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FRAMEWORK FOR RISK MANAGEMENT AND DISPUTES AVOIDANCE IN PPP CONTRACTS FOR ROAD PROJECTS: ROLE OF PAVEMENT PERFORMANCE PREDICTION MODELS

by
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ABSTRACT
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Title: Framework for Risk Management and Disputes Avoidance in PPP Contracts for Road Projects: Role of Pavement Performance Prediction Models

With the increasing reliance on Public-Private Partnerships (PPP) in roadway construction and preservation, and due to the long-term nature of these concession contracts, there arises the need for practical and reliable tools that help in assessing the rights and responsibilities of each of the two main parties involved in a PPP road project – the highway agency and the concessionaire – thus forming a clear basis for the negotiations conducted between PPP parties whenever a change in the contract terms is required.

This study addresses three risks that are directly related to the pavement's technical aspect in PPP highway projects: 1) the non-compliance with the standard construction specifications, 2) the increased legal load limit and 3) the traffic volume risk. This will provide a framework for effectively managing these risks, through an accurate estimation of the effect of each risk on the financial flow of the negatively-impacted PPP partner.

First, the non-compliance of contractors with the standard construction specifications set by transportation agencies is a major concern in all pavement construction projects. In traditional road procurement strategies, the owner imposes "penalties", also known as "pay-adjustment factors" on the contractor in case the latter delivers an out-of-specs pavement construction. Pay-factor assessment methods available in the literature consider only the time to the first heavy maintenance activity and the increased agency cost. Such methodologies are not suitable in the context of a long-term complex PPP road project. Accordingly, the present study proposes a methodology for assessing the pay-adjustment factor to be imposed by the concessionaire on the construction subcontractor based on the predicted performance of the out-of-specs pavement. Both the agency and user costs, as well as all maintenance activities performed throughout the concession period, are included in the analysis. The pay-factor assessment method must be addressed during the negotiation phase and approved by the highway agency or its representative, who will be responsible for monitoring the performance of the pavement throughout the concession period, ensuring that appropriate maintenance is

conducted to maintain the pavement at a satisfactory ride-ability level, as required by the contract terms.

Second, an increased legal truck load limit significantly affects the pavement performance, leading to its accelerated deterioration and imposing additional expenditures for maintaining the road condition at a satisfactory ride-ability level, as required by the contract terms. These expenditures, in a PPP road project, are typically borne by the concessionaire. This study proposes two compensation strategies that can be adopted by the highway agency to remunerate the concessionaire for the increased maintenance costs caused by the increase in the legal truck load limit. The level of compensation depends on the corresponding reduction in the pavement performance throughout the concession period.

Finally, inaccurate traffic volumes forecasts represent a major concern in PPP road projects. The two most common traffic volume risk sharing mechanism are the Minimum Revenue Guarantee (MRG) and the Least Present Value of Revenues (LPVR). Current practices in traffic volume risk sharing mechanisms ignore the effect of the change in traffic volumes on the pavement maintenance costs, therefore leading to an unfair risk management. Accordingly, this study addresses traffic volume risk by investigating the effect of the deviation in traffic levels on two major PPP parameters: the generated tolls and the maintenance costs. Then, the MRG and LPVR are adjusted by incorporating the effect of traffic volume risk on the project's total cash flow, as to ensure a fair risk sharing between PPP partners.

Briefly, the methodologies presented in the study require an accurate prediction of the pavement performance subject to the previously described scenarios: 1) delivering an out-of-specs pavement construction, 2) increasing the legal load limit and 3) encountering lower or higher than forecasted traffic levels. The AASHTOWare Pavement ME was used for the performance prediction, along with the LCCA tool, RealCost and a numerical model developed by the World Bank specifically designed for the financial analysis of PPP road projects.

The findings of the this study imply that the most critical parameter that needs to be carefully monitored by the construction subcontractor is the thickness of the asphalt-concrete layer, followed by the air-voids content in the asphalt mix. The binder content, on the other side, seems to have a relatively low impact on the pavement's performance. This is justified by to the fact that high quality materials are typically used for the construction of PPP road projects, thus increasing the pavement's resistance to rutting. Furthermore, the proposed strategies that can be adopted by the highway agency to compensate the concessionaire for the increase in the allowable truck load limit are dependent on the pavement's characteristics, in terms of the materials used in the different pavement layers, as well as the traffic and climatic conditions. Finally, the results of the conducted financial analysis considering different traffic volumes emphasize the need to include the resulting effect on the maintenance expenditures, as well as the generated toll revenues. In fact, ignoring the impact of the traffic level on the maintenance cost leads to an unfair traffic volume risk sharing between PPP partners.

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ABBREVIATIONS

PPP = public-private partnerships

AASHTOWare Pavement ME = AASHTOWare Mechanistic-Empirical Pavement Design Software

HMA = hot mix asphalt

AC = asphalt concrete

in = inches

ft = feet

mi = mile

IRI = international roughness index

mph = miles per hour

AADTT = annual average daily truck traffic

AADT = annual average daily traffic

LCCA = life-cycle cost analysis

DOT = department of transportation

IRR = internal rate of return

NPV = net present value

CHAPTER 1

INTRODUCTION

The participation of the private sector in the implementation of infrastructure facilities providing public services, known as Public-Private Partnership (PPP), is generally adopted for projects suffering from a shortage in public funds and/or needing enhanced technologies and expertise that cannot be provided by the public sector agencies [1]. The importance of PPPs is revealed with the increasing reliance of highway agencies around the world on this procurement strategy for the execution of projects relating to different sectors including transport, water and wastewater, power and social infrastructure. In 2019, PPPs expanded worldwide to be adopted by more than 62 countries, which is the highest number observed in the last decade [2].

Based on the World Bank statistics, the first half of the year 2019 (H1 2019) showed a 14% increase in the private investment levels compared with the first half of the year 2018 (H1 2018), and 18% increase compared with the average investment over the first halves of the past five years [3]. Furthermore, the private investment in the transport sector accounted for more than half of the global Private Participation in Infrastructure (PPI) investments in H1 2019, scoring an 8% and 34% increase compared to the H1 2018 and the average investment in transport sector over the H1 of the past five years, respectively. Around 76% of the private investments in the transport sector were assigned to the implementation of road projects. The distribution of the private investments in infrastructure over the different sectors from the year 2010 till H1 2019 are shown in Figure 1 [3].

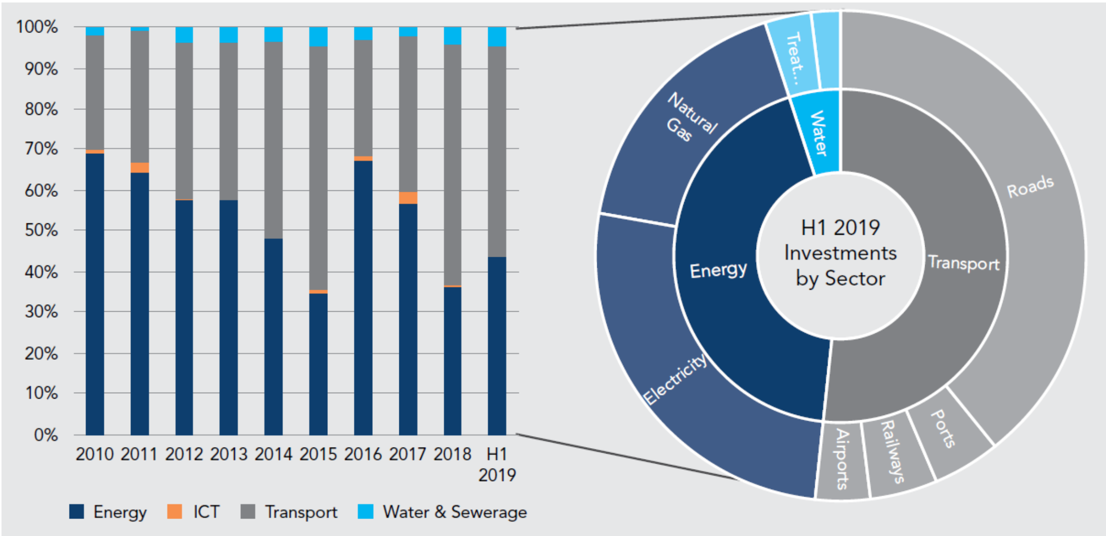

Figure 1 Distribution of the Private Investments over the Different Infrastructure Sectors [3]

The present study focuses on PPP road projects; particularly, in Greenfield PPP road projects – which involve the construction of a new road or a major upgrade of an existing road. In such arrangement, the private party is generally responsible of the design, construction, operation and maintenance of the subject road. With such responsibilities, PPP agreements tend to extend over a 25 to 30 years period [4].

The long-term nature of PPP concessions explains their complexity in terms of their contract administration. While the negotiations aim at organizing the relationship between the pubic authority and the private entity by addressing the concerns of each party, a "perfect" contract cannot be reached. However, with the help of well-directed research and the learning experience evolving with the execution of each PPP road project, the procurement process can be enhanced.

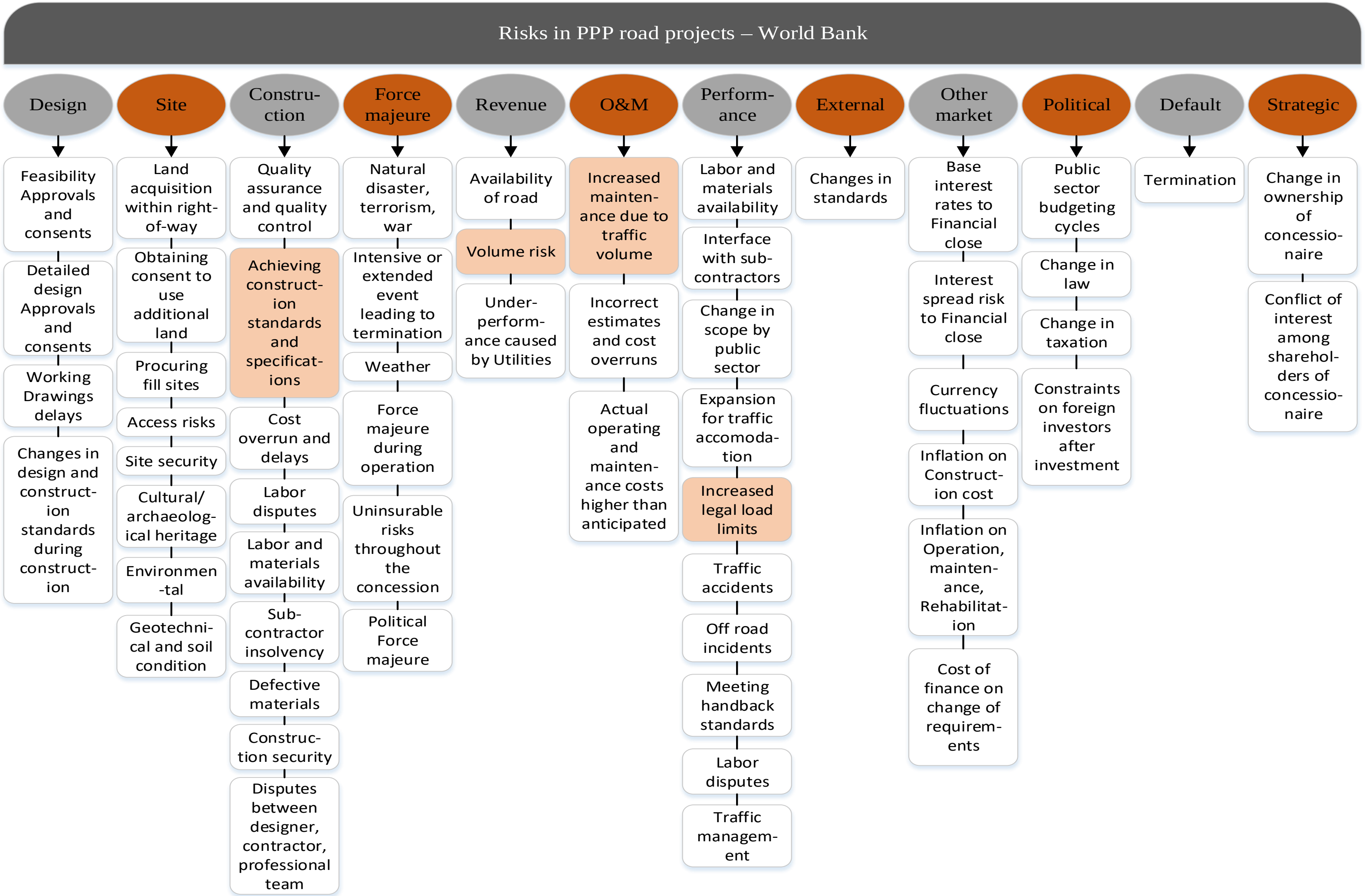

Figure 2 Risks in PPP Road Projects Highlighting Risks Addressed in the Present Study [5]

The World Bank identifies several categories of risks encountered in PPP road projects, as shown in Figure 2 [5]. These risks can be related to the design, site, construction, operation and maintenance or performance of the project. Other risks include, but are not limited to, force majeure, strategic or political conditions governing the project [5].

This study addresses the risks related to the technical aspects in PPP road projects, and more specifically, those that affect the pavement performance. These risks are highlighted in Figure 2.

These risks are addressed in three major modules. The first module deals with the risk of "not achieving the standard construction specifications". The second one addresses the risk of "increased legal load limit", while the third module combines the "volume risk" and "increased maintenance due to traffic volume" as both these risks can be described as the "errors in traffic volume forecasts", or simply "traffic volume risk". In fact, the "volume risk" is the risk of encountering lower-than-forecasted traffic levels, while the "increased maintenance due to traffic volume" refers to the risk of encountering higher-than-forecasted traffic levels that lead to an increase in maintenance costs.

Module 1: Non-compliance with the standard construction specifications.

The first module deals with the non-compliance of the concessionaire with the standard construction specifications enforced by the contract terms. Such issues are encountered at the beginning of the concession period, directly after the end of the pavement's construction works, and are known to affect the level of the pavement performance throughout its service life.

In conventional road procurement strategies, the contractor is generally responsible for constructing the subject road, while the owner operates it. Furthermore, the remuneration of the contractor is based on unit prices, agreed upon by the contract terms, and quantities measured on site [4]. Accordingly, transportation agencies adopt a "pay-adjustment factor", representing a percentage to be deducted from the contractor's compensation payment, in case the latter commits certain construction errors that are likely to negatively affect the pavement performance, and consequently, its service life [6].

The method for determining pay-adjustment factors varies from one agency to another. While some agencies rely on deficiency of index parameters, such as density and asphalt content, for pay-factor assessment, others relate the deduction in payment to the reduction in the pavement serviceability caused by the construction defect [6]. Current research trends show a tendency towards the adoption of performance-based pay-adjustment factors i.e. based on the performance of the pavement in terms of IRI and level of distresses such as fatigue cracking, rutting, among others [7][8][9]. However, the adopted methodologies for developing the pay factors consider only the increase in agency cost resulting from the non-compliant pavement construction and the first rehabilitation activity [7][8]. It is suggested that an enhancement of the estimated pay-factors could be achieved through incorporating the user cost in the cost model and considering all maintenance activities throughout the pavement's service life [8].

In PPP-procured road projects, the risk of the delivery of a non-compliant pavement construction is allocated to the concessionaire and can be passed down to the construction subcontractor(s) [5]. This is justified by the fact that, in PPP projects, the concessionaire holds the responsibility for the design, construction, operation and maintenance of the road throughout the concession period, after which the facility is transferred back to the highway agency [1][4]. Therefore, the out-of-specs pavement delivered by the construction subcontractor within the private consortium, will impose additional expenditures to be endured by the concessionaire.

Therefore, in the case of the occurrence of construction errors, each PPP party will be negatively impacted with consequences and losses likely to be incurred 1) the concessionaire, having to endure additional maintenance cost caused by the accelerated deterioration of the pavement, will be concerned of not being able to achieve the targeted profit out of the project and 2) the highway agency will be concerned that the concessionaire does not maintain the road to a satisfactory level; hence, the condition of the road when transferred back will not meet the contract terms.

In the light of the foregoing, both PPP partners must agree on a procedure for accurately determining the pay factor, imposed on the construction subcontractor, as to protect the interests of both parties, and indirectly, the interests of road users. This requires considering all maintenance activities to be performed throughout the concession period and including the increased user cost in the estimation of the pay factor. With these enhancements applied to the pay-factor estimation methodology, three objectives would be achieved: 1) the construction subcontractor being incentivized to deliver a pavement constructed according to the prescribed specifications, 2) the highway agency being assured that the amount deducted from the construction subcontractor’s payment can maintain the concessionaire’s ability to perform all maintenance works when needed without delay and 3) the concessionaire being capable of adequately maintaining the road facility as per the contract terms without compromising their profit.

The first module investigates the effect of a non-compliant pavement construction on the pavement's life-cycle cost. Three characteristics of the asphalt-concrete are addressed: 1) the air voids percentage, 2) the binder content and 3) the thickness of the AC layer. Then, a methodology is presented to assess the value of the pay factor to be applied in case of an out-of-specs pavement construction, considering the increase in both the agency and user costs resulting from all heavy maintenance activities performed throughout the concession period. The proposed methodology makes use of pavement performance prediction models to assess the decline in the pavement performance caused by the out-of-specs construction. A life-cycle cost analysis (LCCA) is then conducted to estimate the corresponding increase in agency and user costs based on which the pay-adjustment factor is computed.

Module 2: Increased legal load limit.

The second module addresses the risk of having the legal load limit increase by the highway agency. Such risk might be encountered at any stage during the operation of the road facility.

In PPP road projects, bidders prepare their proposals based on the actual traffic characteristics, among which are the permissible loading limits. Nevertheless, a tendency towards increasing the legal truck load limit is gaining momentum [10][11][12][13]. While numerous research studies addressed the effect of such change on the pavement performance, the complexity of long-term agreements requires that additional investigations be carried out to inspect the impact of these changes in traffic characteristics on PPP road concessions. These complexities are attributed to the fact that these traffic-related decisions made by the highway agency affect directly the concessionaire, responsible for maintaining and operating the road facility.

Increasing the legal truck load limit is known to accelerate the pavement deterioration by increasing the rate of development of the pavement distresses such as fatigue cracking and rutting. This results in significant changes in the pavement maintenance expenditures – borne by the concessionaire – and consequently the life cycle cost of the PPP road project. Thus, the concessionaire holds the right to claim a compensation from the highway agency, in case the latter allows the increase in the permissible load limit to materialize.

Accordingly, the present study proposes two procedures that can be adopted by the highway agency to compensate the concessionaire for permitting differing operating conditions. These compensation strategies are related to the "tariff regime" and "the length of the concession period", two parameters extensively discussed during the negotiations between PPP parties [4][14][15]. The level of compensation entitled to the concessionaire is assessed based on the predicted performance of the pavement subject to overloaded trucks. A LCCA is conducted, when needed, to estimate the increase in maintenance costs caused by the accelerated deterioration of the pavement observed when the truck load limit is increased.

Module 3: Changes in traffic volumes.

The responsibility for some changes in road projects characteristics cannot be allocated to any of the two main PPP parties, such as an unexpected increase or decrease in traffic volumes. In fact, the "traffic volume risk" is considered one of the most challenging risks that might be encountered in PPP toll-road projects in terms of its allocation and management [4][16][17][18][19][20][21].

The review of literature shows that the "Minimum Revenue Guarantee" (MRG) and the "Least Present Value of Revenues" (LPVR) are the two most common traffic volume risk sharing mechanisms [19][20][21][22][23][24]. Current practices in the applications of the MRG and the LPVR are to adopt the gross revenues as the trigger variable, instead of the profit, which is equal to the revenues minus the expenses. This is justified by the fact that highway agencies find revenues easier to be monitored than profits, as revenues can be simply estimated knowing the traffic counts and the toll levels, while the exact expenses of the concessionaire are hard to be monitored by the highway agency [21][25].

However, when actual traffic levels deviate from the forecasted ones, not only the revenues, represented by the tolls charged to road users, are affected, but the maintenance expenses as well. Furthermore, the effect of traffic levels on the cash inflow is opposed to its effect on the cash outflow; a higher-than-forecasted traffic level has a favorable effect on the cash inflow, as it results in higher-than-expected toll revenues, while its effect on the cash outflow is disadvantageous, as it accelerates the deterioration of the pavement, consequently increasing the maintenance expenditures borne by the concessionaire. On the contrary, while the lower-than-forecasted traffic levels negatively affect the cash inflow through the generation of lower-than-expected toll revenues, the cash outflow is positively affected through lowering the maintenance expenditures.

Accordingly, when assessing the effect of any deviation in traffic levels away from forecasted ones, the resulting effect on the cash outflow cannot be ignored. This study addresses traffic volume risk by assessing the effect of the errors in traffic volume forecasts on the project's cash inflow, represented by the toll revenues, and the project's outflow, and more specifically the maintenance costs. Note that the change in maintenance costs corresponding to the deviation in traffic levels is estimated based on the predicted performance of the pavement subject to different traffic volumes. Then, the LPVR and the MRG mechanisms are adjusted as to incorporate the resulting effects on both the cash inflow and outflow.

The proposed methodology would achieve the following objectives: 1) to accurately assess the effect of the deviation in traffic levels on the financial balance of the PPP road project, 2) to enhance the MRG mechanism by helping the highway agency in accurately determining the needed subsidy that should be offered to the concessionaire, 3) to enhance the LPVR mechanism by delimiting the contract length based on the actual project's IRR. Having all these enhancement implemented, a fair traffic volume risk sharing between PPP partners is guaranteed, disputes are avoided and renegotiations are facilitated.

The detailed level of input required by the AASHTOWare Mechanistic-Empirical Pavement Design software (AASHTOWare Pavement ME), generally used for pavement design, makes this tool suitable for evaluating the pavement performance when subject to the aforementioned changes in the project characteristics. For instance, the pavement can be modeled with different layers thicknesses and asphalt mixture volumetrics, as well as differing traffic parameters, including traffic counts and truck loading conditions [26]. Nevertheless, the mechanistic-empirical design process, offered by the AASHTOWare Pavement ME, represents an advanced tool for pavement design and performance prediction over the former empirical design procedures, such as the AASHTO 1993, as it uses the theories of mechanics to calculate the stresses and strains developed in the pavement due to the combined effect of traffic loading and climatic conditions, according to the user-defined material properties. Then, the computed stresses and strains are converted into an accumulated pavement damage, over the pavement's design life; consequently, transfer functions are utilized to predict the pavement distresses, such as roughness, fatigue cracking and rutting, based on the previously determined pavement damage [26][27].

Accordingly, this study makes use of the powerful AASHTOWare Pavement ME tool to propose a guiding framework for the two main PPP parties – the highway agency and the concessionaire – to address the identified pavement performance-related risks: 1) the non-compliance with the standard construction specifications, 2) the increased legal load limit and 3) the traffic volume risk. A LCCA tool, RealCost [28], and a numerical model, developed by the World Bank, specifically designed for the financial analysis of PPP road projects [29], are used in conjunction with Pavement ME when needed.

CHAPTER 2

OBJECTIVES

2.1. Problem Statement

The present study addresses three risks encountered in PPP road projects: 1) the non-compliance with the standard construction specifications, 2) the increased legal load limit and 3) the traffic volume risk, which includes 3.a) the risk of a shortage in toll revenues caused by lower-than-forecasted traffic levels and 3.b) the risk of increased operation and maintenance cost caused by higher-than-forecasted traffic levels. A common factor among these risks is that they are all related to the performance of the subject pavement. Consequently, an effective management of these risks requires an accurate prediction of the pavement performance when any of these risks is encountered.

Accordingly, the main objective of this study is to provide PPP parties, the highway agency and the concessionaire, with a framework for the management of each of the three aforementioned risks, making use of a powerful pavement performance prediction tool, the AASHTOWare Pavement ME, used in conjunction with a LCCA tool and a numerical model specifically developed for the financial analysis of PPP road projects.

2.2. Study Objectives

Figure 3 summarizes the goals to be achieved across three modules.

The first module deals with the non-compliance of the construction subcontractor, within the private consortium engaged in the PPP road project, with the construction specifications, in terms of 1) the air-void content in the AC mix, 2) the binder content in the AC mix and 3) the AC layer thickness. In this context, the main objective is to propose a methodology for accurately assessing the pay-adjustment factor imposed in case of the delivery of an out-of-specs pavement construction. The pay-adjustment must cover the additional expenses, in terms of the agency and user costs, endured by the concessionaire/operator due to the declined pavement performance throughout the concession period, therefore ensuring the successful implementation of the road project regarding to the pavement condition throughout the concession period and at handback of the road facility to the highway agency.

The goal of the second module is to present two strategies that can be adopted by the highway agency to compensate the concessionaire for the increased pavement maintenance cost caused by a governmental decision allowing the increase in the legal load limit. These compensation strategies affect the tariff regime and the length of the concession period.

The third module deals with the risk of errors in traffic volume forecasts, known as "traffic volume risk". First, the effect of the deviation in traffic levels (either lower or higher than the forecasted volumes) on the PPP project's cash inflow and cash outflow is assessed. Second, a methodology that ensures a fair risk sharing between PPP partners is proposed.

2.3. Dissertation Organization

This dissertation comprises nine chapters. Chapter 1 covered the Introduction while this Chapter covers the Objectives. Chapter 3 provides a general overview of the main topics addressed in the context of PPP road projects. Then, Chapter 4 explains the basis used for scheduling flexible pavement maintenance activities in subsequent sections of the study. In Chapter 5, the different tools used for the analysis are described. Consequently, Chapter 6 addresses the issue of the non-compliance of the construction subcontractor with the standard construction specifications in terms of the air-void content in the AC mix. Afterwards, Chapter 7 deals with the adverse implications of increasing truck load limit on the pavement performance and proposes two strategies allowing the highway agency for compensating the concessionaire for the endured additional maintenance costs. Lastly, Chapter 8 addresses the risk of errors in traffic volume forecasts. Chapter 9 finally summarizes the findings of the study.

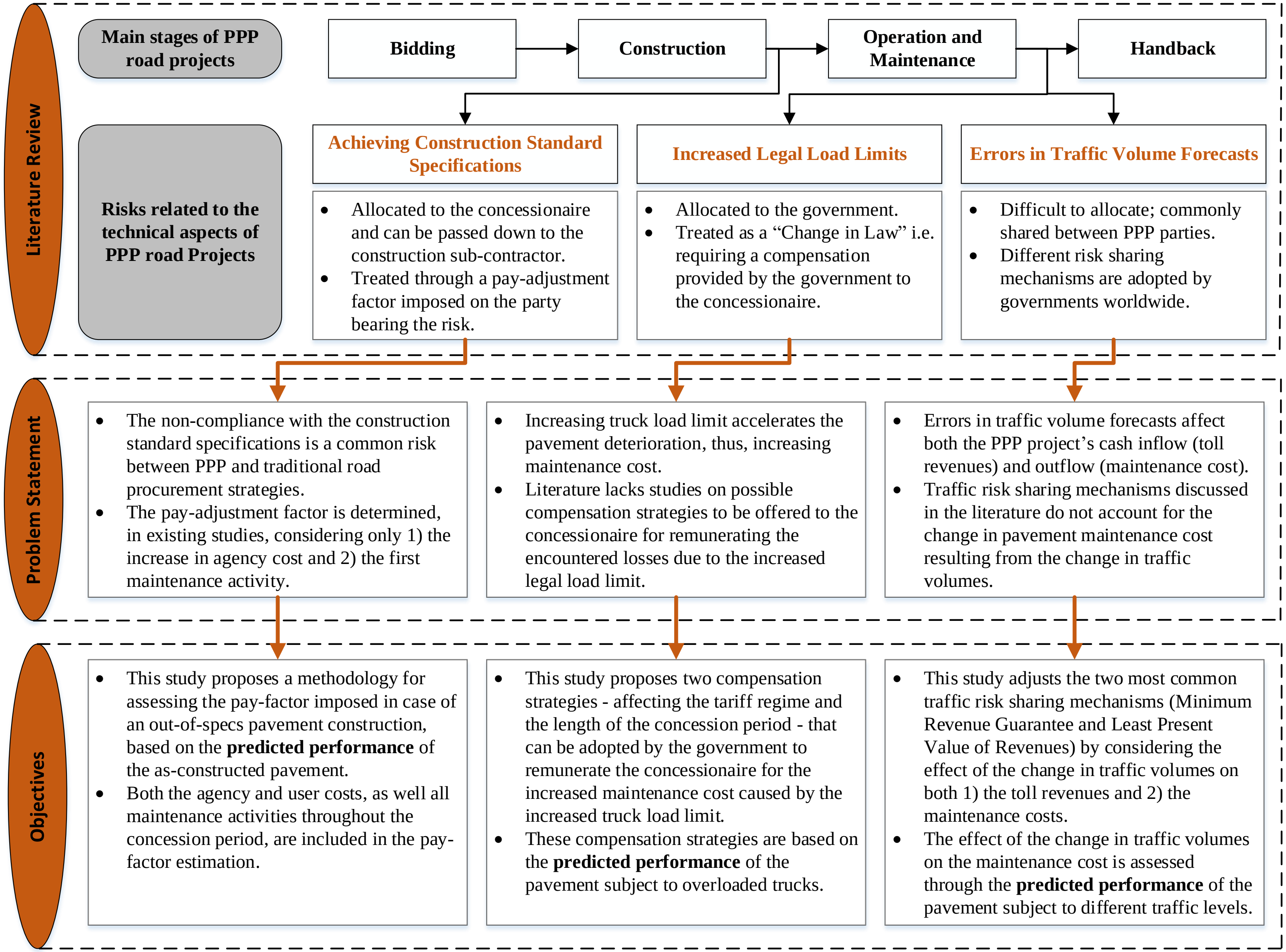

Figure 3 Problem Statement and Objectives of the study

CHAPTER 3

LITERATURE REVIEW

This chapter provides a general overview of Public-Private Partnerships in the transportation sector.

3.1. Research Trends in Public-Private Partnerships

The observed growth in PPP projects resulted in a remarkable tendency among researchers to study the different aspects of these partnerships. Ke et al. [30] reviewed research papers dealing with PPP, published in well reputed construction journals between 1998 and 2008. The authors noticed an increasing interest in research related to all areas of PPPs. Furthermore, the authors classified the reviewed articles in order to identify the most discussed topics in PPPs. Seven major categories were spotted: 1) investment environment, 2) procurement, 3) economics viability, 4) financial package, 5) risk management, 6) governance issue and 7) integration research [30].

Similarly, Tang et al. [31] reviewed PPP studies published between 1998 and 2007 in six top journals in the construction field. The authors classified these research papers into empirical and non-empirical studies. The empirical studies tackled three main topics: 1) risks including risk identifications, management and allocation, 2) relationships including contract management, concessionaire selection and success factors, and 3) financing including attracting private funds for financing PPP projects. On the other side, non-empirical studies focused on developing models for, among others, 1) determining financial viability of PPP projects, 2) assessing risks and 3) calculating the duration of the concession period [31].

A more recent study examined articles published in seven top journals in the construction field, from 1996 to 2016. The classification of the research papers was based on the PPP project lifecycle. The project preparation phase included studies dealing with the concession period, guarantees provided by the highway agency to the concessionaire, financing structure and contract design. The procurement phase was divided into two main parts: 1) studies concerned with the public agency, including concessionaire selection, negotiations and incentive creation, and 2) studies concerned with the private sector, including bid-winning strategies and risk assessment. The third phase addressed the implementation of the PPP projects, comprising research related to risk management, implementation performance – i.e. monitoring performance, overruns and technological innovation - and "dealing with changes" – i.e. renegotiation, sharing excess revenue and disputes. The final phase was the transfer phase which was tackled by only three articles, focusing on residual risk and a review of transferred projects. Other studies investigated factors affecting the success and failure of PPPs. In addition to the transfer phase, the authors noted that the "implementation performance", monitored by the highway agency, needed to be further addressed by researchers [32].

This study aims at filling a part of the gap established by researchers in the area of PPP road projects, by addressing critical changes that are likely to be encountered in the implementation phase and providing PPP partners (the contracting authority and the concessionaire) with a tool to effectively deal with such changes.

3.2. Stages of PPP Projects

Projects procured through public-private partnerships follow mainly a four-stage life cycle: 1) the project preparation phase, 2) the procurement phase, 3) the implementation phase and 4) the transfer phase. While the project preparation phase concerns only the public authority, during which the latter determines the length of the concession period, the guarantees to be offered to the concessionaire and the financing structure to be adopted for the project [32], the procurement phase administrates the relationship between the highway agency and the concessionaire through negotiations that lead to the acceptance of the contract terms by both parties and finally, the signing of the contract.

More specifically, the procurement phase of PPP projects consists of three stages, from the pre-qualification of bidders and the bidding process, to the negotiations and the contract award. For bidders to prepare their proposals, the contracting authority must provide them an access to a "digital data room" which includes, among others, information related to the traffic counts, the toll levels and adjustment formulas and the discounting rate, as well as a preliminary design of the road, the standard construction specifications, the performance indicators for operation and maintenance, in addition to the length of the concession period and the highway agency's guarantees. The "request for proposals" includes also a draft concession contract [4].

3.3. Most Negotiated Parameters in PPP Agreements

After the proposals submittal, the negotiations begin between the contracting authority and bidders.

The main negotiation parameters in PPP road projects include 1) the land acquisition, 2) the project investment costs, 3) the tariff regime, 4) the concession period, 5) the risk allocation, 6) the renegotiation options on specific items and 7) other project-related items [4].

Two research studies, by Ng et al. and Contreras & Angulo, consider the investment return, the tariff regime and the concession period to be the key parameters affecting the success of PPP projects [14][15].

Similarly, Liou & Huang [33] regard the concession period and the tariff regime as the main items discussed during the negotiations between the concessionaire and the contracting authority [33].

Tiong & Alum [34] conducted a survey to rank 13 financial and contractual elements, based on their importance in the negotiation of PPP infrastructure projects procured through Build-Operate-Transfer (BOT) scheme, among both governments and promoters. The output of the survey resulted in the following ranking: 1) initial level of tariff, 2) future tariff increase, 3) financial commitment by promoter's bankers, 4) fixed construction schedule, 5) return on investment, 6) guarantees by promoters, 7) length of concession period, 8) fixed construction cost, 9) high equity by promoters, 10) land acquisition costs, 11) fixed interest rate for loans, 12) profits and revenue sharing with highway agency and 13) no foreign currency exposure in loans and repayments. Furthermore, the authors highlighted the value of the tariff regime as being the prime concern of both PPP parties during the negotiations [34].

The concession period and the tariff regime are two of the most controversial PPP contracts parameters. For instance, the contracting authority favors a short concession period as opposed to the concessionaire who considers a longer concession period to be more beneficial [35]. In fact, the highway agency decides on the length of the concession period as to reclaim the facility as soon as the debt is refunded with a reasonable profit achieved by the concessionaire [1][36]. The latter, however, seeks to achieve the highest possible return on investment, which can be reached by operating the road, and correspondingly collecting tolls from users, for a longer period [35].

Similarly, while the concessionaire desires to increase the values of the collected tolls, the highway agency tends to protect the road users' welfare by imposing reasonable tolls and toll adjustments in the contract, to be respected by the concessionaire [4][36].

In the present study, a methodology is presented to adjust two of these parameters, the concession period and the tariff regime, as to deal with the risk of increased truck load limit.

3.4. PPP Projects Performance Indicators and Deliverables

There are three types of performance indicators to be considered in concession agreements: 1) the construction specifications when the asset is handed over from the construction subcontractor to the concessionaire; those are not addressed in the present study which aims at managing the contract between the highway agency and the concessionaire and not the contract between the concessionaire and the sub-contractors, 2) the performance specifications during the operation period, and 3) the pavement condition when the asset is handed back to the highway agency [37][38].

Furthermore, in PPP road concessions, the project deliverables are specified in terms of the performance of the pavement – mainly the pavement roughness, the rut depth, the cracking percentage – as opposed to the index properties such as –air void percentage, asphalt content, pavement thickness, among others as stated in the quality assurance QA criteria – adopted as the acceptance criteria in conventional road procurement strategies. This can be explained by the fact that, in PPP projects, the concessionaire is given the autonomy of using innovative construction techniques, and the contracting authority is only concerned with the level of performance of the road throughout the concession period [1][4].

The pavement performance specifications are mainly established based on reviewed historic data, related to the pavement smoothness, rut depth, cracking…, measured on “surrogate” roads. These are roads constructed under similar climate, traffic and site conditions, and managed by either the public authority or by the private sector [37][38].

Accordingly, the concessionaire is bound, by the contract terms, to maintain the pavement at a satisfactory level of performance throughout the concession period. The failure of the concessionaire to deliver the required performance targets allows the contracting authority, based on the contract type, to impose payment deductions or penalties, or to adopt a formal warning system that might lead to the termination of the contract in case the concessionaire continues to violate the pavement performance related contract terms [1].

Moreover, the quality of the pavement at handback to the highway agency is clearly described in the contract, as will be elaborated in the following section. Consequently, the performance requirements desired by contracting authority in PPP road projects are protected by the contract terms and the concessionaire holds the legal responsibility to deliver the road facility as described.

3.5. Handback Requirements

A PPP contract always includes different elements related to the transfer of the facility from the concessionaire to the highway agency. Cui et al. identified eight key handback elements: 1) handback plan, 2) inspection requirements, 3) minimum residual life requirements, 4) residual life calculation method, 5) operation and maintenance training sessions, 6) handback reserve account, 7) spare parts and tools, and 8) final handback acceptance. A PPP contract might not include all these parameters. However, there is a tendency to incorporate a more detailed handback process in recent PPP contracts compared to old ones [39].

The handback plan is generally set by the concessionaire then approved by the highway agency prior to the handback process, which begins several years before the expiry of the concession agreement (2 to 3 years for example). The handback plan includes the renewal works as well as inspections to be conducted, in addition to the detailed transfer process [39].

Regarding the inspection requirements, the PPP parties agree on a minimum number of inspections to be held jointly or by a third party, to investigate the condition of the facility and ensure it meets the performance targets set by the contract terms [39].

The highway agency also includes in the contract a minimum remaining service life of the facility to ensure that no major rehabilitation will be required for the specified period after the expiry of the concession agreement [38][39]. The remaining service life cannot be determined accurately, and is generally estimated based on historic data, inspections, testing and, more importantly in road projects, deterioration models [38]. The residual life calculation method is generally proposed by the concessionaire [39].

Furthermore, the concessionaire is required to offer training sessions to the public sector’s employees, if needed, and to provide all spare parts and tools needed for the highway agency to carry on the operation and maintenance works [39].

The “handback reserve account”, also known as “standby letter of credit”, is a main contract item used by the highway agency to pressure the concessionaire for handing back the facility in a satisfactory condition [39][40]. This reserve account is mainly established 5 to 6 years prior to the end of the concession period [38] and can be used by the highway agency in case a major rehabilitation is required during a specified warranty period [38][40].

In this context, the more detailed is the handback elements included in the contract, the more are the highway agency’s interests protected, in terms of ensuring the proper maintenance of the facility and ultimately, a successful implementation and transfer of the PPP road facility.

3.6. Payment Options in PPP Road Projects

The main payment options adopted for PPP projects are 1) road user payment, through tariffs/tolls charged to the facility users 2) availability-based payment and 3) a combination of both. Availability payments are regular payments made by the highway agency to the concessionaire based on the provided service. In PPP road projects, “shadow tolls” are one type of availability payments. In general, tolls should cover all costs, including those related to the operation and maintenance of the toll road, in addition to the concessionaire’s profit. In case tolls fail to cover all the aforementioned costs, the highway agency might consider to support the concessionaire either through and up-front payment or an availability payment [4].

To protect the user’s welfare, the highway agency specifies, in the request for proposal and in the contract, the toll levels that the concessionaire can charge to the road users as well as the toll adjustment formulas [4]. Toll levels depend on several factors including, among others, 1) the vehicle classification (type, weight, number of axles), 2) time of day/ day of week, 3) cost of highway construction and 4) traffic congestion and other traffic conditions [41][42][43].

A “shadow toll” is not collected directly from users, but paid by the highway agency to the concessionaire based on the actual number of vehicles using the road. The adoption of shadow tolls mainly aims at relieving the private partner, partially or totally, from the “demand risk” which be allocated to the highway agency [44][45]. The “demand risk” is function of several factors, such as the users’ willingness to pay, the users satisfaction and the presence of a competing free road parallel to the toll road [46]. Different types of risk will addressed in more details in subsequent sections of the present study.

This study proposes effective ways of incorporating the alternative payment options, such as “shadow tolls” into the PPP contract, in the form of a guarantee provided by the highway agency to the concessionaire, in case the latter’s profit is threatened due to specific governmental decisions, related to truck loads and configurations.

3.7. Disputes in PPP projects

The long-term nature of PPP agreements exposes PPP projects to a wide variety of unforeseen circumstances that might eventually lead to conflicts between the different parties engaged in the PPP concession. Different causes might lead to disputes between PPP partners, related to 1) land acquisition, 2) environmental clearance, 3) technical issues including, but not limited to, change in scope and 4) concession agreement related issues i.e. the non-compliance of any PPP party with the contract terms [47].

Early warnings are one way to prevent disputes. Nonetheless, in case of the occurrence of conflicts caused by the lack of commitment of any partner to the PPP agreement, several dispute resolution techniques are adopted such as partnering, facilitated negotiations to conciliation and mediation [4]. Failing of PPP partners to resolve disputes might, in some cases, lead to the initiation of lawsuits, resulting in a massive delay in the implementation of the project [48].

In large, direct negotiations between PPP partners represent the least expensive dispute resolution technique [4]. The present study identifies different changes in a PPP road project's characteristics that might lead to disputes between PPP partners and proposes resolution techniques, to be discussed and agreed upon during negotiations, and included in the PPP contract, to avoid future disputes and renegotiations of the contract terms.

CHAPTER 4

ASPHALT-CONCRETE PAVEMENT PERFORMANCE AND MAINTENANCE

In this chapter, the performance thresholds adopted by different transportation agencies for scheduling maintenance works are reviewed. Then, a general overview of pavement maintenance techniques is provided with a focus on AC overlays of existing flexible pavements.

4.1. Flexible Pavements Performance Thresholds

The National Highway Performance Program (NHPP) adopts a three levels rating system: good, fair and poor for the three main flexible pavement distresses: the pavement roughness measured by the International Roughness Index (IRI), fatigue cracking and rutting. A good IRI rating is given for IRI values below 95 in/mile, while a fair rating for values between 95 and 170 and a poor rating for IRI higher than 170 in/mile. Similarly, the performance thresholds are 5 and 20% for fatigue cracking (good if fatigue cracking is less than 5%, fair if between 5 and 20% and poor if higher than 20%) and 0.2 and 0.4 in for rutting. The overall rating of the pavement is “good” if the ratings of the three distresses are “good”. If two or more distresses are “poor”, then the pavement is also considered “poor”. The remaining combinations of distresses rating correspond to a “fair” rating of the pavement [49]. The State of California, however, adopts a similar pavement rating system, excluding rutting and differentiating between two types of fatigue cracking, A and B, in which Type B fatigue cracking is more severe than Type A cracking [49].

The Florida Department of Transportation (DOT) recommends that the friction layer be removed and replaced when the IRI value reaches 110 in/mile. The rutting threshold is 0.25 in for Category 1 roads (design speed higher than 55 mph) and 0.4 in for Category 2 roads (design speed lower than 55 mph). For fatigue cracking, a maintenance is required when a cumulative length of cracks wider than 1/8 in is higher than 30 ft and 300 ft for Category 1 and Category 2 roads respectively [50].

Different types of performance indices are also adopted for ranking the pavement condition, among which some are based on pavement distresses, such as the pavement condition index PCI and the pavement condition rating PCR [51]. In the present study, the performance thresholds adopted for scheduling the heavy maintenance activities are 25% total cracking and 0.4 in total rut depth.

4.2. Maintenance Types for Flexible Pavements

There are three main types of pavement maintenance activities: 1) preventative and corrective treatment, such as thin AC overlays and chip seal; those are applied when the pavement is relatively in a good condition, 2) capital preventive maintenance; these are applied for pavements with minor defects and include medium AC overlays and 3) major pavement rehabilitation such as thick AC overlays (> 3in) or full-depth pavement replacement; such rehabilitation works are needed for pavements suffering from severe structural distresses. The service lives of these maintenance works vary from 4 to 7 years for the preventative treatments, 5 to 10 years for the capital preventive maintenance and might reach 20 years when a major rehabilitation is applied [49].

For the analyses conducted in this study, maintenance is limited to the application of a relatively thick AC overlay over existing flexible pavement whenever the pre-defined performance thresholds are reached. Other minor maintenance works, such as preventive, routine and corrective treatments, are not considered for the analysis.

The service life of the AC overlay must be determined for accurately estimating the life cycle cost of the considered pavement using RealCost. The review of literature reveals that the survival time of AC overlays is function of several project characteristics, including the AC thickness, the condition of the existing pavement prior to the overlay placement, the climatic conditions (temperature, precipitation) and the traffic volumes [51].

A study by Irfan et al. [52] summarized the findings of previous research done on AC overlays service life. A nationwide survey of highway agencies in North America showed that the minimum and maximum service lives of AC overlays are 2 years and 9-10 years respectively. The New York State DOT and the Federal Highway Administration (FHWA) reported that the service life of AC overlays is 6 or more, 8 and 8 to 11 years respectively. Similarly, the Ohio DOT reported that the service life of AC overlays ranges between 8 to 10 years. The review of the Long-Term Pavement Performance (LTPP) data resulted in a 3 to 8 years expected life of AC overlays [52].

A report prepared by Johnson on flexible pavement maintenance techniques revealed a significant difference in AC overlays' service life expectancies in the US as some states report a service life as low as 2-4 years while others report as many as 10 years [53].

