, P_{nk} is the percent increase in the damage factor due to increasing truck load limit by k percent ($k = 10\%$, 20%, or 30%), and the value of the shadow toll to be paid by the government for each overloaded truck would be $t_n \times P_{nk}$.

For instance, a 20% overloaded Class 9 truck caused a 15.29% higher damage than the normally loaded Class 9 truck. Accordingly, if the driver of a Class 9 truck is charged a toll of t_9 (cent/km) in the default loading condition, then the government must pay the concessionaire, in addition to the toll charged to the truck driver, a shadow toll valued at 15% of t_9, in the case where the government increases truck load limit by 20%. The shadow toll to be paid by the government to the concessionaire, in case an increase of 10%, 20%, or 30% in the truck load limit is allowed, is presented as a percentage of the toll charged to truck driver for Classes 5, 9, and 12 in Figs. 9–11, respectively.

Table 2. Damage factors for different truck type/truck load combinations for the reference pavement structure

	Damage factor			
Truck class	Default loading	10% overloaded	20% overloaded	30% overloaded
Class 5	11.75	12.75	13.82	15.04
Class 6	27.15	29.26	31.34	33.42
Class 7	41.37	44.17	50.20	54.36
Class 8	19.29	21.22	23.31	25.40
Class 9	33.83	36.44	39.00	41.69
Class 10	38.81	41.57	44.55	47.67
Class 11	23.60	25.80	27.99	30.52
Class 12	31.78	34.20	36.81	39.48
Class 13	45.97	49.27	54.05	62.70

Table 3. Percent increase in the damage factors for different truck type–truck load combinations for the reference pavement structure

	Percent increase in damage factor relative to default loading case			
Truck class	Default loading	10% overloaded	20% overloaded	30% overloaded
Class 5	0	8.50	17.59	27.98
Class 6	0	7.79	15.45	23.11
Class 7	0	6.76	21.34	31.38
Class 8	0	10.00	20.81	31.68
Class 9	0	7.72	15.29	23.25
Class 10	0	7.12	14.78	22.81
Class 11	0	9.33	18.59	29.30
Class 12	0	7.61	15.83	24.25
Class 13	0	7.18	17.56	36.38

The rate of the shadow toll for Class 9 trucks was around 8% (between 7.6% and 8.2%) of the toll charged to truck driver, in the case of increasing the permissible truck load by 10%, for all the considered pavement structures, except for two cases: (1) under the Montana climatic condition where the shadow toll was only 4.9% of t_9, and (2) for relatively thinner pavement (6 in AC layer), the shadow toll to be paid by the government was assessed at 13.6% of t_9.

In fact, for the Montana climate, it is noticed that the value of the shadow toll was significantly low relative to the other pavement structures for all truck classes. This can be explained by the formation of thermal cracks, which are independent of the truck type as well as the truck loading condition. This led to small differences among the damage factors calculated for the different truck type–truck load combinations, and consequently to lower values of the shadow toll. Furthermore, the highest rates of the shadow toll were observed for relatively thinner pavements (6 in AC layer) and for higher traffic volumes (AADTT = 4,000).

Concessionaire Compensation by Extending the Concession Period

The government might choose to extend the concession period as to allow the concessionaire to recompense the encountered losses caused by the increase in truck load limit, in case the governing legal system and the concession contract allows for such an arrangement.

Pavement Performance Modeling under Different Truck Loading Conditions

In the previous section, the pavement was subject to each truck class alone aiming at quantifying the damage caused by each truck type, and consequently to relate the toll value to the evaluated damage. However, in this section all truck types must be considered simultaneously to assess the length of the extension of the concession period. The percentage of each truck class among all trucks is specified in Pavement ME using a vehicle class distribution (VCD) (Attia and Ahmed 2014). For simplicity reasons, the default VCD, shown in Fig. 12, is adopted (MDOT 2015). The methodology for determining the length of the extension of the concession period as