It can be concluded that the service life of an AC overlay is highly dependent of the project's specific characteristics, in terms of the material properties, climatic and traffic conditions. Accordingly, the AASHTOWare Pavement ME is used to estimate the service life of the AC overlays, as described in Chapter 5, section 5.1.3.

CHAPTER 5

TOOLS

This chapter describes the different tools used in the dissertation and provides the corresponding input parameters. Note that the US customary measurement system is adopted throughout the study in compliance with the AASHTOWare Pavement ME input requirements. However, the pavement construction and maintenance costs are estimated per lane-km as to be directly used in the World Bank's financial model for PPP road projects.

5.1. AASHTOWare Pavement ME

5.1.1. Overview

The AASHTOWare Mechanistic-Empirical Pavement Design software allows for the prediction of the performance of a wide variety of pavement structures, in terms of pavement distresses. For flexible pavements, these distresses include the International Roughness Index (IRI), the permanent deformation/rutting of the different pavement layers, the bottom-up and top-down fatigue cracking as well as the thermal cracking. Similarly, Pavement ME can be used for modelling the performance of rigid pavements and overlays including AC overlay over existing flexible and rigid pavements [26].

AASHTOWare Pavement ME requires detailed inputs related to the climatic conditions, traffic characteristics and material properties. The traffic data include, but are not limited to, the Average Annual Daily Truck Traffic (AADTT), the operational speed, the percentage of each truck type among the AADTT, known as the Vehicle

Class Distribution VCD, and the truck loading conditions represented by an Axle Load Distribution. For the AC layer, the main input parameters required by Pavement are the layer thickness, the mix volumetrics (air void content and effective binder content) and the mechanical properties, represented by the aggregate gradation and PG grade for level 3 analysis [26].

Furthermore, the mechanistic-empirical design process, offered by the AASHTOWare Pavement ME, represents an advanced tool for pavement design and performance prediction over the former empirical design procedures, such as the AASHTO 1993, as it uses the theories of mechanics to calculate the stresses and strains developed in the pavement due to the combined effect of traffic loading and climatic conditions, according to the user-defined material properties. Then, the computed stresses and strains are converted into an accumulated pavement damage, over the pavement's design life; consequently, transfer functions are utilized to predict the pavement distresses, such as roughness, fatigue cracking and rutting, based on the previously determined pavement damage [26][27].

This study makes use of this powerful tool to predict the performance of flexible pavements and AC overlays when critical changes in the project characteristics are encountered. These changes are related to 1) the quality of the pavement construction in terms of the compliance with the standard specifications related to the asphalt mix volumetrics and the AC layer thickness and 2) the traffic characteristics related to truck loading and configurations and traffic volumes.

5.1.2. Input Parameters

In the present study, the proposed methodologies are applied to various pavement structures, subject to different climatic and traffic conditions. The choice of the AASHTOWare Pavement ME input parameters is based on data collected from the literature. Chatti et al. [54] investigated the effect of heavy trucks on the damage of flexible pavements with thick (> 6 to around 10 inches) and relatively thinner (≤ 6 inches) asphalt concrete (AC) layer.

Attia and Ahmed [55] studied the impact of vehicle class and tire pressure on the performance of flexible pavements using the Mechanistic-Empirical Pavement Design Guide (Pavement ME) considering thin and thick pavements. For thin pavements (2 in AC layer), the Annual Average Daily Truck Traffic AADTT was assigned two values, 1000 and 4000. For thick pavements (6 in AC layer), the AADTT was assigned a range of 7000 to 14000. For all performed software runs, the default Vehicle Class Distribution (VCD) was considered. Note that the "vehicle class distribution" represents the percentage of each truck type among all trucks [55].

Similarly, Al-Qadi et al. [56] considered thin and thick flexible pavement structures with strong and weak material properties obtained from the Federal Highway Administration (FHWA)'s Long-Term Pavement Performance (LTPP) program. Thick structures included 11 in thick AC layers, with a maximum speed limit of 70 mph, while thin ones consisted of a 4 in thick AC layer and maximum speed of 40 mph. Three temperature profiles (122, 68, and 18 °F) were adopted [56].

A 4 in thick AC layer over a 12 in base was tested by Wu and Harvey [57] under channelized traffic to study the impact of wheel wander on rutting.

Based on the traffic highway information collected by the FHWA across the United States, the ADTT (average daily truck traffic) ranges between 1000 and 7000 [58].

Table 1 provides the main input parameters for the Pavement ME Pavement runs. The data in bold correspond to the reference pavement structure. Note that for a PPP highway project, high traffic volumes are expected, accordingly, thick pavement layers and high quality materials are chosen, as to ensure a satisfying performance of the pavement.

The three climatic stations chosen, Virginia, Montana and Texas, represent moderate, cold and hot climates with a mean annual air temperature of 53.8, 46.7 and 70.5 °F respectively. Runs for strong and relatively weaker pavement materials are conducted, as well as different layers thicknesses. The 25 mph operational speed corresponds to the deceleration areas before reaching toll booths.

Table 1 Pavement ME Input Parameters

<table>
<tr><th colspan="2">Input</th><th>Value/Characteristic</th></tr>
<tr><td colspan="2">Pavement type</td><td>New asphalt-concrete (AC) pavement</td></tr>
<tr><td colspan="2">Design life</td><td>30 years</td></tr>
<tr><td rowspan="2">Traffic data</td><td>Annual Average Daily Truck Traffic AADTT</td><td>4,000 – 5,000</td></tr>
<tr><td>Operational Speed</td><td>60 mph – 25 mph</td></tr>
<tr><td rowspan="4">AC layer properties</td><td>AC layer thickness</td><td>8 in – 7 in</td></tr>
<tr><td>PG grade</td><td>PG 76-22 – PG 88-22</td></tr>
<tr><td>Air voids</td><td>7% (default)</td></tr>
<tr><td>Effective Binder Content</td><td>11.6% (default)</td></tr>
<tr><td rowspan="2">Base layer</td><td>Base thickness</td><td>12 in – 15 in</td></tr>
<tr><td>Base type</td><td>A-1-a – A-2-4</td></tr>
<tr><td colspan="2">Subgrade type</td><td>A-1-a – A-3</td></tr>
<tr><td colspan="2">Climate station</td><td>ROANOKE, Virginia
GREAT FALLS, Montana</td></tr>
</table>

	SAN ANTONIO, Texas
Calibration factors	National

The default Vehicle Class Distribution represents the percentage of each truck class among all trucks and is shown in Table 2.

Table 2 Default Vehicle Class Distribution in AASHTOWare Pavement ME [26]

Vehicle Class	% 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
Total	100

Note that the input data related to the AC volumetrics i.e. air void content and effective binder content, AC layer thickness as well as those related to the traffic characteristics, such as the truck traffic counts (AADTT), truck loading and vehicle class distribution are varied in subsequent sections of the study and are addressed in details when needed.

5.1.3. Analysis of AC overlays in Pavement ME

This study uses the AASHTOWare Pavement ME to model the performance of AC overlays of existing asphalt pavement to accurately determine the service life of these overlays when applied to different pavement structures under varying traffic and climatic conditions.

Three levels of analyses are offered by Pavement ME. For the level 1 analysis, the user must specify 1) the milled thickness from the existing AC layer, 2) the amount and severity of transverse cracking (in ft/mile) observed prior to the overlay placement and 3) the rut depths for each pavement layer prior to the overlay placement. Level 2 analysis requires the same inputs as Level 1 in addition to the amount and severity of fatigue cracking observed prior to the overlay placement. Finally, level 3 analysis is based on a rating of the existing pavement condition (good, fair, poor) and the total rut depth reached before placing the overlay. Level 2 analysis is selected for this study and the distresses values (rut depths, fatigue cracking and transverse cracking) reached at the time of maintenance i.e. overlay placement are obtained from the output of the Pavement ME modeling of the initial pavement.

The same distresses predicted by Pavement ME for flexible pavements (IRI, permanent deformation, bottom-up, top-down and transverse cracking) are predicted for the flexible pavement with the AC overlay, in addition to the reflective cracking propagating from the existing AC layer to the overlay [26].

Throughout this study, a heavy maintenance activity, in which the top 5 in of the existing AC layer are milled, then a 5 in asphalt overlay is placed, is considered.

5.2. RealCost

5.2.1. Overview

RealCost is a tool used for Life-Cycle Cost Analysis (LCCA) of roadway transportation projects. The LCCA is generally used to compare between the life cycle costs of different alternatives, represented by varying construction and maintenance works. RealCost allows for the estimation of both the agency and user costs [28]. The agency costs are those related to the construction and maintenance activities, while user costs include the vehicle operating costs, travel time and crashes. Both expenditures are affected by the timing, duration and number of construction and maintenance activities conducted during the service life of the facility [59].

RealCost requires different types of inputs, including, but not limited to, 1) the time value of users, 2) the analysis period, 3) the discount rate used for reverting future expenses to the present value, 4) the traffic data, such as the Annual Average daily traffic (AADT), the percentages of passenger cars, single unit trucks and combination trucks among the AADT, the annual growth of traffic, the speed limit and the number of lanes during normal operating conditions and more importantly 5) the construction and maintenance works for each alternative, including the cost and the service life of each activity, the work zone duration and length, the work zone speed limit and the number of lanes open during work zone [28].

RealCost provides the agency and user costs for each alternative in three forms: 1) an undiscounted form, 2) present value and 3) EUAC = equivalent uniform annual cost. An expenditure stream also shows the timeline of the different activities manifested for each alternative as well as the corresponding agency cost and user cost. The remaining life values are also provided if the user chooses to include them in the analysis [28].

Different types of inputs are required for conducting the life-cycle cost analysis using RealCost.

5.2.2. Input Parameters

5.2.2.1. Economic Variables

These include the time values for the different vehicle types, and are left as the default values pre-defined in the software: 13.96, 22.34 and 26.89 $/hour for passenger cars, single unit trucks and combination trucks respectively [28].

5.2.2.2. Analysis Options

Both agency costs and user costs, as well as the remaining service life values, are determined by the software. The analysis period is 30 years, as to match the Pavement ME inputs. A 12% discount rate is considered throughout this study [60].

Finally, the number of alternatives will be determined in each chapter based on the conducted analysis.

5.2.2.3. Traffic Data

The traffic data are determined as to match the Pavement ME inputs. In Pavement ME, the annual average daily truck traffic (AADTT) is considered to be 4,000. In RealCost, the user is asked to define the annual average daily traffic (AADT) which includes the counts of all vehicle types (cars and trucks), along with the proportion of each vehicle type (passenger cars, single unit trucks and combination trucks) as a percentage of the AADT.

The AADT was taken equal to 20,000 vehicles per day, among which 2,000 are trucks. Thus, the percentage of trucks (single unit and combination) is 20% of the AADT and the percentage of cars is 80% of the AADT.

Among the 4,000 trucks, 20.5% are single unit trucks (classes 4, 5, 6, 7 and 8) and the remaining 79.5% are combination trucks (classes 9, 10, 11, 12 and 13). These percentages are calculated based on the vehicle class distribution adopted in this study and shown in Table 2. Accordingly, knowing that trucks (AADTT) represent 20% of the AADT, then the percentage of single unit trucks is (20.5 x 20)/100 = 4.1% of the AADT while the percentage of combination trucks is (79.5 x 20)/100 = 15.9% of the AADT.

Briefly, the percentages of passenger cars, single unit trucks and combination trucks are 80%, 4.1% and 15.9% of the AADT, respectively.

Note that these same percentages are used for determining the RealCost traffic data when the AADTT is Pavement ME is varied.

More specifically, when the AADTT is increased to 5,000 instead of 4,000: The AADT is therefore calculated as to have the percentage of trucks equal to 20% of the AADT. Accordingly, the AADT is (100 x 5000)/20 = 25,000. The same vehicle class distribution is considered, meaning that the single unit trucks and combination trucks still represent 20.5% and 79.5% of the AADTT respectively. The detailed traffic data for RealCost are presented in Table 3.

Table 3 Traffic Data for RealCost

Scenario	**AADTT (truck counts) in Pavement ME is 4,000**	**AADTT (truck counts) in Pavement ME is 5,000**
AADT (traffic counts including trucks and cars)	20,000	25,000
% of trucks of the AADT	20%	20%
% of passenger cars of the AADT	80%	80%

% of single unit trucks of the AADTT	20.5%	20.5%
% of single unit trucks of the AADT	4.1%	4.1%
% of combination trucks of the AADTT	79.5%	79.5%
% of combination trucks of the AADT	15.9%	15.9%

The speed limit under normal operation condition is 60 mph or 25 mph, based on the corresponding Pavement ME scenario. The number of lanes in each direction during normal conditions is 3 lanes.

5.2.3.4. Construction and Maintenance Works Inputs

The LCCA requires an estimation of the pavement's construction and maintenance costs.

The costs of the construction of the different pavement layers are estimated based on the following unit prices. The asphalt concrete placement costs between 85 and $150 per ton and each 1 cubic foot of asphalt weighs 145 pounds (0.0725 tons) [61]. The volume of asphalt is first determined knowing the thickness of the AC layer and the section dimensions, then the quantity of the asphalt needed, in tons, is calculated to finally estimate the cost of placement of the asphalt concrete layer, assuming a unit price of $150 per ton. Furthermore, the cost of the asphalt increases for higher performance mixes. For instance, for a PG 82-22, the cost increases by 10%, compared to the cost of a PG 76-22 [61]. The base layer costs 5, 8.8 and $11.3 per square yard for a thickness of 4, 6 and 10 in respectively [62]. Accordingly, a 12 in base costs $12.55 per square yard. The earthwork operations are estimated as to contribute to about 25% of the total road construction [63][64]. Finally the detailed design and supervision costs are estimated as 15% of the total construction cost [65][66].

Note that the construction costs for the different scenarios are estimated for 1 lane-km (1 km = 0.62 miles) and is modified when different layers thicknesses and material types are considered, as shown in Table 4. The different climatic conditions and traffic characteristics are not considered to affect the pavement construction cost. Note that the cost is estimated per lane-km as to meet the input requirements of the World Bank's financial model, as explained later in section 5.3.

Table 4 Pavement Construction Costs

Scenario	Pavement Construction Cost (1000$ per lane-km)
Reference Pavement Structure	497.81
7 in AC layer	446.10
PG 82-22	539.17
15 in Base layer	510.38

Similarly, the cost of the overlay placement is assessed based on the following unit prices: milling 2 inches of asphalt concrete costs $1.5 per square yard, while the milling of 4 inches costs $2.5 per square yard. An asphalt concrete overlay is priced at $8 per square yard and $16 per square yard for a thickness of 2 in and 4 in respectively [67]. Accordingly, milling 5 inches costs $3.11 per square yard and placing a 5 inches asphalt overlay costs $20 per square yard. Finally, the cost of the heavy maintenance considered throughout this study is $101,093 per lane-km.

In addition to the costs of the pavement's construction and overlay placement, the number of maintenance activities (in this study, overlays placement), required throughout the service life of the pavement (30 years), must be specified. The number of maintenance works is project specific and is determined for each pavement structure, and for each scenario - considering different project characteristics related 1) to the quality of pavement construction and 2) traffic data - based on the service lives of the initial pavement and of the overlay, predicted using AASHTOWare Pavement ME.

The work zone duration for the placement of the overlay (10 days) and the work zone speed limit (40 mph) were chosen based on a demonstration example of the LCCA of an AC pavement provided in the RealCost user manual [28]. Note that for the initial pavement construction, there will be no traffic; accordingly, no user cost shall be assigned for this activity. Consequently, the work zone duration for the initial construction was considered to be zero. In such case, the initial construction expenditures would only be considered in the assessment of the agency cost [28].

5.3. World Bank's Financial Model

The World Bank provides an Excel-based numerical model specifically designed for the financial analysis of PPP road projects [29]. The use of such model is of significant use when complex risks such as traffic volume risk are addressed. The reference pavement structure described in section 5.1 is taken as a case study.

5.3.1. Financial Model's Input Parameters

The financial model requires detailed inputs categorized as follows [4][29].

5.3.1.1. General and Construction

In this category, the concession period, important dates and construction data are provided [4][29]. For the considered case study, the study year is set to 2020. A 30-year concession period, among which the first 3 years are for construction works, is adopted as to match the AASHTOWare Pavement ME and RealCost inputs. The operation period starts in 2023.

The construction cost per km is required. Based on section 5.2.3.4, the construction of the reference pavement costs $497,810 per lane-km. considering a 6-lanes highway (3 lanes in each direction as considered for AASHTOWare Pavement ME and RealCost), the construction cost per km is $2,986,860, approximately 3 million USD per km. A total length of 150 km is considered, resulting in a total construction cost of 450 million USD.

5.3.1.2. Traffic, Toll and Other Revenues

The project's cash inflow is determined based on generated toll revenues as well as other types of revenues directly specified by the user. An indexation rate (which is an escalation rate) is used for adjusting tolls and revenues [4][29].

The input traffic data are based on the reference pavement case, with an initial daily traffic of 20,000, among which 16,000 are cars and 4,000 are trucks, and a 3% linear annual growth of traffic. Common toll levels in the U.S. (0.10 and 0.12 USD/km for cars and trucks respectively) are adopted as to maintain their compatibility with the construction and maintenance costs, which were also estimated based on the U.S. unit prices [68].

The only source of revenues is considered to be the tolls charged to road users; accordingly, other revenues are set to be zero.

The indexation (adjustment) of tolls and revenues is 2%, which is the default value of the model.

5.3.1.3. Recurrent Costs

Under this category, data necessary to estimate the project's cash outflow are entered. These are constituted of: 1) the concessionaire costs; these cover the concession management expenses, 2) the operation costs; these include mainly the personnel costs, administration costs and toll collection costs, 3) the cost and frequency of a recurrent heavy maintenance and 4) the yearly cost of light maintenance activities [4].

The concessionaire and operation costs are estimated as a percentage of the construction cost, based on reviewed PPP road case studies from literature. Based on a case study by the World Bank, a yearly concessionaire cost of 2 million USD and a yearly operation cost of 6 million USD are estimated for a project having a 687.5 million USD initial construction cost. Accordingly, the concessionaire cost and the operation cost correspond to 0.30% and 0.87% of the initial construction cost respectively [4]. Another study by Chen and Subprasom valued the operation cost at 1.13 million USD for a project construction cost of 138.55 million USD, corresponding to 0.82% of the construction cost [60]. Zhang et al. adopted an operation cost equal to 0.42% of the initial construction cost [69]. Accordingly, for the present case study, with an initial construction cost of 450 million USD, the concessionaire cost and the operation costs were valued at 0.3% and 0.9% of the initial construction cost respectively.

The heavy maintenance activity considered herein is the same thick overlay (milling 5 in and overlaying 5 in) described in section 5.2.3.4. This maintenance activity costs $101,093 per lane-km, corresponding to 20% of the initial construction cost ($497,810 per lane-km). In this context, it should be noted that a heavy maintenance cost equal to 20% of the initial construction cost is compliant with the literature [7][70]. The frequency of this heavy maintenance is determined based on the AASHTOWare Pavement ME pavement performance modeling in subsequent sections of the study.

The yearly light maintenance cost ranges between 0 and 5% of the initial construction cost [4][29]. An average value of 2.5% of the initial construction cost is adopted.

5.3.1.4. Financial Structure

The financial structure of the PPP road project comprises three sources of financing: equity, debt and highway agency's subsidy.

An important feature of the model is the possibility of setting the highway agency's subsidy either as an input (directly specified by the user) or an output. In the latter case, the model determines the needed subsidy for the concessionaire to meet an annual debt service cover ratio (ADSCR) defined by the user. The ADSCR measures the ability of the concessionaire to cover their debt for any operating year "i" [4][29].

$$\text{ADSCRi} = \frac{CBDSi}{DSi} \quad \text{(Eq. 1) [4]}$$

CBDSi is the net cash flow before debt service at year "i", which is equal to the amount of cash remaining in the project company after having paid the operation costs and taxes.

DS_i is the debt service remaining at year i (principal and interests) [4][29].

In this study, the subsidy is set to be determined by the model as to achieve an ADSCR of 1.3 (default model value).

Furthermore, a 40/60 equity/debt ratio is adopted [33].

5.3.1.5. Depreciation

Depreciation is applied to project assets (i.e. construction costs) as well as capitalized interest during the construction period for the three tranches of debt over the operation period. Three depreciation types are available: linear, decreasing and progressive. For simplicity, a linear depreciation is selected for this study, meaning that the total amount of assets and capitalized interests at the end of the construction period is depreciated annually by the same amount until the end of the concession period [4][29].

5.3.1.5. Taxation and Inflation

The model considers two main type of taxes, corporate taxes (tax on profit) and VAT taxes. The user can also define a third type of taxes if applicable. The inflation rate is the escalation rate used for adjusting costs [4][29]. The model's default values are adopted, equaling to a 30% corporate tax rate, 19.6% VAT rate and 2% inflation rate.

5.3.1.6. Private Partner

The minimum values of the project's internal rate of return (IRR) and equity IRR (in nominal terms and in real terms) are used for the assessment of the concessionaire's cash flow [4][29].

The project's IRR represents the financial return of the project regardless of the financial structure, and is calculated based on the following equation:

$\sum (Ri- Ii – Ci)/ (1+r)^{i} = 0$ (Eq. 2) [4]

Ri are the operating revenues at year "i".

Ii is the amount invested in year "i".

C_i are the operating costs at year “i".

“r” is the project’s IRR.

The equity IRR (or return on equity) represents the yield of the project for shareholders, and is determined based on the remuneration of their investment through dividends:

$\sum (D_i - I_i)/ (1+r)^{i} = 0$ (Eq. 3) [4].

D_i is the dividend at year “i".

I_i is the amount invested by shareholders in year “i".

“r” is the equity IRR.

Note that the dividend at year “i” represents the cash available for distribution at year “i” after servicing debt and paying all the required operation costs and taxes [4][29].

The nominal value of any parameter P (which can be the project IRR, the equity IRR, the highway agency’s discount rate) is calculated based on its real value and the inflation rate, as follows:

P nominal = P real + inflation rate at the year of study + (P real)*(inflation rate at the year of study) (Eq. 4) [4].

A 15% minimum equity IRR in real terms is specified, which corresponds to a 17.3% minimum equity IRR in nominal terms [4], knowing that the inflation rate is set at 2%.

The minimum project IRR in real terms is set as 9.8%, in order to obtain a 12% minimum project IRR in nominal terms. This can be explained by the fact that the model uses the minimum project IRR in nominal terms as the discount rate for assessing the present values of the concessionaire’s cash flow [4][29]. A 12% IRR is chosen as to match the 12% discount rate used for RealCost. Furthermore, an IRR of 12% is a common value used in literature for PPP road projects [14][35][60].

5.3.1.7. Public Authority

The present value of highway agency's cash flow is estimated based on a user-defined discount rate. The default value of 8% (in real terms) pre-defined in the model is considered. Note that the highway agency's cash inflow mainly includes the taxes collected from the concessionaire, while their outflow corresponds to the subsidy provided to the concessionaire [4][29].

5.3.2. Financial Model's Output

From the concessionaire's perspective, the financial model assesses the project IRR, the equity IRR, the investment pay-back period, the project net present value (NPV) and the dividends, at the end of the concession period. Similarly, the present value of the highway agency's return is provided. This comprises the subsidy paid to the concessionaire in addition to the taxes collected from the concessionaire. Note that detailed the full project cash flows are provided for each year of the concession period. These include the yearly operating revenues, operating costs, taxes, debt service, subsidies, net profit and dividends [4][29].

CHAPTER 6

NON-COMPLIANCE WITH STANDARD CONSTRUCTION SPECIFICATIONS IN PPP ROAD PROJECTS

6.1. Introduction

The contractor, in any road construction project, is required to meet the Standard Construction Specifications related to all aspects of hot mix asphalt production and placement. These specifications include, among others, target values and tolerances for the asphalt mix (AC) volumetrics (percentage of air voids and binder) as well as the layers thicknesses [71]. Thinner AC layers and/or higher than target air void and binder contents in the AC mix result in an accelerated deterioration of the pavement, and consequently a recurrent need for maintenance works. This leads to an increased life-cycle cost, in terms of both the agency cost and the user cost [7].

In conventional road procurement strategies, highway agencies adopt a "pay-adjustment factor", representing a percentage to be deducted from the contractor's compensation payment, in case the latter commits certain construction errors that are likely to affect the pavement performance, and consequently, its service life [6]. In the extreme case of a defective construction, the owner/general contractor has the right to order the general contractor/subcontractor to remove, replace or repair the defective road section, based on the terms of the general contract/subcontract [72]. Currently adopted methodologies for estimating pay-factors consider only the increase in agency cost resulting from the non-compliant pavement construction and the first rehabilitation/heavy maintenance activity [7][8].

In PPP road projects, the non-compliance of the construction subcontractor with the standard construction specifications will directly impact the concessionaire who will be operating and maintaining the road facility throughout the concession period. Furthermore, even if the highway agency in PPP road projects is not directly concerned with the construction errors committed by the construction contractor, these errors will inevitably affect 1) the performance of the pavement throughout the concession period and 2) the quality of the pavement at hand back, both constituting major concerns for the highway agency. Accordingly, both PPP partners must agree on a procedure for accurately determining the pay factor. This requires considering all maintenance activities to be performed throughout the concession period and including the increased user cost in the estimation of the pay factor.

This chapter investigates the effect of a non-compliant pavement construction on the pavement's life-cycle cost. Three characteristics of the asphalt-concrete are addresses: 1) the air voids percentage, 2) the binder content and 3) the thickness of the AC layer. Then, a methodology is presented to assess the value of the pay factor to be applied in case of an out-of-specs pavement construction, considering the increase in both the agency and user costs resulting from all heavy maintenance activities performed throughout the concession period. The steps followed for the pay-factor assessment are illustrated in Figure 4.

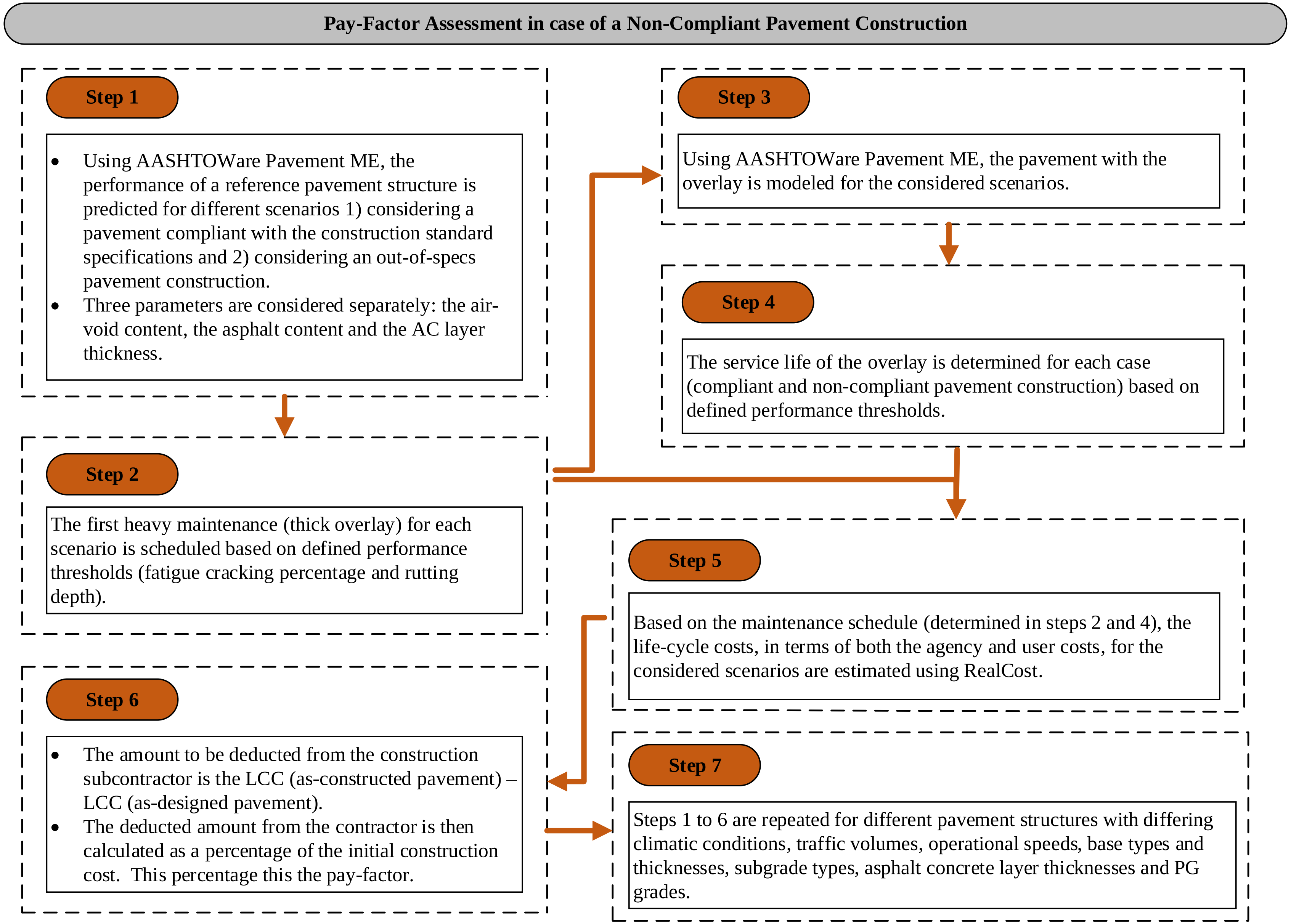

Figure 4 Pay-Factor Assessment Method

6.2. Literature Review

6.2.1. Review of the Standard Construction Specifications of some States in the U.S

Table 5 provides the target air voids percentage and density of the AC mix as well as the acceptable tolerances adopted by some states in the U.S. Furthrermore,

Table 6 summarizes some of the U.S. states requirements regarding the binder content by weight of the AC mix, and the percentage of voids in mineral aggregates. The voids in mineral aggregates VMA includes the volume of air voids plus the effective binder content. Note that part of the amount of binder added to the asphalt mix is absorbed by the aggregates while the remaining is responsible for coating and binding the aggregates. The latter (unabsorbed binder) is referred to as the effective binder content [73]. In AASHTOWare Pavement ME, the user must specify the effective binder content in the AC mix rather than the total binder content [26].

Table 5 Standard Construction Specifications related to the AC Compaction in some states in the U.S.

State	Specifications related to the air voids percentage in the asphalt mix	Specifications related to the density of the asphalt mix
North Carolina [74]	Based on the mix type, the % air voids varies from 3 to 6% Tolerance ± 2.0%	Based on the mix type, the density varies from 90 to 91.5% Tolerance +2.0%
California [75]	Target air voids 7% Tolerance ± 1.0%	91 to 97%
Texas [76]	In place air voids from 5 to 9% Tolerance ± 1.0%	Based on the mix type, density varies from 89% to 96%
West Virginia [77]		92 to 96%
Pennsylvania [78]	Target ± 2.0%	90 to 97%
Arizona [79]	In-place air-voids: Target value 7% Upper limit 9%	NA

	Lower limit 4% Tolerance: Target value – 2.0% or +1.5%	
Florida [50]	2.3 to 6%	Minimum 89.5% Target density is 93%

Table 6 Standard Construction Specifications related to Percentages of Binder and Voids in Mineral Aggregates in the AC Mix in some states in the U.S.

State	Specifications related to the binder content by weight of total mix	Specifications related to the voids in mineral aggregate (VMA)
North Carolina [74]	Based on the mix type, 4.5 to 7 % Tolerance ± 0.7%	Based on mix type 12.5 to 16 % Tolerance - 1.0%
California [75]	Target ± 0.2%	Based on mix type 12.5 to 18.5 %
Texas [76]	6.5 to 11 % Tolerance ± 0.3%	11 to 15%
Pennsylvania [78]	Based on gradation 19 mm and smaller: ± 0.7% 25 mm and larger ± 0.8%	Based on gradation, minimum VMA varies from 11 to 16%
Arizona [79]	Target value ± 0.5%	Based on mix type, 14.5 to 18%
Florida [50]	Target ± 0.55%	NA

6.2.2. Effect of AC Mix Volumetrics on Flexible Pavement Performance

The air void content in an AC mix is directly related to its density. A high density, or low air voids content, reduces the permeability of the pavement, and might lead to flushing, meaning that the excess asphalt binder squeezes out of the mix to pavement’s surface. On the other side, a high air voids content allows the penetration of damaging air and water [73].

The performance of flexible pavements is significantly affected by the content of air voids in the AC mix, especially in terms of fatigue properties. In fact, laboratory investigations revealed that each one percent increase in air voids might lead to a 35 percent decrease in the fatigue life of flexible pavements [80][81].

Another study by the AAPA (Australian Asphalt Pavement Association) indicated that the density of AC mixtures affect the pavement's rutting, fatigue life, structural strength, permeability and raveling. A low air voids percentage (less than 2%), meaning that reduces the pavement's resistance rutting. Furthermore, fatigue testing of two similar mixes, one compacted to 5% air voids while the other to 8% air voids, showed a 50% reduction in fatigue life and 20% reduction in stiffness, or load carrying capacity with the increased air voids content [82].

The asphalt/binder content should be adequately controlled during preparation of the AC mix. The rutting characteristics of AC mixes are significantly affected by the binder content [83]. In fact, rutting of flexible pavements is attributed to one or both of the following reasons: 1) the poor aggregate interlock which is influenced by the angularity and roughness of the aggregates used in the AC mix and 2) the poor bonding related to the amount of binder responsible for coating and binding the aggregates in the AC mix [84]. An increased binder content softens the AC mix, thus increasing its rutting susceptibility. Contrarily, increasing the binder content improves the mix's resistance to fatigue cracking [85]. In the following section, a review of pay-adjustment factor assessment methods is conducted.

6.2.3. Pay-adjustment Factors

The method for determining pay-adjustment factors varies from one agency to another. While some agencies rely on experience for pay factors assessment, others relate the deduction in payment to the reduction in the pavement serviceability caused by the construction defect. Furthermore, pay-adjustment factors differ based on the subject construction parameter; they are mainly adopted for construction errors related to 1) density of the asphalt concrete mix, 2) the asphalt concrete volumetrics, 3) the aggregate gradation and 4) the pavement thickness, and 5) the pavement smoothness [6].

A report prepared for the California Department of Transportation correlated the pay-adjustment factors to the estimated reduction in the pavement performance measured in terms of fatigue cracking and rutting. Fatigue cracking was predicted using the performance model resulting from the CAL/APT program while rutting prediction was based on the performance model deriving from the WesTrack accelerated pavement test program. The pay-factors for higher-than-target air void content considered both distress types, fatigue cracking and rutting. As for the AC layer thickness, the decline in fatigue performance was solely considered for the pay-factor assessment. Finally, for higher-than-target binder content, rutting was the main factor influencing the value of the pay-factor. Note that the controversial effect of low binder content values, in terms of improving the mix’s rutting performance while accelerating the development of fatigue cracks was not considered to require any penalty or bonus. The cost model adopted for pay-factor assessment considered only the time for the first rehabilitation activity. The rehabilitation costs were estimated as follows: 1) rutting failures requiring a resurfacing activity priced at 20% of the cost of new pavement construction and 2) fatigue cracking failure requiring a rehabilitation priced at 50% of the cost of new pavement construction. Pay-factors were assessed based on a 20-year pavement life and only agency costs were included in the analysis. The authors suggested that an enhancement of the estimated pay-factors might be achieved through 1) the incorporation of the user cost in the cost model, 2) the consideration of all rehabilitation activities throughout the pavement life, 3) the inclusion of the ride quality as a pavement performance index and 4) the inclusion of rigid pavements in the analysis [8].

Popescu and Monismith [7] developed a procedure for the assessment of pay-adjustment factors imposed in the case of the delivery of an out-of-specs flexible pavement construction. Fatigue cracking and rutting models, based on a combination of 1) mechanistic-empirical pavement performance analysis, 2) laboratory testing of AC performance and 3) full-scale accelerated pavement testing with varying mix variables, were considered. Fatigue performance was related to the air-void content and asphalt content in the AC mix, as well as the AC layer thickness. Rutting performance was based on the air-void content, asphalt content and aggregate gradation. Only agency cost was included on the analysis, and the pavement target lives were 10 and 20 years. The first rehabilitation activity was solely considered for the analysis, valued at 50% of the cost of new pavement construction for both distress types [7].

As stated previously, the pay-adjustment factor in this study is determined considering all heavy maintenance activities throughout the pavement service life and including both the agency and user costs. The pay-factor is therefore valued as the difference between the life-cycle costs (net present values) of the as-designed and the as-constructed pavement [7][9].

6.3. Deficiency in Air-Void Content in the Asphalt Mix

6.3.1. Pavement Performance Prediction using AASHTOWare Pavement ME

The as-constructed air voids percentage of the overall volume AC mix is directly input in the AASHTOWare Pavement ME [26].

6.3.1.1. AASHTOWare Pavement ME Inputs

The AASHTOWare Pavement ME input parameters are provided in Chapter 5, section 5.1. For the present section, only the air void content is varied. The target as-constructed air voids percentage is considered to be 7%. The performance of each pavement structure is predicted using AASHTOWare Pavement ME for the following 3 cases: 1) 7% air voids, 2) 8% air voids and 3) 9% air voids.

6.3.1.2. AASHTOWare Pavement ME Outputs

The performance of the reference pavement, in terms of IRI (International Roughness Index), rutting and fatigue cracking, for the three considered air voids content, are shown in Figure 5 to Figure 10. The percent total cracking is calculated by converting the predicted top-down cracking from ft/mile to percentage and then adding the obtained percent top-down cracking to the predicted percent bottom-up cracking.

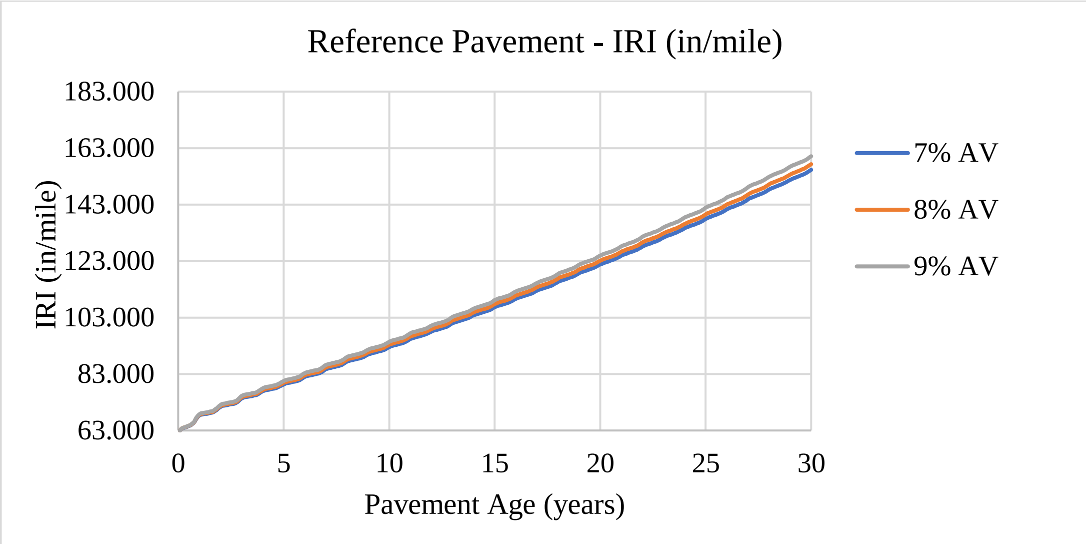

Figure 5 Predicted IRI for the Reference Pavement Structure for 7%, 8% and 9% Air Voids in the AC Mix

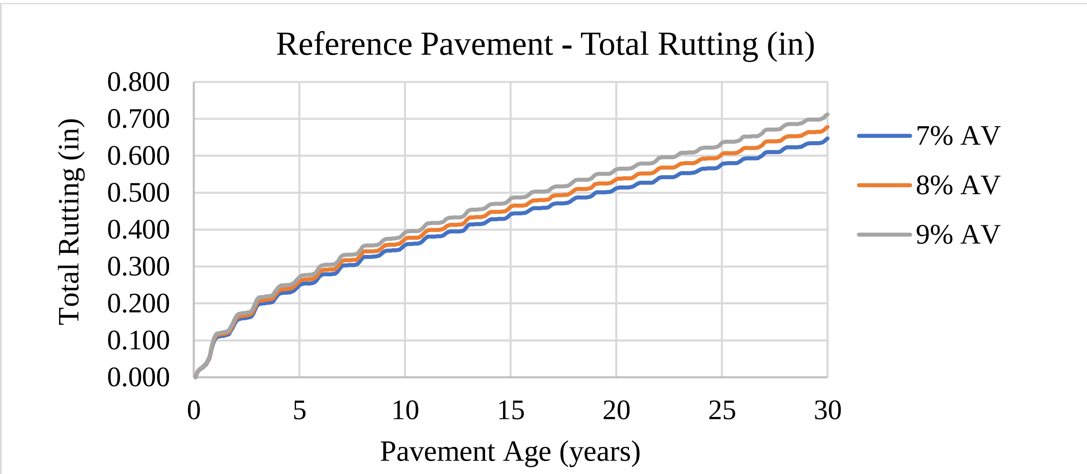

Figure 6 Predicted Total Rutting for the Reference Pavement Structure for 7%, 8% and 9% Air Voids in the AC Mix

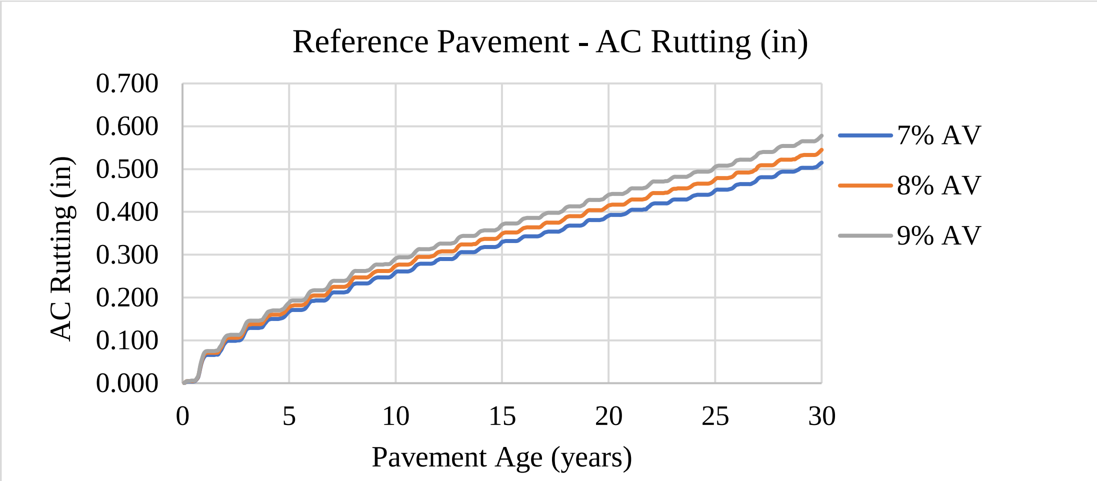

Figure 7 Predicted AC Rutting for the Reference Pavement Structure for 7%, 8% and 9% Air Voids in the AC Mix

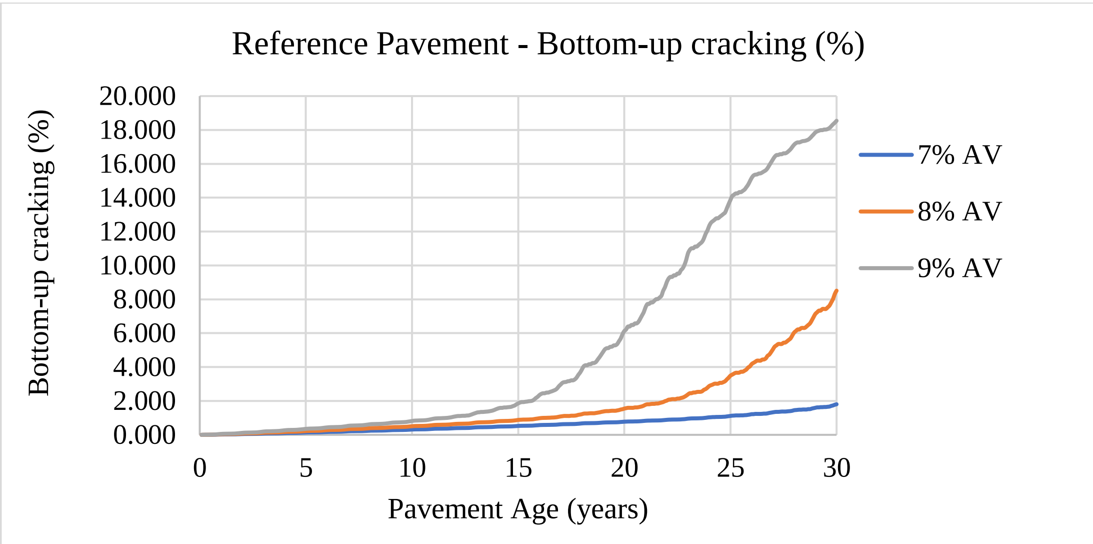

Figure 8 Predicted Bottom-up Cracking for the Reference Pavement Structure for 7%, 8% and 9% Air Voids in the AC Mix

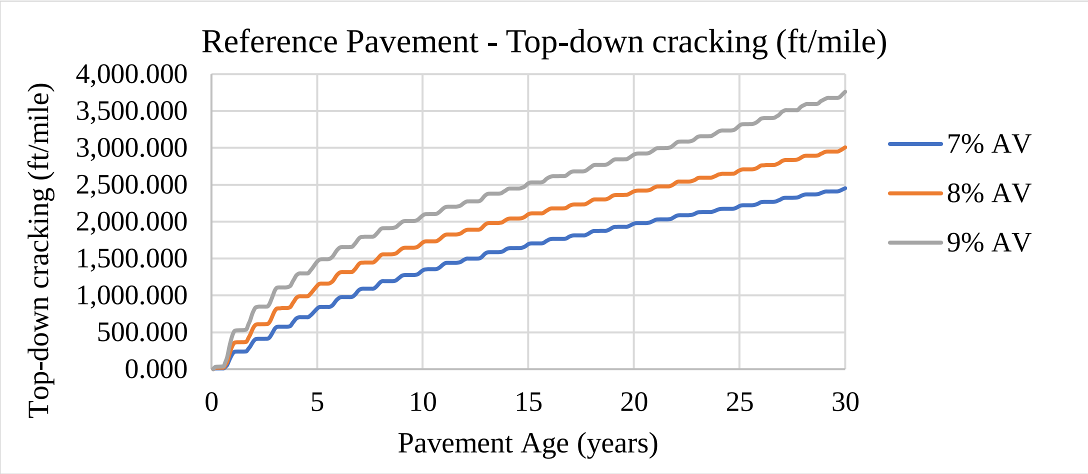

Figure 9 Predicted Top-down Cracking for the Reference Pavement Structure for 7%, 8% and 9% Air Voids in the AC Mix

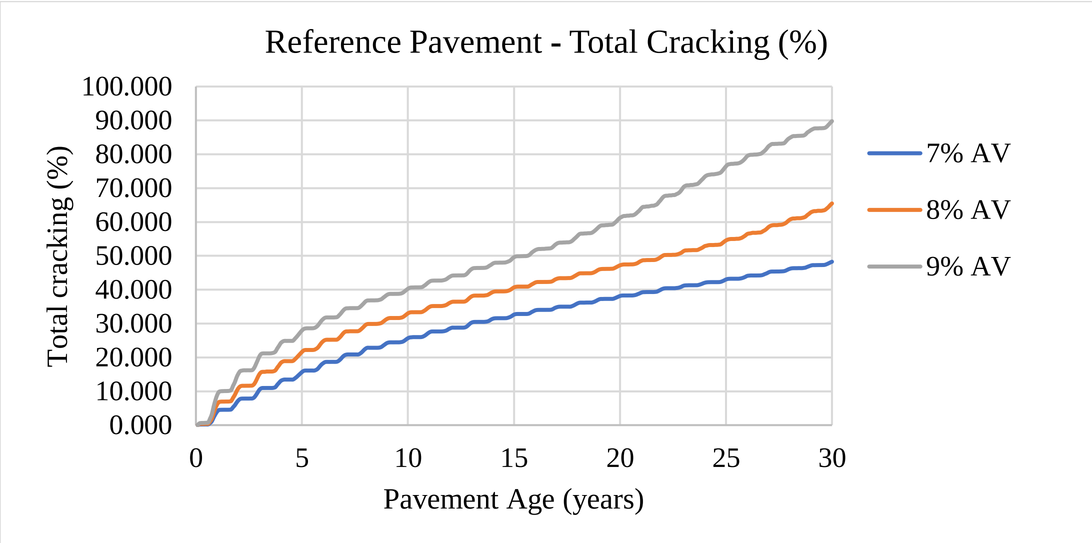

Figure 10 Total Cracking for the Reference Pavement Structure for 7%, 8% and 9% Air Voids in the AC Mix

A significant change in the predicted cracking is noticed for the varying percentage of air voids in the asphalt concrete mix. Conversely, the predicted IRI and rutting (total rutting and AC rutting) show minimal difference between the three considered cases.

6.3.1.3. Modeling Overlays in AASHTOWare Pavement ME

As observed in Figure 10, for the case of a compliant pavement construction with the specifications (7% air voids), 25% total cracking is reached after 10 years, while for the cases of 8% and 9% air voids, 25% total cracking is reached respectively after 6 years and 4.5 years. Note that the total rut depth at 25% total rutting is 0.35 in, 0.3 in and 0.25 in respectively for the three considered cases (7, 8 and 9% air void content) which is still lower than the 0.4 in total rut threshold [49]. In other words, for the considered case study, the threshold for cracking is reached before that for rutting, and the maintenance is scheduled accordingly.

In this section, a heavy maintenance (thick overlay) is considered to be conducted when the total cracking reaches 25%. As explained in chapter 3, the service life of an overlay depends on several factors. Accordingly, the AASHTOWare Pavement ME is used to model the performance of a 5 inches overlay placed on top of each pavement considered in section 6.3.1.2. The same inputs used for modeling the initial pavement, in terms of traffic, climate, base and subgrade data, are used for the overlays modeling. The additional required inputs for modeling the overlay are shown in Table 7.

Table 7 Input Parameters for Overlay Modeling for the Reference Pavement Structure considering three Air Voids Percentages (7%, 8% and 9%)

	Input Parameter	**Case 1**	**Case 2**	**Case 3**
Existing AC layer	Milled thickness	5 in	5 in	5 in
	Remaining layer thickness	3 in	3 in	3 in
	Air voids %	**7%**	**8%**	**9%**
AC Overlay	Overlay thickness	5 in	5 in	5 in
	PG grade	PG 76-22	PG 76-22	PG 76-22

	Air voids	7%	7%	7%
	Effective Binder Content	11.6% (default)	11.6% (default)	11.6% (default)
Maintenance related inputs	% total cracking before placement of the overlay	25%	25%	25%

Despite the fact that the air voids content in flexible pavements tend to decrease with time due to repeated loading [86], the air voids percentage in the existing AC layer were considered unchanged (7%, 8% and 9%). Accordingly, the only difference in the input parameters is the air voids percentage in the existing AC layer.

Regarding the AC overlay, the same inputs are adopted all the three cases, considering that the maintenance is conducted for the three pavement structures (same overlay thickness and material properties). Consequently, the maintenance cost can be considered to be fixed across all the three cases. Alternatively stated, for the life-cycle cost assessment in the following section, the costs for the overlays placement is considered the same for the three considered pavement structures, and the difference resides in the number and timing of maintenance activities needed for each case.

As mentioned previously, the purpose of modeling the overlay performance is to determine its service life. The service life of the overlay is delimited by the time when the total cracking reaches 25% and another overlay is therefore needed. The total cracking is the sum of the predicted bottom-up cracking, reflective cracking and top-down cracking. The predicted performance of the same 5 in overlay placed on top of the reference pavement structure with different air voids content in the existing AC layer (7%, 8% and 9%) are shown in Figure 11 to Figure 16.

It can observed that the performance of the overlay is not affected by the air void content in the existing AC layer, due to the presence of the same 5 in AC overlay, having the same thickness and same properties, in terms of the binder characteristics as well as the mix volumetrics.

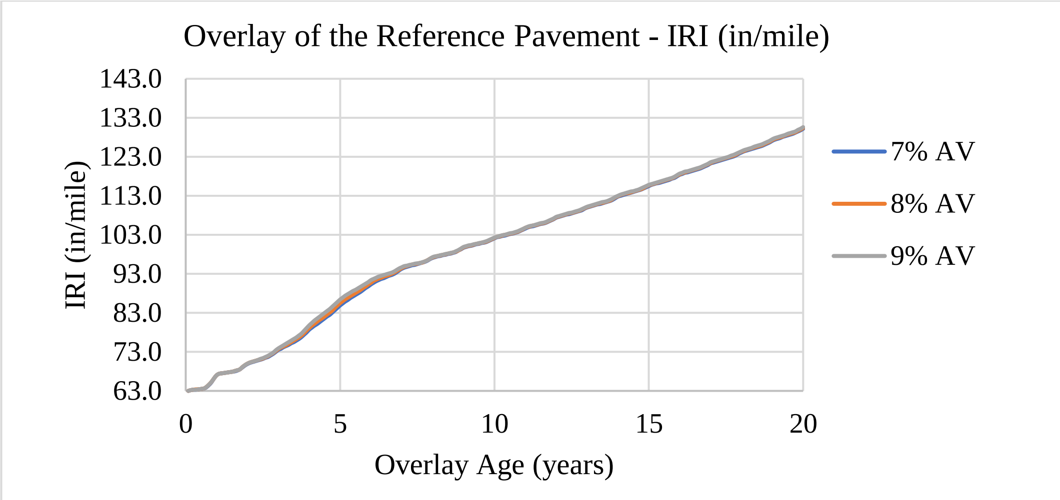

Figure 11 Predicted IRI for the AC Overlay of the Reference Pavement Structure Considering Different Air Voids Percentages in the Existing AC Layer

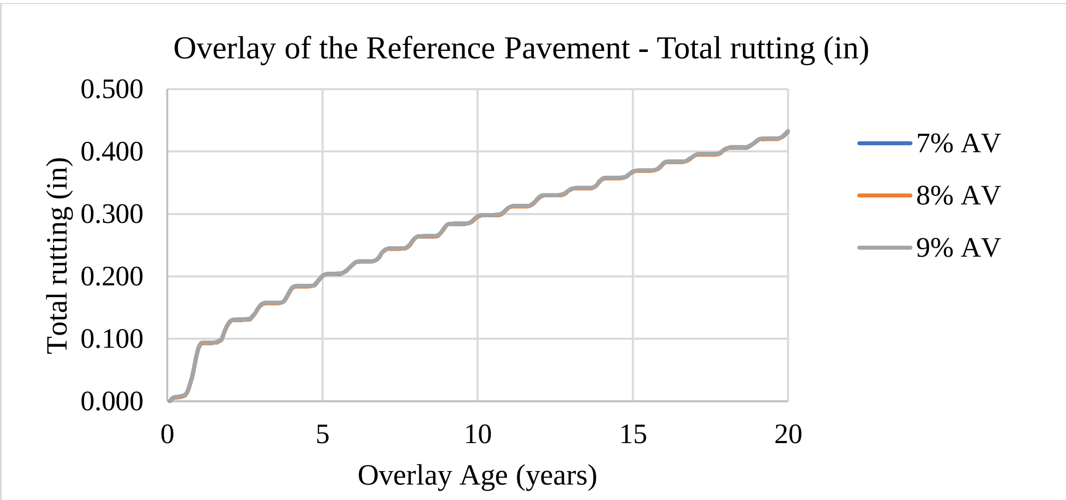

Figure 12 Predicted Total Rutting for the AC Overlay of the Reference Pavement Structure Considering Different Air Voids Percentages in the Existing AC Layer

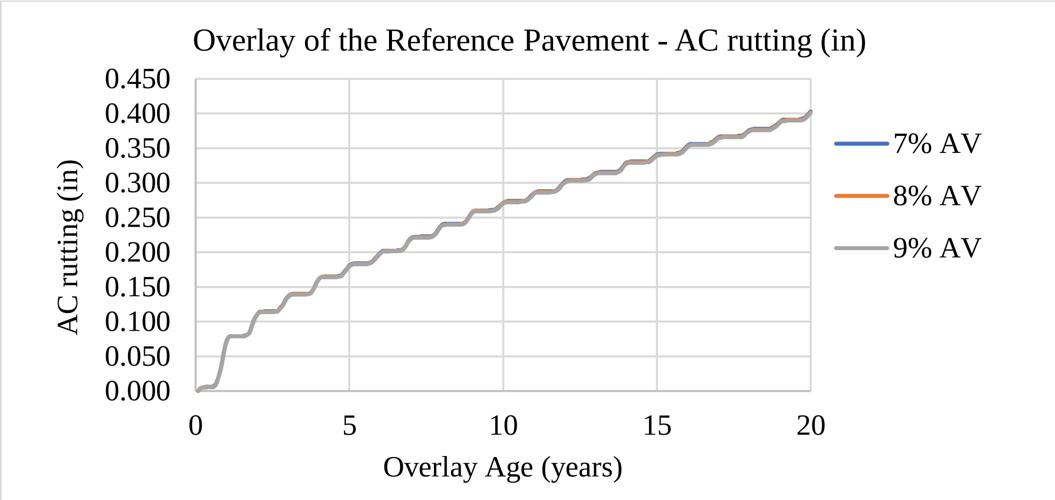

Figure 13 Predicted AC Rutting for the AC Overlay of the Reference Pavement Structure Considering Different Air Voids Percentages in the Existing AC Layer

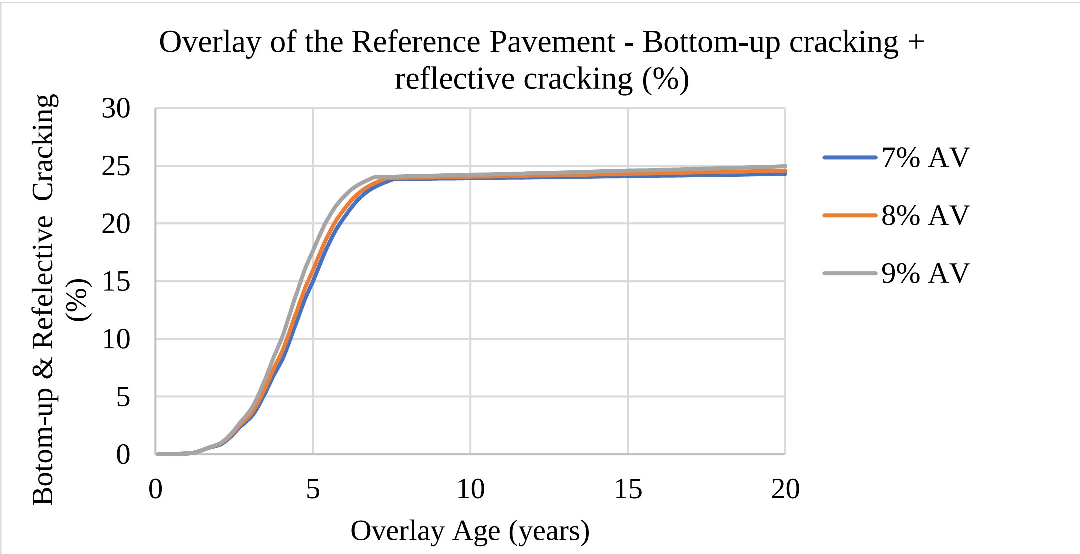

Figure 14 Predicted Bottom-up and Reflective Cracking for the AC Overlay of the Reference Pavement Structure Considering Different Air Voids Percentages in the Existing AC Layer

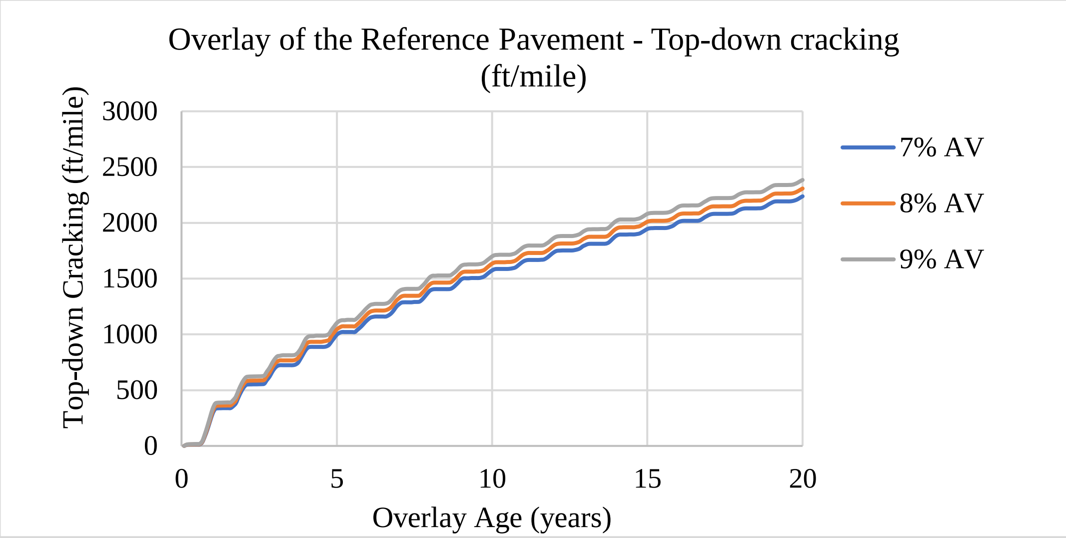

Figure 15 Predicted Top-down Cracking for the AC Overlay of the Reference Pavement Structure Considering Different Air Voids Percentages in the Existing AC Layer

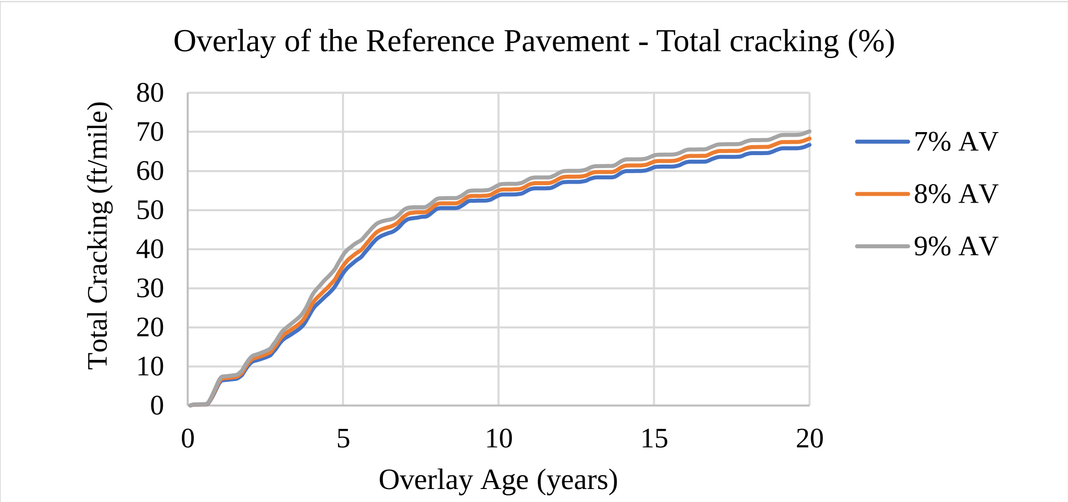

Figure 16 Total Cracking for the AC Overlay of the Reference Pavement Structure Considering Different Air Voids Percentages in the Existing AC Layer

The main conclusion from the overlays modeling is the service life of the overlay for the three considered cases: 7%, 8% and 9% air voids in the AC mix of the existing AC layer. Figure 16 shows that 25% total cracking is reached almost at the same time for the three cases, after 4.08 years, 3.92 years and 3.83 years for air-void contents of 7%, 8% and 9% respectively in the existing AC layer.

In the following section, the results of the AASHTOWare Pavement ME runs are used to assess the life-cycle cost of the considered pavement structures with the different air voids content in the initially constructed pavement.

6.3.2. Life-Cycle Cost Assessment Using RealCost

6.3.2.1. Scheduling Maintenance Works

The importance of the performed AASHTOWare Pavement ME runs is reflected in the planning of the maintenance works required for each considered pavement structure. If 25% total cracking is set as the threshold for the placement of an overlay, then, based on the results of section 6.3.1.2, the first maintenance is needed after 10 years, 6 years and 4.5 years respectively for 1) the case of a compliant pavement construction with 7% air voids in the AC mix, 2) the case of a non-compliant pavement construction with 8% air voids in the AC mix and 3) the case of a non-compliant pavement construction with 9% air voids in the AC mix. Furthermore, if the same overlay, with the same thickness and same binder characteristics and AC mix volumetrics, is placed on top of each considered pavement structure, this overlay will last approximately 4 years before the total cracking reaches 25% again and a second maintenance is needed, based on the results of section 6.3.1.3.

6.3.2.2. RealCost Inputs

The input parameters used for the life-cycle cost analysis are provided in Chapter 5, section 5.2. Table 8 summarizes the common input parameters for the three considered pavement structures/alternatives (reference pavement structure with 7%, 8% and 9% air voids).

Both the user cost and agency cost are calculated by the software. The remaining service life for both the user cost and the agency cost are included in the analysis.

Table 8 RealCost Common Inputs Parameters for LCCA of Three Pavement Structures (7%, 8% and 9% Air Voids Content)

	Input Parameter	Value
Economic variables	Value of time for passenger cars ($/hour)	13.96 (software default)
	Value of time for single unit trucks ($/hour)	22.34 (software default)
	Value of time for combination trucks ($/hour)	26.89 (software default)
Analysis options	Include user cost in analysis	Yes
	Include user cost remaining life value	Yes
	User Cost Computation Method	Calculated by the software
	Include agency cost remaining life value	Yes
	Traffic direction	Both
	Analysis period	30 years
	Beginning of analysis period	2021
	Discount rate	12%
	Number of alternatives	3 alternatives (7%, 8% and 9% air voids)
Traffic data	AADT construction year (total for both directions)	20,000
	Cars as percentage of AADT	80%
	Single unit trucks as a percentage of AADT	4.1%
	Combination trucks as a percentage of AADT	15.9%
	Annual growth rate of traffic	3%
	Speed limit under normal operating conditions	60 mph
	Number of lanes in each direction during normal operating conditions	3

As previously mentioned, the input data shown in Table 8 are common to the three alternatives except for the number of maintenance activities required for each pavement alternative. Table 9 shows the RealCost input parameters corresponding to the work activities for each pavement structure alternative. The detailed construction and maintenance cost estimation is provided in Chapter 5, section 5.2.

Table 9 RealCost Input Parameters Corresponding to the Three Pavement Structure Alternatives (7%, 8% and 9% Air Voids Content)

Activities	Input Parameter	Alternative 1 7% Air Voids	Alternative 2 8% Air Voids	Alternative 3 9% Air Voids
Initial construction	Agency construction cost (1000$)	497.81	497.81	497.81
	Work zone duration (days)	0	0	0
	Activity service life	**10 years**	**6 years**	**4.5 years**
Thick Overlay	**Number of repetitions of maintenance activity**	**5**	**6**	**6**
	Agency construction cost (1000$)	101.09	101.09	101.09
	Work zone duration (days)	10 days	10 days	10 days
	Activity service life	**4 years**	**4 years**	**4 years**
	Work zone length	0.6 miles (1 km)	0.6 miles (1 km)	0.6 miles (1 km)
	Work zone speed limit	40 mph	40 mph	40 mph

	Number of lanes open in each direction during work zone	2	2	2

The inputs in bold are based on the AASHTOWare Pavement ME analysis previously conducted, scheduling the first maintenance activity and the overlay service life for each alternative.

The remaining inputs are determined as explained in Chapter 5. Note that for the initial pavement construction, there will be no traffic; accordingly, no user cost shall be assigned for this activity. Consequently, the work zone duration for the initial construction is considered to be zero. In such case, the initial construction expenditures will only be considered in the assessment of the agency cost [28].

6.3.2.3. RealCost Output

Table 10 displays the scheduling of the construction and maintenance activities, as well as the corresponding agency and user costs for the three alternatives: 1) the pavement compliant with the standard construction specifications with a 7% air void content in the AC mix, 2) the out-of-specs pavement with an 8% air void content in the AC mix and 3) the out-of-specs pavement with a 9% air void content in the AC mix. The last row in the table provides the remaining life values for both the agency and user costs.

Table 10 Scheduling and Costs of Construction and Maintenance Activities for the Reference Pavement Considering 7%, 8% and 9% Air Void Content in the AC Mix

Alternatives			7% AV		8% AV		9% AV	
Year	Concession year	Operation year	Agency Cost (1000$)	User cost (1000$)	Agency Cost (1000$)	User cost (1000$)	Agency Cost (1000$)	User cost (1000$)
2021	1		497.81		497.81		497.81	
2022	2							
2023	3	1						
2024	4	2						
2025	5	3						
2026	6	4						
2027	7	5						
2028	8	6					101.09	34.44
2029	9	7			101.09	35.48		
2030	10	8						
2031	11	9						
2032	12	10					101.09	38.77
2033	13	11	101.09	39.93	101.09	39.93		
2034	14	12						

2035	15	13						
2036	16	14					101.09	43.63
2037	17	15	101.09	44.94	101.09	44.94		
2038	18	16						
2039	19	17						
2040	20	18					101.09	49.11
2041	21	19	101.09	50.58	101.09	50.58		
2042	22	20						
2043	23	21						
2044	24	22					101.09	55.27
2045	25	23	101.09	56.93	101.09	56.93		
2046	26	24						
2047	27	25						
2048	28	26					101.09	62.21
2049	29	27	101.09	64.08	101.09	64.08		
2050	30	28						
2051	31		-50.54	-32.04	-50.54	-32.04	-14.66	-9.02

Table 11 presents a comparison between the present values of the agency and user costs of the three pavement alternatives, and estimates the pay-adjustment factor to be imposed on the construction subcontractor based on the total increased cost (agency and user costs) resulting from all maintenance activities to be performed throughout the 30-years concession period.

Table 11 Pay Factor Estimation for a Non-compliant Pavement Construction in Terms of the Target Air Voids Content in the AC Mix

Life-cycle present value	**Alternative 1 7% air voids**	**Alternative 2 8% air voids**	**Alternative 3 9% air voids**
Agency cost (1000$)	559.93	600.76	614.52
User cost (1000$)	28.19	42.52	47.09
Total cost (1000$)	588.11	643.28	661.61
Total additional cost in present value (1000$)		643.28 – 588.11 = 55.17	661.61 – 588.11 = 73.5
Pay factor as % of construction cost		(55.17 x 100)/ 497.81 = 11.08%	(73.5 x 100)/ 497.81 = 14.76%

The pay-factor is the difference between the life-cycle costs (net present values) of the as-designed and the as-constructed pavement [7].

Pay Adjustment = $LCC_{con} – LCC_{des}$.

The pay factor is then calculated as a percentage of the construction cost.

For the reference pavement structure, considering that the target air-void content is 7%, a 1% higher-than-target air void content imposes a reduction of 11.08% of the payment due to the construction subcontractor. Similarly, the pay-adjustment factor for a 2% higher-than-expected air-void content is 14.76%.

6.3.3. Estimated Pay-Adjustment Factors for Deficient Air Void Content in the AC Mix

Following the same steps shown in section 6.3.1, AASHTOWare Pavement ME is used to schedule maintenance activities for different pavement structures, with different materials properties and subject to different traffic and climatic conditions. Table 12 shows the scheduling of the first maintenance and the overlay service life for the different pavement structures, considering a pavement construction compliant with the standard specifications (7% air void content) and non-compliant pavement construction with 8% and 9% air void contents in the AC mix. Note that the considered maintenance is a thick 5 in overlay (milling 5 in and overlaying 5 in) for all the considered scenarios.

RealCost is then used, as described in section 6.3.2, to calculate the life-cycle agency and user costs for all the considered scenarios, and consequently, to estimate the corresponding pay-adjustment factors. Note that the construction and maintenance costs used for the LCCA are as described in Chapter 5.

Figure 17 shows the estimated pay-adjustment factors for all the considered pavement structures, for a non-complaint construction with 1% and 2% higher-than-targeted air void content. The pay-factor for a (target + 1%) air void content in the AC mix ranges between 7 and 11%, while for a (target + 2%) air void content in the AC mix between 13.5 and 23.5% of the initial construction cost.

The lowest pay-factor is observed for the low speed case (25 mph instead of 60 mph). This can be explained by the fact that the first maintenance scheduling does not vary significantly between the three scenarios (with three air-void contents); in fact, the first maintenance is scheduled 2 and 3 years earlier respectively for 8% and 9% air-void content compared to the default case with 7% air-void content in the AC mix, whereas for the reference case, the first maintenance is 4 and 5.5 years earlier respectively for 8 and 9% air-void content compared to a 7% air-void content in the AC mix. This is due to the fact that the speed has a lower effect on the pavement performance compared to other parameters, such as the materials properties, climatic conditions and traffic counts, which are known to significantly affect the pavement performance.

However, there is no specific trend for the pay-factor. This is due to the fact that the estimated pay-factors are highly dependent on the maintenance pricing which is specific to each pavement. Furthermore, the pay-factor is determined for each case base on its corresponding default agency and user costs (those determined based on the 7% air-void content), and not based on the agency and user costs calculated for the reference pavement with a 7% air-void AC mix. Following, a brief explanation of the observed results is provided.

For the 8% air-void content, the first maintenance is 4 years earlier in the case of the reference pavement, while under Montana climate, the first maintenance is only 3 years earlier, which explains a lowest pay-factor estimated under the Montana climate compared to the reference case. A similar observation for the remaining cases such as Texas, with a 1 year difference between the first maintenance of a 7% and an 8% air-void content in the AC mix.

The highest pay-factors are observed for the higher truck level (AADTT 5000) and the weak subgrade (A-3) for both scenarios: target + 1% and target + 2% air-void content; both these parameters (the truck level and the subgrade type) have a significant influence on the fatigue performance of the pavement.

For the thinner AC layer (7 in), it is noticed that the pay-factors for both the 8% and 9% air-void contents are relatively lower than the others. This is explained by the fact that, for this specific case, the life-cycle costs for the 7% air-void scenario is already very high, which resulted in a lower difference between the life-cycle costs of the 7% air-void scenario and those corresponding to 8 and 9% air-void contents.

Table 12 First Maintenance Scheduling and Overlay Service Life for the Different Pavement Structures Considering 7%, 8% and 9% Air Void Content in the AC Mix

Pavement Structure	**7% Air Void**		**8% Air Void**		**9% Air Void**	
	First maintenance (years)	**Overlay service life (years)**	**First maintenance (years)**	**Overlay service life (years)**	**First maintenance (years)**	**Overlay service life (years)**
Reference	10	4	6	4	4.5	4
Montana	9	4	6	4	4	4
Texas	4	3.58	3	3.33	2	3
Base A-2-4	5	3	3.75	2.75	2.67	2.67
Subgrade A-3	8	2.75	5.67	2.67	4	2.5
PG 82-22	12	4.75	7	4.5	5	4
25 mph	7	4	5	3.92	3.75	3.75
AADTT 5000	8	3.42	5	3.25	3.83	3
7 in AC layer	4	3	3	3	2	3
15 in Base Layer	11	4	7	3.92	5	3.75

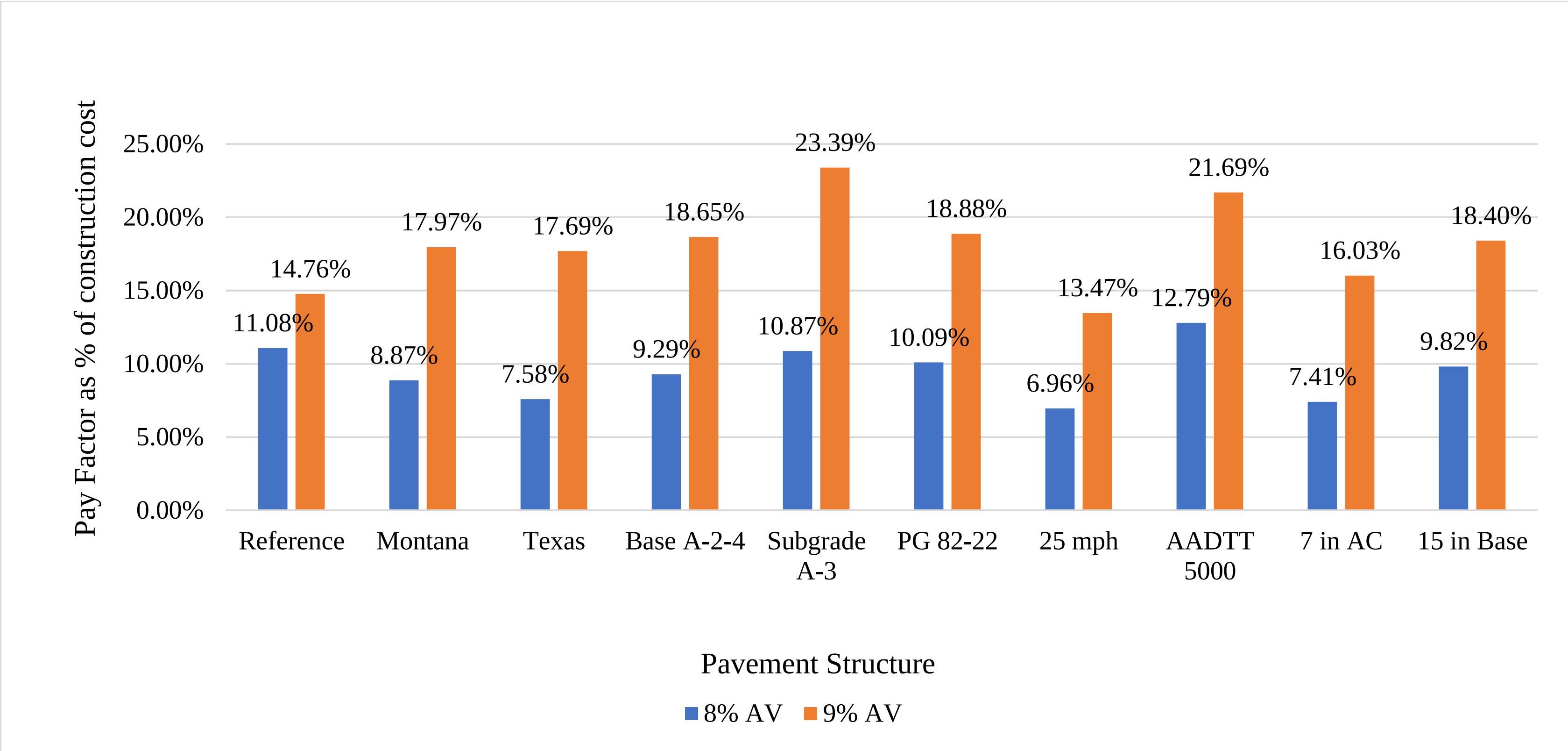

Figure 17 Estimated Pay-Adjustment Factor for Different Pavement Structures for a Non-Compliant Pavement Construction in Terms of the Target Air-Void Content (Target of 7%)

6.4. Deficiency in the Binder Content in the Asphalt Mix

6.4.1. Pavement Performance Prediction using AASHTOWare Pavement ME

6.4.1.1. Introduction

In AASHTOWare Pavement ME, the effective binder content by volume of the total mix is directly input instead of the binder content [26]. However, the standard construction specifications specify the acceptable values and tolerances for the binder content by weight of the AC mix, as shown in Table 6. Briefly, the binder content refers to the total weight of binder used in the AC mix, among which a part is absorbed by the aggregates, while the remaining part, called the "effective binder content", is the amount of binder that effectively forms a bonding film on the aggregate surfaces [87].

Knowing the binder content by weight of total mix and the percentage of binder absorbed by the aggregates, the effective binder content by weight of total mix can be directly determined by subtracting the weight of absorbed binder from the total weight of binder. Then, the effective binder content by volume of total mix is determined as follows:

Effective binder content by volume of total mix = [100* (bulk specific gravity of compacted mix * effective binder content by weight of total mix) / 1.02] where 1.02 is the multiplier for correcting asphalt volumes to the Basis of 60°F / 15.6°C. Considering that 2% of the total binder weight are absorbed by the aggregates and a 2.25 bulk specific gravity of compacted of mix, the effective binder content and the total binder content can be mutually determined [87].

6.4.1.2. AASHTOWare Pavement ME Inputs

The AASHTOWare Pavement ME input parameters are provided in Chapter 5, section 5.1. For the present section, only the effective binder content is varied. The target as-constructed effective binder content by volume of total mix is considered to be 11.6%, which is the software's default value. The corresponding binder content by weight of total mix is calculated following, as explained in section 6.4.1.1:

Effective binder content by volume of total mix = 100* (bulk specific gravity of compacted mix * effective binder content by weight of total mix) / 1.02

- ➔ 11.6% = 100*(2.25* effective binder content by weight of total mix) / 1.02
- ➔ Effective binder content by weight of total mix = 5.26%
- ➔ Binder content by weight of total mix = effective binder content by weight of total mix + absorbed binder = 5.26% + 2% = 7.26%.

Accordingly, the target binder content by weight of total mix is 7.26% - an acceptable value based on the standard construction specifications of different U.S. states shown in Table 6.

It is noticed, from Table 6, that the tolerance ranges for the binder content by weight of total mix are relatively small in different U.S. states, going from very low values (± 0.2% in California) to ± 0.8% in Pennsylvania. In AASHTOWare Pavement ME, the maximum effective binder content input is 15% [26]. Accordingly, the pavement performance is determined for the following three scenarios: 1) a construction that is compliant with the standard construction specifications, with 11.6% effective binder content by volume of total mix (corresponding to 7.26% binder content by weight of total mix), 2) a non-compliant pavement construction with 13% effective binder content by volume of total mix (corresponding to 7.89% = target + 0.63 binder content by weight of total mix) and 3) a non-compliant pavement construction with

15% effective binder content by volume of total mix (corresponding to 8.8% = target + 1.54 binder content by weight of total mix).

Note that the pay-factor for a non-compliant pavement construction in terms of the binder content will be determined based solely on the rutting performance, even though the lowest binder content improves the fatigue performance of the pavement, as will be shown in the subsequent sections. A lower-than-target binder content, on the other side, improves the rutting resistance of the pavement while accelerating the formation of fatigue cracking. These dry mixes (lower-than-target binder content) are not addressed herein [7].

6.4.1.3. AASHTOWare Pavement ME Outputs

Figure 18 to Figure 23 show the performance of the reference pavement, in terms of IRI (international roughness index), rutting and fatigue cracking, for the three considered binder contents in the AC mix.

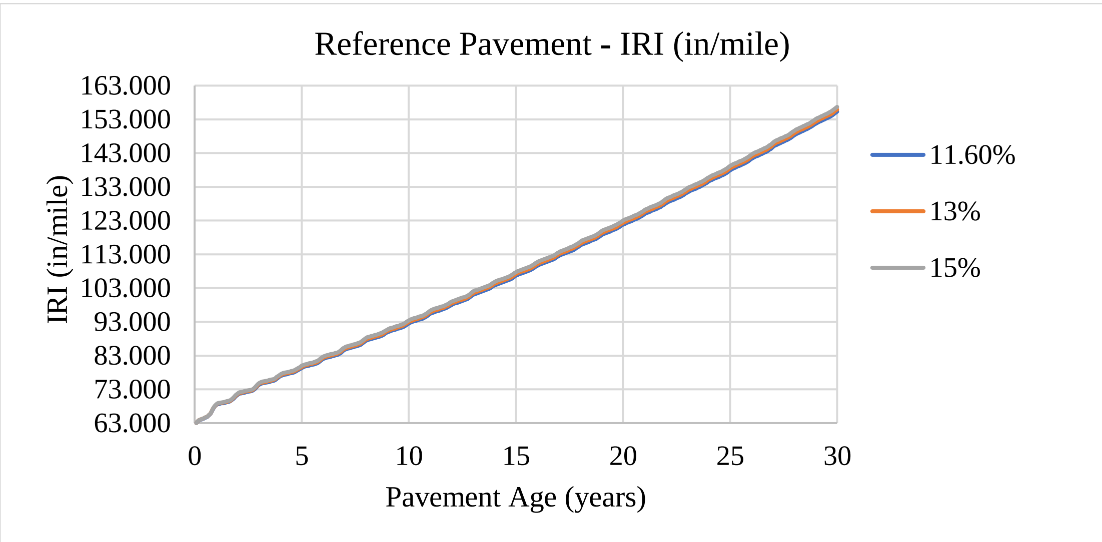

Figure 18 Predicted IRI for the Reference Pavement Structure for 11.6%, 13% and 15% Effective Binder Content in the AC Mix

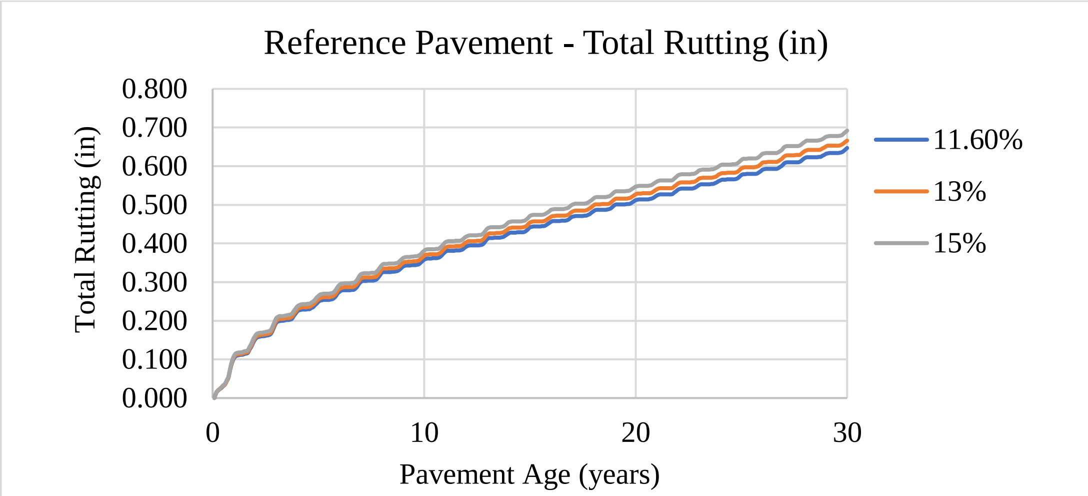

Figure 19 Predicted Total Rutting for the Reference Pavement Structure for 11.6%, 13% and 15% Effective Binder Content in the AC Mix

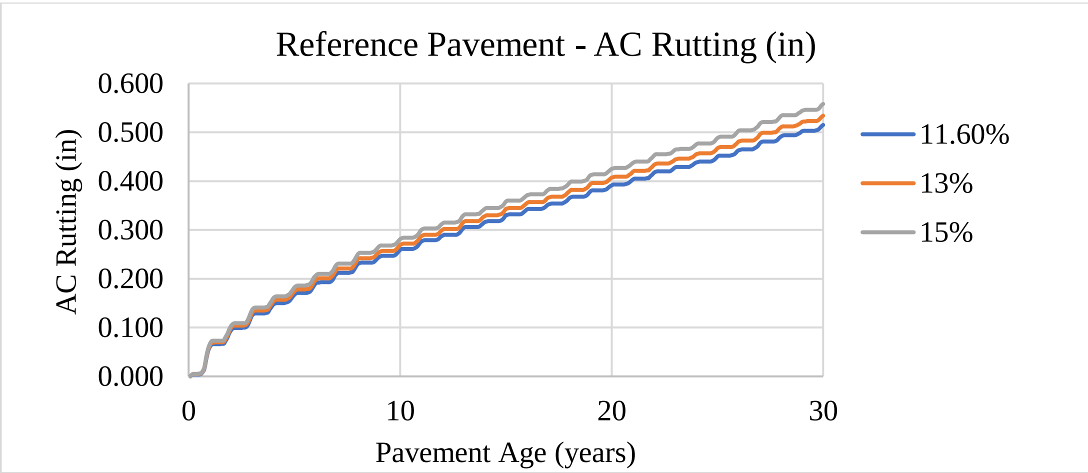

Figure 20 Predicted AC Rutting for the Reference Pavement Structure for 11.6%, 13% and 15% Effective Binder Content in the AC Mix

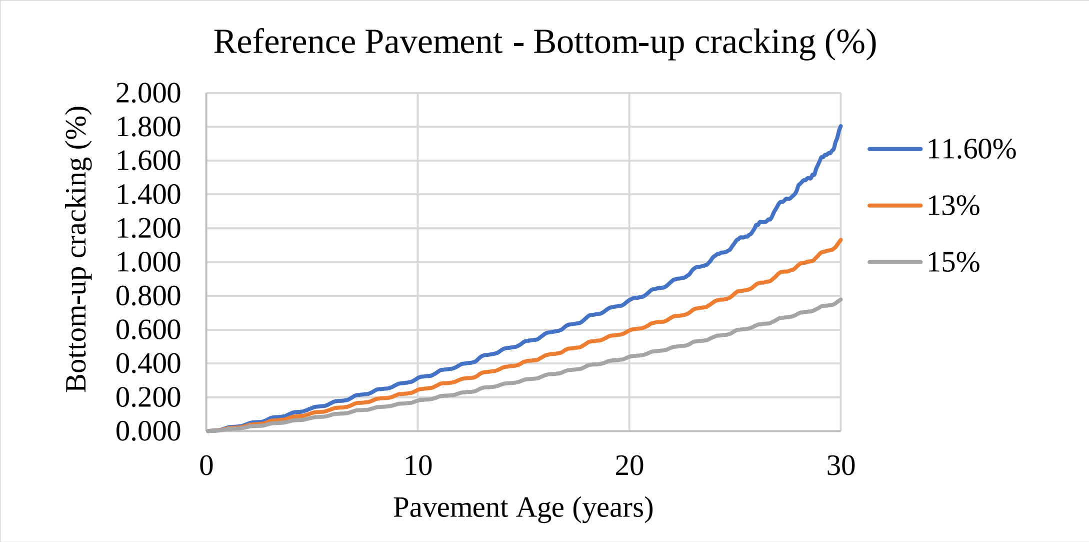

Figure 21 Predicted Bottom-up Cracking for the Reference Pavement Structure for 11.6%, 13% and 15% Effective Binder Content in the AC Mix

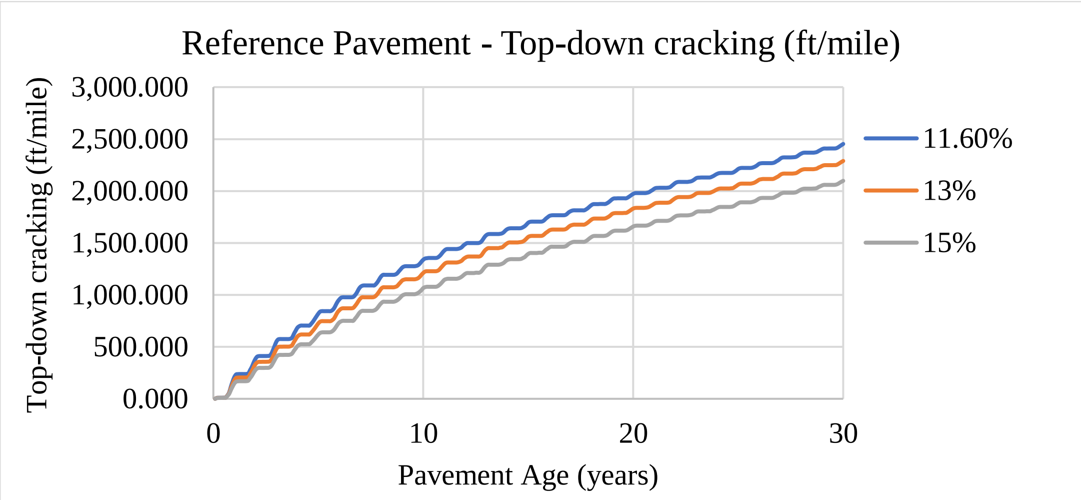

Figure 22 Predicted Top-down Cracking for the Reference Pavement Structure for 11.6%, 13% and 15% Effective Binder Content in the AC Mix

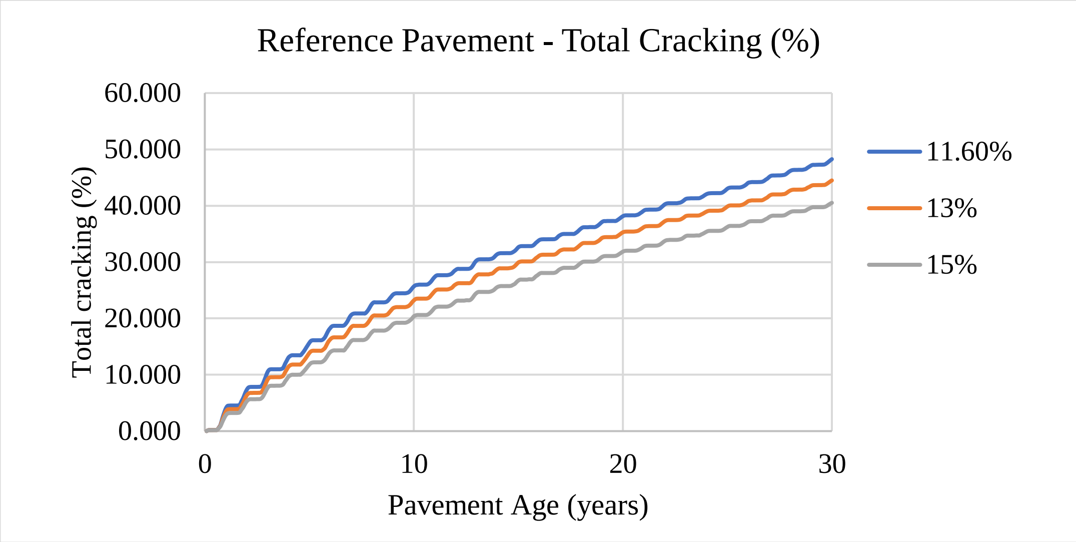

Figure 23 Total Cracking for the Reference Pavement Structure for 11.6%, 13% and 15% Effective Binder Content in the AC Mix

As previously stated, a higher binder content accelerates rutting (Figure 19 and Figure 20) and retards the formation of bottom-up and top-down cracks (Figure 21 and Figure 22). In the present study, the pay-factor for higher-than-target binder content is determined based only on the resulting reduction rutting, regardless of the cracking performance [7]. The threshold for scheduling maintenance works based on rutting performance on the pavement is considered to be 0.4 in total rut depth, as per the NHPP rating system [49]. For the reference pavement structure considered herein, 0.4 in total rut depth is reached after 13, 12 and 11 years respectively for the cases where the effective binder content by volume of total mix is 11.6, 13 and 15%.