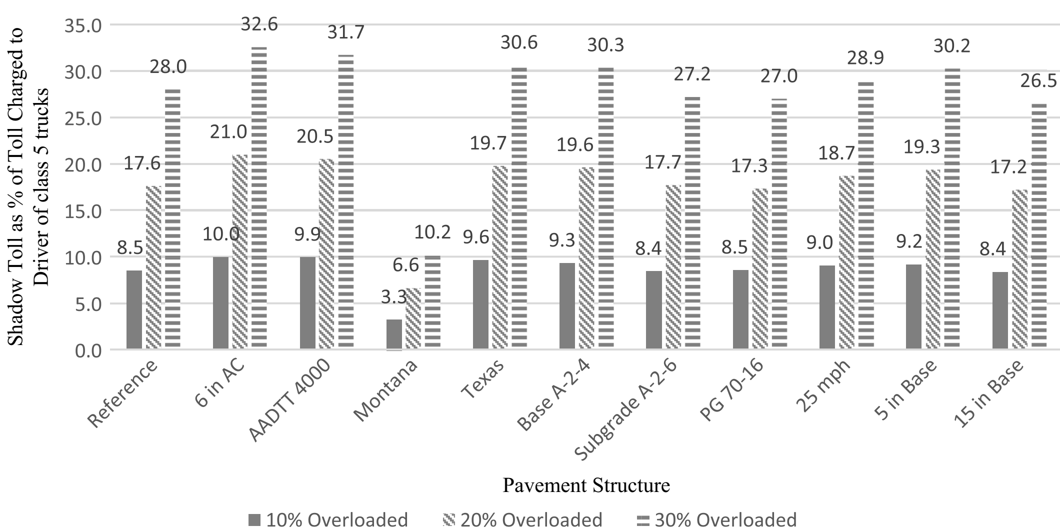

Fig. 9. Shadow toll for 10%, 20%, and 30% overloaded Class 5 trucks.

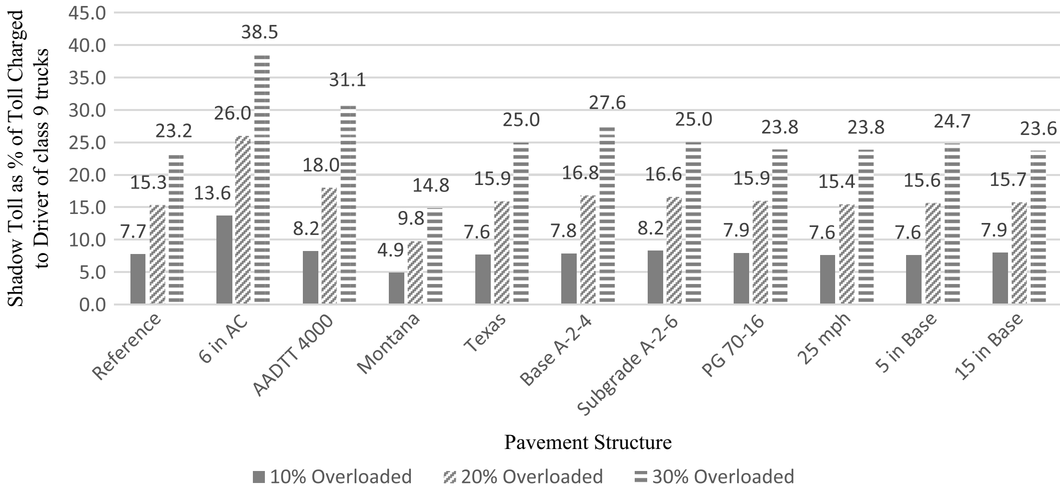

Fig. 10. Shadow toll for 10%, 20%, and 30% overloaded Class 9 trucks.