The predicted performance of the same 5 in overlay placed on top of the reference pavement structure with different effective binder content by volume of total mix in the existing AC layer (11.6%, 13% and 15%) are shown in Figure 24 to Figure 29.

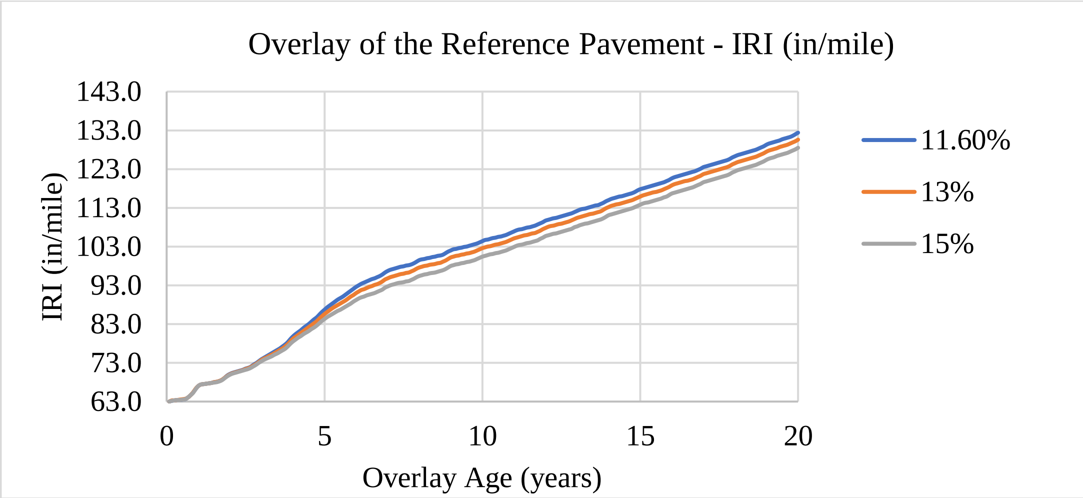

Figure 24 Predicted IRI for the AC Overlay of the Reference Pavement Structure Considering Different Effective Binder Content in the Existing AC Layer

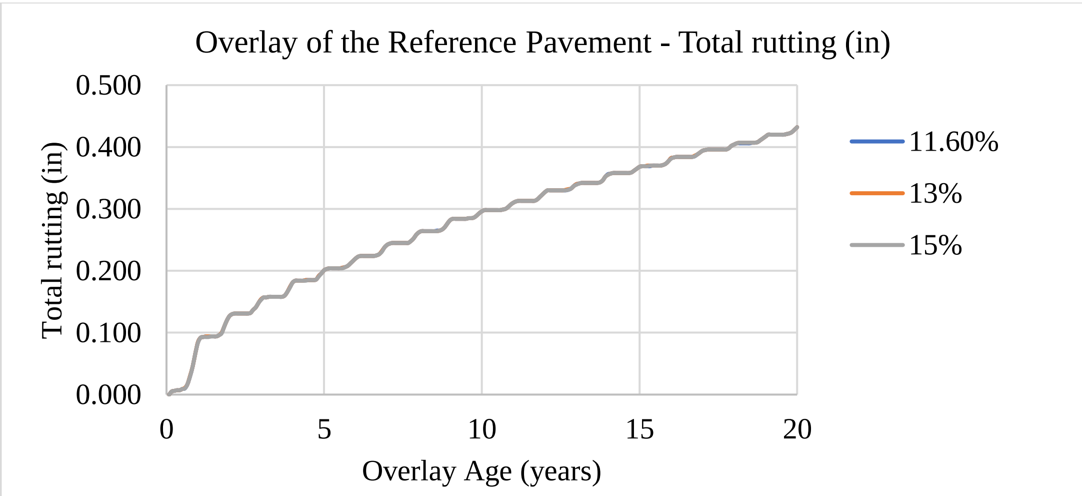

Figure 25 Predicted Total Rutting for the AC Overlay of the Reference Pavement Structure Considering Different Effective Binder Content in the Existing AC Layer

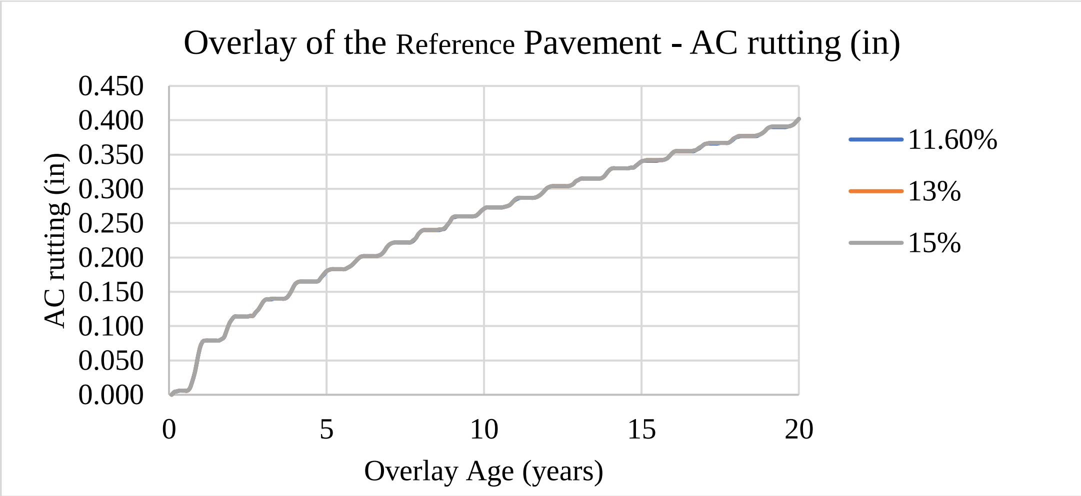

Figure 26 Predicted AC Rutting for the AC Overlay of the Reference Pavement Structure Considering Different Effective Binder Content in the Existing AC Layer

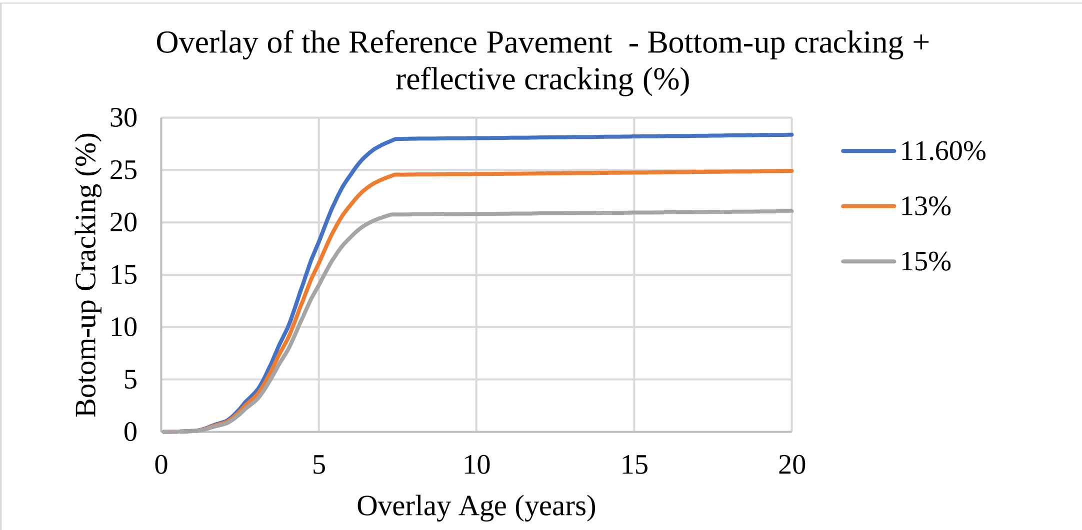

Figure 27 Predicted Bottom-up and Reflective Cracking for the AC Overlay of the Reference Pavement Structure Considering Different Effective Binder Content in the Existing AC Layer

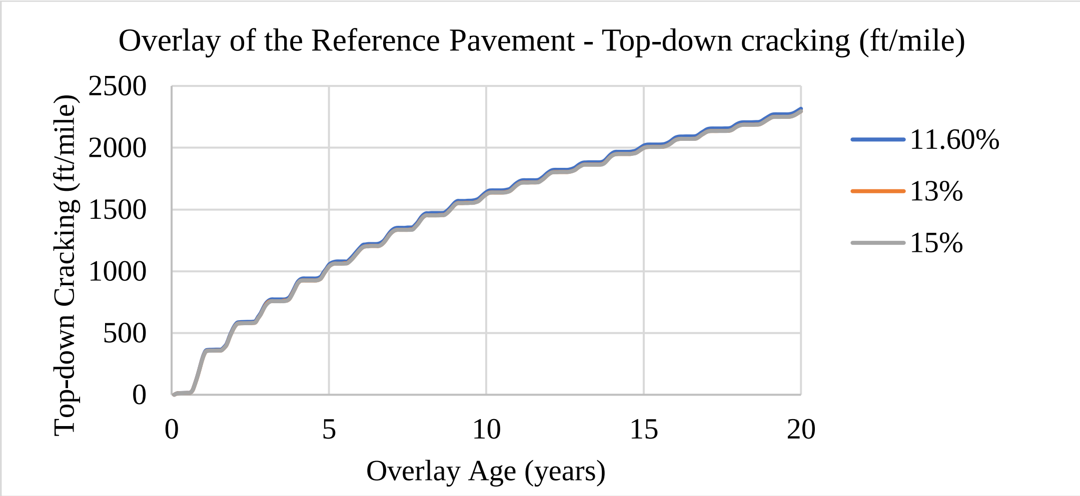

Figure 28 Predicted Top-down Cracking for the AC Overlay of the Reference Pavement Structure Considering Different Effective Binder Content in the Existing AC Layer

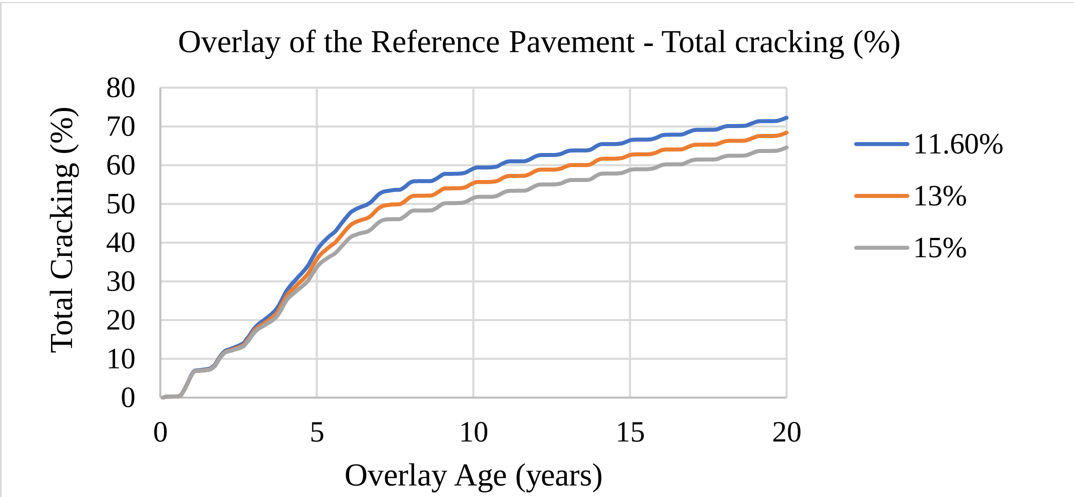

Figure 29 Total Cracking for the AC Overlay of the Reference Pavement Structure Considering Different Effective Binder Content in the Existing AC Layer

As shown in Figure 25, a 0.4 in total rut depth is reached after 18 years of the overlay placement for the three considered scenarios i.e. considering an effective binder content by volume of total mix of 11.6%, 13% and 15%. This is due to the placement of a thick overlay, with an 11.6% effective binder content by volume of total mix, over the existing pavement which masked the effect of the high binder content in the existing AC layer. Note that the long service life of the overlay can be explained by the fact that

1) a thick overlay is considered (milling 5 in and overlaying 5 in) and 2) the considered pavement structures are less susceptible to rutting than to cracking due to the use of a high PG grade asphalt binder (PG 76-22), which is the same binder used for the AC overlay.

As previously mentioned, the pay-factor for a non-compliant pavement construction in terms of the binder content will be determined based solely on the rutting performance, despite the resulting improvement in cracking performance.

6.4.2. LCCA Using RealCost

The input parameters used for the life-cycle cost analysis are provided in Chapter 5 and are summarized in Table 8, however, instead of considering three different air-void contents in the AC mix, three effective binder contents by volume of total mix are considered: 1) a construction that is compliant with the standard construction specifications, with 11.6% effective binder content by volume of total mix (corresponding to 7.26% binder content by weight of total mix), 2) a non-compliant pavement construction with 13% effective binder content by volume of total mix (corresponding to 7.89% = target + 0.63 binder content by weight of total mix) and 3) a non-compliant pavement construction with 15% effective binder content by volume of total mix (corresponding to 8.8% = target + 1.54 binder content by weight of total mix).

Based on the results of Section 6.4.1.3, the first heavy maintenance is scheduled after 13, 12 and 11 years respectively for the cases where the effective binder content by volume of total mix is 11.6, 13 and 15%, and the thick overlay service life is 18 years for the three scenarios.

Table 13Table 10 displays the scheduling of the construction and maintenance activities, as well as the corresponding agency and user costs for the three alternatives. The last row in the table provides the remaining life values for both the agency and user costs.

Table 13 Scheduling and Costs of Construction and Maintenance Activities for the Reference Pavement Considering 11.6%, 13% and 15% Effective Binder Content by Volume of the AC Mix

Alternatives			11.6% effective binder content by volume of total mix		13% effective binder content by volume of total mix		15% effective binder content by volume of total mix	
Year	Concession year	Operation year	Agency Cost (1000$)	User cost (1000$)	Agency Cost (1000$)	User cost (1000$)	Agency Cost (1000$)	User cost (1000$)
2021	1		497.81		497.81		497.81	
2022	2							
2023	3	1						
2024	4	2						
2025	5	3						
2026	6	4						
2027	7	5						
2028	8	6						
2029	9	7						
2030	10	8						
2031	11	9						
2032	12	10						
2033	13	11						

2034	14	12					101.09	41.13
2035	15	13			101.09	42.36		
2036	16	14	101.09	43.63				
2037	17	15						
2038	18	16						
2039	19	17						
2040	20	18						
2041	21	19						
2042	22	20						
2043	23	21						
2044	24	22						
2045	25	23						
2046	26	24						
2047	27	25						
2048	28	26						
2049	29	27						
2050	30	28						
2051	31		-16.85	-7.27	-11.23	-4.71	-5.62	-2.28

Table 14Table 11 presents a comparison between the present values of the agency and user costs of the three pavement alternatives, and estimates the pay-adjustment factor to be imposed on the construction subcontractor based on the total increased cost (agency and user costs) resulting from all maintenance activities to be performed throughout the 30-years concession period.

Table 14 Pay Factor Estimation for a Non-compliant Pavement Construction in Terms of the Target Binder Content in the AC Mix

Life-cycle present value	**Alternative 1 11.6% effective binder content by volume of total mix**	**Alternative 2 13% effective binder content by volume of total mix**	**Alternative 3 15% effective binder content by volume of total mix**
Agency cost (1000$)	515.10	517.55	520.27
User cost (1000$)	7.46	8.27	9.14
Total cost (1000$)	522.56	525.82	529.41
Total additional cost in present value (1000$)		525.82 – 522.56 = 3.26	529.41– 522.56 = 6.85
Pay factor as % of construction cost		(3.26 x 100)/ 497.81 = 0.66%	(6.85 x 100)/ 497.81 = 1.37%

For the reference pavement structure, considering that the target binder content by weight of total mix is 7.26%, a 0.63% higher-than-target binder content imposes a reduction of 0.66% of the payment due to the construction subcontractor. Similarly, the pay-adjustment factor for a 1.54% higher-than-expected binder content is 1.37%.

The estimated pay-factors for higher-than-target binder content are very low, as compared to those estimated in section 6.3.3 for the higher-than-target air-void content in the AC mix. This is due to two factors: 1) the range of the binder contents considered is the study is limited; the considered scenarios are target binder content by weight of total mix + 0.63% and target binder content by weight of total mix + 1.54% (because the maximum effective binder by volume of total mix than can be input into AASHTOWare Pavement is 15%, which corresponds, in the present study, to the target binder content by weight of total mix (7.26%) + 1.54%) and 2) the considered pavement structures are less susceptible to rutting than to cracking due to the use of a high PG grade asphalt binder (PG 76-22), which is the same binder used for the overlays.

6.4.3. Estimated Pay-Adjustment Factors for Deficient Binder Content in the AC Mix

Following the same steps shown in section 6.4.1, AASHTOWare Pavement ME is used to schedule maintenance activities for different pavement structures, with different materials properties and subject to different traffic and climatic conditions. Table 15 shows the scheduling of the first maintenance and the overlay service life for the different pavement structures, considering a pavement construction compliant with the standard specifications (7.26% binder content by weight of total mix corresponding to 11.6% effective binder content by volume of total mix) and non-compliant pavement construction with 7.89% and 8.8% binder content by weight of total mix (corresponding to 13% and 15% effective binder content by volume of total mix respectively). Note that the considered maintenance is a thick 5 in overlay (milling 5 in and overlaying 5 in) for all the considered scenarios.

RealCost is then used, as described in section 6.4.2, to calculate the life-cycle agency and user costs for all the considered scenarios, and consequently, to estimate the corresponding pay-adjustment factors. Note that the construction and maintenance costs used for the LCCA are as described in Chapter 5.

Figure 30Figure 17 shows the estimated pay-adjustment factors for all the considered pavement structures, for a non-complaint construction with 0.63% and 1.54% higher-than-targeted binder content by weight of total mix - or 1.4% and 3.4% higher-than-targeted effective binder content by volume of total mix.

As previously explained, the pay-factors estimated for the higher-than-target binder content are low for all the considered cases due to the limited binder content ranges and the high PG grade binder used in the AC mix.

In fact, as can be inferred from Table 15, for all the considered scenarios, the rutting threshold is reached after 10 years from the beginning of the operating period, except for the pavement subject to hot climatic conditions (Texas) where the rutting threshold is reached after 5 years. Furthermore, the higher binder content resulted in a maximum 2-year earlier scheduling of the first maintenance, and in some cases, only few months earlier compared to the case complying with the target binder content. The higher binder content, however, did not affect the service life of the thick overlay, as the latter masked the effect of the non-compliant existing AC layer.

The highest pay-factors for the higher-than-target binder content are observed, as expected, for hot climatic conditions (Texas) and low speed limit (25 mph). The type of subgrade and the materials used for the base layer did not affect the pay-factor. A higher PG grade (PG 82-22) resulted in a slight decrease in the estimated pay-factor; this is due to the fact that the PG 76-22 already showed a significant resistance to rutting. A high pay-factor have resulted if a PG 64-22 binder was used; however, for the case of a highway project procured through a long-term PPP contract, it is unlikely to use such binder.

Furthermore, based on the obtained results, it can be concluded that for the case of a toll road, where high quality materials (especially the binder used in the AC mix) are used to ensure the longest possible service life, a relatively high tolerance for the binder content can be accepted, compared to the limited ranges observed in the reviewed standard construction specifications (Table 6), as it is expected that rutting failure of the pavement will be delayed compared to cracking failure.

Finally, a low binder content, although improves rutting resistance of the pavement, can lead to stripping, potholes and fatigue problems. However, this case is not addressed in the reviewed literature [7][8][9]. Nevertheless, a similar methodology to the one presented in this study can be adopted by highway agencies for estimating the value of the pay-factor to be imposed on the construction subcontractor in case a lower-than-target binder content is encountered.

Table 15 First Maintenance Scheduling and Overlay Service Life for the Different Pavement Structures Considering 11.6%, 13% and 15% Effective Binder Content by Volume of AC Mix

Pavement Structure	**11.6% effective binder content by volume of total mix (7.26% binder content by weight of total mix)**		**13% effective binder content by volume of total mix (7.89% binder content by weight of total mix)**		**15% effective binder content by volume of total mix (8.8% binder content by weight of total mix)**	
	First maintenance (years)	**Overlay service life (years)**	**First maintenance (years)**	**Overlay service life (years)**	**First maintenance (years)**	**Overlay service life (years)**
Reference	13	18	12	18	11	18
Montana	11	18	10	18	9.83	18
Texas	5.67	7	5.08	7	4.92	7
Base A-2-4	12.67	18	11.83	18	10.92	18
Subgrade A-3	13	17	12	17	11	17
PG 82-22	14	20	13	20	12	20
25 mph	11	14	10	14	9	14
AADTT 5000	11	15	10	15	9.83	15
7 in AC layer	11	16	10.83	16	10	16
15 in Base Layer	13	17	12	17	11	17

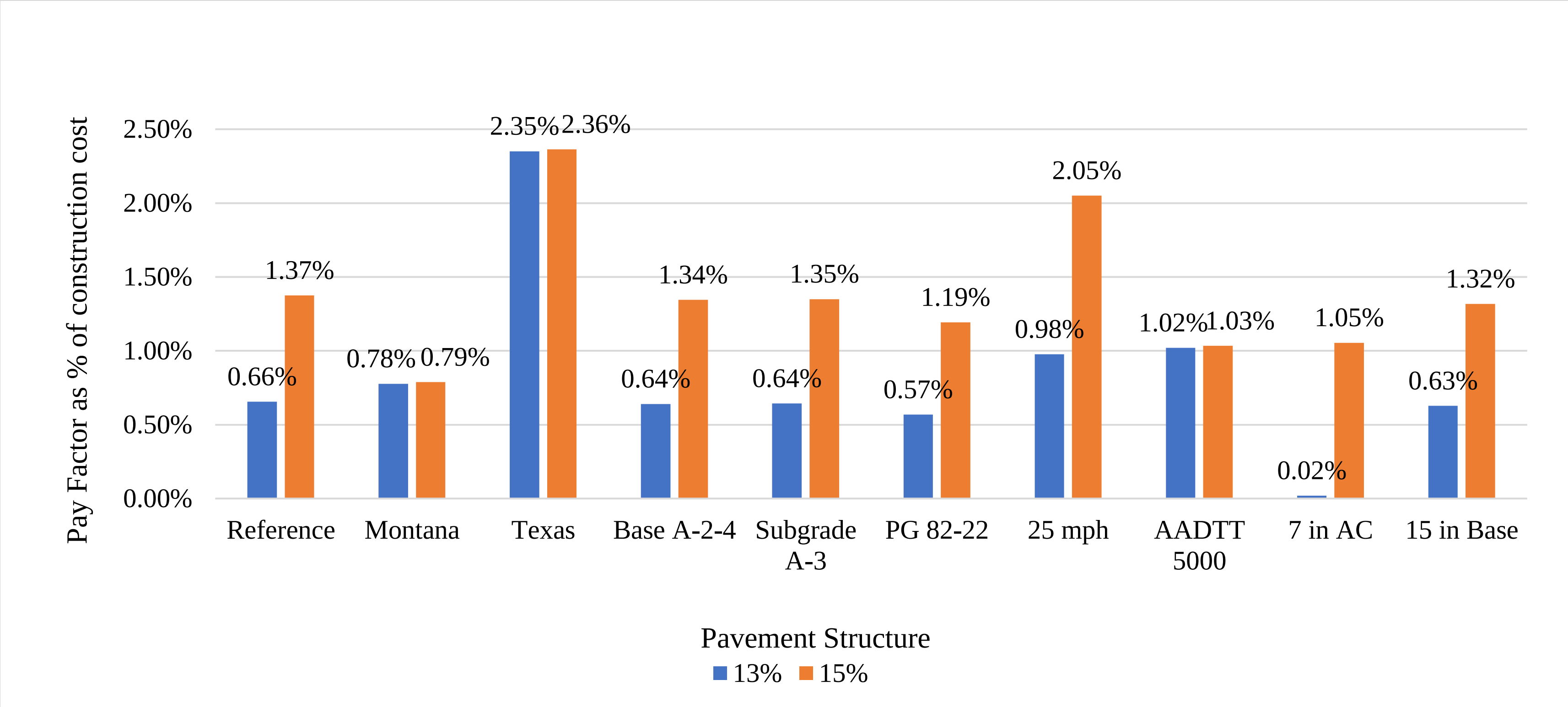

Figure 30 Estimated Pay-Adjustment Factor for Different Pavement Structures for a Non-Compliant Pavement Construction in Terms of the Target Effective Binder Content by Volume of Total Mix (Target 11.6%)

6.5. Non-Compliant Pavement Construction in terms of the Thickness of the AC Layer

6.5.1. Pavement Performance Prediction using AASHTOWare Pavement ME

6.5.1.1. AASHTOWare Pavement ME Inputs

The AASHTOWare Pavement ME input parameters are provided in Chapter 5, section 5.1. For the present section, only the AC layer thickness is varied. The design thickness of the pavement is 8 in for all the considered pavement structures, expect for the 7 in AC layer scenario. The performance of each pavement structure is predicted using AASHTOWare Pavement ME for the following 3 cases: 1) actual AC layer thickness is equal to the design thickness, 2) actual AC layer thickness is equal to the design thickness – ½ in and 3) actual AC layer thickness is equal to the design thickness – 1 in.

6.5.1.2. AASHTOWare Pavement ME Outputs

The performance of the reference pavement, in terms of IRI (international roughness index), rutting and cracking, for the three considered air voids content, are shown in Figure 31 to Figure 36.

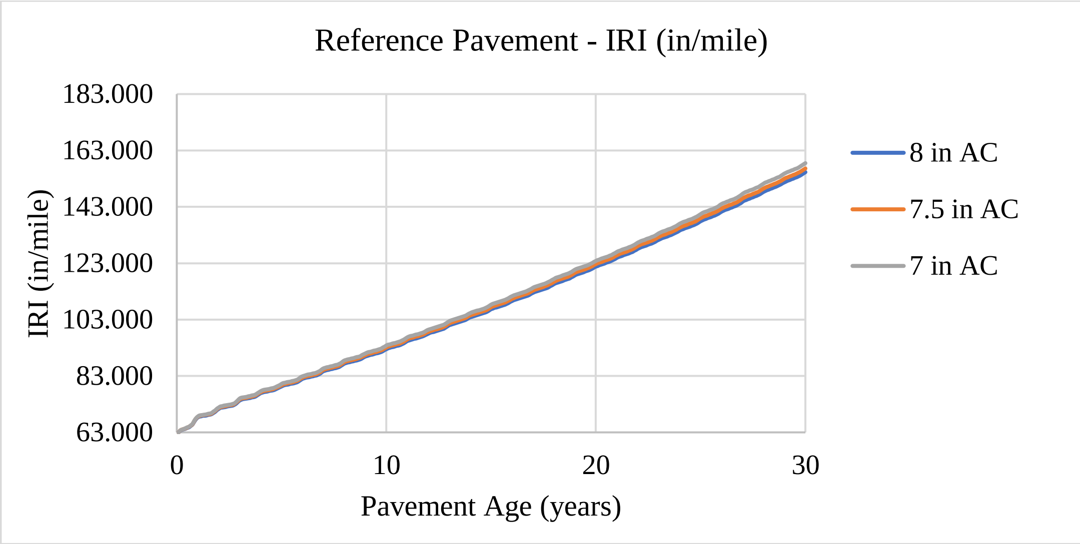

Figure 31 Predicted IRI for the Reference Pavement Structure for Different AC Layer Thicknesses

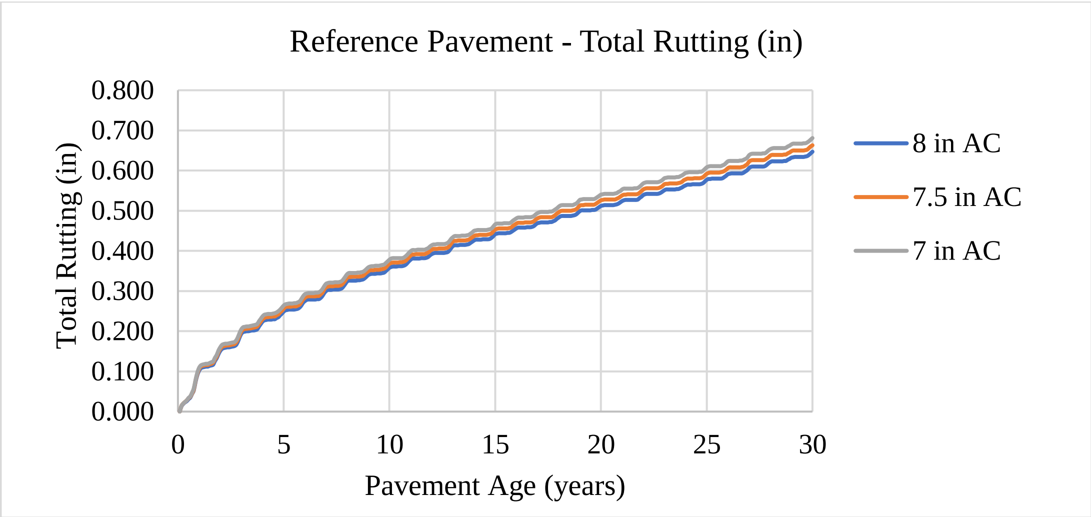

Figure 32 Predicted Total Rutting for the Reference Pavement Structure for Different AC Layer Thicknesses

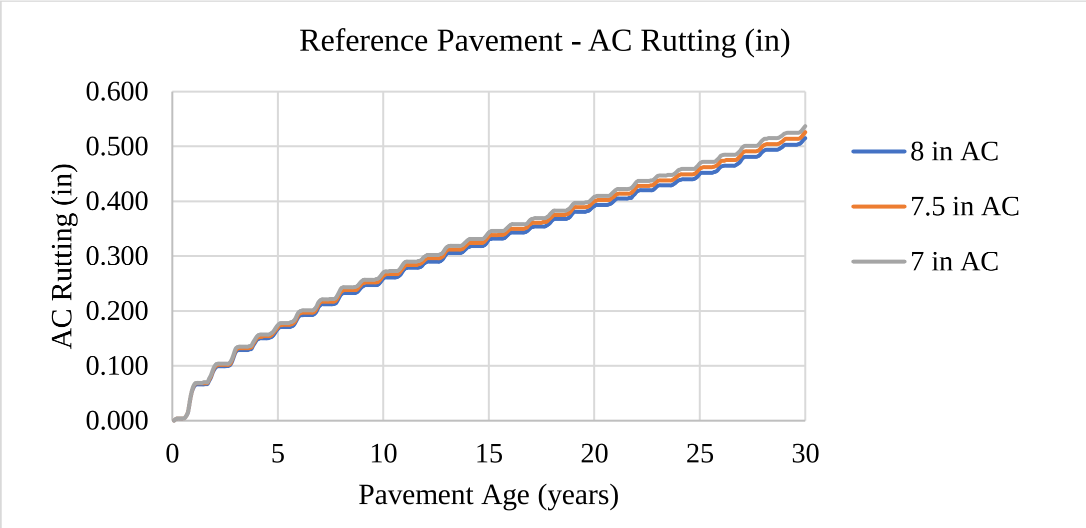

Figure 33 Predicted AC Rutting for the Reference Pavement Structure for Different AC Layer Thicknesses

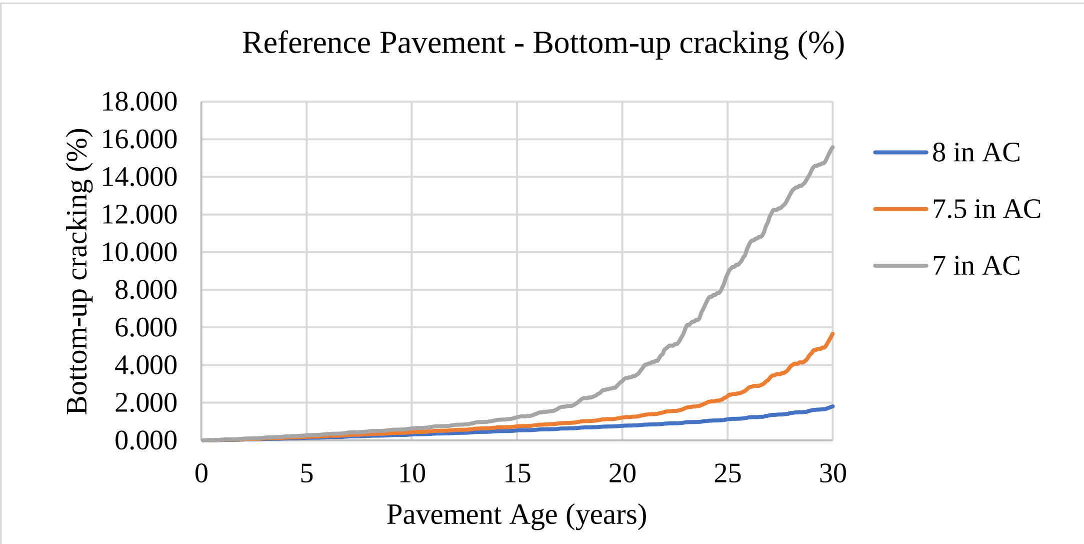

Figure 34 Predicted Bottom-up Cracking for the Reference Pavement Structure for Different AC Layer Thicknesses

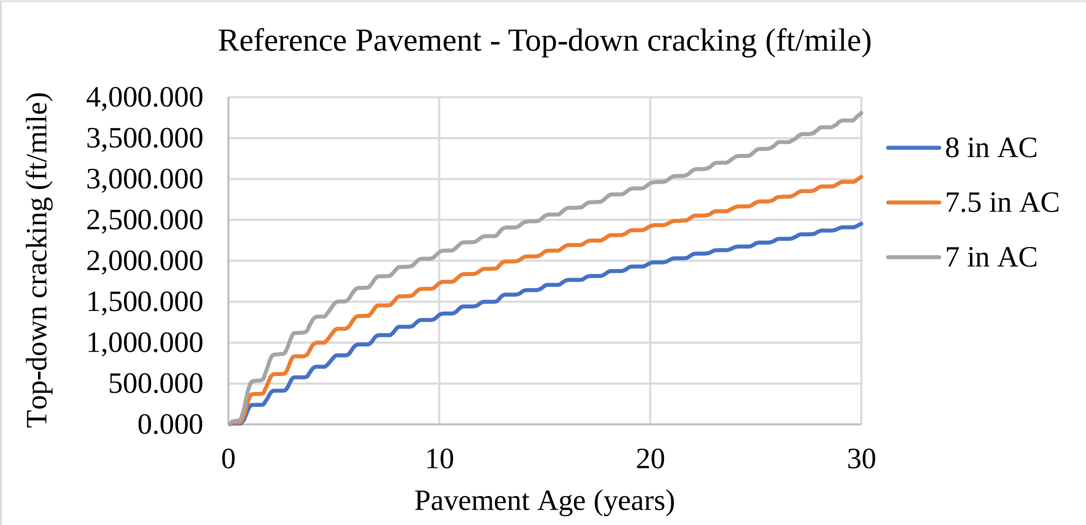

Figure 35 Predicted Top-down Cracking for the Reference Pavement Structure for Different AC Layer Thicknesses

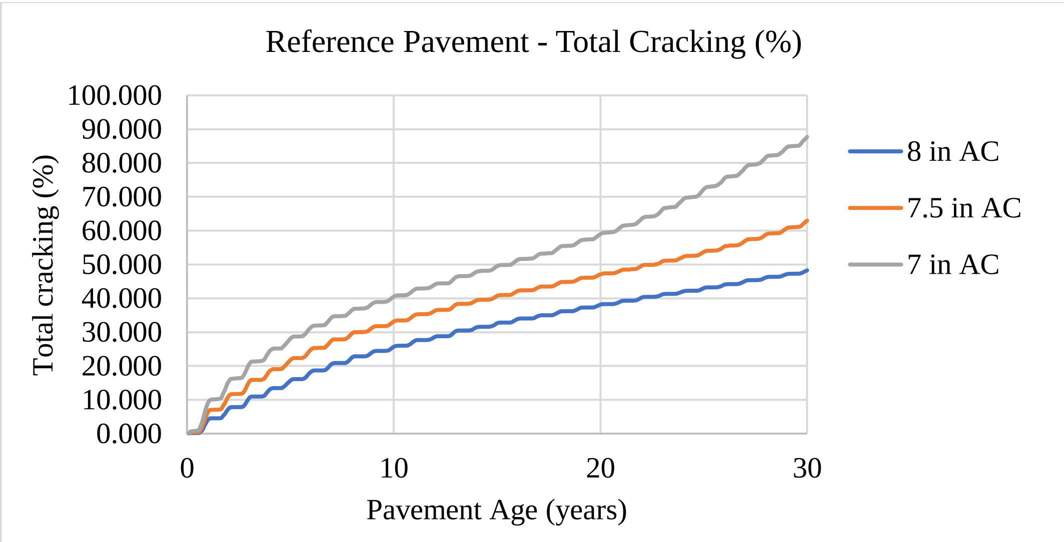

Figure 36 Total Cracking for the Reference Pavement Structure for Different AC Layer Thicknesses

For the reference pavement structure considered herein, 25% total cracking is reached after 10, 6 and 4 years respectively for the cases where the AC layer is 1) equal to the design thickness, 2) ½ in thinner than the design thickness and 3) 1 in thinner than the design thickness.

The predicted performance of the same 5 in overlay placed on top of the reference pavement structure with different thicknesses of the existing AC layer (actual thickness equal to 1) design thickness, 2) design thickness - ½ in and 3) design thickness – 1 in) are shown in Figure 37 to Figure 42.