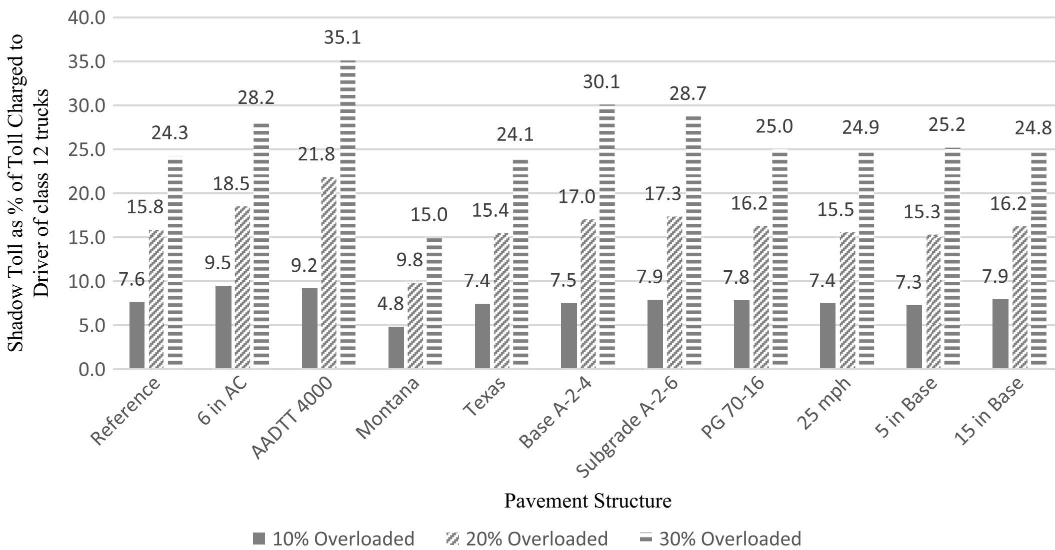

Fig. 11. Shadow toll for 10%, 20%, and 30% overloaded Class 12 trucks.

a means for compensating the concessionaire for increasing truck load limit is shown in Table 4.

For each pavement structure, four simulations were needed, considering the following loading conditions: (1) default axle load distribution is considered for all truck types, and (2) when government increases truck load limit by 10%, 20%, and 30%. The predicted distresses for the four cases are shown in Figs. 13–18.

Based on the National Highway Performance Program (NHPP), a pavement condition is considered to be poor for an IRI value of 170 in./mile or higher, when fatigue cracking reaches 20%, or when rutting depth reaches 0.4 in (Caltrans 2020). Based on the predicted distresses shown in Figs. 14–19, the first rehabilitation is scheduled after 7, 6, 5, and 4 years, respectively, for the cases where the reference pavement is subject to trucks loaded based on the default loading condition and when overloaded by 10%, 20%, and 30%, corresponding to the time by which total fatigue cracking reaches 20% and the total rut depth 0.25 in.

Pavement ME allows the modeling of pavement overlays; thus, a 4-in. AC overlay of the reference pavement structure was modeled for the four loading conditions, and the service life of the overlay was delimited by the time the total fatigue cracking reaches 20% again. The predicted distresses of the modeled AC overlays under the different loading conditions are shown in Figs. 19–24.

The 20% total fatigue cracking was reached, concurrently with 0.1 in total rut depth, after 3 years for the default loading condition, and after 2.5, 2, and 1.5 years for the 10%, 20%, and 30% increase in truck load limit, respectively.

Life-Cycle Cost Assessment

RealCost was used to assess the life-cycle costs (USDOT 2010) of the reference pavement subject to the four different loading conditions. The scheduling of the rehabilitation activities was determined based on the Pavement ME analysis previously conducted, as shown in Table 5.

The costs of pavement construction and overlay placement were estimated for a pavement section of 1 mi long and 48 ft wide