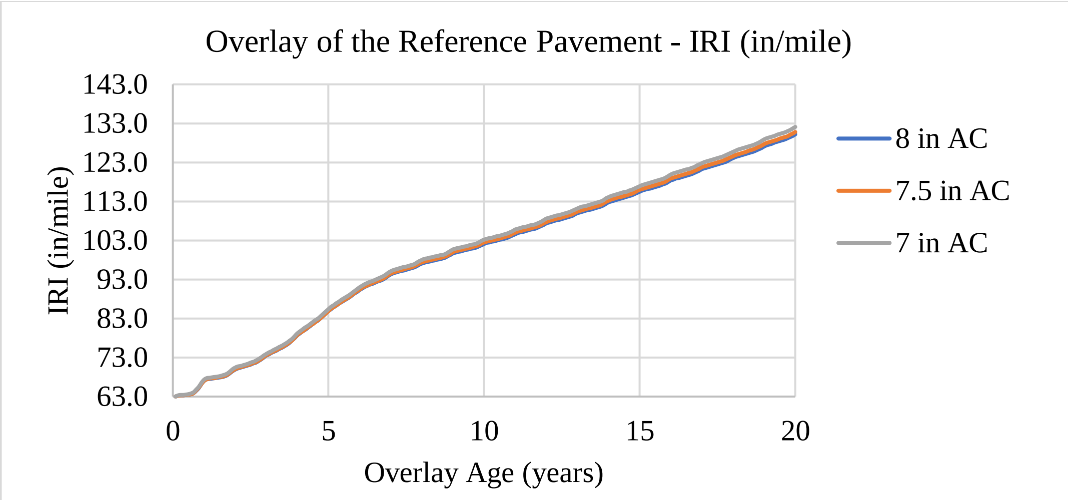

Figure 37 Predicted IRI for the AC Overlay of the Reference Pavement Structure Considering Different Thicknesses of the Existing AC Layer

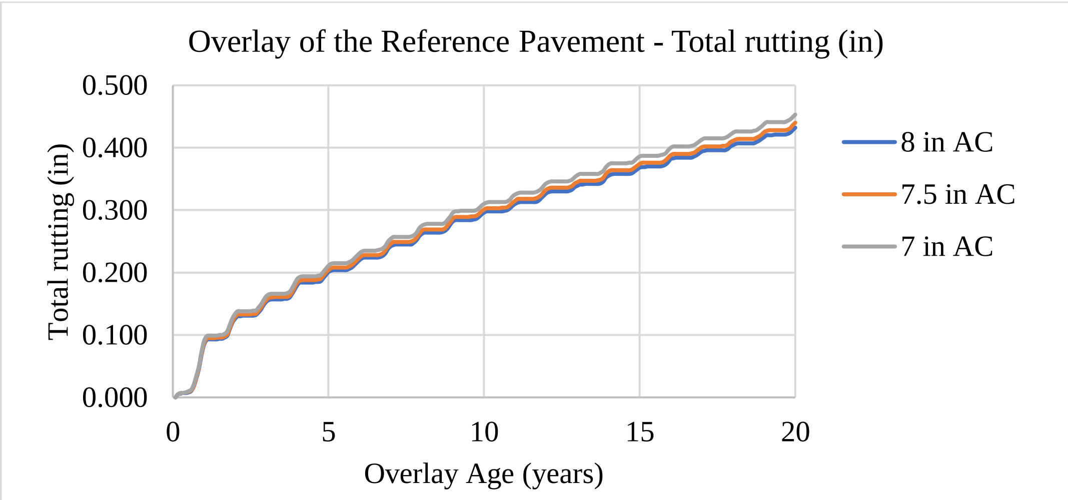

Figure 38 Predicted Total Rutting for the AC Overlay of the Reference Pavement Structure Considering Different Thicknesses of the Existing AC Layer

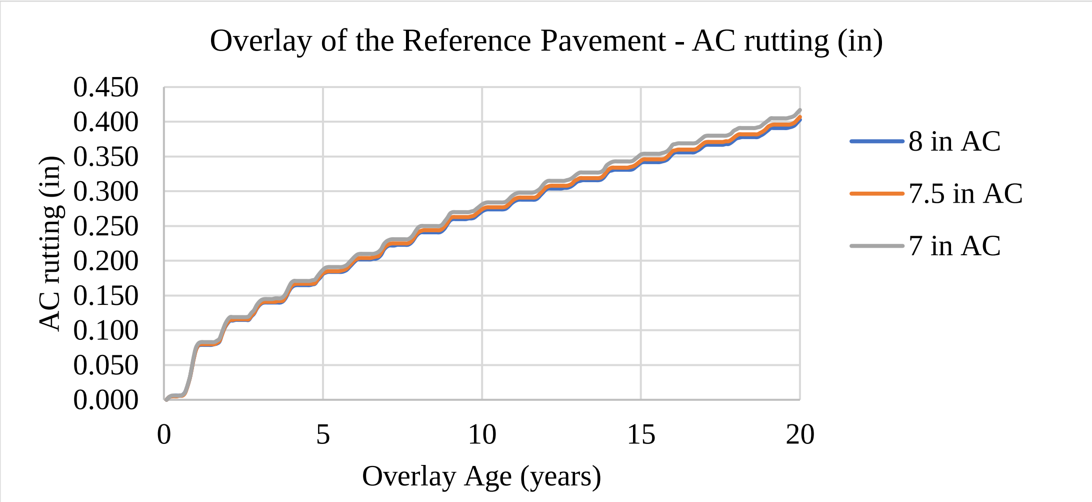

Figure 39 Predicted AC Rutting for the AC Overlay of the Reference Pavement Structure Considering Different Thicknesses of the Existing AC Layer

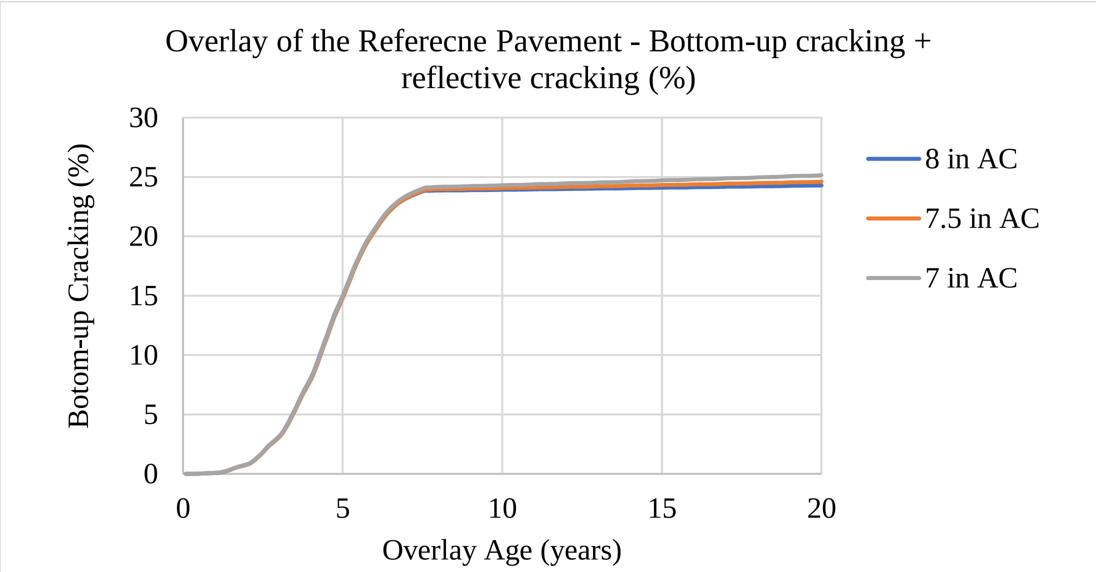

Figure 40 Predicted Bottom-up and Reflective Cracking for the AC Overlay of the Reference Pavement Structure Considering Different Thicknesses of the Existing AC Layer

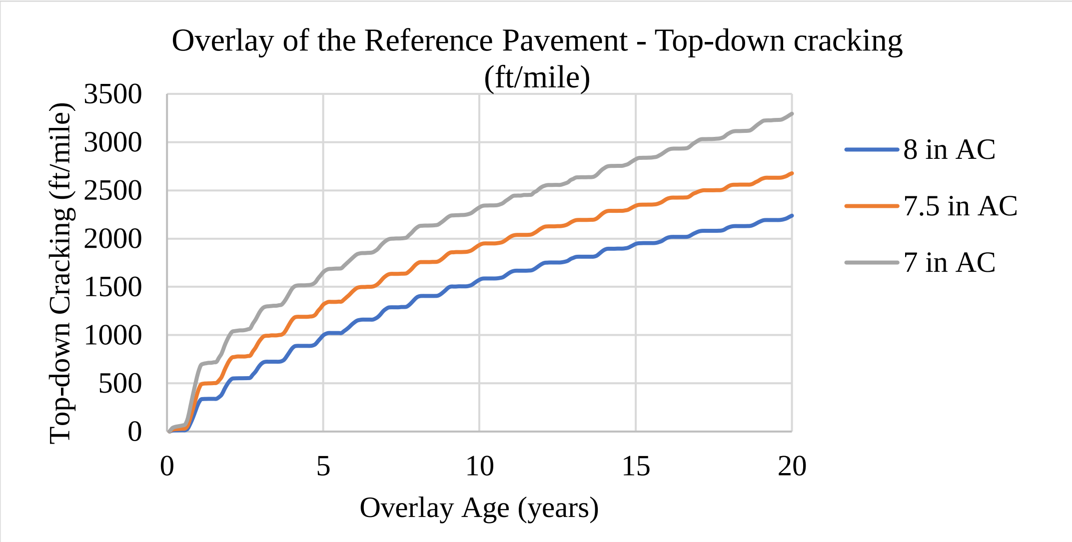

Figure 41 Predicted Top-down Cracking for the AC Overlay of the Reference Pavement Structure Considering Different Thicknesses of the Existing AC Layer

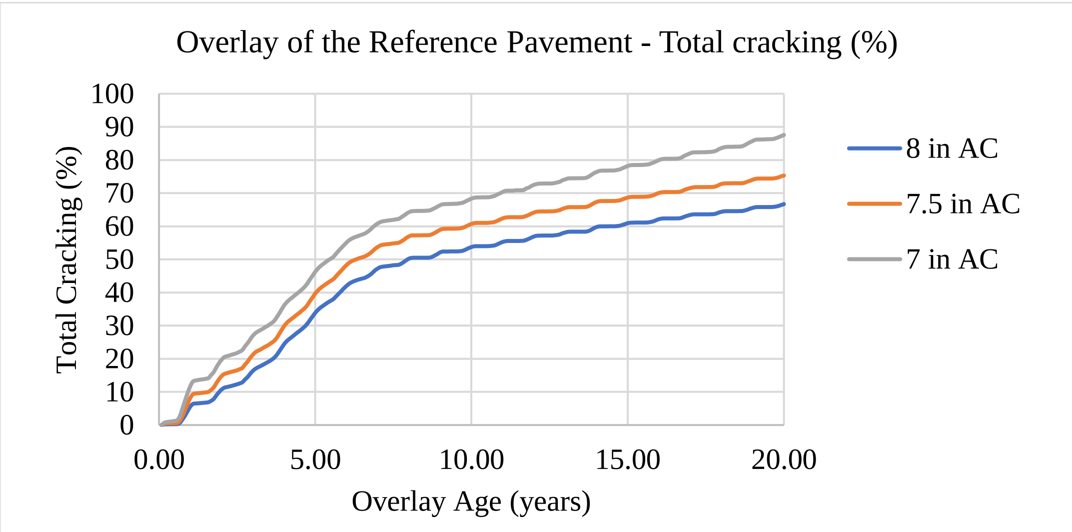

Figure 42 Total Cracking for the AC Overlay of the Reference Pavement Structure Considering Different Thicknesses of the Existing AC Layer

Figure 42 shows that the service life of the overlay, delimited by the time when total cracking reaches 25%, is 4, 3.5 and 3 years respectively for the case where the actual thickness of the existing AC layer is equal to 1) the design thickness (8 in), 2) the design thickness – ½ in (7.5 in) and 3) the design thickness – 1 in (7 in).

6.5.2. LCCA Using RealCost

The input parameters used for the life-cycle cost analysis are provided in Chapter 5, section 5.2, and are summarized in Table 8, however, instead of considering three different air-void contents in the AC mix, the following scenarios (alternatives) are considered: the actual thickness of the existing AC layer is equal to 1) the design thickness (8 in), 2) the design thickness – ½ in (7.5 in) and 3) the design thickness – 1 in (7 in).

Based on the results of section 6.5.1.2, the first heavy maintenance is scheduled after 10, 6 and 4 years, and the overlay service life is 4, 3.5 and 3, respectively for the cases where the actual thickness of the existing AC layer is equal to 1) the design thickness (8 in), 2) the design thickness – ½ in (7.5 in) and 3) the design thickness – 1 in (7 in).

Table 16Table 13Table 10 displays the scheduling of the construction and maintenance activities, as well as the corresponding agency and user costs for the three alternatives. The last row in the table provides the remaining life values for both the agency and user costs.

Table 16 Scheduling and Costs of Construction and Maintenance Activities for the Reference Pavement Considering an 8 in, 7.5 in and 7 in Thick Existing AC Layer

Alternatives			Actual thickness = design thickness = 8 in		Actual thickness = design thickness – ½ in = 7.5 in		Actual thickness = design thickness – 1 in = 7 in	
Year	Concession year	Operation year	Agency Cost (1000$)	User cost (1000$)	Agency Cost (1000$)	User cost (1000$)	Agency Cost (1000$)	User cost (1000$)
2021	1		497.81		497.81		497.81	
2022	2							
2023	3	1						
2024	4	2						
2025	5	3						
2026	6	4						
2027	7	5					101.09	33.44
2028	8	6						
2029	9	7			101.09	35.48		
2030	10	8					101.09	36.54
2031	11	9						
2032	12	10						
2033	13	11	101.09	39.93	101.09	39.93	101.09	39.93

2034	14	12						
2035	15	13						
2036	16	14			101.09	44.94	101.09	43.63
2037	17	15	101.09	44.94				
2038	18	16					101.09	47.68
2039	19	17						
2040	20	18			101.09	50.58		
2041	21	19	101.09	50.58			101.09	52.10
2042	22	20						
2043	23	21						
2044	24	22			101.09	56.93	101.09	56.93
2045	25	23	101.09	56.93				
2046	26	24						
2047	27	25			101.09	64.08	101.09	62.21
2048	28	26						
2049	29	27	101.09	64.08				
2050	30	28					101.09	67.98
2051	31		-50.54	-32.04	-0.55	-0.35	-58.58	-39.39

Table 17 presents a comparison between the present values of the agency and user costs of the three pavement alternatives, and estimates the pay-adjustment factor to be imposed on the construction subcontractor based on the total increased cost (agency and user costs) resulting from all maintenance activities to be performed throughout the 30-years concession period.

Table 17 Pay Factor Estimation for a Non-compliant Pavement Construction in Terms of the Thickness of the AC layer

Life-cycle present value	**Alternative 1 Actual thickness = design thickness = 8 in**	**Alternative 2 Actual thickness = design thickness – ½ in = 7.5 in**	**Alternative 3 Actual thickness = design thickness – 1 in = 7 in**
Agency cost (1000$)	559.93	607.54	669.69
User cost (1000$)	28.19	46.22	69.38
Total cost (1000$)	588.12	653.76	739.08
Total additional cost in present value (1000$)		653.76– 588.12 = 65.64	701.49– 588.12 = 150.96
Pay factor as % of construction cost		(65.64 x 100)/ 497.81 = 13.19%	(150.96 x 100)/ 497.81 = 30.32%

For the reference pavement structure, the pay-adjustment factors for a ½ in and a 1 in thinner AC layer are respectively 13.19% and 30.32%.

6.5.3. Estimated Pay-Adjustment Factors for a Non-Compliant Pavement Construction in terms of the Thickness of the AC Layer

Following the same steps shown in section 6.5.1, AASHTOWare Pavement ME is used to schedule maintenance activities for different pavement structures, with different materials properties and subject to different traffic and climatic conditions. Table 18Table 15 shows the scheduling of the first maintenance and the overlay service life for the different pavement structures, considering the cases where the actual thickness of the existing AC layer is equal to 1) the design thickness, 2) the design thickness – ½ in and 3) the design thickness – 1 in. Note the following: 1) the design thickness for all scenarios is 8 in, except for the case named “7 in AC” where the design thickness is 7 in and 2) the considered maintenance is a thick 5 in overlay (milling 5 in and overlaying 5 in) for all the considered scenarios.

RealCost is then used, as described in section 6.5.2, to calculate the life-cycle agency and user costs for all the considered scenarios, and consequently, to estimate the corresponding pay-adjustment factors. Note that the construction and maintenance costs used for the LCCA are as described in Chapter 5.

Figure 43Figure 17 shows the estimated pay-adjustment factors for all the considered pavement structures, for the aforementioned scenarios.

Table 18 First Maintenance Scheduling and Overlay Service Life for the Different Pavement Structures Considering an 8 in, 7.5 in and 7 in Thick Existing AC Layer

Pavement Structure	**Actual thickness = design thickness**		**Actual thickness = design thickness – ½ in**		**Actual thickness = design thickness – 1 in**	
	First maintenance (years)	**Overlay service life (years)**	**First maintenance (years)**	**Overlay service life (years)**	**First maintenance (years)**	**Overlay service life (years)**
Reference	10	4	6	3.5	4	3
Montana	9	4	6	3.5	4.5	3
Texas	4	3.5	3	3	2.5	2
Base A-2-4	5	3	3.75	2	2	1.75
Subgrade A-3	8	2.75	5.5	2.5	4	2
PG 82-22	11.75	4.75	7	4	5	3
25 mph	7	4	5	3.5	3.75	2.75
AADTT 5000	8	3.5	5	3	4	2.5
7 in AC layer	4	3	3	2	2	1.75
15 in Base Layer	11	4	6.75	3.5	4.75	3

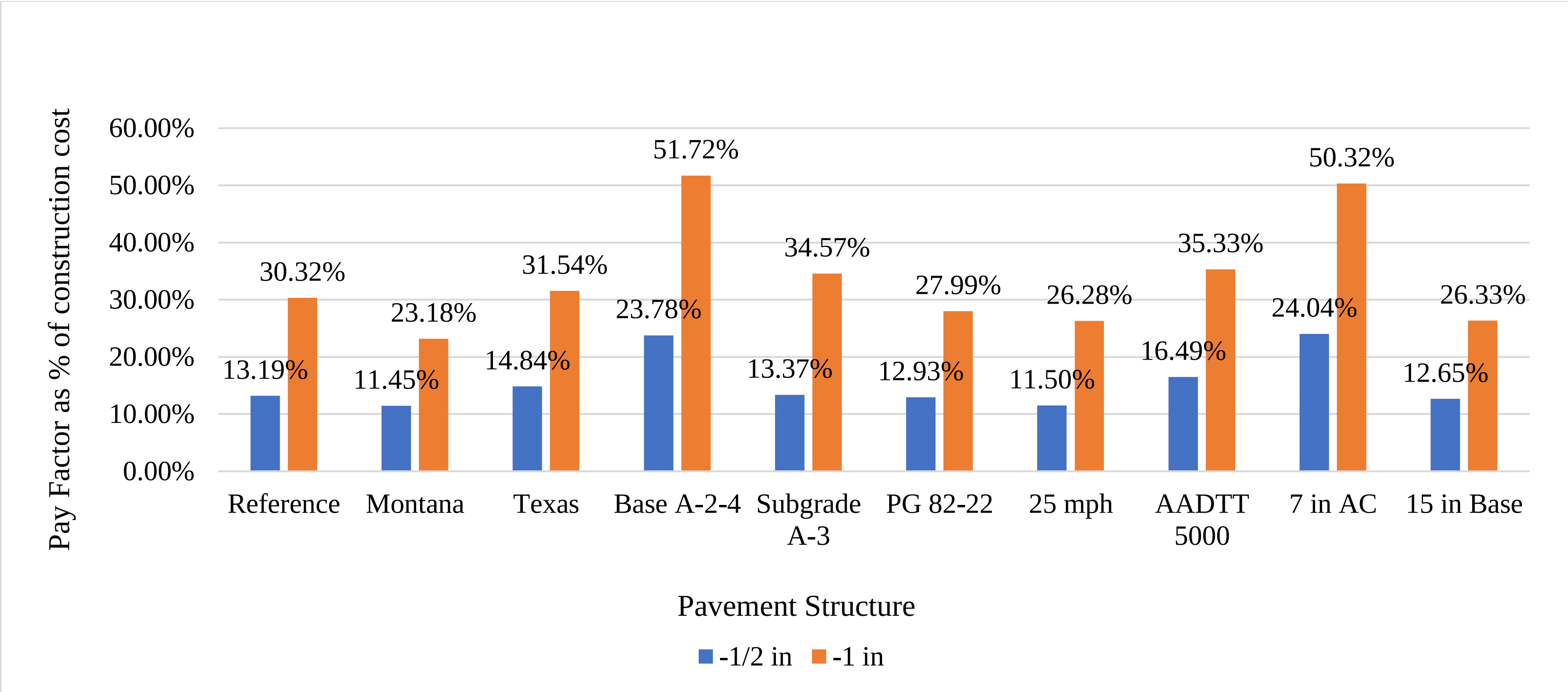

Figure 43 Estimated Pay-Adjustment Factor for Different Pavement Structures for a Non-Compliant Pavement Construction in Terms of the AC Layer Thickness

Based on the obtained results, it can be inferred that a low-quality of materials for any pavement layer (the AC layer, the base layer or the subgrade) will result in a higher pay-adjustment factor caused by the corresponding accelerated failure of the pavement, in terms of the total cracking performance. The quality of the base layer material seems to have the highest effect on the value of the pay-factor. The PG grade of the binder used in the AC mix did not show a significant effect on the estimated pay-factor. This can be explained by the fact that both PG grades considered for the analysis (PG 76-22 and PG 82-22) are considered to be high quality materials.

The design thickness of the AC layer is also an important parameter affecting the value of the pay-factor; for the case of a relatively thin designed AC layer (7 in), any additional reduction in the thickness will reduce the pavement's resistance to fatigue, accordingly increasing the pay factor. Similarly, a thicker base layer results in a lower pay-adjustment factor. Furthermore, a higher traffic volume leads to a higher pay-factor imposed for the reduction in the thickness of the AC layer.

The climatic conditions and the operational speed have a relatively low effect on the estimated pay-factor compared to the aforementioned parameters (material quality, layers thicknesses and traffic volume).

Finally, it is noticed that the estimated pay-factors for the non-compliance with the design AC layer thickness are significantly higher than those estimated for the off-target air void content and asphalt content in the AC mix. This can be explained by the fact that the effect of the reduced thickness remains visible in the overlay performance, while the effect of a higher-than-target air-void content or binder content in the existing AC layer was masked by the placement of a thick overlay. This finding emphasizes the importance of considering all maintenance activities for estimating the pay-adjustment factor, as some construction errors affect only the time to the first maintenance activities while others influence the pavement performance throughout its entire service life.

6.6. Summary and Conclusions

The main parameters tested for compliance with the specifications are the air-void content and the binder content in the AC mix as well as the thickness of the AC layer. In general, the pay-factor is determined based on the increased maintenance cost resulting from the out-of-specs pavement construction. An enhancement to the existing pay-factor estimation strategies can be achieved by considering all maintenance activities to be performed throughout the pavement's service life instead of considering only the first maintenance activity and including both the increased agency and user costs in the pay-factor estimation instead of considering solely the increase in the agency cost. These enhancements are of great importance in complex, long-term PPP contracts for road projects, involving two main parties, the highway agency and the concessionaire, in addition to several subcontractors, among which is the construction subcontractor.

This chapter provided a methodology for estimating the pay-adjustment factor to be imposed on the construction subcontractor in case of the delivery of an out-of-specs pavement construction in terms of the air-void content, the binder content in the AC mix and the thickness of the AC layer, based on the corresponding increase in both the agency and the user costs, and considering all maintenance activities performed throughout the concession period.

Based on the obtained results, the following conclusions can be drawn: 1) in PPP road projects, where high quality materials are used, especially in terms of the binder type used in the AC mix, rutting failure is not a concern; consequently, a relatively high tolerance of the binder content in the AC mix can be implemented; 2) both the air-void content in the AC mix and the thickness of the AC layer should be accurately controlled by construction subcontractor, due to their significant effect on the pavement's service life and life-cycle costs.

Nevertheless, the importance of the presented work does not reside in the estimated values of the pay-factors, but in the adopted methodology that effectively incorporates pavement performance prediction models in the treatment of the risk of not achieving the standard construction specifications in PPP road projects, and consequently avoiding disputes between PPP main parties.

CHAPTER 7

CONCESSIONAIRE COMPENSATION STRATEGIES FOR INCREASING TRUCK LOAD LIMIT

7.1. Introduction and Literature Review

For decades, highway agencies around the world intended to increase truck weight limits [10][11][12][13]. For instance, the Minnesota state legislature has periodically altered its regulations as to account for possible truck weight limit increase in specific areas of the state. The Local Road Research Board conducted a review of literature to investigate the effect of such 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 [12]. Hajek et al. developed a methodology for assessing the pavement cost in the case of a modification in truck weights and dimensions regulations [10]. OBrien et al. [11] investigated the implications of increasing the Gross Vehicle Weight limits on bridges. The impact of increased truck weights on pavement distresses has been extensively discussed in literature. However, in a PPP road context, and due to the complex nature of PPP contractual agreements, the drawbacks of overloaded trucks must be studied from two different perspectives.

The review of states legislatures regarding truck load limit in the US indicates specific cases for which highway agencies allow trucks to be overloaded. For instance, axle weight tolerances for agricultural commodities on non-Interstate highways of 35% for 2-axle trucks, 20% for 3, 4-axle trucks and 10% for 5-axle trucks are allowed in Illinois. In Nebraska, a 15% overweight axle load for beans and 20% overweight axle load for refuse are authorized after the issuance of an “overweight permit” for non-Interstate highways. In Texas, trucks may operate at 10% over state limits, and 12% for agricultural movements for non-Interstate highways as well [12]. The present study considers the cases where highway agencies increase the axle load limit for all truck types by 10%, 20% and 30%.

In PPP road projects, bidders prepare their proposals based on the actual traffic characteristics, including, but not limited to, trucks loading conditions. The highway agency’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. The concessionaire, in such case, holds the right to claim a compensation from the highway agency. To prevent future disputes between PPP partners, such change in truck loading regulations must be addressed during the negotiations, and PPP partners must include in the contract the form of compensation to be offered by the highway agency in case the latter increases the permissible truck load limit.

This chapter presents two compensation strategies that can be adopted by the highway agency for remunerating the concessionaire in case of the occurrence of a change in law regarding the maximum permissible truck load. These compensation strategies affect the tariff regime and the length of the concession period, the most negotiated items in PPP contracts [14][15][33].

The highway agency might pay the concessionaire a “shadow toll” for each overloaded truck. As explained in Chapter 3, section 3.6, a “shadow toll” is a form of availability-based payments; these are regular payments made by the highway agency to the concessionaire based on the provided service [4]. Alternatively stated, a “shadow toll" is not collected directly from users, but paid by the highway agency to the concessionaire based on the actual number and characteristics of vehicles using the road [44][45].

Extending the concession period has been adopted by highway agencies to solve disputes in several scenarios. The tunnel under the Channel between the UK and France, also referred to as the Eurotunnel or Chunnel, one of the largest PPP infrastructure projects, faced several disagreements between PPP partners, one caused by additional expenditures imposed by the highway agency during the construction. This was solved by a 10-year extension of the concession period in favor of the concessionaire [4].

The remuneration rate, in terms of the value of the shadow toll or the length of the extension of the concession period, is evaluated based on the quantified additional damage resulting from the change in truck loading condition. This study uses the Pavement ME to predict the pavement performance and to schedule maintenance works for various truck loading conditions. When required, the RealCost software is used to perform the pavement life cycle cost analysis. The adopted methodologies to re-assess the values of the toll or concession period are explained in details in the following sections.

7.2. Modeling the Load Increase in AASHTOWare Pavement ME

Truck loading in AASHTOWare Pavement ME is modeled using an axle load spectra approach. The percentages of single axles carrying a load ranging from 3,000 to 41,000 pounds, at 1,000 pounds intervals, are specified for each truck type (classes 4 to 13) and for each month. The same inputs are required for tandem, tridem and quad axles with ranges from 6,000 to 82,000 pounds at 2,000 pounds intervals for the tandem axles and from 12,000 to 102,000 pounds at 3,000 pounds intervals for tridem and quad axles. The software provides the default axle load distributions (ALD) as calibrated based on LTPP test sections from around the US and Canada [26].

In the present study, the AASHTOWare Pavement ME is used to predict the response of a pavement for four scenarios: all trucks are loaded based on the default axle load distribution pre-defined in the software and truck classes 5 to 13 are overloaded by 10%, 20% and 30%. Class 4 trucks (buses) are not considered 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 is modeled by shifting the axle load distribution for each truck class (5 to 13) and for each axle type (single, tandem, tridem and quad) as to obtain a 10%, 20% or 30% higher average axle load. The default single axle load distribution for class 9 trucks, as well as the shifted axle load distributions for the 10%, 20% and 30% overloaded class 9 trucks are shown in Figure 44 and Table 19. The same was done for the single, tandem, tridem and quad axle load for truck classes 5 to 13, and the corresponding plots are available in Appendix A.

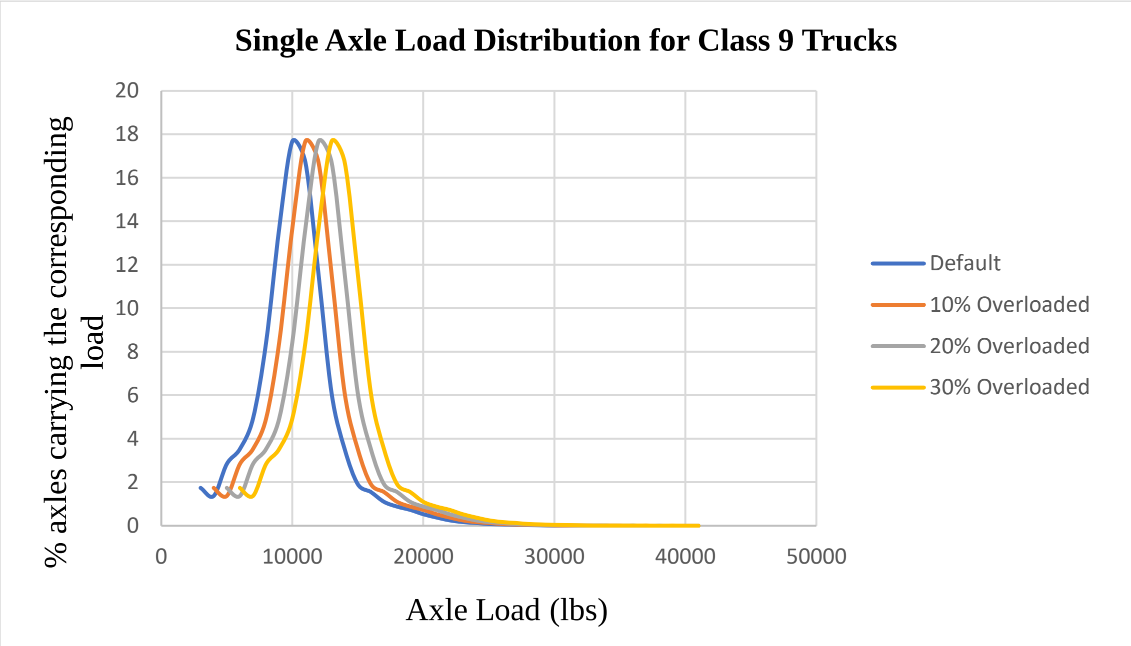

Figure 44 Single Axle Load Distribution for Class 9 Trucks for the Default Loading Condition and for the Cases of Increasing Truck Load Limit by 10, 20 and 30%

Table 19 Single Axle Load Distribution for Class 9 Trucks for the Default Loading Condition and for the Cases of Increasing Truck Load Limit by 10, 20 and 30%

Axle Load (lbs)	Percentage of single axles carrying the corresponding load			
	Default Loading Condition	10% Overloaded	20% Overloaded	30% Overloaded
3000	1.74	0	0	0
4000	1.37	1.74	0	0
5000	2.84	1.37	1.74	0
6000	3.53	2.84	1.37	1.74
7000	4.93	3.53	2.84	1.37
8000	8.43	4.93	3.53	2.84
9000	13.67	8.43	4.93	3.53
10000	17.68	13.67	8.43	4.93
11000	16.71	17.68	13.67	8.43
12000	11.57	16.71	17.68	13.67
13000	6.09	11.57	16.71	17.68
14000	3.52	6.09	11.57	16.71
15000	1.91	3.52	6.09	11.57
16000	1.55	1.91	3.52	6.09
17000	1.1	1.55	1.91	3.52
18000	0.88	1.1	1.55	1.91
19000	0.73	0.88	1.1	1.55

20000	0.53	0.73	0.88	1.1
21000	0.38	0.53	0.73	0.88
22000	0.25	0.38	0.53	0.73
23000	0.17	0.25	0.38	0.53
24000	0.13	0.17	0.25	0.38
25000	0.08	0.13	0.17	0.25
26000	0.06	0.08	0.13	0.17
27000	0.04	0.06	0.08	0.13
28000	0.03	0.04	0.06	0.08
29000	0.02	0.03	0.04	0.06
30000	0.01	0.02	0.03	0.04
31000	0.01	0.01	0.02	0.03
32000	0.01	0.01	0.01	0.02
33000	0.01	0.01	0.01	0.01
34000	0.01	0.01	0.01	0.01
35000	0	0.01	0.01	0.01
36000	0.01	0	0.01	0.01
37000	0	0.01	0	0.01
38000	0	0	0.01	0
39000	0	0	0	0.01
40000	0	0	0	0
41000	0	0	0	0
Total	100	100	100	100
Average axle load (lbs)	10400	11400	12400	13400
% increase in the average axle load relative to default		9.62	19.23	28.85

The average axle load for each loading condition is calculated as follows:

Average Axle Load (AAL) = $\sum(AL_i * P_i)/100$ (Eq.5).

where AL_i is the axle load ranging from 3,000 to 41,000 pounds,

and P_i is the percentage of axles carrying the load AL_i.

The average single axle loads for class 9 trucks are 10400, 11400, 12400 and 13400 lbs for the default loading condition and for the 10%, 20% and 30% overloaded trucks respectively (Table 19).

The percentage increase in the average axle load is calculated relative to the default average axle load as follows:

Percent increase in Average Axle Load for x% overloaded class 9 trucks =

100* (AAL_{OVx}– $AAL_{default}$)/ ($AAL_{default}$) (Eq. 6).

where AAL_{OVx} is the average axle load for x% overloaded class 9 trucks, x = 10, 20 or 30 and $AAL_{default}$ is the average axle load for the default axle load distribution.

For instance, the percent increase in the average single axle load for 10% overloaded class 9 trucks relative to the default loading case is 100(11400 - 10400)/10400= 9.62%. Similarly, for 20% and 30% overloaded trucks, the percent increase in the average single axle load are 19.2 and 28.8 % respectively. Note that an increase of the average axle load by exactly 10, 20 and 30% could not be achieved because of the fixed axle load values pre-defined in the software.

The same steps are repeated for truck classes 5 to 13 to obtain the input axle load distributions for all truck types carrying a 10%, 20% and 30% overload.

The default single, tandem, tridem and quad average axle loads as well as the average axle loads for 10%, 20% and 30% overloaded trucks for truck classes 5 to 13 are shown respectively in Table 20 to Table 23.

Table 20 Average Single Axle Load for Truck Classes 5 – 13 for the Default Loading Condition and for the Cases of Increasing Truck Load Limit by 10, 20 and 30%

	Average Single Axle Load (lbs)

Truck Class	Default Loading Condition	10% Overloaded	20% Overloaded	30% Overloaded
Class 5	7591.8	8591.8	9591.8	10591.8
% increase relative to default		13.17	26.34	39.52
Class 6	10767.4	11767.4	12763.7	13765.5
% increase relative to default		9.29	18.54	27.84
Class 7	13443.5	14513.6	16436.8	17432.7
% increase relative to default		7.96	22.27	29.67
Class 8	9178.4	10178.4	11178.4	12174.9
% increase relative to default		10.90	21.79	32.65
Class 9	10399.5	11399.5	12399.5	13399.5
% increase relative to default		9.62	19.23	28.85
Class 10	10273	11273	12258.2	13265.6
% increase relative to default		9.73	19.32	29.13
Class 11	11241.6	12241.6	13234.2	14236
% increase relative to default		8.90	17.73	26.64
Class 12	10496.6	11496.6	12496.6	13496.6
% increase relative to default		9.53	19.05	28.58
Class 13	10226.4	11226.4	12226.4	13222.9
% increase relative to default		9.78	19.56	29.30

Table 21 Average Tandem Axle Load for Truck Classes 5 – 13 for the Default Loading Condition and for the Cases of Increasing Truck Load Limit by 10, 20 and 30%

Truck Class	Average Tandem Axle Load (lbs)			
	Default Loading Condition	10% Overloaded	20% Overloaded	30% Overloaded
Class 5	14490.4	16490.4	18490.4	20490.4
% increase relative to default		13.80	27.60	41.41
Class 6	19934.4	21934.4	23934.4	25934.4
% increase relative to default		10.03	20.07	30.10
Class 7	23116.2	25116.2	27101.4	31047
% increase relative to default		8.65	17.24	34.31

Class 8	15008.2	17008.2	19008.2	21008.2
% increase relative to default		13.33	26.65	39.98
Class 9	23022.6	25022.6	27022.6	29022.6
% increase relative to default		8.69	17.37	26.06
Class 10	24699	26699	28699	30692
% increase relative to default		8.10	16.19	24.26
Class 11	20972	22972	24972	26972
% increase relative to default		9.54	19.07	28.61
Class 12	21267.4	23267.4	25267.4	27260.2
% increase relative to default		9.40	18.81	28.18
Class 13	24398.6	26398.6	28339.4	32297
% increase relative to default		8.20	16.15	32.37

Table 22 Average Tridem Axle Load for Truck Classes 5 – 13 for the Default Loading Condition and for the Cases of Increasing Truck Load Limit by 10, 20 and 30%

Truck Class	**Average Tridem Axle Load (lbs)**			
	Default Loading Condition	**10% Overloaded**	**20% Overloaded**	**30% Overloaded**
Class 5	28997.4	31997.4	35788.5	37128
% increase relative to default		10.35	23.42	28.04
Class 6	28045.8	31045.8	33193.2	36811.2
% increase relative to default		10.70	18.35	31.25
Class 7	41935.2	44908.2	50909.7	53810.7
% increase relative to default		7.09	21.40	28.32
Class 8	36453.6	39399.6	42322.2	45399
% increase relative to default		8.08	16.10	24.54
Class 9	16731	19731	19731	22731
% increase relative to default		17.93	17.93	35.86
Class 10	30067.8	33058.8	36050.7	39050.4
% increase relative to default		9.95	19.90	29.87
Class 11	21916.2	24916.2	27916.2	27916.2

% increase relative to default		13.69	27.38	27.38
Class 12	32849.7	35642.7	38644.8	41681.7
% increase relative to default		8.50	17.64	26.89
Class 13	39246.3	42138.3	48100.8	50799.6
% increase relative to default		7.37	22.56	29.44

Table 23 Average Quad Axle Load for Truck Classes 5 – 13 for the Default Loading Condition and for the Cases of Increasing Truck Load Limit by 10, 20 and 30%

Truck Class	**Average Quad Axle Load (lbs)**			
	Default Loading Condition	**10% Overloaded**	**20% Overloaded**	**30% Overloaded**
Class 5	28987.5	31987.5	34258.5	37119
% increase relative to default		10.35	18.18	28.05
Class 6	28046.7	31046.7	33223.5	36812.1
% increase relative to default		10.70	18.46	31.25
Class 7	41935.2	44908.2	50918.1	53810.7
% increase relative to default		7.09	21.42	28.32
Class 8	36453.6	39399.6	42328.2	45408.6
% increase relative to default		8.08	16.12	24.57
Class 9	16731	19731	19731	22731
% increase relative to default		17.93	17.93	35.86
Class 10	30068.7	33059.7	36051.6	39027.3
% increase relative to default		9.95	19.90	29.79
Class 11	21916.2	24916.2	27916.2	27916.2
% increase relative to default		13.69	27.38	27.38
Class 12	32849.7	35642.7	38565.6	41735.7
% increase relative to default		8.50	17.40	27.05
Class 13	39243.3	42135.3	47989.8	50804.1
% increase relative to default		7.37	22.29	29.46

7.3. Concessionaire Compensation through a Shadow Toll paid by the Highway Agency

In the case of the availability of public funds, the highway agency 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, as shown in Figure 45.

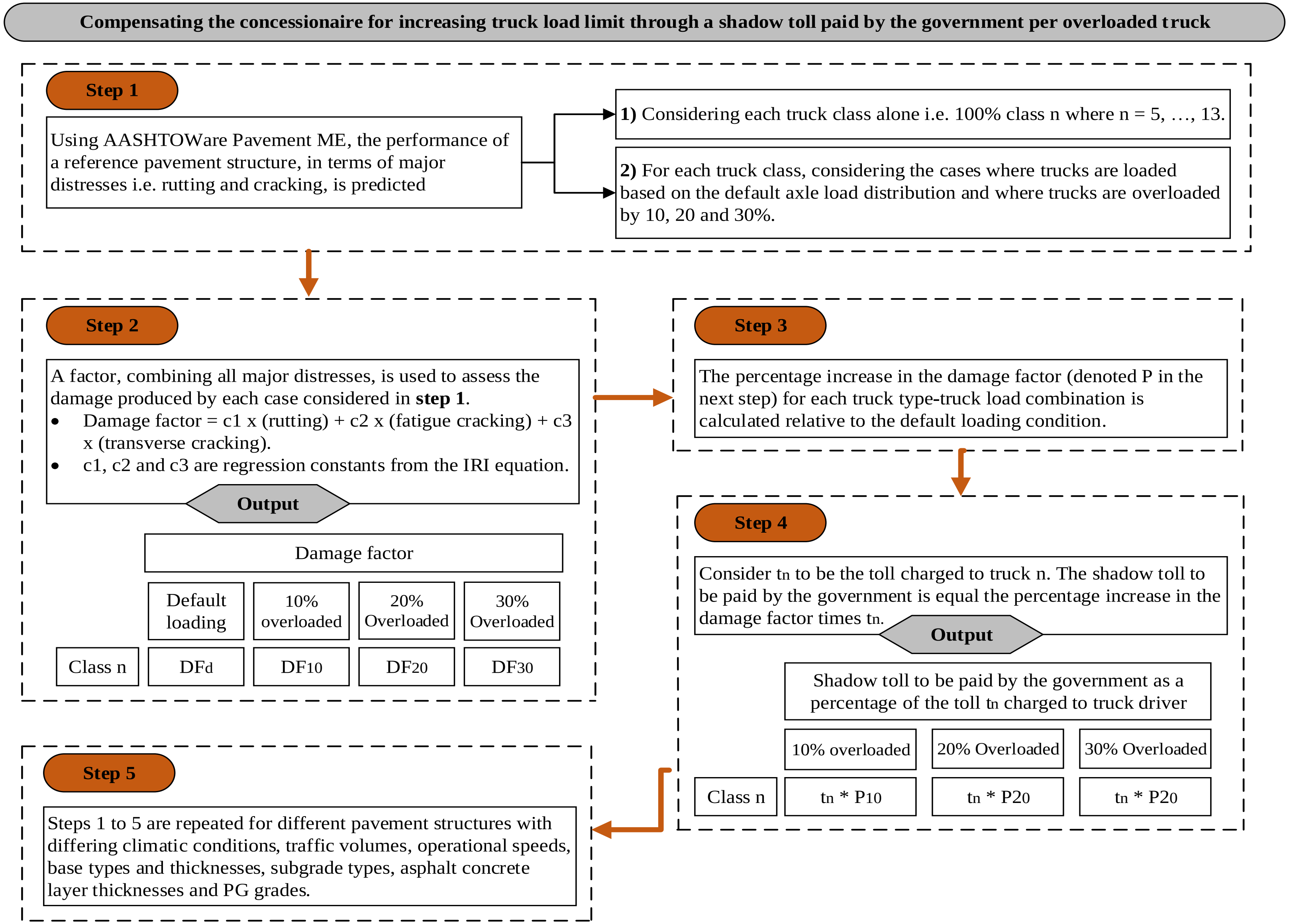

Figure 45 Methodology for Determining the Shadow Toll Paid by the Highway Agency to Compensate the Concessionaire for Increasing Truck Load Limit

7.3.1. Pavement Performance Prediction using AASHTOWare Pavement ME

The shadow toll is determined for each truck type individually; thus, each truck class (5 to 13) is 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 is considered to include 100% class n trucks. Furthermore, for each class n trucks, four loading conditions are modeled: 1) trucks are loaded based on the default axle load distribution pre-defined in Pavement ME, and trucks are overloaded by 2) 10%, 3) 20% and 4) 30%. The axle load distributions for 10, 20 and 30% overloaded trucks are established, for class n trucks, as explained in the previous section.

These runs are repeated for different pavement structures with varying climatic conditions, material properties, layers thicknesses and traffic volumes. In total, for each considered pavement structure, 36 runs are conducted: 9 different truck classes (classes 5 to 13), and for each truck class, four loading conditions (default axle load distribution, 10%, 20% and 30% overloaded), as shown in Table 24.

Table 24 Runs Conducted for the Reference Pavement Structure

	Axle Load Distribution			
Truck class considered	**Default ALD**	**10% overloaded**	**20% overloaded**	**30% overloaded**
100% class 5	Run 1	Run 2	Run 3	Run 4
100% class 6	Run 5	Run 6	Run 7	Run 8
100% class 7	Run 9	Run 10	Run 11	Run 12
100% class 8	Run 13	Run 14	Run 15	Run 16
100% class 9	Run 17	Run 18	Run 19	Run 20
100% class 10	Run 21	Run 22	Run 23	Run 24
100% class 11	Run 25	Run 26	Run 27	Run 28
100% class 12	Run 29	Run 30	Run 31	Run 32
100% class 13	Run 33	Run 34	Run 35	Run 36

7.3.2. AASHTOWare Pavement ME Output

An example of the predicted performance of the reference pavement structure, in terms of the International Roughness Index (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 Figure 46 to Figure 51 , respectively. The percent total cracking is calculated by converting the predicted top-down cracking from ft/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 is observed from the software runs.