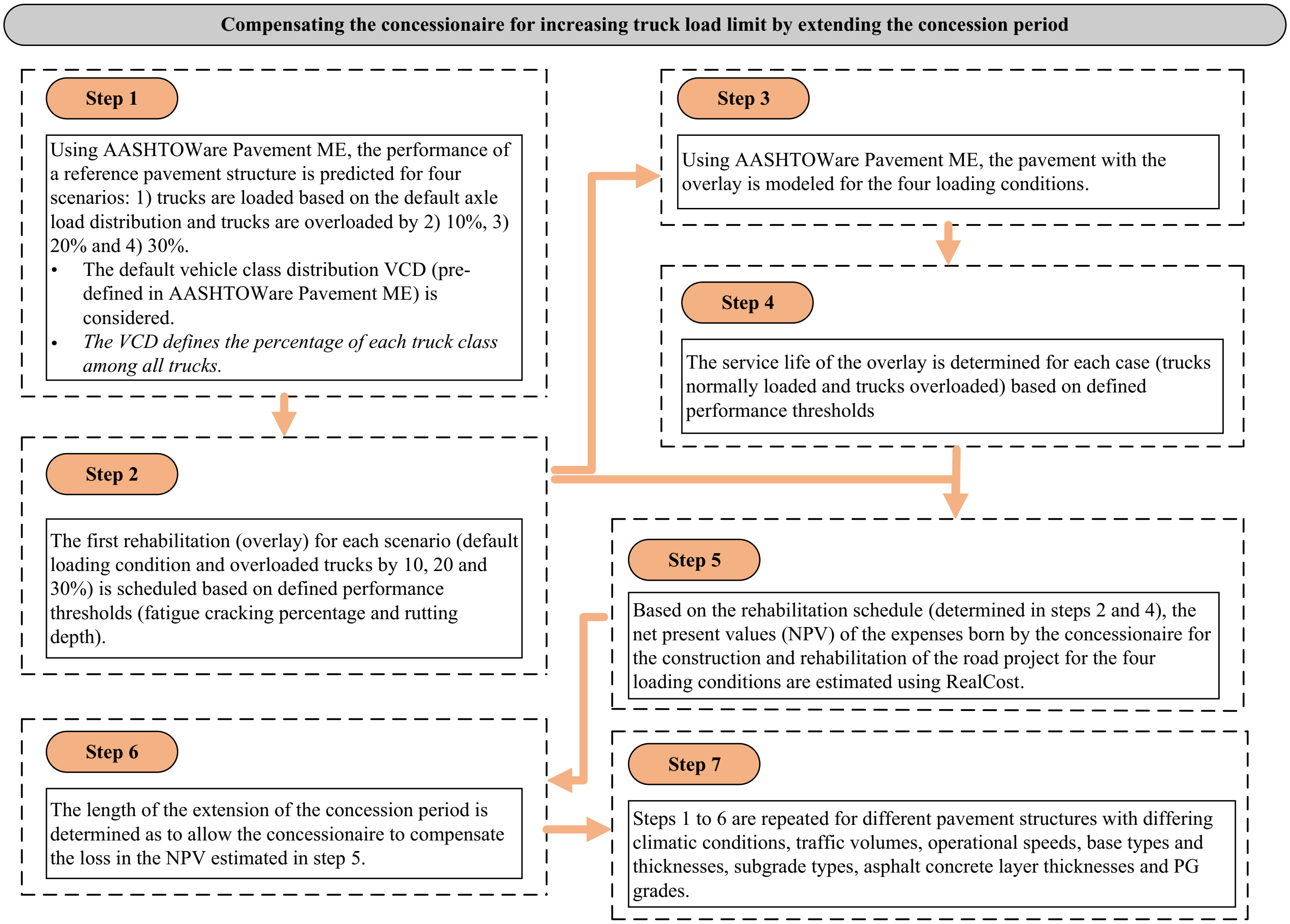

Fig. 12. Methodology for determining the length of extension of the concession period for compensating the concessionaire.

Table 4. Default vehicle class distribution

Truck class	Percent of AADTT (%)
Class 4	1.3
Class 5	8.5
Class 6	2.8
Class 7	0.3
Class 8	7.6
Class 9	74
Class 10	1.2
Class 11	3.4
Class 12	0.6
Class 13	0.3

Fig. 13. Predicted IRI for the reference pavement structure under different truck loading conditions.