Figure 46 Predicted IRI for the Reference Pavement Structure Subject to Class 9 trucks when 1) loaded based on the Default Axle Load Distribution and when Overloaded by 2) 10%, 3) 20% and 4) 30%

Figure 47 Predicted Total Rutting for the Reference Pavement Structure Subject to Class 9 trucks when 1) loaded based on the Default Axle Load Distribution and when Overloaded by 2) 10%, 3) 20% and 4) 30%

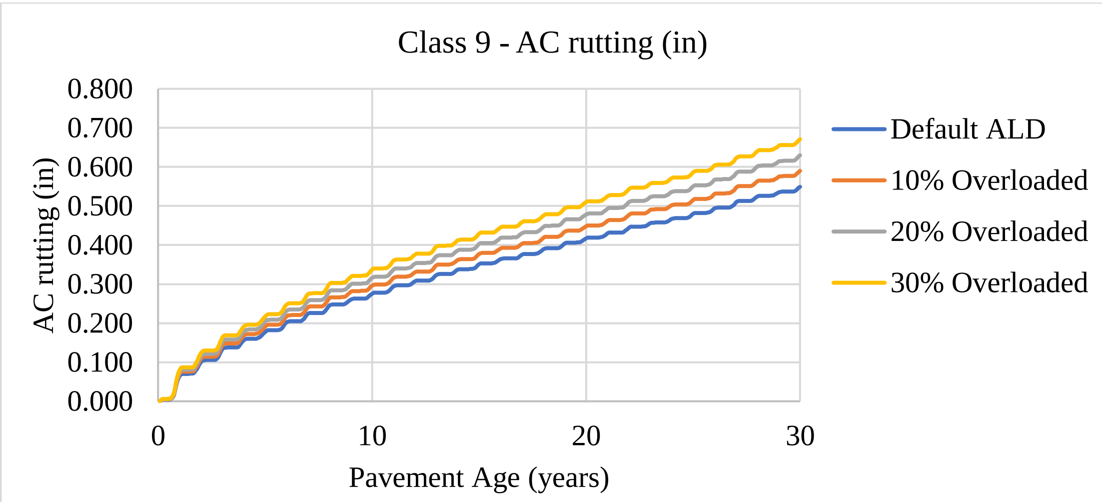

Figure 48 Predicted AC Rutting for the Reference Pavement Structure Subject to Class 9 trucks when 1) loaded based on the Default Axle Load Distribution and when Overloaded by 2) 10%, 3) 20% and 4) 30%

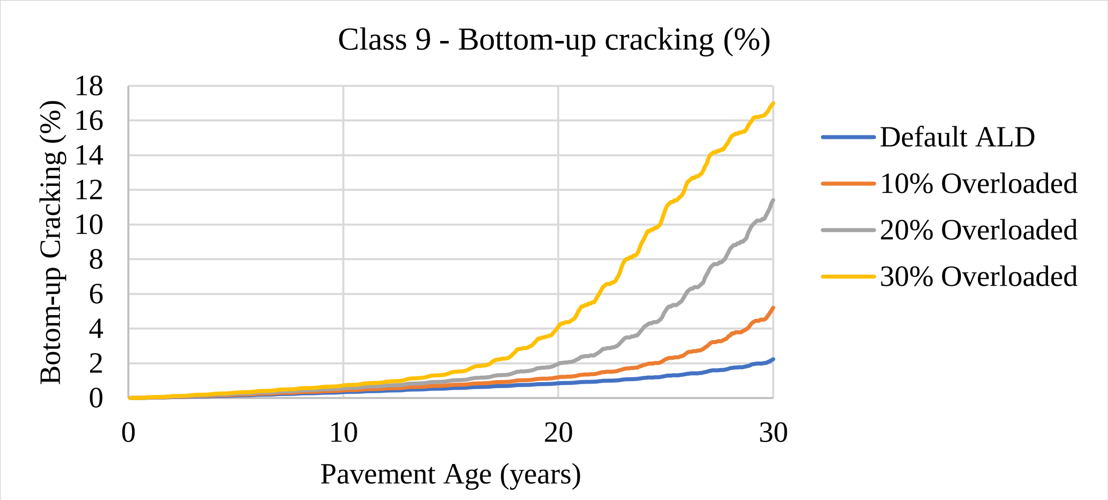

Figure 49 Predicted Bottom-up Cracking for the Reference Pavement Structure Subject to Class 9 trucks when 1) loaded based on the Default Axle Load Distribution and when Overloaded by 2) 10%, 3) 20% and 4) 30%

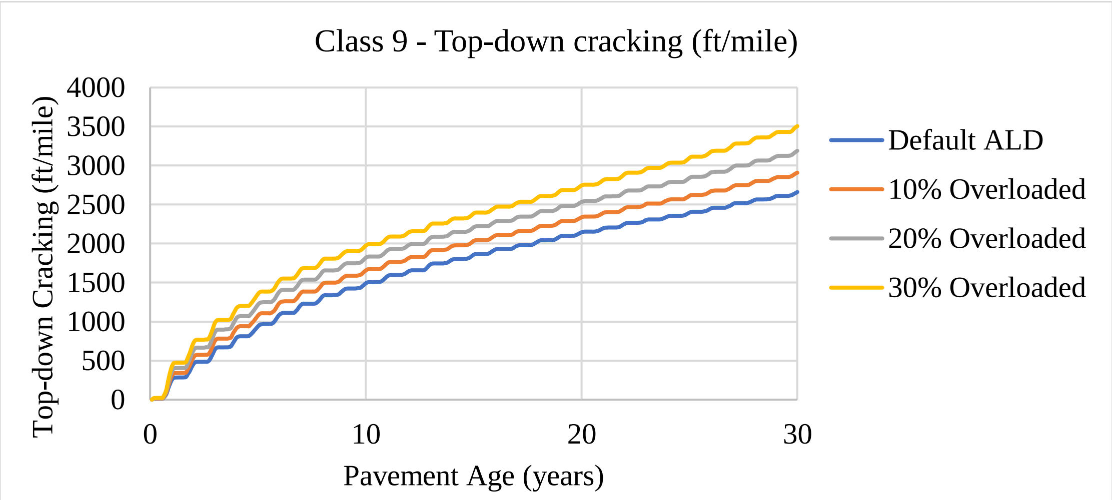

Figure 50 Predicted Top-down Cracking for the Reference Pavement Structure Subject to Class 9 trucks when 1) loaded based on the Default Axle Load Distribution and when Overloaded by 2) 10%, 3) 20% and 4) 30%

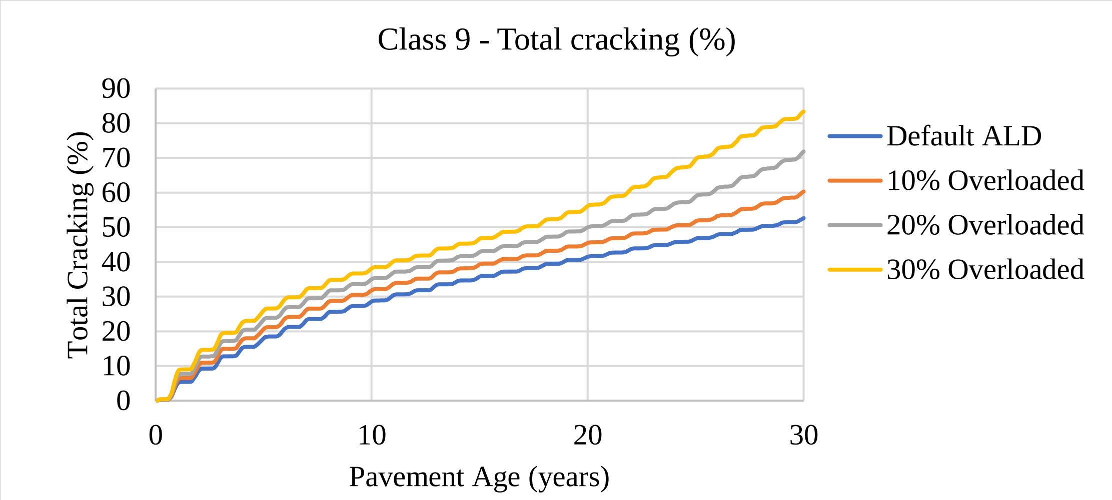

Figure 51 Total Cracking for the Reference Pavement Structure Subject to Class 9 trucks when 1) loaded based on the Default Axle Load Distribution and when Overloaded by 2) 10%, 3) 20% and 4) 30%

The predicted pavement distresses at 30 years for truck classes 5 to 13 when 1) loaded based on the Default Axle Load Distribution and when Overloaded by 2) 10%, 3) 20% and 4) 30% are shown respectively in Table 25, Table 26,

Table 27 and Table 28.

Table 25 Predicted Distresses at 30 years for the Reference Pavement Structure subject to Trucks Loaded based on the Default Axle Load Distribution

Truck Class	IRI (in/mi)	Total Rutting (in)	Bottom-up cracking (%)	Top-down cracking (ft/mile)	Thermal cracking (ft/mile)
Class 5	143.80	0.37	0.36	352.09	0.00
Class 6	152.00	0.57	0.97	2018.58	0.00
Class 7	160.60	0.75	8.32	3836.23	0.00
Class 8	150.00	0.52	0.96	1005.16	0.00
Class 9	156.60	0.68	2.24	2661.01	0.00
Class 10	159.80	0.75	3.02	3255.83	0.00
Class 11	156.50	0.67	11.30	1225.69	0.00
Class 12	158.70	0.72	6.49	2129.59	0.00
Class 13	166.70	0.88	18.34	4040.08	0.00

Table 26 Predicted Distresses at 30 years for the Reference Pavement Structure subject to the 10% Overloaded Trucks

Truck Class	IRI (in/mi)	Total Rutting (in)	Bottom-up cracking (%)	Top-down cracking (ft/mile)	Thermal cracking (ft/mile)
Class 5	145.00	0.40	0.47	430.56	0.00
Class 6	153.50	0.60	1.38	2189.06	0.00
Class 7	163.00	0.79	14.70	4259.53	0.00
Class 8	151.60	0.56	1.40	1173.31	0.00
Class 9	158.50	0.72	5.21	2908.79	0.00
Class 10	162.10	0.79	7.05	3616.68	0.00
Class 11	158.80	0.71	17.13	1392.50	0.00
Class 12	160.70	0.76	13.39	2314.34	0.00
Class 13	169.30	0.92	20.27	4485.86	0.00

Table 27 Predicted Distresses at 30 years for the Reference Pavement Structure subject to the 20% Overloaded Trucks

Truck Class	IRI (in/mi)	Total Rutting (in)	Bottom-up cracking (%)	Top-down cracking (ft/mile)	Thermal cracking (ft/mile)
Class 5	146.10	0.42	0.62	521.83	0.00
Class 6	155.00	0.63	2.38	2363.00	0.00
Class 7	167.30	0.86	19.84	5250.53	0.00
Class 8	153.20	0.59	2.54	1345.63	0.00
Class 9	160.80	0.76	11.41	3189.98	0.00
Class 10	164.60	0.84	13.30	4029.41	0.00
Class 11	160.90	0.75	19.71	1554.20	0.00
Class 12	163.10	0.81	18.21	2510.15	0.00
Class 13	172.40	0.98	21.55	5140.71	0.00

Table 28 Predicted Distresses at 30 years for the Reference Pavement Structure subject to the 30% Overloaded Trucks

Truck Class	IRI (in/mi)	Total Rutting (in)	Bottom-up cracking (%)	Top-down cracking (ft/mile)	Thermal cracking (ft/mile)
Class 5	147.30	0.45	0.81	626.11	0.00

Class 6	156.60	0.67	5.05	2544.26	0.00
Class 7	169.80	0.90	21.13	5869.19	0.00
Class 8	154.90	0.63	5.70	1522.08	0.00
Class 9	163.20	0.81	17.00	3504.88	0.00
Class 10	167.10	0.88	17.89	4507.21	0.00
Class 11	162.80	0.79	21.14	1718.41	0.00
Class 12	165.40	0.85	20.31	2721.85	0.00
Class 13	176.70	1.05	23.37	6054.38	0.00

7.3.3. Damage Factor Definition and Calculation

The shadow toll to be paid by the highway agency 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. 7 [88].

$$IRI = IRI_0 + c_1 (RD) + c_2 (FC_{total}) + c_3 (TC) + c_4 (SF) \qquad \text{(Eq. 7).}$$

where,

IRI = International Roughness Index (in/mile),

IRI_0 = initial IRI after construction (in/mile),

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 AC 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 runs 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. 8) which includes all pavement distresses, inspired from the IRI equation, is adopted to assess the pavement damage caused by different truck types with different loading conditions.

Damage factor = c1*(total rutting) + c2*(total cracking) + c3*(thermal cracking) (Eq. 8).

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, are omitted and the distresses included in the damage factor equation are those predicted by Pavement ME after 30 years.

Taking for example class 9 trucks, the predicted distresses at 20 years respectively for the default loading and for 10%, 20% and 30% overloaded trucks are as follows: total rutting 0.68, 0.72, 0.76 and 0.81 in and total cracking 52.64, 60.30, 71.83 and 81.38 %. No thermal cracking is observed. The damage factor for the default loading condition is therefore 40*(0.68) + 0.4*(52.64) + 0.008(0) = 48.09.

Considering the reference pavement structures subject to different truck types under different loading conditions, 36 damage factors are determined for each truck class/truck load combination, provided in Table 29.

Table 29 Damage Factors for Different Truck type/Truck load Combinations for the Reference Pavement Structure

Truck class	Damage Factor			
	Default Axle Load Distribution	10% overloaded	20% overloaded	30% overloaded
Class 5	17.61	19.37	21.16	23.19
% increase relative to default case		9.98	20.14	31.66
Class 6	38.28	41.10	44.17	48.01
% increase relative to default case		7.36	15.40	25.43
Class 7	62.35	69.67	82.15	89.04
% increase relative to default case		11.74	31.76	42.80
Class 8	28.76	31.69	34.97	39.01
% increase relative to default case		10.20	21.61	35.65
Class 9	48.09	52.84	59.17	65.55
% increase relative to default case		9.87	23.03	36.30
Class 10	55.67	61.82	69.25	76.50
% increase relative to default case		11.04	24.38	37.41
Class 11	40.49	45.84	49.66	53.07
% increase relative to default case		13.22	22.65	31.09
Class 12	47.53	53.37	58.62	62.86
% increase relative to default case		12.29	23.34	32.26
Class 13	72.98	79.05	86.69	97.21
% increase relative to default case		8.31	18.77	33.19

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

For instance, a 20% overloaded class 9 truck caused a 23.03% higher damage compared to the case where class 9 trucks are loaded based on the default axle load distribution. 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 highway agency must pay the concessionaire, in addition to the toll charged to the truck driver, a shadow toll valued at 23.03% of t_9, in case the highway agency increases truck load limit by 20%. The shadow toll to be paid 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 Figure 52, Figure 53 and Figure 54 respectively. The estimated shadow tolls for classes 6, 7, 8, 10, 11 and 13 are available in Appendix B.

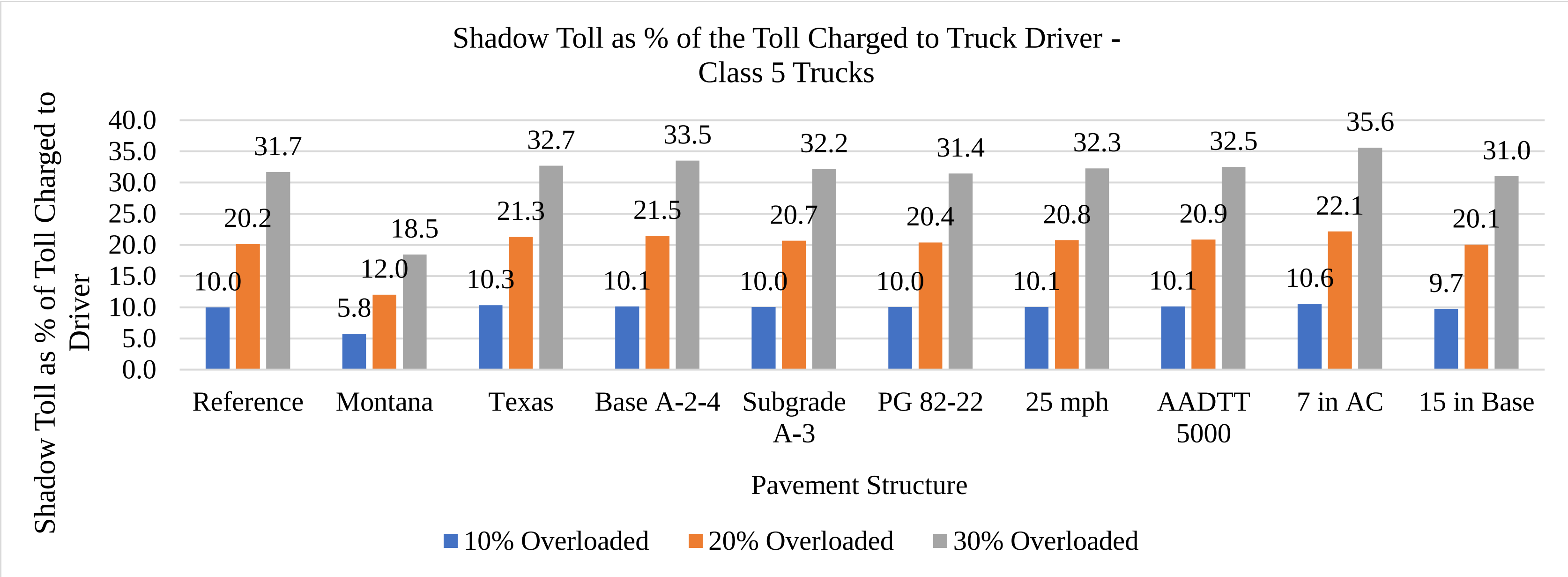

Figure 52 Shadow Toll for 10%, 20% and 30% Overloaded Class 5 Trucks

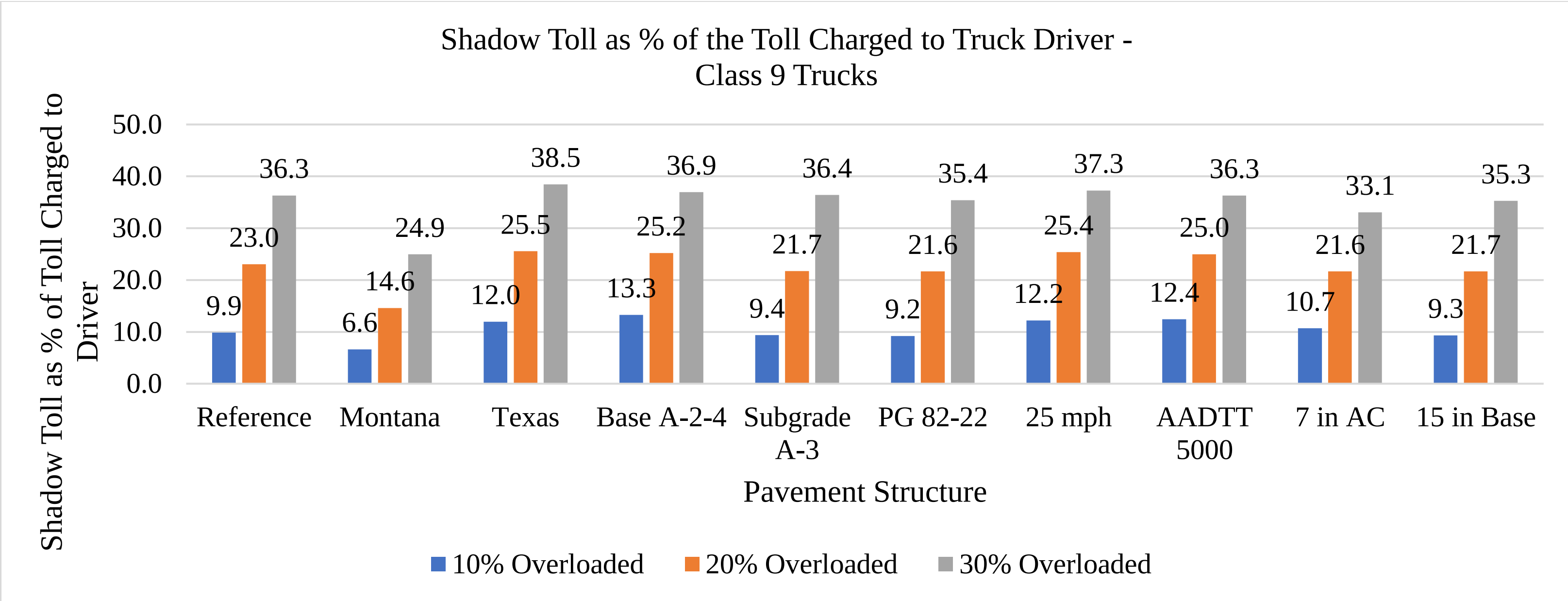

Figure 53 Shadow Toll for 10%, 20% and 30% Overloaded Class 9 Trucks

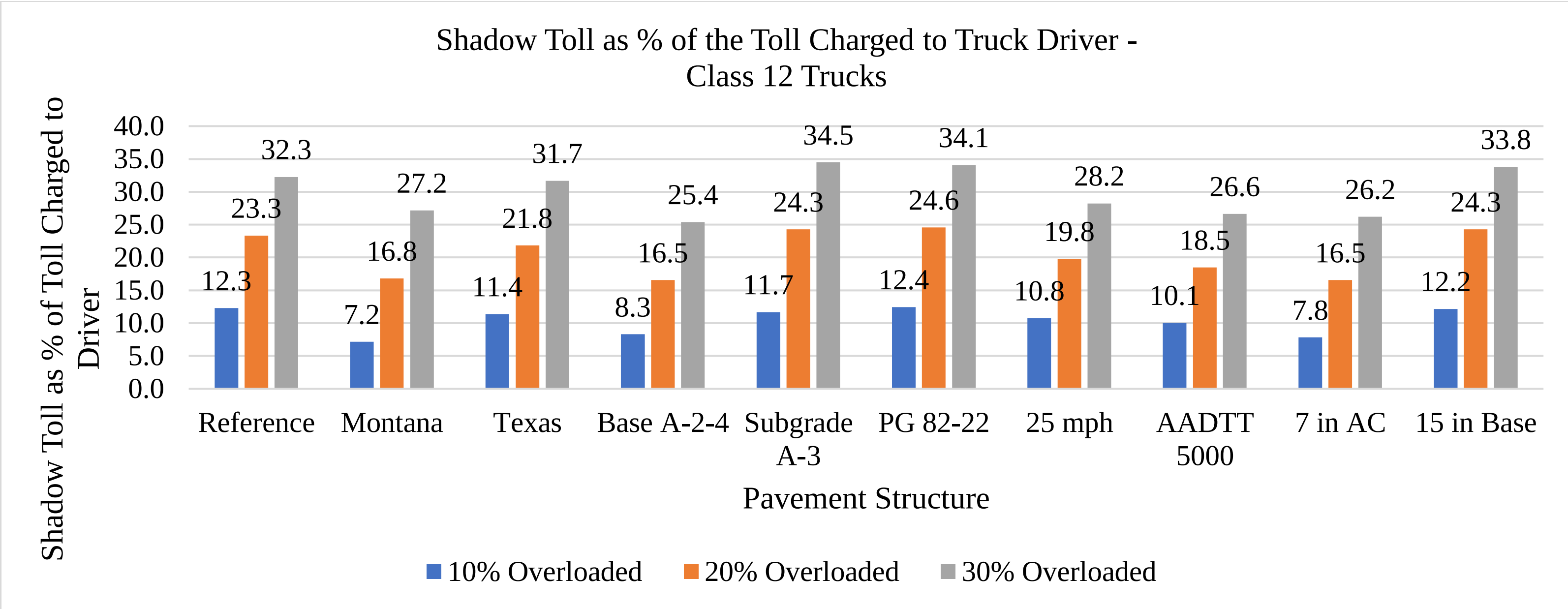

Figure 54 Shadow Toll for 10%, 20% and 30% Overloaded Class 12 Trucks

For the case where the legal truck load limit is increased by 10%, the shadow tolls determined for class 5 trucks are around 10% of the toll charged to the truck driver for all the considered cases, except for the Montana climate where the corresponding shadow toll is 5.8% of the toll charged to the truck driver. Furthermore, the highest rates of the shadow toll are observed for relatively thinner pavements (7 in AC layer) and for higher traffic volumes (AADTT 5000).

The rate of the shadow toll for class 9 trucks is between 6.6 and 13.3%, 14.6 and 25.2% and 24.9 and 37.3% of the toll charged to truck driver, respectively for the cases where the permissible truck load limit is increased by 10%, 20% and 30%.

In summary, different trends of shadow tolls for different loading conditions are observed for each truck class. For the Montana climate, however, it is noticed that the value of the shadow toll is 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 leads to small differences among the damage factors calculated for the different truck type – truck load combinations, and consequently to low values of the shadow toll.

7.4. Concessionaire Compensation by Extending the Concession Period

The highway agency 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. The methodology for determining the length of the extension of the concession period as a means to compensate the concessionaire for increasing truck load limit is shown in Figure 55.

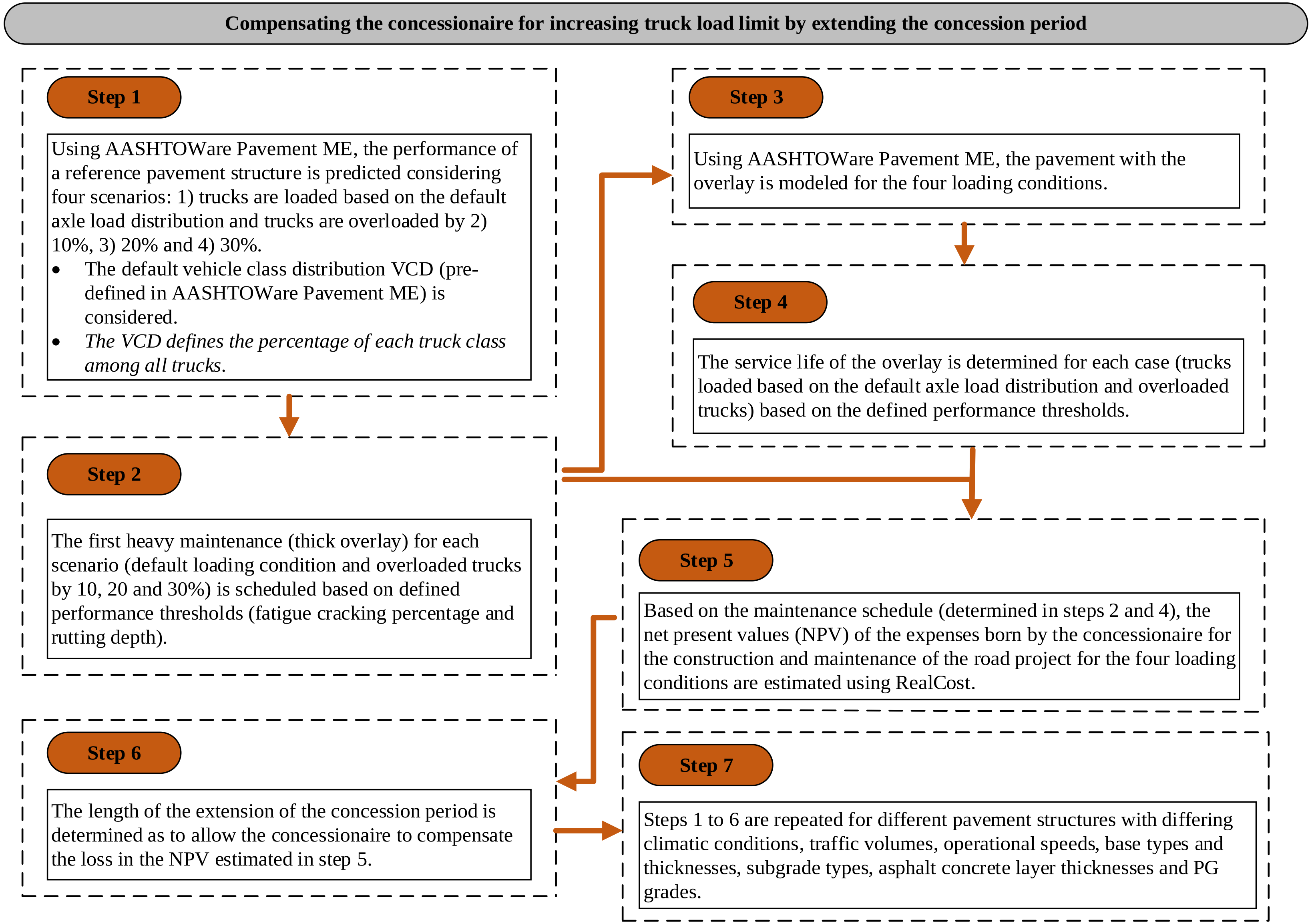

Figure 55 Methodology for Determining the length of Extension of the Concession Period as a Means to Compensate the Concessionaire for Increasing Truck Load Limit

7.4.1. Pavement Performance Prediction using AASHTOWare Pavement ME

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. In this section, however, 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). For simplicity reasons, the default VCD, shown in Table 2, is adopted.

For each pavement structure, four runs are needed, considering the following loading conditions: 1) default axle load distribution is considered for all truck types, and when highway agency increases truck load limit by 2) 10%, 3) 20% and 4) 30%. The predicted distresses for the four loading conditions considering the reference pavement structure are shown in Figure 56 to Figure 61.

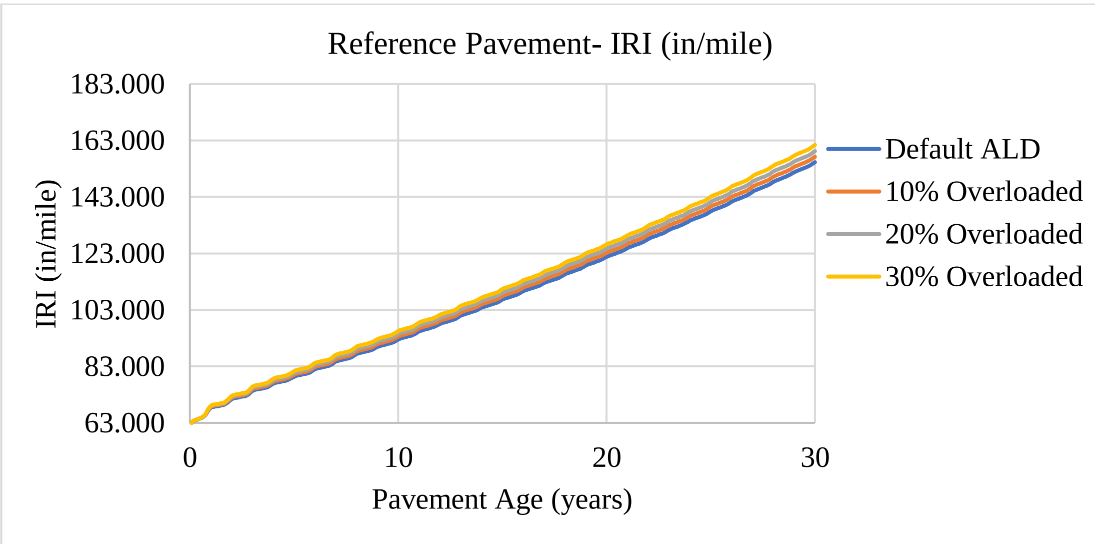

Figure 56 Predicted IRI for the Reference Pavement Structure when all Trucks are loaded based on the Default Axle Load Distribution and when Overloaded by 2) 10%, 3) 20% and 4) 30%

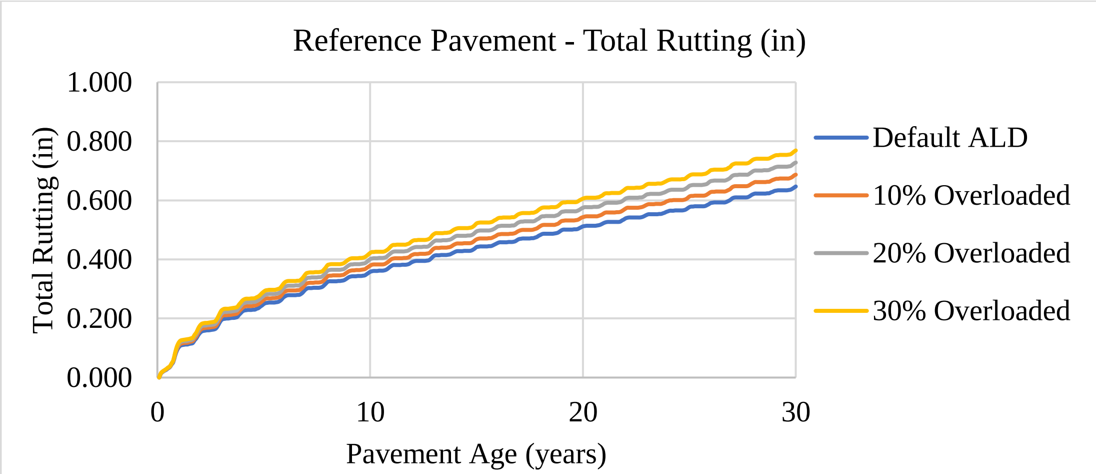

Figure 57 Predicted Total Rutting for the Reference Pavement Structure when all Trucks are loaded based on the Default Axle Load Distribution and when Overloaded by 2) 10%, 3) 20% and 4) 30%

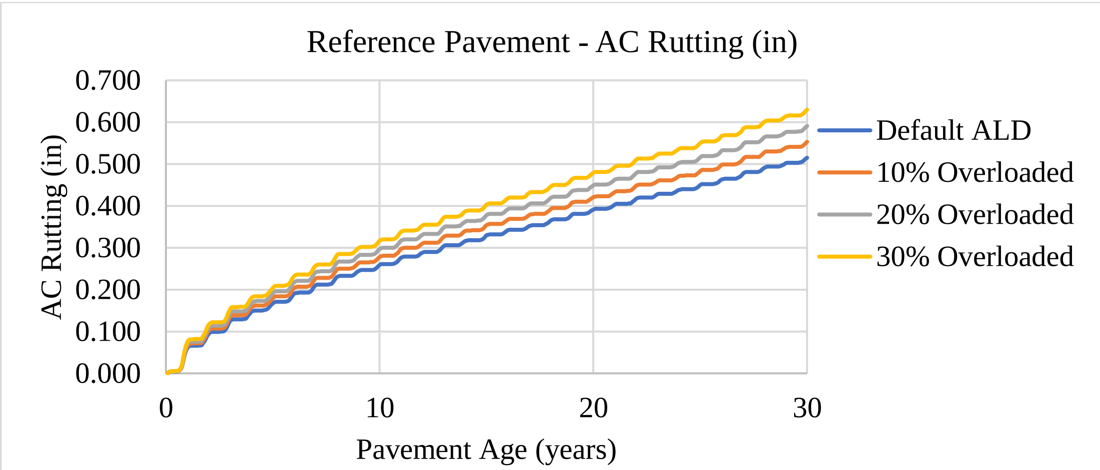

Figure 58 Predicted AC Rutting for the Reference Pavement Structure when all Trucks are loaded based on the Default Axle Load Distribution and when Overloaded by 2) 10%, 3) 20% and 4) 30%

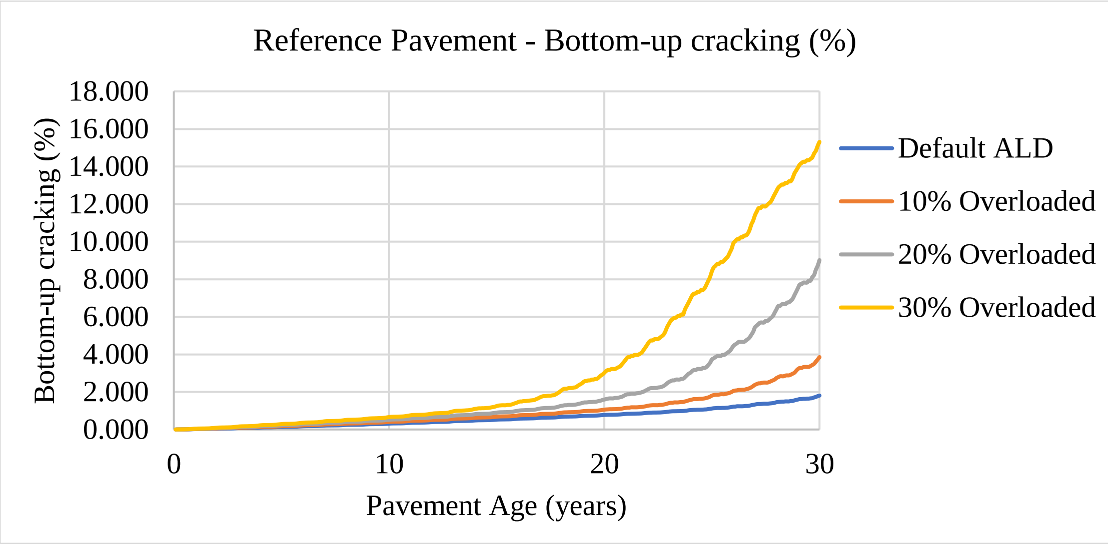

Figure 59 Predicted Bottom-up Cracking for the Reference Pavement Structure when all Trucks are loaded based on the Default Axle Load Distribution and when Overloaded by 2) 10%, 3) 20% and 4) 30%

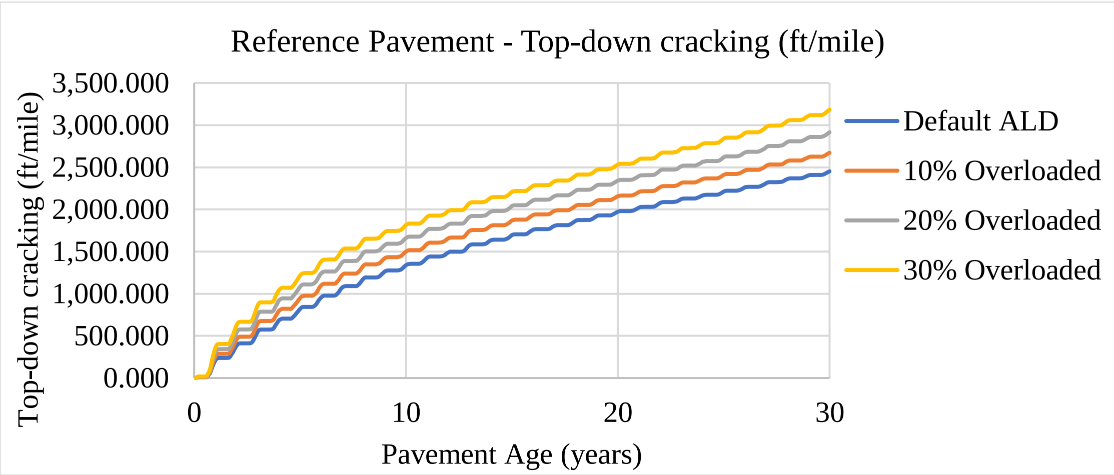

Figure 60 Predicted Top-down Cracking for the Reference Pavement Structure when all Trucks are loaded based on the Default Axle Load Distribution and when Overloaded by 2) 10%, 3) 20% and 4) 30%

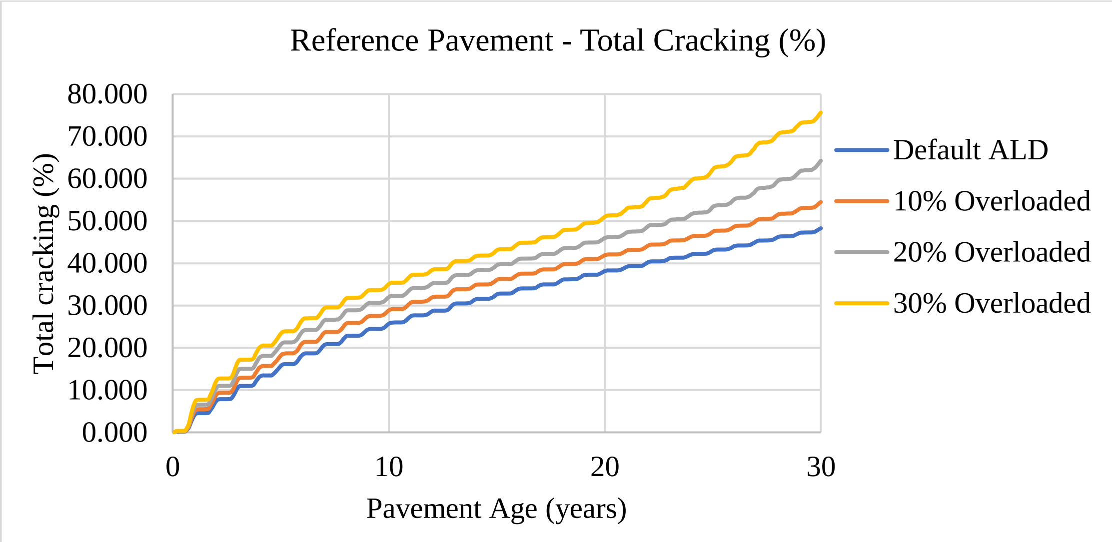

Figure 61 Total Cracking for the Reference Pavement Structure when all Trucks are loaded based on the Default Axle Load Distribution and when Overloaded by 2) 10%, 3) 20% and 4) 30%

As shown in Figure 56, the IRI plots almost overlap for the four considered cases; this can be related to the fact that the IRI prediction in Pavement ME are governed by the site factor, as explained previously. Table 30 provides the number of years needed for the pavement to develop 25% total cracking under the four considered loading conditions as well as the predicted rut depth at that stage.

Table 30 Scheduling First Maintenance for the Reference Pavement Structure under Default Loading Condition and when Truck Load Limit is Increased by 10%, 20% and 30%

Loading condition	**25% total cracking is reached after**	**Total rut depth at 25% total cracking**
Default axle load distribution	10 years	0.354 in
Truck load limit increased by 10%	8 years	0.336 in
Truck load limit increased by 20%	7 years	0.321 in
Truck load limit increased by 30%	6 years	0.309 in

As shown in Table 30, the rut depths are comparable for the four considered cases; accordingly, a first heavy maintenance is scheduled at 25% total cracking, after 10, 8, 7 and 6 years respectively for default loading condition, 10%, 20% and 30% increase in truck load limit. Pavement ME allows the modeling of pavement overlays; thus, a 5 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 cracking reaches 25% again. The predicted distresses of the modeled AC overlays under the different loading conditions are shown in Figure 62 to Figure 67.

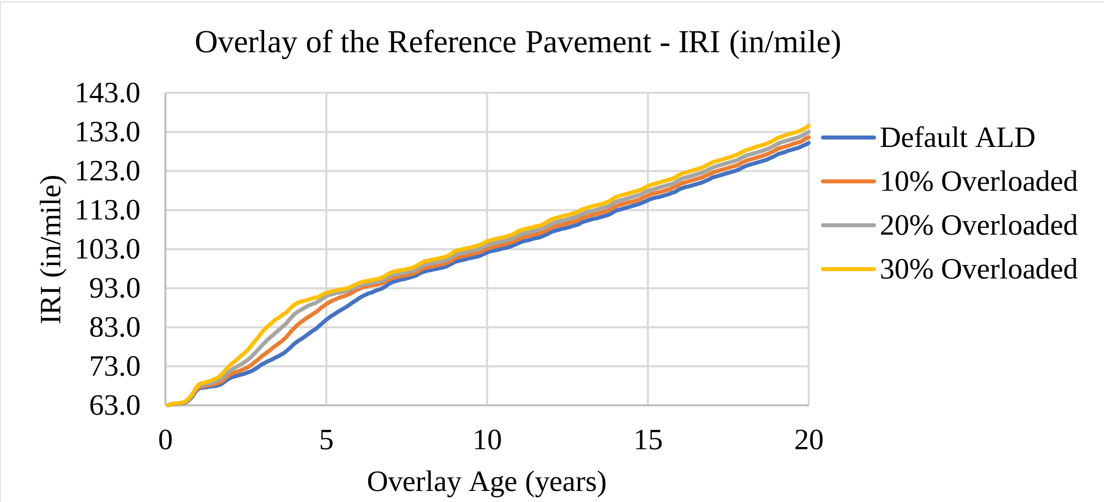

Figure 62 Predicted IRI for the Overlay of the Reference Pavement Structure when all Trucks are Loaded Based on the Default Axle Load Distribution and when Overloaded by 2) 10%, 3) 20% and 4) 30%

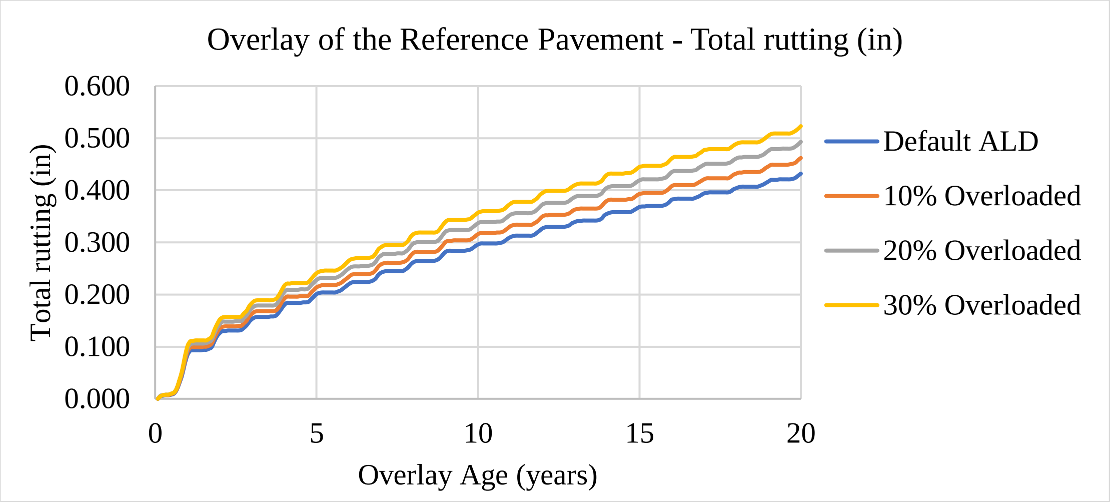

Figure 63 Predicted Total Rutting for the Overlay of the Reference Pavement Structure when all Trucks are Loaded Based on the Default Axle Load Distribution and when Overloaded by 2) 10%, 3) 20% and 4) 30%

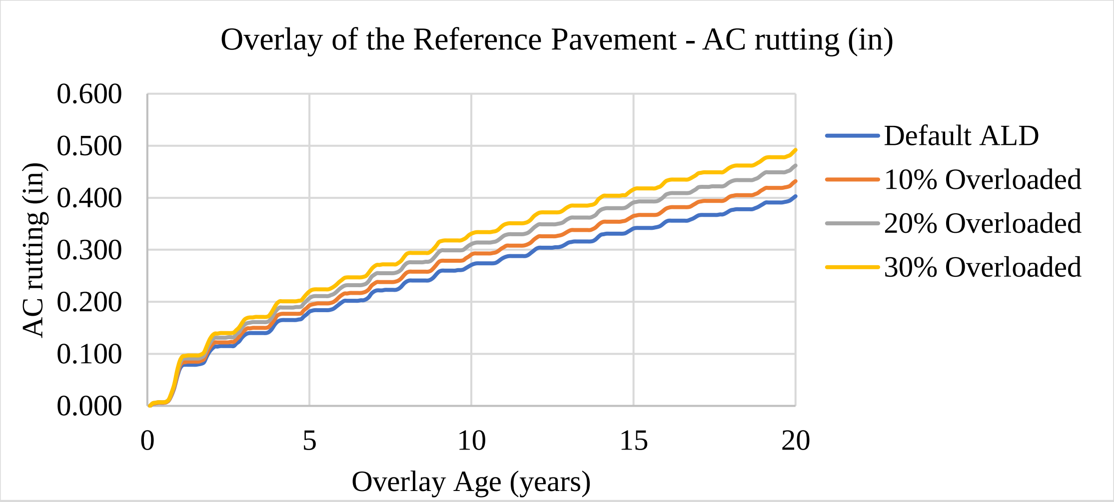

Figure 64 Predicted AC Rutting for the Overlay of the Reference Pavement Structure when all Trucks are Loaded Based on the Default Axle Load Distribution and when Overloaded by 2) 10%, 3) 20% and 4) 30%

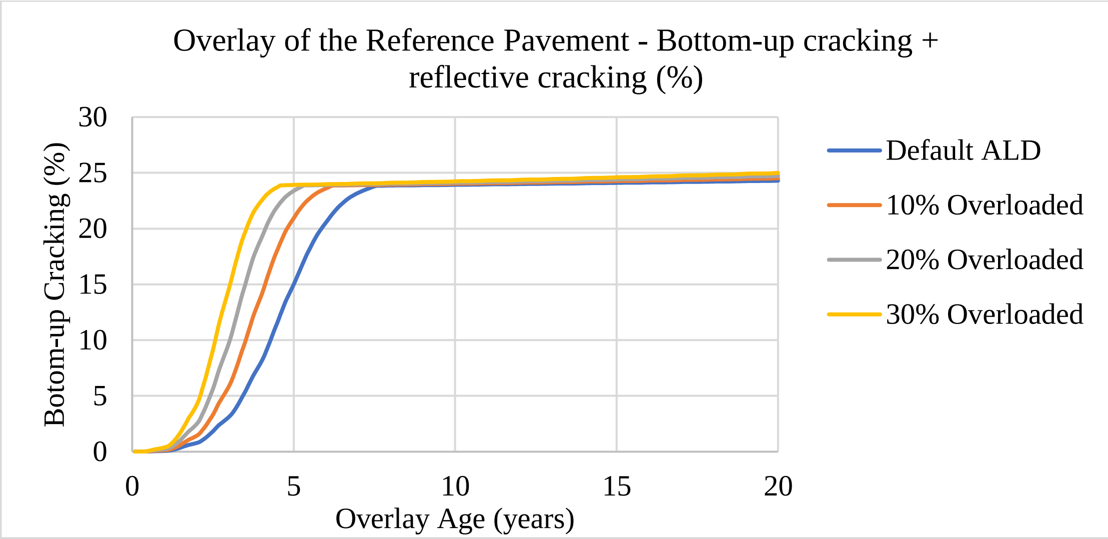

Figure 65 Predicted Bottom-up and Reflective Cracking for the Overlay of the Reference Pavement Structure when all Trucks are Loaded Based on the Default Axle Load Distribution and when Overloaded by 2) 10%, 3) 20% and 4) 30%

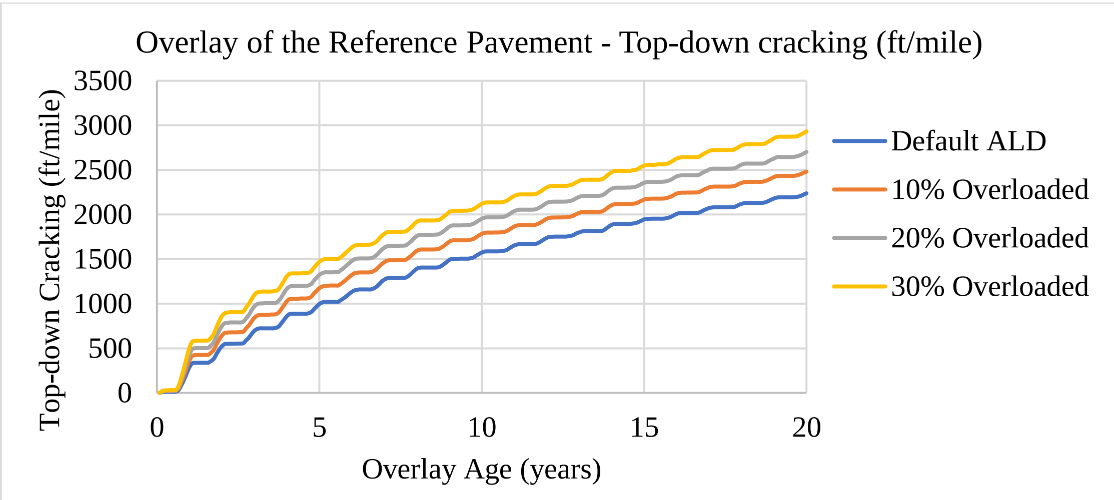

Figure 66 Predicted Top-down Cracking for the Overlay of the Reference Pavement Structure when all Trucks are Loaded Based on the Default Axle Load Distribution and when Overloaded by 2) 10%, 3) 20% and 4) 30%

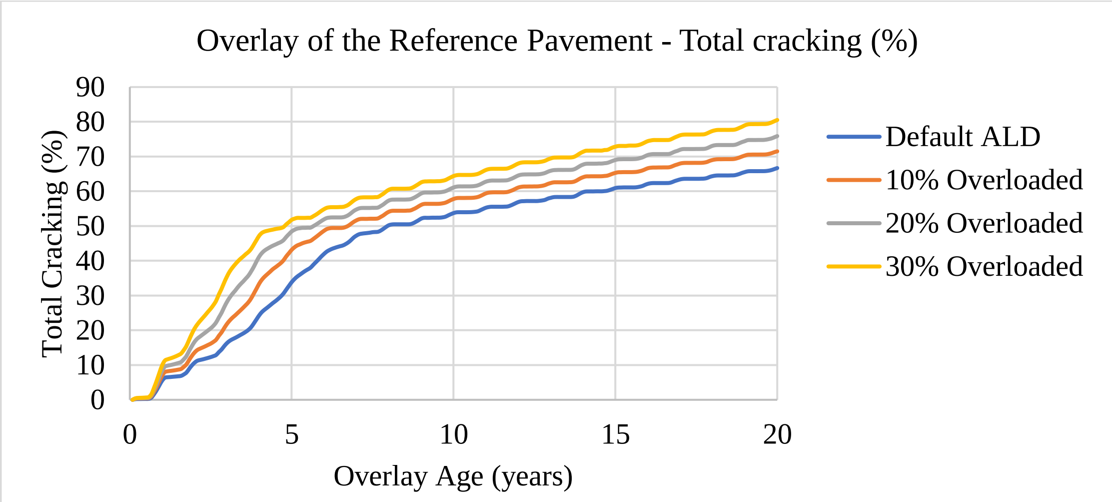

Figure 67 Total Cracking for the Overlay of the Reference Pavement Structure when all Trucks are Loaded Based on the Default Axle Load Distribution and when Overloaded by 2) 10%, 3) 20% and 4) 30%

25% total cracking is reached, concurrently with 0.16 in total rut depth, after 4, 3.5, 3 and 2.5 years for default loading condition, 10%, 20% and 30% increase in truck load limit, respectively.