(four lanes, each lane being 12 ft wide). The asphalt concrete placement cost was determined assuming a unit price of \$150/t. Furthermore, the cost of the asphalt increases for higher performance mixes. For instance, for a PG 76-22, the cost increases by 10% (Sciencing.com 2017). The base course costs \$5, \$8.8, and \$11.3/yd^2 for a thickness of 4, 6, and 10 in., respectively (NMDOT 2011). Based on these data, the cost of the reference pavement construction for the considered section dimensions was around \$2,155,575.

Similarly, the cost of the overlay placement was assessed. Milling 2 in. of asphalt concrete costs \$1.5/yd^2, while the milling of 4 in. costs \$2.5/yd^2. An asphalt concrete overlay is priced at \$8/yd^2 and \$16/yd^2 for a thickness of 2 and 4 in., respectively (Drexel Technologies Plan Room 2015). Accordingly, milling 2 in. and placing a 4-in. asphalt overlay costs \$492,800 for a section of 1 mi long and 48 ft wide.

Table 6 presents the calculated life-cycle present value of the agency costs for the four considered alternatives.

The extension of the concession period must be sufficient to allow the concessionaire to recover the additional life-cycle agency cost imposed by the increase in truckload limit. This extension is highly

Fig. 14. Predicted total rutting for the reference pavement structure under different truck loading conditions.

Fig. 15. Predicted AC rutting for the reference pavement structure under different truck loading conditions.

Fig. 16. Predicted bottom-up cracking for the reference pavement structure under different truck loading conditions.

Fig. 17. Predicted top-down cracking for the reference pavement structure under different truck loading conditions.

Fig. 18. Total cracking for the reference pavement structure under different truck loading conditions.

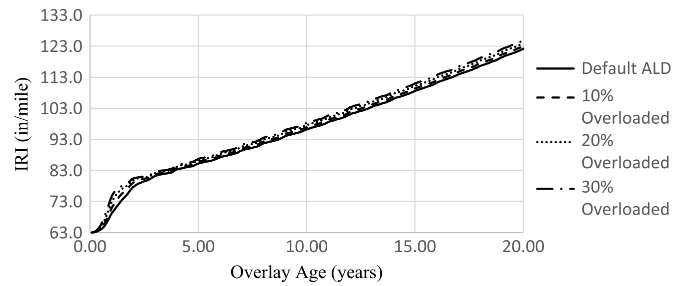

Fig. 19. Predicted IRI for the overlay of the reference pavement structure under different truck loading conditions.

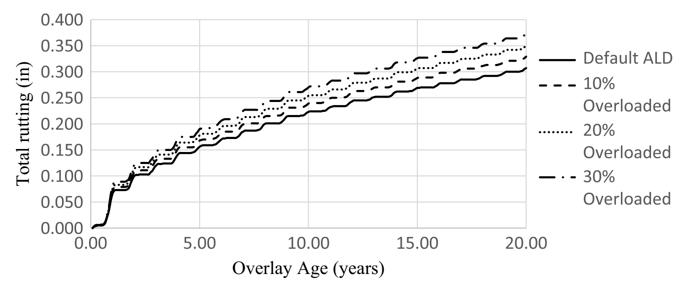

Fig. 20. Predicted total rutting for the overlay of the reference pavement structure under different truck loading conditions.

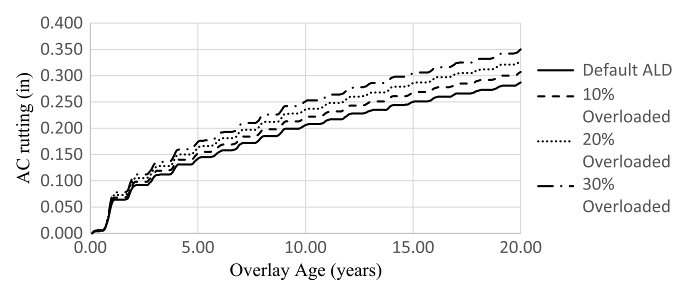

Fig. 21. Predicted AC rutting for the overlay of the reference pavement structure under different truck loading conditions.

influenced by the toll revenues generated during the extended period. For simplicity reasons, this study will consider that the rate of toll revenues during the extended period will follow a similar pattern to that observed during the initial concession period. Accordingly, considering that the concessionaire needs 20 years (initial length of the concession period for the considered pavement structure) to recover its investment in the case of the default loading condition, then the concession period must be extended by 12.6%, 31.2%, or

62.5%, corresponding to a 2.5-, 6.2-, or 12.5-year extension, in case the government increases truck load limit respectively by 10%, 20%, or 30%. However, if the toll revenues rate during the extended period was higher than that observed throughout the initial concession period, a shorter extension will be sufficient.

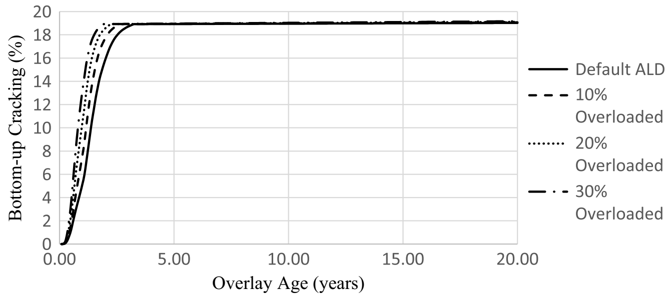

Fig. 22. Predicted bottom-up and reflective cracking for the overlay of the reference pavement structure under different truck loading conditions.

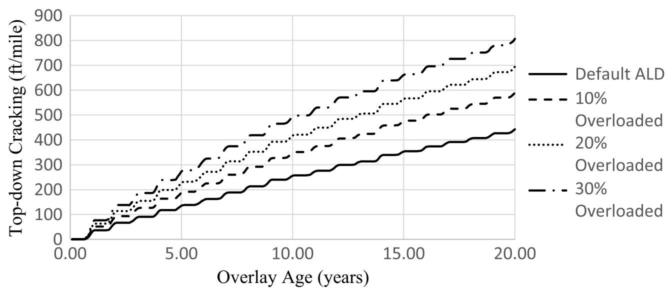

Fig. 23. Predicted top-down cracking for the overlay of the reference pavement structure under different truck loading conditions.

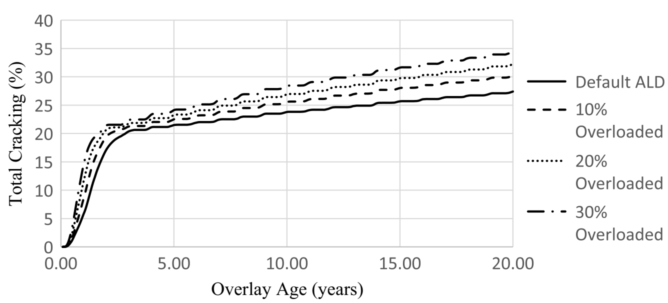

Fig. 24. Total cracking for the overlay of the reference pavement structure under different truck loading conditions.

The proposed methodology can be customized as to take into account the project-specific data related to the rate of toll revenues generation, if available.

The lengths of the extension of the concession period for the different pavement structures, assuming a constant rate of the generated toll revenues, are shown in Fig. 25, for an increase in truck load limit by 10%, 20%, and 30%.

For a 10%, 20%, and 30% increase in truck load limit, the length of the extension of the concession period ranged between 2.5 and 4.6 years, 5.8 and 8 years, and 8.2 and 15.9 years, respectively.

Discussions and Practical Implications

This study provided a methodology for avoiding disputes arising from changes in truck loading regulations in PPP road projects. Two concessionaire compensation strategies were proposed and applied to various flexible pavement structures, along with different climatic and traffic characteristics.