7.4.2. Life-Cycle Cost Assessment using RealCost

RealCost was used to assess the life-cycle costs of the reference pavement subject to subject to four different loading conditions, corresponding to the four alternatives shown in

Table 31. The inputs in bold, corresponding to the timing of the heavy maintenance activities, are based on the Pavement ME analysis previously conducted. The remaining inputs, related to the pricing of the pavement construction and overlay placement, the work zone durations, work zone length and work zone speed limit are explained in Chapter 5. Table 32Table 10 displays the scheduling of the construction and maintenance activities, as well as the corresponding agency and user costs for the four alternatives. The last row in the table provides the remaining life values for both the agency and user costs.

Table 31 RealCost Inputs Parameter for the Reference Pavement Structure subject to Default Loading Condition and the cases of Increasing Truck Load Limit by 10%, 20% and 30%

Activities	**Input Parameter**	**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%**
Initial construction	Agency construction cost (1000$)	497.81	497.81	497.81	497.81
	Work zone duration (days)	0	0	0	0
	Activity service life	**10 years**	**8 years**	**7 years**	**6 years**
Heavy Maintenance (Mill 5 in and overlay 5 in)	**Number of maintenance activities needed**	**5**	**6**	**7**	**9**
	Agency construction cost (1000$)	101.09	101.09	101.09	101.09
	Work zone duration (days)	10 days	10 days	10 days	10 days
	Activity service life	**4 years**	**3.5 years**	**3 years**	**2.5 years**
	Work zone length	0.6 miles	0.6 miles	0.6 miles	0.6 miles
	Work zone speed limit	40 mph	40 mph	40 mph	40 mph

Table 32 Scheduling and Costs of Construction and Maintenance Activities for the Reference Pavement Considering 11.6%, 13% and 15% Effective Binder Content by Volume of the AC Mix

Concession Year	Default ALD		10% overloaded		20% overloaded		30% overloaded	
	Agency Cost (1000$)	User cost (1000$)	Agency Cost (1000$)	User cost (1000$)	Agency Cost (1000$)	User cost (1000$)	Agency Cost (1000$)	User cost (1000$)
1	497.81		497.81		497.81		497.81	
2								
3								
4								
5								
6								
7								
8								
9							101.09	35.48
10					101.09	36.54		
11			101.09	37.64			101.09	37.64
12								
13	101.09	39.93			101.09	39.93		
14							101.09	39.93
15			101.09	42.36				
16					101.09	43.63		

17	101.09	44.94					101.09	42.36
18			101.09	47.68				
19					101.09	47.68	101.09	44.94
20								
21	101.09	50.58	101.09	53.66			101.09	47.68
22					101.09	52.10		
23								
24							101.09	50.58
25	101.09	56.93	101.09	60.40	101.09	56.93		
26								
27							101.09	53.66
28					101.09	62.21		
29	101.09	64.08	101.09	67.98			101.09	56.93
30								
31	-50.54	-32.04	-28.88	-19.42			-20.22	-11.39

Table 33 presents the calculated life-cycle present value of the agency costs for the four considered alternatives. The present study aims at proposing compensation techniques that can be adopted by the highway agency to remunerate the concessionaire for the latter's economic losses encountered due to a governmental decision related to increasing the permissible truck load limit. Accordingly, only the estimated agency costs are addressed herein. Compensation of road users for the increased user cost requires a separate study.

Table 33 Concession Period Extension for a 10, 20 and 30% Increase in Truck Load Limit Considering the Reference Pavement Structure

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 (1000$)	559.93	586.17	612.58	650.80
% increase relative to alternative 1		4.69	9.4	16.23
Length of the extension of concession period		1.41	2.82	4.87

Considering that the concessionaire needs 30 years (initial length of the concession period for the considered pavement structure) to recover their investment in the case of the default loading condition, then the concession period must be extended by 4.69%, 9.4% or 16.23%, corresponding to 1.41, 2.82 or 4.87 years extension, in case the highway agency increases truck load limit respectively by 10, 20 or 30%. The lengths of the extension of the concession period for the different pavement structures are shown in Figure 68, for an increase in truck load limit by 10, 20 and 30%.

For a 10%, 20% and 30% increase in truck load limit, and considering a 30 years initial concession period, the length of the extension of the concession term ranges between 1.23 and 2.17 years, 2.82 and 4.92 years and 4.69 and 7.41 years respectively.

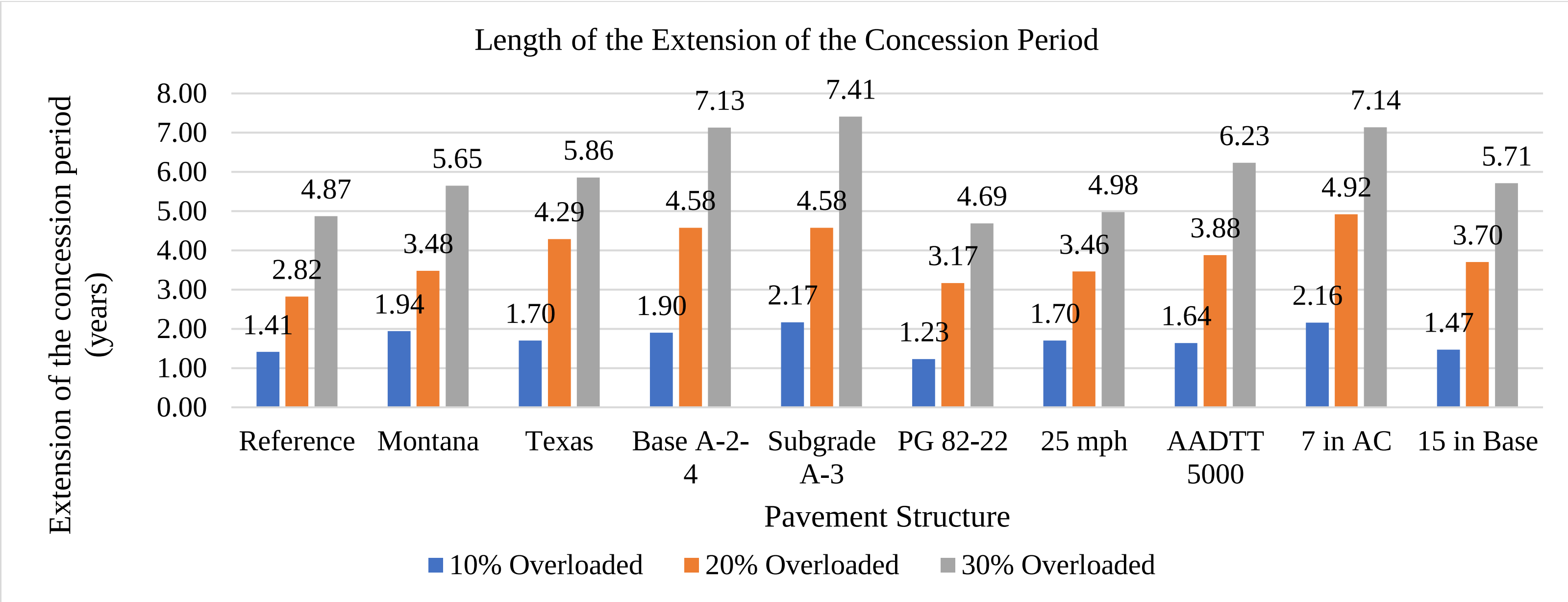

Figure 68 Extension of the Concession Period for 10%, 20% and 30% Increase in Truck Load Limit

7.5. Conclusions

The tendency of highway 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. The present study proposes two strategies that can be adopted by the highway agency to compensate the concessionaire in case of a change in truck loading legislatures.

First, a shadow toll paid by the highway agency represents one possible remuneration type. The rate of the shadow toll is assessed per truck class, for varying pavement structures, based on the quantified increased damage resulting from overloaded trucks. The highest values of shadow tolls are observed for relatively thin pavements and high traffic volumes. Taking class 9 trucks as an example, the average values of the shadow tolls are 10.5%, 22.5% and 35% of the toll charged to the truck driver, respectively for the cases where trucks are 10, 20 and 30% overloaded.

Second, an extension of the concession allows the concessionaire to recover the encountered losses caused by increasing the permissible truck load. A methodology is presented to assess the sufficient concession period extension lengths for different pavement structures. For a 10%, 20% and 30% increase in truck load limit, and considering a 30 years initial concession period, the average length of the extension of the concession term is 1.7, 3.9 and 6 years respectively.

CHAPTER 8

ERRORS IN TRAFFIC VOLUME FORECASTS

8.1. Introduction and Literature Review

Traffic volume is one of the parameters that cannot be accurately forecasted, especially over a long period of time as in the case of PPP road projects. In PPP toll road projects, the main source of revenues is tolls charged to road users, which might be complemented, or not, with other forms of revenues such as subsidies or grants provided by the highway agency. Accordingly, any deviation in expected traffic volumes will directly impact the toll revenues. Simply stated, lower-than-forecasted traffic levels lead to lower-than-expected toll revenue and higher-than-forecasted traffic levels lead to higher-than-expected toll revenues. The review of existing case studies in PPP toll roads that witnessed actual traffic levels lower or higher than forecasted shows that in almost all these projects, the contract terms were renegotiated as to provide a compensation for the party who initiated the renegotiations (either the highway agency or the concessionaire). In general, lower-than-forecasted traffic levels require a compensation to be provided by the highway agency to the concessionaire who lost a part of the expected toll revenues. Contrarily, higher-than-expected traffic levels leads to a renegotiation initiated by the highway agency claiming a share in the resulting additional toll revenues [4].

Nevertheless, it seems that a shortage in traffic levels is a more frequent event faced in PPP toll-road projects compared to the possibility of encountering higher-than-forecasted traffic levels [16][17][18][19][20]. In fact, the shortfall in traffic levels led in many cases to the cancellation of the PPP project by the private partner [4][22].

Furthermore, researchers related the reluctance of the private sector to participating in PPP road projects, among other factors, to the possible shortfall in revenues caused by the inaccurate prediction of traffic volumes [16][21].

Briefly, traffic volume risk is considered to be one of the most challenging risks that might be encountered in PPP toll-road projects in terms of its allocation and treatment, as will be illustrated in the following sections [4][16][17][18][19][20][21].

8.1.1. Actual Traffic Levels vs. Forecasted Traffic Levels

Li and Hensher [89] reviewed available data on traffic levels during the first year of operation for a wide variety of PPP road projects. In Mexico, 23 out of 52 toll roads awarded between 1987 and 1995 failed due to overestimated traffic levels forecasts. A survey by Standard and Poor, including 87 toll roads from Europe and Australasia, showed that forecasted traffic levels were 20-30% higher than actual numbers during the first year of operation. Naess et al. compared traffic levels between toll roads and free roads in Europe; it was observed that forecasted traffic levels tend to be overestimated in toll roads and underestimated in free road projects. Similar results were found for American toll roads with 42% overestimation in traffic volumes. In Sydney, Australia, actual traffic levels observed during the first year operation were 45% lower than predicted numbers. Furthermore, the investigation of traffic levels for 15 US toll roads opened between 1986 and 1999 showed that the average error in traffic volume forecasts was -45.3% during the first year of operation [89].

Based on Vassallo and Solino [20], the actual traffic volumes for 82 highway concession projects averaged around 76% of their forecasted values during the first year of operation, with a standard deviation of 0.26.

Furthermore, the review of available data on actual traffic levels compared to forecasted ones in different transportation sectors concluded that 50% of road projects exhibited errors in traffic forecasts reaching up to ± 20%, regardless of the adopted procurement strategy, and that forecasts are not getting more accurate over time [22].

De Rus and Nombela [23] provided examples on actual toll roads that suffered from a shortage in traffic levels, such as the Dulles Greenway, in Virginia, USA, where the forecasted volume of traffic was 34,000 vehicles per day while actual traffic levels were as low as 23,000 vehicles per day. Similarly, the M1 project in Hungary encountered a 50% lower-than-expected traffic levels. Finally, for 52 concessions awarded in Mexico between 1987 and 1995, the actual traffic level was on average 68% lower than the forecasted volumes [23].

The different traffic volume risk mitigation mechanisms adopted by highway agencies worldwide are described and compared next.

8.1.2. Traffic Volume Risk Mitigation Mechanisms

While most highway agencies developed mechanisms for sharing traffic volume risk with the concessionaire (as will be explained next), others, and mainly the Government of India, decided to relief the concessionaire from traffic volume risk, as a way to attract private investment after the failure of several PPP road projects caused by traffic revenue risk. Consequently, the Government of India developed the annuity-based BOT model, a traffic-risk neutral PPP model, based on which the concessionaire is paid through fixed semi-annual annuity. Accordingly, the concessionaire's income is independent of the actual level of traffic and the traffic volume risk is totally transferred to the highway agency, who is considered to be the party best able to manage it [16].

On the other side, a more common approach for mitigating traffic volume risk is to have it shared between both PPP partners. Three main traffic volume risk mitigation mechanism can be identified: 1) traffic volume risk sharing based on annual revenues, 2) traffic volume risk sharing based on accumulated toll revenues and 3) traffic volume risk sharing based on profit and the internal rate of return [4][20][24].

The first mechanism guarantees a certain level of traffic or revenues. A minimum and maximum level of revenues/traffic are fixed, outside which, at either end, the following mechanism is initiated: 1) if at any year, the actual level of revenues/traffic is below the minimum specified target, the highway agency will compensate the concessionaire for the corresponding shortage in toll revenues through a subsidy; on the other side, 2) if the actual revenues/traffic level is higher than the maximum specified target, the concessionaire must share the extra revenues with the highway agency. One example of the traffic volume risk sharing based on annual revenues is the Minimum Revenue Guarantee (MRG), adopted in Chile, Korea and Colombia [4][20][24].

Under a traffic volume risk sharing mechanism based on the accumulated revenues, the length of the concession period is linked to actual traffic levels. In other words, the concession term is delimited by the time when the concessionaire achieves target revenue/traffic. Accordingly, if actual traffic levels are lower-than-forecasted, the contract period will be extended until the concessionaire achieves the pre-defined target revenue/traffic. Contrarily, if actual traffic levels are higher than forecasted, the concession period will be shortened. Furthermore, a minimum and a maximum contract terms are set on the contract. An example of this traffic volume risk sharing mechanism is the Least Present Value of Revenues (LPVR) which was adopted for Severn Bridge in the UK and Lusoponte Bridge in Portugal, as well as several highway concessions in Chile [4][20][24].

The third traffic volume risk sharing mechanism is based on rebalancing the economic terms of the contract by changing either the contract duration or the toll levels, or through subsidies (paid by the highway agency in the case of a lower-than-forecasted traffic levels) or revenue sharing (in the case of a higher-than-forecasted traffic levels). Note that these changes not pre-established, but negotiated when the actual internal rate of return (IRR) or profit falls below or rises above the target levels. One form of this traffic volume risk sharing mechanism is the Regulated Return Mechanism (RRM), mainly adopted in France and Spain [4][20][24].

Figure 69 illustrates the different mechanism adopted for mitigating traffic volume risk, either by having the risk totally assumed by the highway agency or by having it shared between PPP partners. The present study tackles traffic volume risk in toll-road PPP projects, i.e. where the traffic volume risk is shared between PPP partners. Accordingly, traffic volume risk mitigation mechanism that assign the risk to one partner (the highway agency) will not be further discussed.

Following, the three main traffic volume risk sharing mechanisms are addressed in details and evaluated. Furthermore a quick overview of the experience of different countries with these sharing mechanisms is provided.

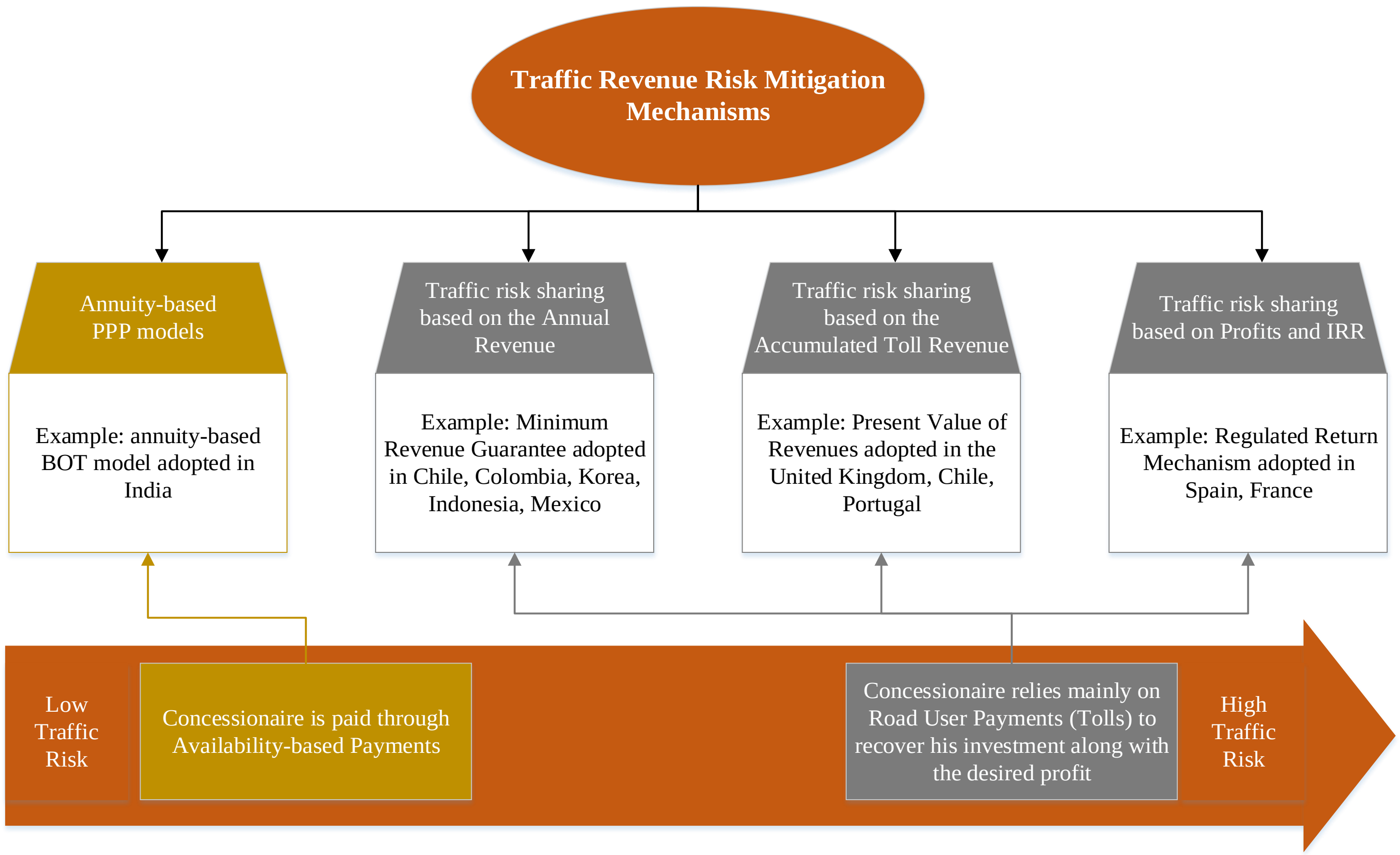

Figure 69 Traffic Volume Risk Mitigation Mechanisms

8.1.3. Traffic Volume Risk Sharing Mechanisms Worldwide

8.1.3.1. Chile

During the 1998-2002 economic recession, highway concessions in Chile suffered from low traffic volumes. As a result, the Chilean government implemented three traffic volume risk sharing mechanisms: 1) the Minimum Income Guarantee (MIG), 2) the Least Present Value of the Revenues (LPVR), and 3) the Revenue Distribution Mechanism (RDM). Note that these mechanisms were not mutually exclusive, meaning that some concessions implemented two different mechanisms simultaneously [24].

Some concessions effectively combined the MIG and the LPVR. Note that in such concessions, the LPVR was used as a bidding criterion - i.e. the concession is awarded to the bidder who settles for the lowest total amount of revenues (discounted at a pre-determined rate) to be achieved during the concession term [23] – in addition to being a traffic volume risk sharing mechanism [24].

The MIG mechanism works as follows: the total amount, in present value, that the highway agency can offer to the concessionaire as a compensation for a lowest-than-forecasted traffic levels is equal to the present value of (70% of initial investment plus the total operation and maintenance costs). This value was fixed by the highway agency based on the fact that, in Chile, the percentage of debt in project finance structure is on average equal to 70%:

$$\text{VNA (MIG)} = 0.7 \sum_{i=1}^{i=s} \frac{Ii}{(1+\rho)^{\wedge}i} + \sum_{i=s}^{i=T} \frac{OCi + MCi}{(1+\rho)^{\wedge}i} \quad \text{(Eq. 9).}$$

VNA (MIG) = present value of the guaranteed revenues.

Ii = upfront investment estimated by the highway agency in year i.

OCi = operation costs estimated by the highway agency in year i.

MC_i = maintenance costs estimated by the highway agency in year i.

S = length of the construction period (years).

T = length of the concession contract (years).

ρ = discount rate established by the highway agency for each project.

Then, an average value of the MIG is calculated considering an annual traffic growth equal to "g":

$$MIG_{average} = \frac{\text{VNA (MIG)}}{(T-s).\sum_{i=s}^{i=T} \frac{(1+g)^{\wedge}i}{(1+\rho)^{\wedge}i}} \quad \text{(Eq. 10)}$$

Finally, the annual minimum income guarantee line is established:

$$MIG_i = MIG_{average}.\ [(1+g)^{i}] \quad \text{(Eq. 11)}$$

MIG_i = minimum income guarantee in year i.

Briefly, in any year "i", if the actual revenues fall below the MIGi, the highway agency will pay the concessionaire the difference between actual revenues and MIGi.

On the contrary, for the case of a higher-than-forecasted traffic levels, the concessionaire will have to share the extra revenues with the highway agency, when the internal rate of return of 15% is reached [20].

As for the LPVR mechanism, in which the concession term is delimited by the time when a trigger internal rate of return is reached, the Chilean Concessions Law establishes a maximum duration of 50 years [24].

Finally, the RDM is a mechanism that resembles to a combination of the MIG and the LPVR, as it guarantees a pre-fixed amount of revenues (in present value) and adopts a variable concession term. However, the RM was customized based on the specific circumstances of the Chilean highway concessions. Accordingly, the RDM will not be further discussed in the present study [24].

8.1.3.2. South Korea

South Korea adopted the MRG as a traffic volume risk sharing mechanism. Between 1999 and 2003, the government guaranteed 80-90% of the revenues for the entire operation period. In 2003, the government reduced the period over which the MRG is applicable to cover only 15 years of the operation period, and changed the level of the guarantee as follows: during the first five years, 90% of the revenues were guaranteed, followed by 80% for the next five years and 70% for the final five years. In 2006, the revenue guarantee period was further reduced from 15 years to 10 years, with 75% of the revenues guaranteed during the first five years and 65% guaranteed during the final five years. After 2009, the government of South Korea replaced the MRG with a "New Risk Sharing Scheme". As previously stated, in the present study, only common traffic volume risk sharing mechanisms that are adopted by several countries are addressed. Accordingly, the "New Risk Sharing Scheme" will not be further discussed herein [21].

8.1.3.3. Brazil

As opposed to the South Korean experience, the government of Brazil evolved from adopting regulated return mechanism, which is based on rebalancing the economic terms of the contract by changing either the contract duration or the toll levels, to a full implementation of the MRG mechanism. The government of Brazil guaranteed 60% of the revenues (up to 40% shortfall in the expected revenues). Furthermore, when higher-than-forecasted traffic volumes are encountered, the government is entitled to 50% of the resulting extra revenues [21].

8.1.3.4. Colombia

The government of Colombia adopts the MRG as traffic volume risk sharing mechanism, by guaranteeing a pre-specified level of revenues on a yearly basis [19].

8.1.3.5. Indonesia

After a full implementation of the MRG, the government of Indonesia limited the applicability of the MRG to the cases where the encountered shortage in traffic volumes is the direct result of a governmental action, such as breaching the non-competing agreement by allowing the construction of a free road parallel to the toll road [90].

8.1.3.6. Portugal

The traffic volume risk sharing mechanism adopted in Portugal is the LPVR. One example is the Lusoponte Bridge, awarded in 1990, for which the length of the concession period was delimited by the time when the cumulative traffic flow reaches 2250 million vehicles, with a maximum of 38 years [24]. Another example is the Litoral Centro Highway concession, awarded in 2003, for which, the concession would expire when a 784 million euros total revenues in present value is reached. Furthermore, the minimum and maximum concession terms were set to be 22 and 30 years respectively [21].

8.1.3.7. United Kingdom

The United Kingdom adopts the LPVR. The Dartford Bridge and the Second Severn crossing projects are examples of highway concession projects where the LPVR was implemented to mitigate traffic volume risk [21].

8.1.3.8. Spain

Spain adopts the RRM mechanism for mitigating traffic volume risk. Under this mechanism, each bidder establishes, in their proposal, a top and a bottom band (curve) representing their minimum and maximum acceptable revenues. The winning bidder is the one accepting the lowest possible revenues. This mechanism compares the following parameters: 1) the accumulated present value of revenues estimated based on the forecasted traffic levels, 2) the real accumulated present value of revenues estimated base on the actual traffic levels and 3) the top and bottom bands established by the concessionaire (winning bidder). As long as the real revenues fall within the top and bottom bands, no sharing mechanism triggered. However, when the real revenues fall below the bottom band, one or more of the following economic parameters: the toll level, the length of the concession period and/or the highway agency's subsidy, is/are changed in order to rebalance the financial terms of the concession, i.e. to have the real accumulated present value of revenues fall again within the top and bottom bands. Note that the government of Spain chose the accumulated present value of revenues as the trigger variable for the RRM mechanism, instead of adopting the accumulated present value of profit (where the profit is equal to the revenues minus the expenses) due to the fact that revenues are easier to estimate: the only needed data for calculating revenues is the traffic count and the toll level, while monitoring the concessionaire expenses is relatively hard for the highway agency [25].

8.1.3.9. France

France adopts the RRM. The new Millau Bridge is one example of highway concession projects where the RRM was implemented to mitigate traffic volume risk [21].

8.1.3.10. The United States

The U.S. Department of Transportation conducted a rigorous comparison between the different traffic volume risk sharing mechanisms, and concluded that the LPVR and the MRG are best suited for the U.S. toll road projects [21]. The details of the comparison are provided in the following section.

8.1.3.11. Greece

Traffic volume risk was originally allocated to the concessionaire. However, the 2010 economic crisis in Greece significantly affected highway concessions as the resulting shortage in traffic levels averaged 40% and reached up to 55% lower-than-expected traffic levels in some stations. Accordingly, the Greek government had to undertake traffic volume risk by compensating the concessionaires for the shortage in traffic revenues. Finally, experts recommended that the government establishes, in the tender document, a minimum and a maximum traffic thresholds, between which traffic volume risk is allocated to the concessionaire. Furthermore, actual traffic levels lower than the minimum thresholds trigger a compensation from the government while traffic levels higher than the maximum threshold provides the government with the right to share the extra revenues with the concessionaire [91]. Such mechanism is very similar to the MRG.

8.1.3.12. Australia

Since 2003, 7 of 8 toll road projects in Australia were procured though PPP. Traffic volume risk was originally allocated to the concessionaire. The following six case studies: 1) the Eastlink, 2) the Airport Link, 3) the Clem 7, 4) the Lane Cove Tunnel, 5) the North Connex and 6) the Peninsula Link were reviewed by Regan et al to examine the effect of different traffic volume risk allocations on the success of these projects. Note that traffic volume risk was allocated to the concessionaire for the first five PPP projects, while totally transferred to the government for the Peninsula link project. The first four projects failed to generate the expected revenues due to shortage in traffic levels. Consequently, the Eastlink was sold at around half its development cost 8 years after commissioning, while the Airport Link, the Clem 7 and the Lane Cove Tunnel were placed under administration within 18 months of commissioning. The North Connex, however, was a link between two major toll roads (the M2 and the M7), therefore, did not suffer from a shortage in traffic levels. For the Peninsula Link, the government undertook traffic volume risk by providing availability payments to the concessionaire. Accordingly, the following policy changes were introduced in 2009 by the government, in order to ensure the successful implementation of PPP road projects: 1) providing the concessionaire with up-front capital contributions and 2) adopting availability payments as the concessionaire payment strategy instead of tolls charged to road users [92].

Nevertheless, interviews conducted with Australian Stakeholders considered that traffic volume risk is better managed by the private sector, given to their expertise in traffic modelling and their wide access to financial instruments, enhancing their ability to manage financial distress [93].

8.1.3.13. Canada

No reference that clearly indicates the traffic volume risk sharing mechanism used in Canada was found. However, the Autoroute 25 concession in Quebec, Canada is a unique example of an availability payment PPP project combined with a revenue risk sharing mechanism. This mechanism works as follows: 1) tolls are collected by the government and given to the concessionaire under the form of availability payments, 2) the government guarantees up to 60% of the expected revenues, 3) the concessionaire is entitled to the actual revenues between 60% and 120% of the forecasted revenues, and 4) the government is entitled to 50% of actual revenues higher than 120% of the forecasted levels [21].

8.1.3.14. Summary

Figure 70 illustrates the traffic volume risk mitigation mechanisms adopted by highway agencies across America, Europe, Asia and Australia.

Traffic volume risk is undertook by the government in India and Australia through availability payments provided to the concessionaire instead of the adoption of tolls charged to road users.

Nevertheless, a more common approach for mitigating traffic volume risk is through different risk sharing mechanisms adopted by different countries. The three most common traffic volume risk sharing mechanisms are 1) the minimum revenues guarantee MRG, 2) the least present value of revenues LPVR and 3) the regulated return mechanism. Furthermore, for countries with no specific traffic volume risk sharing mechanism adopted, recommendations tend towards the implementation of mechanisms such as the MRG and the LPVR. Accordingly, the analysis in the following sections will be limited to these two mechanisms.

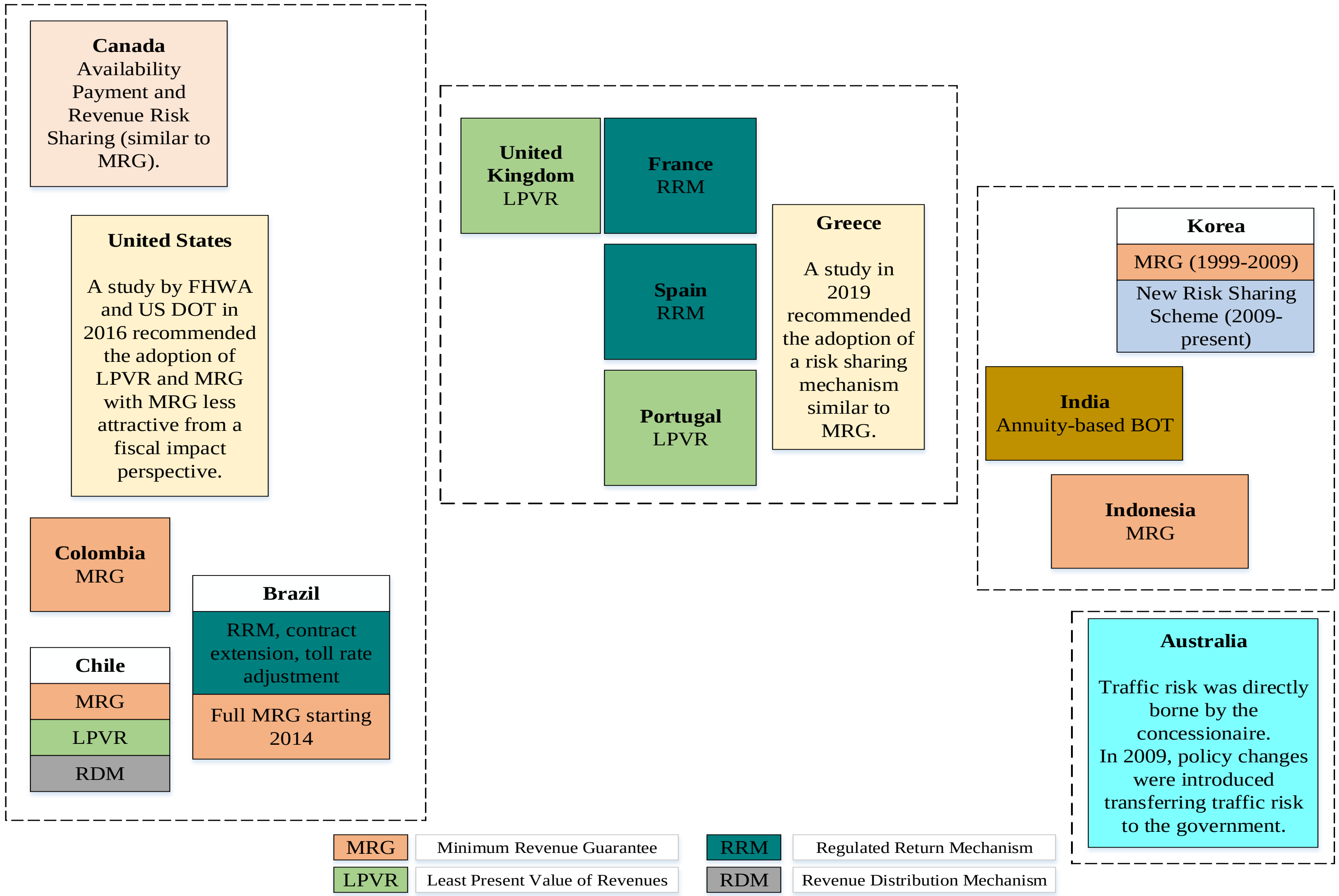

Figure 70 Traffic Volume Risk Mitigation Mechanisms Worldwide

8.1.4. Assessment of the Different Traffic Volume Risk Mitigation Mechanisms

8.1.4.1. Effect of the Allocation of Traffic Volume Risk to the Highway Agency on the Value for Money

The Indian and Australian governments decided to undertake traffic volume risk by remunerating the concessionaire through availability payments instead of tolls charged to road users. In the present study, this mitigation mechanism will not be further discussed, due to the fact that allocating traffic volume risk to the highway agency significantly lowers the Value for Money (VFM) of the road project.

Briefly, the VFM is used to assess the feasibility of commissioning a road project as a PPP: it compares between the highway agency's costs for pursuing the project 1) as a PPP and 2) through traditional procurement strategies [94].

Figure 71 illustrates the method for assessing the VFM: the VFM is the difference between two costs: 1) the PSC, or public sector comparator, representing the highway agency's cost of pursuing the project through traditional procurement, and 2) PPP bid which is the cost, for the highway agency, of pursuing the project as a PPP [94].

The PSC includes: 1) the raw PSC, representing the construction and operation costs (borne by the highway agency in traditional procurement strategies); 2) the competitive neutrality, a factor allowing for a fair comparison between the PSC and the PPP bid costs, by removing the inherent competitive advantages or disadvantages that are accessible for the highway agency, but inaccessible for the private sector (taxes and fees for example) as well as 3) transferrable risks and retained risks. Note that the cost of all risks is included in the PSC as the highway agency will be the party bearing all risks [94].

On the other side, the PPP bid cost, representing the highway agency's cost for pursuing the project as a PPP, includes only 1) the service payments, which are all the payments provided by the highway agency to the concessionaire (if any, in form of availability payments for example) and 2) the retained risks, which are the risks that the highway agency undertake under PPP procurement [94].

Accordingly, the more risks are transferred to the private sector, the higher is the value for money, meaning that commissioning the project as a PPP will result is significant savings for the highway agency. On the contrary, having traffic volume risk retained by the latter, through availability payments provided by the latter to the concessionaire, will increase both the service payments and the retained risks, and consequently the PPP bid cost. This leads to a reduced value for money, and, in extreme cases, a negative value for money could be generated, meaning that the project would have been better pursued through traditional procurement than as a PPP.

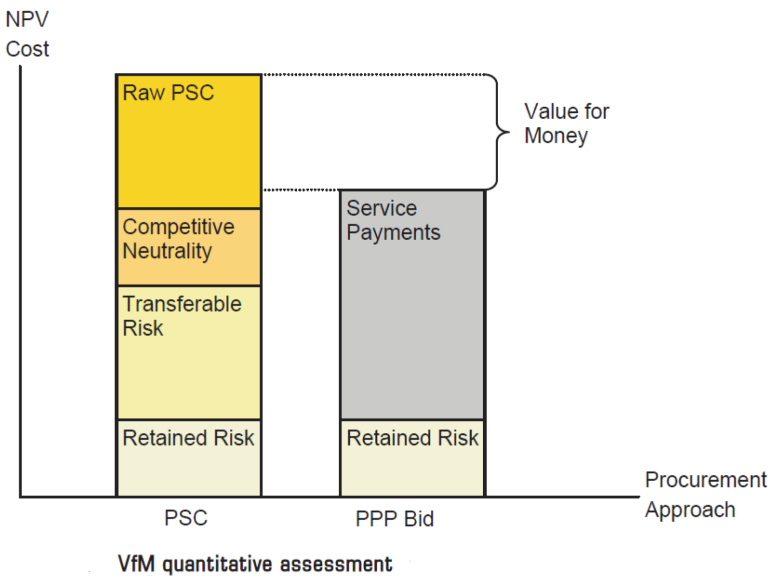

Figure 71 Value For Money Assessment for PPP Projects [94]

In fact, based on the Australian experience, the average VFM for projects where traffic volume risk was allocated to the concessionaire was 9%, while for projects allocating traffic volume risk to the highway agency, the VFM was as low as 1% [92] . With such a low VFM (only 1% cost saving when commissioning the road as a PPP compared to the cost of pursuing the project through traditional procurement strategies), the suitability of implementing such projects as a PPP is questionable.

8.1.4.2. Comparing the Three Main Traffic Volume Risk Sharing Mechanisms

The first criteria for comparing the MRG, the LPVR and the RRM is the ease of implementation. The MRG has been extensively used in different countries, accordingly, the MRG is considered to be relatively easy to implement as most concessionaires are familiar with it. The LPVR is also easy to implement, as it is adopted by many countries not only as a traffic volume risk sharing mechanism but also as a bidding criteria. The RRM, on the other side, is a complex mechanism: the experience of Latin America with RRM was problematic and disputes arose between PPP partners over IRR calculations, such as the Mexico Fumisa Airport P3 [21].

The main advantage of the MRG mechanism is that it provides short term liquidity allowing the concessionaire to cover debt finance. The LPVR does not provide a short-term liquidity, however, allowing the extension of the concession term improves the possibilities for a successful restructuring with lenders, in case the generated revenues fail to meet the debt service obligations. For the RRM, in case the adopted compensation strategy is an increase in toll levels or a subsidy paid by the highway agency to the concessionaire, then short-term liquidity is provided. Contrarily, if an extension of the concession term is adopted, short-term liquidity is not provided [21].

One of the main drawback of the MRG is the resulting contingent liabilities that might not be affordable for the highway agency, in case traffic levels become substantially lower than forecasted. On the other side the LPVR does not have any direct fiscal impact, as the concessionaire compensation is based on time, not money. For the RRM, in case a subsidy is provided by the highway agency to re-establish the balance of the economic terms of the contract, this will result in a direct fiscal impact; contrarily, if toll levels of the concession term are modified, no fiscal impact is generated [4][21].

Furthermore, all the three mechanisms enhance finance-ability as they provide significant protection to the concessionaire, and consequently to lenders, against traffic volume risk [21].

One disadvantage of the LPVR is that in extreme downside cases, the maximum extension of the concession term might not be sufficient for the concessionaire to generate the desired profit [4]. Moreover, the RRM might be considered as working against the road users' interest as it allows the increase of toll levels. However, such measurement can be limited to few occasions [4]. Based on Chile's experience, the LPVR was more effective than the MRG in terms of reducing the renegotiation pressures by the concessionaire [24].

Finally, another drawback of the MRG is that highway agencies are unsure of the level of guarantee that should be provided to the concessionaire, which led, in many cases to over-guarantee [22]. In fact, the experience of South Korea is one example of an MRG mechanism that evolved from being too generous (by guaranteeing 80-90% of the forecasted revenues over the entire concession period) to gradually lowering both the level of guaranteed traffic (to a level as low as 65% of forecasted volume) and the period of the MRG (to cover only 10 years of the operation period) [21]. Similarly, the government of Indonesia limited the applicability of the MRG mechanism to the cases where the shortage in traffic levels is a direct result of a governmental action, such as breaching the non-competition agreement [90].

8.2. Problem Statement and Objectives

The current trend in the applications of the MRG and the LPVR is to adopt the gross revenues as the trigger variable, instead of the profit, which is equal to the revenues minus the expenses. In fact, the described MRG mechanisms guaranteed specific levels of revenues (not profit) which are directly related to traffic levels and are independent of the expenses [21]. Furthermore, in projects where the LPVR is adopted, the contracts were set to end when a certain level of revenues or traffic is reached [21][24] . This is justified by the fact that highway agencies find revenues easier to be monitored than profits, as revenues can be simply estimated knowing the traffic counts and the toll levels, while the exact expenses of the concessionaire are hard to monitor, and sometimes might even be exaggerated by the concessionaire [21][25].