The first compensation strategy was in the form of shadow tolls paid by the government to the concessionaire per overloaded trucks. The values of these shadow tolls were quantified based on a damage factor calculated for different truck class–truck load combinations. The damage factor was established on the basis of the IRI equation, which includes the major flexible pavement distresses, i.e., rutting, fatigue, and thermal cracking. The highest values of shadow tolls were observed for relatively thin flexible pavements and high traffic volumes. This can be explained by the fact that thin pavement layers and high truck traffic volumes lead to high distress levels, which are directly incorporated in the damage factor equation, resulting in high damage values and consequently significant toll rates. Furthermore, regions with cold climate, where thermal cracks are observed, exhibited the lowest toll values, as thermal cracks are constant regardless of the truck type and load. Based on the obtained results, it can be concluded that the value of the shadow toll is sensitive to (1) the type of the overloaded truck, where Classes 7, 10, and 13 resulted the highest values of the shadow toll, while the lowest values were observed for Class 6 trucks; (2) the project's characteristics, with a strong influence observed for the climatic conditions and the traffic volume, two parameters directly affecting the rate of the development of pavement damage; and (3) the allowable increase in the truck load, where the higher the truck load limit, the higher the rate of pavement deterioration, and thus the highest shadow toll shall be imposed.

In this context, it should be noted that the results provided herein were based on the nationally calibrated regression constants for the IRI equation, which are also used for the damage factor assessment. Furthermore, the Pavement ME simulations also considered the nationally calibrated factors for all distress models. Therefore, for road projects located in regions where local calibration factors are available, these should be used for the Pavement ME simulations and for

Table 5. Scheduling of rehabilitation activities for RealCost analysis

Activity	Alternative 1: default loading	Alternative 2: truck load limit increased by 10%	Alternative 3: truck load limit increased by 20%	Alternative 4: truck load limit increased by 30%
First rehabilitation	Year 7	Year 6	Year 5	Year 4
Overlay service life (years)	3	2.5	2	1.5
Number of rehabilitations needed	5	6	8	11

Table 6. RealCost output

Life-cycle present value	Alternative 1: default loading	Alternative 2: truck load limit increased by 10%	Alternative 3: truck load limit increased by 20%	Alternative 4: truck load limit increased by 30%
Agency cost ($1,000)	3,664.76	4,126.54	4,809.71	5,956.20
Percent increase relative to Alternative 1 (%)	—	12.6	31.2	62.5
Concession period extension (years)	—	2.5	6.2	12.5

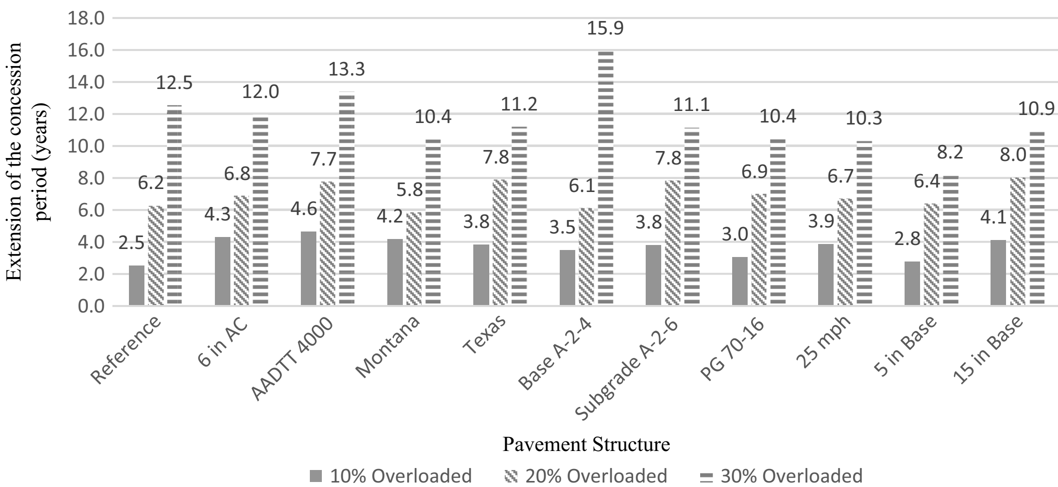

Fig. 25. Extension of the concession period for 10%, 20%, and 30% increase in truck load limit.

the damage factor assessment to produce more accurate shadow toll rates.

The second compensation considered the extension of the concession term so as to allow the concessionaire to recover the additional maintenance expenditures caused by the increase in truck load limit. The AASHTOWare Pavement ME was used to schedule heavy maintenance activities by modeling the performance of (1) the initial pavement, and (2) the pavement with a thick overlay considering different loading conditions. Finally, a LCCA was conducted using RealCost to determine the increase in the maintenance costs, borne by the concessionaire, caused by the increased legal load limit. The length of the extension of the concession term was estimated as to allow the concessionaire to recover the resulting losses. Different pavement structures with different material properties, climatic conditions, and traffic conditions were included in the analysis. It was noticed that a longer extension of the concession period is required for scenarios showing an accelerated deterioration of the pavement, such as low quality of materials, high traffic levels, and high truck loading limit. Briefly, for a 10%, 20%, and 30% increase in truck load limit, and considering a 20-year initial concession period, the average length of the extension of the concession term is 3.5, 6.9, and 12 years, respectively.

As previously mentioned, the Pavement ME simulations, for the initial road project and the overlay, considered the nationally calibrated factors for all distress models; therefore, local calibration factors corresponding to the project location, if available, must be used for the analysis to obtain more accurate results. Furthermore, the performance thresholds adopted to schedule rehabilitation activities must be in accordance with the pavement maintenance standards of the corresponding transportation agency. For the LCCA, the costs of pavement construction and overlay placement, as well as other RealCost input parameters related to the project's economical and technical aspects, are project specific. More importantly, the length of the extended concession is highly dependent on the toll revenues generated during the extended term. The presented results were obtained assuming that the toll revenues generation rate during the extended period follows a similar pattern to that observed during the initial concession period. Accordingly, the proposed methodology should be adjusted in order to consider any available data on the toll revenues generation during the extended concession term.

Lastly, the type of the compensation is to be decided by the government based on several factors. For instance, shadow tolls can be provided only in the case of the availability of public funds. Moreover, the extension of the concession period cannot be applied unless the legal framework that regulates the corresponding PPP project allows such an extension.

All things considered, the proposed techniques represent a general guideline for PPP partners, the government and the concessionaire, to quantify the impact of the legislative change in truck load regulations on the contract terms and to decide on a strategy that ensures a fair compensation is decided in favor of the concessionaire, therefore contributing in the avoidance of dispute occurrence.

Conclusions

The tendency of transportation agencies around the world to increasing truck load limit leads to an accelerated deterioration of pavements and imposes additional expenditures for pavement maintenance works. These expenditures, in a PPP road project, are borne by the concessionaire, unless the PPP agreement allows relief

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either in the form of additional availability payments or extension of the concession term. The present study proposed two strategies for consideration by the government to compensate the concessionaire in case of a change in truck loading legislations, and consequently to avoid dispute occurrence. The proposed strategies were based on the prediction of flexible pavements performance using AASHTOWare Pavement ME. First, the government could provide direct compensation in the form of an increase in availability payments, and more specifically shadow tolls per overloaded truck. The availability payment increase would be set based on truck class, varying pavement structures, and evidence of damage resulting from overloaded trucks. It was observed that the value of the shadow toll is highly influenced by the truck class, truck load, pavement structure, climatic conditions, and truck traffic volumes. The highest values of shadow tolls would apply to projects with relatively thin pavements and high traffic volumes. Second, an extension of the concession term allows the concessionaire to recover the encountered losses caused by increasing the permissible truck load. A methodology was presented to assess the sufficient concession period extension lengths for different pavement structures. This extension depends, to a great extent, on the project's characteristics in terms of the pavement structure, climatic conditions and traffic volumes, as well as on the toll revenues generation rate during the extended concession period. For a 10%, 20%, and 30% increase in truck load limit, the length of the extension of the concession period ranged between 2.5 and 4.6 years, 5.8 and 8 years, and 8.2 and 15.9 years, respectively. The proposed methodologies are expected to guide PPP partners in avoiding disputes arising from the legislative changes concerning truck load regulations, as they ensure that a fair compensation is granted to the concessionaire without compromising the government's interests.

Data Availability Statement

All data, models, and code generated or used during the study appear in the published article.

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