However, when actual traffic levels deviate from the forecasted ones, not only the revenues, represented by the tolls charged to road users, are affected, but the maintenance expenses as well. Furthermore, the effect of traffic levels on the cash inflow is opposed to its effect on the cash outflow; a higher-than-forecasted traffic level has a favorable effect on the cash inflow, as it results in higher-than-expected toll revenues, while its effect on the cash outflow is disadvantageous, as it accelerates the deterioration of the pavement, consequently increasing the maintenance expenditures borne by the concessionaire. On the contrary, while the lower-than-forecasted traffic levels negatively affect the cash inflow through the generation of lower-than-expected toll revenues, the cash outflow is positively affected through lowering the maintenance expenditures.

Accordingly, when assessing the effect of any deviation in traffic levels away from forecasted ones, the resulting effect on the cash outflow cannot be ignored. Thus, the main objective of this study is to addresses traffic volume risk by assessing the effect of the errors in traffic volume forecasts on the project's cash inflow, represented by the toll revenues, and the project's outflow, and more specifically the maintenance cost.

Moreover, based on the reviewed literature, the most challenging step for the highway agency in the implementation of the MRG mechanism is deciding on the level of guarantee to be offered to the concessionaire in case a shortage in traffic levels is encountered. Furthermore, the main advantage of the MRG over the LPVR is that it provides short-term liquidity necessary for the concessionaire to cover debt service. Accordingly, this study estimates the value of the subsidy to be provided by the highway authority to the concessionaire as to allow the latter to cover their debt service.

Briefly, the enhanced MRG mechanism proposed in this study would achieve the following objectives: 1) having the subsidy assessed on the basis of allowing the concessionaire to cover debt service instead of guaranteeing a certain level of traffic (which might be as low as 60% and as high as 90%, as per the reviewed MRG applications in different countries, without being based on any technical explanation), and 2) having considered the effect of the deviation in traffic levels on both the project's cash inflow and cash outflow, as opposed to current trends in MRG applications, where only the resulting effect on cash inflow is taken into consideration.

As for the LPVR mechanism, incorporating the effect of changes in traffic levels on the maintenance expenditures significantly affects the evolution of the project's IRR, and consequently the length of the concession term. The proposed methodology shall achieve the following objectives: 1) offering the highway agency a tool for estimating the possible increase/decrease in the concessionaire's expenses (and more specifically, those related to the heavy maintenance activities) corresponding to any encountered increase/decrease in traffic levels, and 2) implementing a LPVR mechanism based on the actual project's IRR, i.e. taking into account the effect of differing traffic levels on both the generated toll revenues and the maintenance cost.

8.3. Methodology

The complex nature of the traffic volume risk requires a full and detailed financial analysis. The World Bank's numerical model is used for this purpose. As explained in Chapter 5, section 5.3, the World Bank's financial model requires a variety of input parameters, among which are those related to the project's cash inflow – the traffic counts and toll levels – and cash outflow – yearly concessionaire cost, yearly operation cost, heavy maintenance cost and frequency and yearly light maintenance cost. Accordingly, the model can directly account for the effect of any change in traffic levels on the project's cash inflow, simply by inputting the value of the real traffic counts. As for the cash outflow, the change in traffic levels is considered to affect only the frequency of the heavy maintenance activity. No effect on operation, concessionaire and light maintenance costs is assumed.

The scheduling of the heavy maintenance activity is estimated through the prediction of the performance of the road project using AASHTOWare Pavement ME.

The reference pavement structure is taken as a case study, and seven different traffic levels are considered: 1) the case where actual traffic levels are equal to the forecasted number, the cases where actual traffic levels are 2) 10% lower, 3) 20% lower and 4) 30% lower than forecasted, and the cases where actual traffic levels are 2) 10% higher, 3) 20% higher and 4) 30% higher than forecasted.

Then the aforementioned scenarios are financially analyzed using the World Bank's numerical model. The latter computes the concessionaire's return in terms of the project's IRR, equity IRR, project's NPV and the highway agency's financial flow in terms of the subsidies to be paid to the concessionaire on one side and the collected taxes on the other side. The model's output is used to enhance the MRG and the LPVR mechanisms as previously explained.

8.4. Results

8.4.1. Pavement Performance Prediction using AASHTOWare Pavement ME

The reference pavement structure is taken as a case study. The performance of the reference pavement is modelled considering seven different traffic levels: 1) the case where actual traffic levels are equal to the forecasted number, the cases where actual traffic levels are 2) 10% lower, 3) 20% lower and 4) 30% lower than forecasted, and the cases where actual traffic levels are 2) 10% higher, 3) 20% higher and 4) 30% higher than forecasted. Table 34 provides the different traffic levels considered for the analysis, in terms of the initial level of total traffic, including both truck traffic and cars traffic.

Table 34 Traffic Levels Considered for the Analysis

Scenario	**Initial annual average daily truck traffic AADTT**	**Initial annual average daily traffic AADT (trucks + cars)**	**Initial annual average daily cars traffic**
Actual traffic = forecasted	4,000	20,000	16,000
Actual traffic is 10% lower than forecasted	3,600	18,000	14,400
Actual traffic is 20% lower than forecasted	3,200	16,000	12,800
Actual traffic is 30% lower than forecasted	2,800	14,000	11,200
Actual traffic is 10% higher than forecasted	4,400	22,000	17,600
Actual traffic is 20% higher than forecasted	4,800	24,000	19,200
Actual traffic is 30% higher than forecasted	5,200	26,000	20,800

Figure 72 to Figure 77 illustrate the predicted performance of the case study, in terms of IRI, total cracking, AC cracking, bottom-up cracking, top-down cracking and total cracking, considering the aforementioned scenarios.

Figure 72 Predicted IRI for the Reference Pavement Considering Different Traffic Levels

Figure 73 Predicted Total rutting for the Reference Pavement Considering Different Traffic Levels

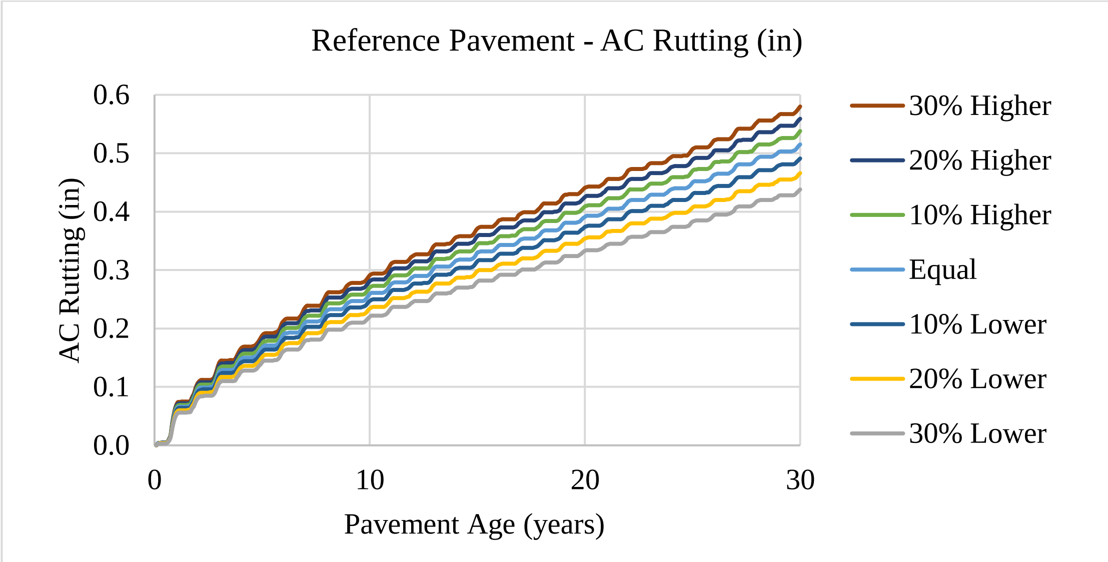

Figure 74 Predicted AC rutting for the Reference Pavement Considering Different Traffic Levels

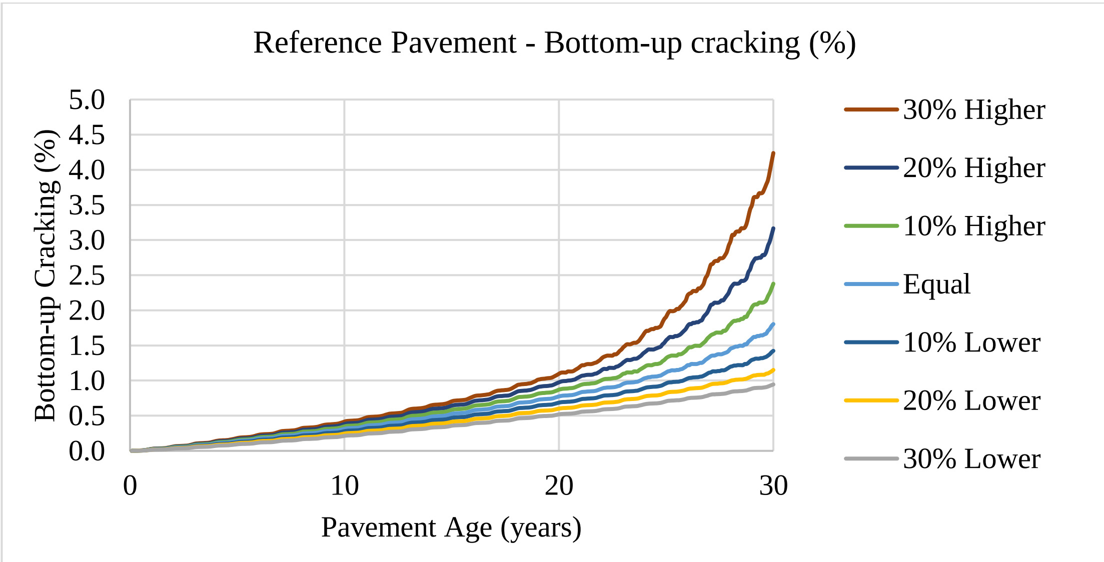

Figure 75 Predicted Bottom-up Cracking for the Reference Pavement Considering Different Traffic Levels

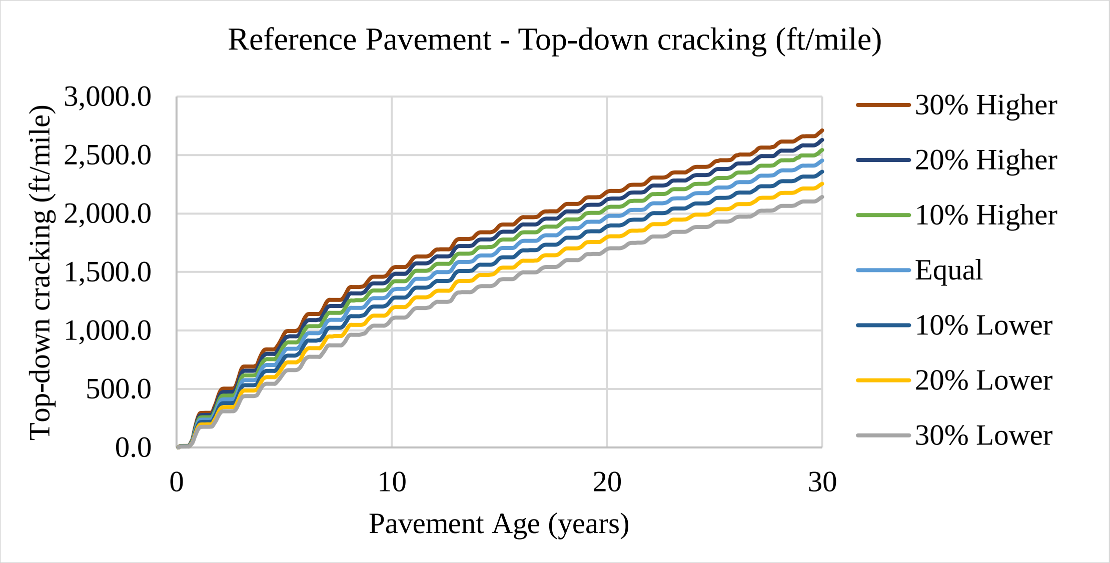

Figure 76 Predicted Top-down Cracking for the Reference Pavement Considering Different Traffic Levels

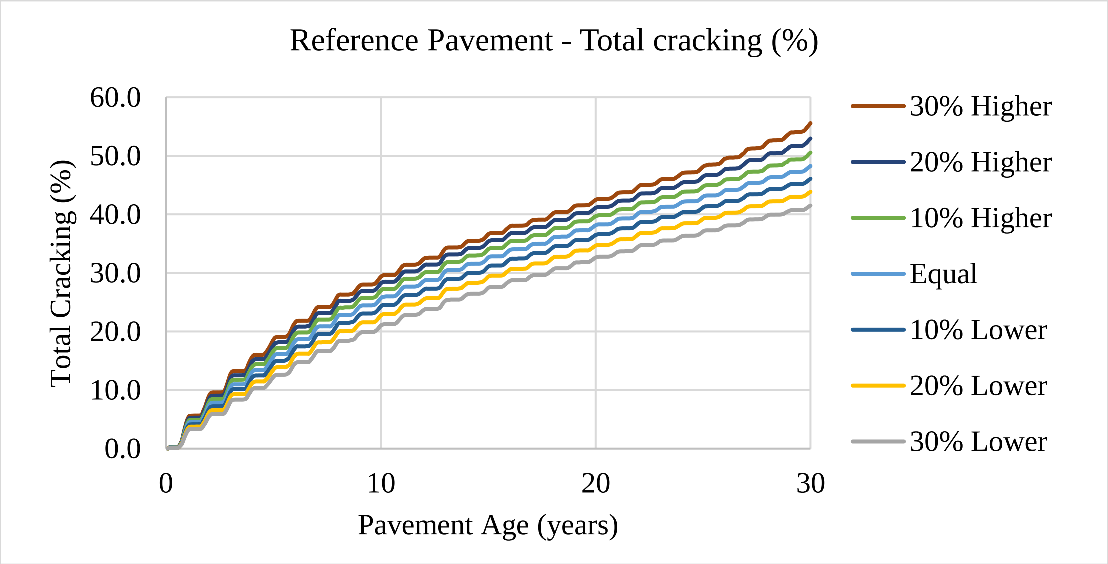

Figure 77 Total Cracking for the Reference Pavement Considering Different Traffic Levels

The 25% total cracking threshold is reached after 10 years for the case where actual traffic level is equal to forecasted, after 9, 8 and 7.5 years respectively for the cases where actual traffic levels are 10, 20 and 30% higher-than-forecasted, and after 11, 12 and 13 years respectively for the cases where actual traffic levels are 10, 20 and

30% lower-than-forecasted. Note that for all the considered scenarios, the total cracking threshold (25%) is reached before the total rut depth threshold (0.4 in) and the first heavy maintenance is scheduled accordingly.

A heavy maintenance (milling 5 in and overlaying 5 in) is conducted when the total cracking reaches 25%. Figure 78 to Figure 83 represent the predicted performance of a thick overlay placed on top of the existing reference pavement considering different traffic levels.

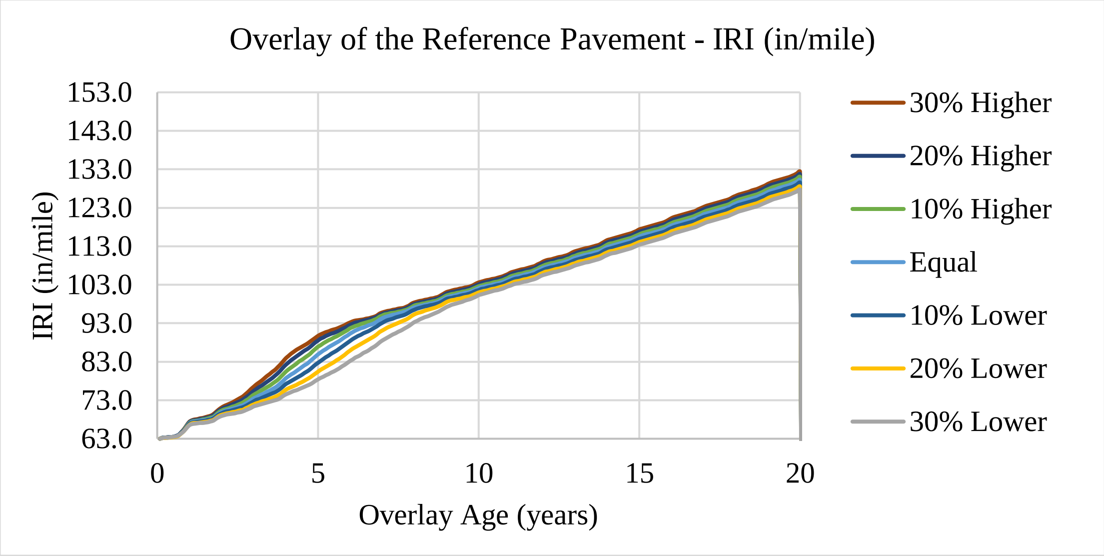

Figure 78 Predicted IRI for the Overlay of the Reference Pavement Considering Different Traffic Levels

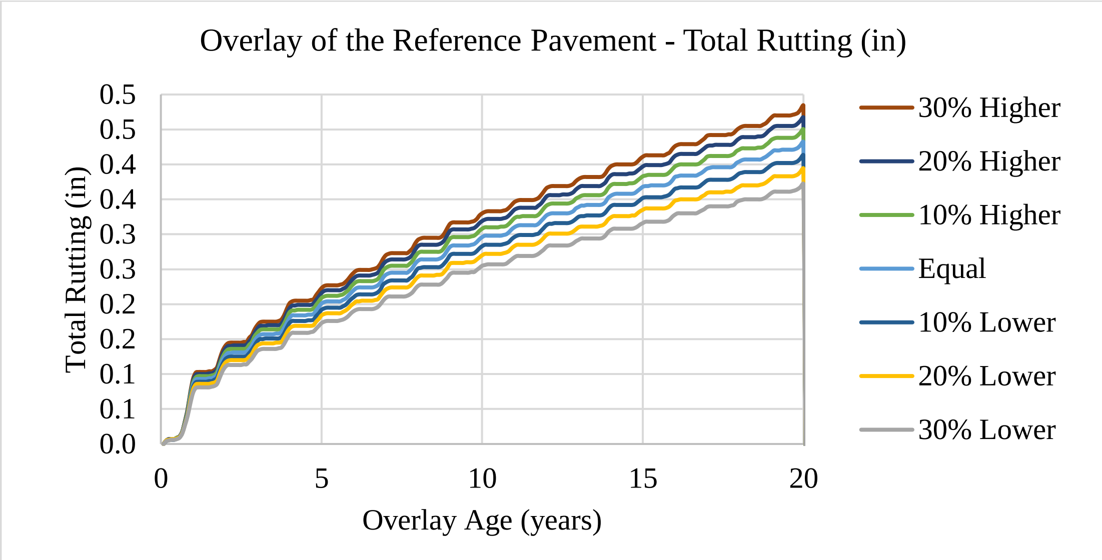

Figure 79 Predicted Total Rutting for the Overlay of the Reference Pavement Considering Different Traffic Levels

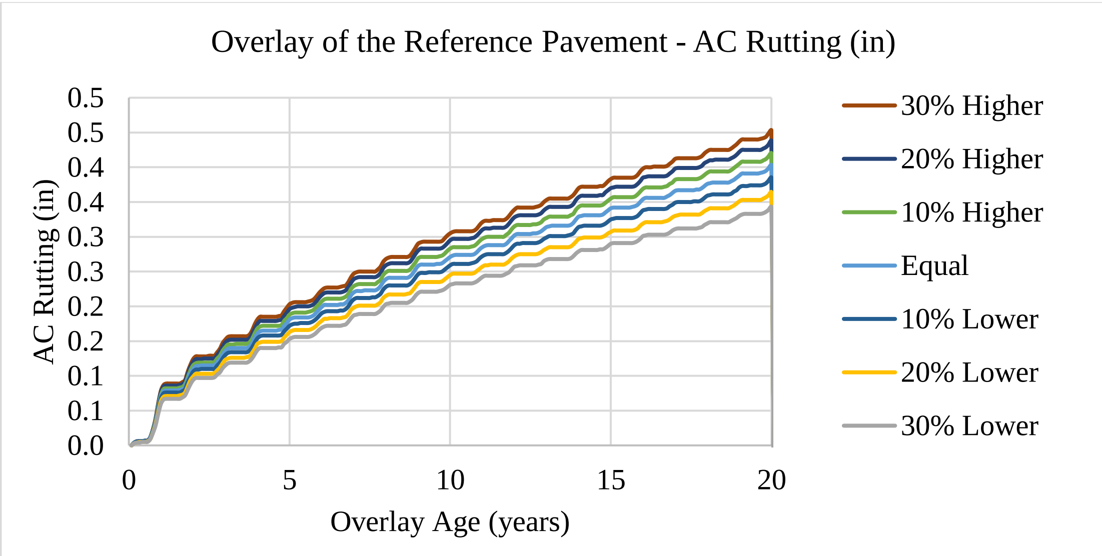

Figure 80 Predicted AC Rutting for the Overlay of the Reference Pavement Considering Different Traffic Levels

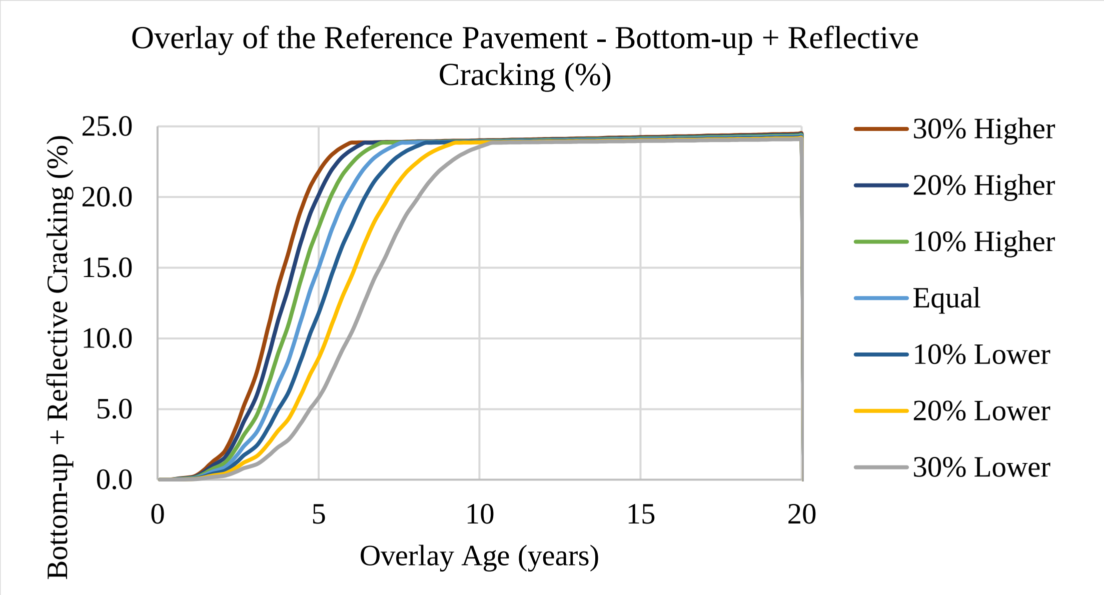

Figure 81 Predicted Bottom-up and Reflective Cracking for the Overlay of the Reference Pavement Considering Different Traffic Levels

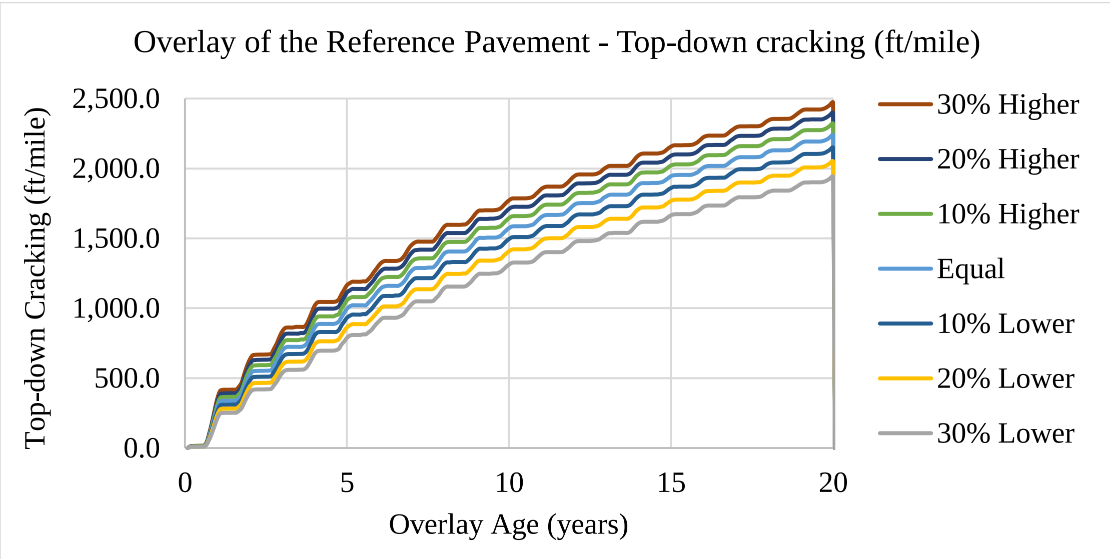

Figure 82 Predicted Top-down Cracking for the Overlay of the Reference Pavement Considering Different Traffic Levels

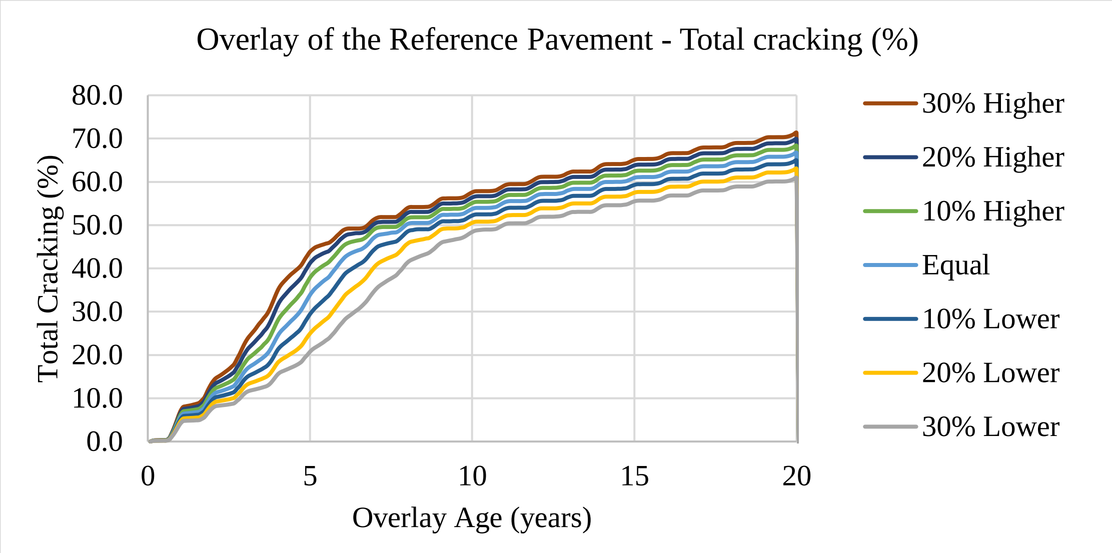

Figure 83 Total Cracking for the Overlay of the Reference Pavement Considering Different Traffic Levels

The service life of the overlay is 4 years for the case where actual traffic level is equal to forecasted, 3.83, 3.5 and 3 years respectively for the cases where actual traffic levels are 10, 20 and 30% higher-than-forecasted, and 4.5, 5 and 5.75 years respectively for the cases where actual traffic levels are 10, 20 and 30% lower-than-forecasted.

8.4.2. Financial Analysis

8.4.2.1. Financial Model's Input Parameters

The input parameters used for the financial model are shown in Table 35, based on section 5.3.1 in Chapter 5. Note that the inputs in bold are those to be changed based on the previously described scenarios considering different traffic levels.

Table 35 Financial Model's Input Parameters

Input Parameter	**Value**

General and Construction	Study year			2020
	Beginning of Operating period			2023
	Concession life (including construction period)			30
	Construction period			2
	Length of the highway (km)			150
	Construction cost (million USD per km)			3
	Total construction (million USD)			450
Traffic – Toll – Other Revenues	Type of traffic growth			Linear
	Initial daily traffic category 1 (cars)			**16,000**
	Initial daily traffic category 2 (trucks)			**4,000**
	Yearly traffic increase			3%
	Toll category 1 (USD/km)			0.10
	Toll category 2 (USD/km)			0.12
	Other revenues (million USD)			0
	Indexation of tolls and revenues			2%
Recurrent Costs	Concessionaire cost (million USD per year)			1.4
	Operation costs (million USD per year)			4.1
	Highway heavy maintenance cost as percentage of the construction cost			20%
	Frequency of highway heavy maintenance			**Every 5 years**
	Light maintenance cost per year as percentage of the construction cost			2.5%
Financial Structure	Investment subsidy (as a percentage of the total construction cost)			Model output
	Equity (as a percentage of the total construction cost)			40%
	Debt	First tranche	Maturity	10 years
			Interest rate	4%
			Grace period	2 years
		Second tranche	Maturity	5 years
			Interest rate	4.5%
			Grace period	2 years
		Third tranche	Maturity	5 years
			Interest rate	5%
			Grace period	2 years
Depreciation	Depreciation			Linear
	Duration of amortization			26 years

	Coefficient	2.5
Taxation and Inflation	Corporate tax	30%
	Other tax	0%
	VAT tax	19.6%
	Inflation rate at year of study	2%
Private Partner	Minimum Equity IRR in real terms	15%
	Minimum Equity IRR in nominal terms	17.3%
	Minimum Project IRR in real terms	9.8%
	Minimum Project IRR in nominal terms	12%
Public Authorities	Discount Rate for the state in real terms	8%
	Discount Rate for the state in nominal terms	10.16%

The frequency of the heavy maintenance is estimated as follows: based on the AASHTOWare Pavement ME results obtained in section 8.3.1, the first heavy maintenance, for the reference pavement case, is scheduled after 10 years, and the service life of the overlay is 4 years. However, the financial model allows to input only one value for the frequency of the heavy maintenance activity. Accordingly, an average value of the frequency of the heavy maintenance activity is estimated as to generate a present value equal to the one resulting from all the maintenance activities performed throughout the concession period, as explained next.

Table 36 Present Value of All Maintenance Activities for the Case Study

Year	Concession year	Operation year	Maintenance activities	Cost (million USD)	Present value
2021	1	_			
2022	2	_			
2023	3	1			
2024	4	2			
2025	5	3			
2026	6	4			
2027	7	5			
2028	8	6			
2029	9	7			
2030	10	8			

2031	11	9			
2032	12	10			
2033	13	11	M1	90	23.10
2034	14	12			
2035	15	13			
2036	16	14			
2037	17	15	M2	90	14.68
2038	18	16			
2039	19	17			
2040	20	18			
2041	21	19	M3	90	9.33
2042	22	20			
2043	23	21			
2044	24	22			
2045	25	23	M4	90	5.93
2046	26	24			
2047	27	25			
2048	28	26			
2049	29	27	M5	90	3.77
2050	30	28			
2051	31	remaining life value		-45.00	-1.50
Present value of all maintenance activities					55.31

Table 36 shows all heavy maintenance activities (denoted M1 – M5) performed for the considered case study throughout the concession period, as well as the corresponding cost (90 million USD). The last column provides the present value of each maintenance activity, considering a discount rate of 12%. The present value is calculated as follows:

$PV = FV / (1+r)^n$ (Eq. 12)

FV is the future value.

"r" is the discount rate = 12%.

"n" is the investment period, which is equal to the year when the maintenance is performed minus the first year.

The average frequency of the heavy maintenance “x” is then calculated by solving the following equation:

$\sum PVi = FV / (1+r)^x$

$\sum PVi$ is present value of all maintenance activities throughout the concession period = 55.31.

FV is the heavy maintenance cost = 90 million USD.

“r” is the discount rate = 12%.

$55.31 = 90 / (1+0.12)^x$

Using “Solver” in Excel, x = 5 years.

In other words, performing the heavy maintenance activities every 5 years will generate the same present value as the one generated considering a first maintenance performed after 10 years, then every 4 years (considering the same maintenance cost and the same discount rate).

Table 37 provides the estimated average frequency of the heavy maintenance activity for the different considered scenarios, i.e. the cases where actual traffic levels are 1) equal to forecasted, 2) 10% lower than forecasted, 3) 20% lower than forecasted, 4) 30% lower than forecasted, and 5) 10% higher than forecasted, 6) 20% higher than forecasted and 7) 30% higher than forecasted.

Table 37 Average Frequency of Heavy Maintenance Activity Considering Different Traffic Levels

Scenario (AADTT)	**First maintenance (years)**	**Overlay service life (years)**	**Average frequency of maintenance activities (years)**
2,800 (30% lower)	13	5.75	10.78
3,200 (20% lower)	11.83	5.08	9.144

3,600 (10% lower)	10.83	4.58	7.34
4,000 (reference)	9.92	4	5
4,400 (10% higher)	8.92	3.83	4.16
4,800 (20% higher)	8	3.58	2.18
5,200 (30% higher)	7.83	3.25	0.977

8.4.2.2. Financial Analysis for the Case where Actual Traffic Levels are Equal to Forecasted

For this scenario, the initial number of cars and trucks are respectively 16,000 and 4,000 and the frequency of the heavy maintenance is 5 years. The model's output in terms of the concessionaire's return and the highway agency's financial flow are shown in Table 38.

Table 38 Financial Analysis Results for the Case where Actual Traffic Levels are Equal to Forecasted

Category	Output	Value
Concessionaire's return	Project IRR after tax (nominal terms) %	15.44%
	Project IRR after tax (real terms) %	13.17%
	Payback period (years into operating period)	8
	Project NPV (million USD)	145
	Equity IRR after tax (nominal terms) %	20.34%
	Equity IRR after tax (real terms) %	17.98%
	Sum dividends in real terms (million USD)	1,912
Highway Agency's financial flow	Sum subsidies in real terms (million USD)	43.6
	PV on subsidy at 8% in real terms (million USD)	31.7
	Sum VAT and other taxes in real terms (million USD)	801.2
	PV on VAT and other taxes in real terms (million USD)	235.1
	Sum corporate taxes in real terms (million USD)	810
	PV on corporate taxes in real terms (million USD)	199.5
	Sum state revenues (- subsidy + VAT + corporate tax)	1567.6

	PV on state revenues in real terms	403

8.4.2.3. Financial Analysis for a 10% Lower-than-Forecasted Traffic Levels

For this scenario, the initial number of cars and trucks are respectively 14,400 and 3,600 (Table 34) and the frequency of the heavy maintenance, corresponding to a 10% shortage in traffic levels, is 7 years (Table 37).

Two different analyses are conducted: 1) the effect of the shortage in traffic levels on both the cash inflow and the cash outflow is considered, meaning that the initial traffic count is changed from 16,000 cars and 4,000 trucks to 14,400 cars and 3,600 trucks and the frequency of the heavy maintenance changed from 5 years to 7 years and 2) the effect of shortage in traffic levels on the cash outflow is ignored, as to imitate current practices in the application of different risk sharing mechanisms; in other words, the initial traffic count is changed from 16,000 cars and 4,000 trucks to 14,400 cars and 3,600 trucks but the frequency of the heavy maintenance will be left as 5 years. The corresponding results are shown in Table 39.

Table 39 Financial Analysis Results for the Case where Actual Traffic Levels are 10% Lower than Forecasted

Category	Output	Value considering the effect on cash inflow and cash outflow	Value ignoring the effect on cash outflow
Concessionaire's return	Project IRR after tax (nominal terms) %	14.51%	13.80%
	Project IRR after tax (real terms) %	12.27%	11.57%
	Payback period (years into operating period)	8	9
	Project NPV (million USD)	104	74

	Equity IRR after tax (nominal terms) %	19.28%	18.49%
	Equity IRR after tax (real terms) %	16.94%	16.17%
	Sum dividends in real terms (million USD)	1,736	1,646
Highway Agency's financial flow	Sum subsidies in real terms (million USD)	57.6	73
	PV on subsidy at 8% in real terms (million USD)	41.9	53.3
	Sum VAT and other taxes in real terms (million USD)	721.1	721.1
	PV on VAT and other taxes in real terms (million USD)	211.6	211.6
	Sum corporate taxes in real terms (million USD)	736.2	698.4
	PV on corporate taxes in real terms (million USD)	182.9	172.8
	Sum state revenues (-subsidy + VAT + corporate tax)	1399.7	1346.5
	PV on state revenues in real terms	352.6	331.1

By comparing the results of Table 38 and Table 39, corresponding to the cases where actual traffic levels are equal to forecasted (reference scenario) and 10% lower than forecasted respectively, it can be concluded that, if the maintenance cost is not updated based on the encountered shortage in traffic levels, the concessionaire is likely to be over-compensated. In fact, the project's NPV for the reference case (actual traffic = forecasted) is 145 million USD and is reduced to 104 million USD in case the actual traffic is 10% lower than forecasted, considering the effect of this shortage in traffic levels on both the generated toll revenues and the maintenance expenditures. However, if the effect of the lower-than-forecasted traffic levels on the maintenance frequency, and consequently the maintenance cost, is ignored, the estimated project's NPV (74 million USD) would be significantly lower than the actual one. A similar trend is observed for the project's IRR, equity IRR and dividends.

These observations can be explained by examining the operating revenues and operating costs for both scenarios, provided in Table 40. Note that the operating revenues correspond to the toll revenues, as no additional source of revenues was considered in the analysis. The operating costs are the sum of the concessionaire, operation, heavy maintenance and light maintenance costs. As previously stated, the concessionaire, operation, and light maintenance costs are common to all scenarios, only the heavy maintenance costs vary based on the specified frequency.

As can be inferred from the last row in Table 40, when actual traffic level are 10% lower than forecasted, the generated toll revenues, in present value, are 100*(1213.16 - 1091.84)/1213.16 = 10% lower than expected, resulting in some losses for the concessionaire; however, the total operating costs, are also lower than originally forecasted by 100*(341.89 – 291.29)/341.89 = 14.8%, therefore representing a kind of compensation to the concessionaire.

Accordingly, when the heavy maintenance frequency, and consequently the operating costs, are not updated based on the actual traffic levels, the estimated losses of the concessionaire, resulting from the shortage in traffic levels, are exaggerated, and the subsidy required to be paid by the highway agency is also over-estimated.

This observation is further emphasized by examining the cumulated net profit for 1) the reference case where actual traffic levels are equal to forecasted, 2) the case where actual traffic levels are 10% lower than forecasted and both the operating revenues and operating costs are updated accordingly, and 3) the case where actual traffic levels are 10% lower than forecasted but only the operating revenues are updated, without considering any effect on the operating costs, as seen in Figure 84.

Table 40 Operating Revenues and Operating Costs for the Cases where Actual Traffic Levels are 1) Equal to Forecasted and 2) 10% Lower-than-Forecasted

Year	Operation Year	Operating/Toll Revenues (million USD)		Operating costs (million USD)	
		Actual traffic = forecasted	Actual traffic 10% lower than forecasted	Actual traffic = forecasted	Actual traffic 10% lower than forecasted
2021	-	-	-	-	-
2022	-	-	-	-	-
2023	1	101.05	90.94	-36.88	-31.42
2024	2	106.16	95.54	-37.61	-32.05
2025	3	111.53	100.38	-38.37	-32.69
2026	4	117.17	105.46	-39.13	-33.34
2027	5	123.10	110.79	-39.92	-34.01
2028	6	129.33	116.40	-40.72	-34.69
2029	7	135.88	122.29	-41.53	-35.38
2030	8	142.75	128.48	-42.36	-36.09
2031	9	149.97	134.98	-43.21	-36.81
2032	10	157.56	141.81	-44.07	-37.55
2033	11	165.54	148.98	-44.95	-38.30
2034	12	173.91	156.52	-45.85	-39.07
2035	13	182.71	164.44	-46.77	-39.85
2036	14	191.96	172.76	-47.70	-40.64
2037	15	201.67	181.50	-48.66	-41.46
2038	16	211.87	190.69	-49.63	-42.29
2039	17	222.59	200.34	-50.62	-43.13
2040	18	233.86	210.47	-51.64	-43.99
2041	19	245.69	221.12	-52.67	-44.87
2042	20	258.12	232.31	-53.72	-45.77
2043	21	271.18	244.07	-54.80	-46.69
2044	22	284.91	256.42	-55.89	-47.62
2045	23	299.32	269.39	-57.01	-48.57
2046	24	314.47	283.02	-58.15	-49.55
2047	25	330.38	297.34	-59.31	-50.54
2048	26	347.10	312.39	-60.50	-51.55
2049	27	364.66	328.19	-61.71	-52.58
2050	28	383.11	344.80	-62.94	-53.63
Present value to the first year of the concession		**1,213.16**	**1,091.84**	**-341.89**	**-291.29**

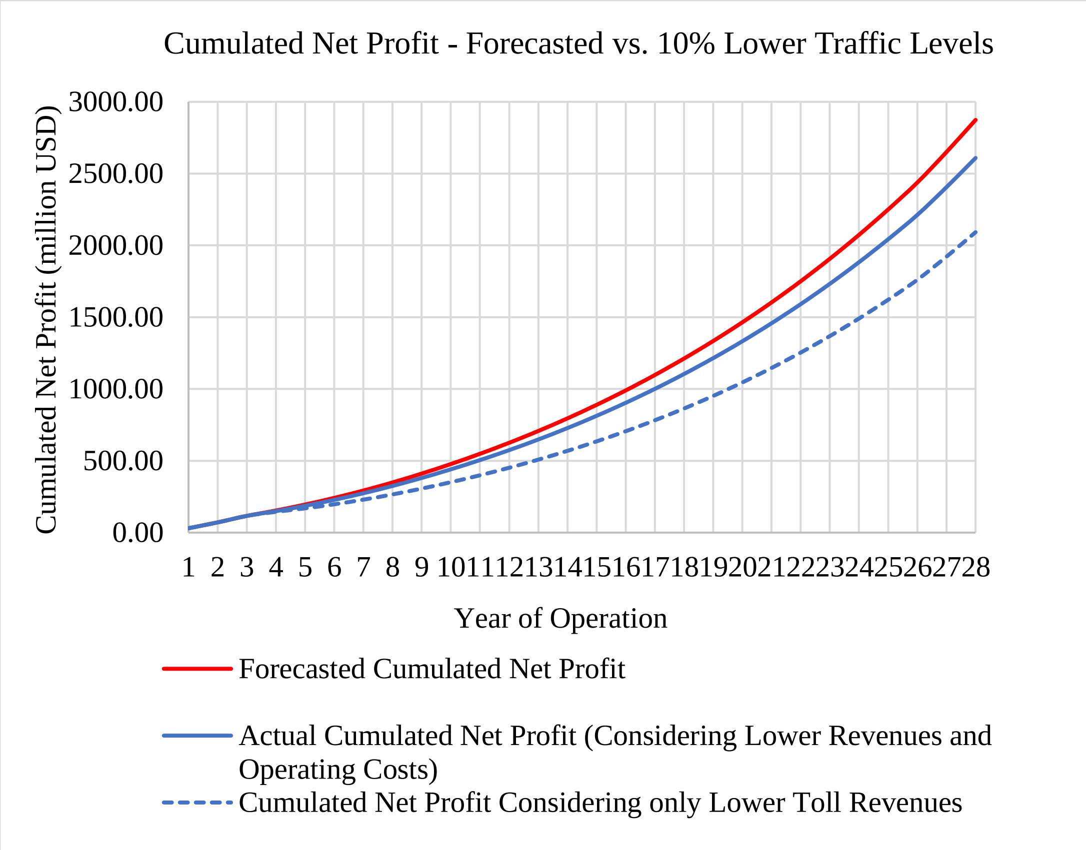

Figure 84 Cumulated Net Profit for the Cases where Actual Traffic Levels are 1) Equal to Forecasted and 2) 10% Lower-than-Forecasted

8.4.2.3.1. Adjusted MRG Mechanism

The concept of the MRG traffic volume risk sharing mechanism is to provide a subsidy paid by the highway agency to the concessionaire as to compensate the losses resulting from a shortage in traffic levels. The value of the required subsidy that allows the concessionaire to maintain a user-defined annual debt service coverage ratio (ADSCR) is directly provided by the model.

Considering the reference case where actual traffic levels are equal to forecasted, the needed subsidy, in present value, is 31.7 million USD (Table 38). In case the actual traffic levels turn out to be 10% lower-than-forecasted, if the resulting effect on both the operating revenues and operating costs is considered, then the needed subsidy increases to 41.9 million USD. However, if the effect of lower traffic levels on maintenance expenditures is ignored, as observed in current practices of the MRG mechanism, the estimated subsidy is 53.3 million USD (Table 39), which is 27% higher than the actually needed subsidy (41.9 million USD) to achieve the desired ADSCR. Accordingly, by accurately estimating the resulting effect of any shortage in traffic levels on the operating revenues and operating costs, the highway agency's contingent liabilities can be reduced without compromising the concessionaire's profit.

8.4.2.3.2. Adjusted LPVR Mechanism

Suppose that a LPVR mechanism is adopted, and that the concession term is set to end when the equity IRR in nominal terms reaches 15%. The evolution of the equity IRR in nominal terms for the cases where actual traffic levels are 1) equal to forecasted, 2) 10% lower than forecasted considering the resulting effect on both the operating revenues and operating costs and 3) 10% lower than forecasted considering the resulting effect on the operating revenues only, are provided in Table 41.

Table 41 Equity IRR in Nominal Terms for the Cases where Actual Traffic Levels are 1) Equal to Forecasted and 2) 10% Lower-than-Forecasted

Year	Concession year	Equity IRR in nominal terms		
		Actual traffic = forecasted	Actual traffic 10% lower than forecasted considering effect on operating revenues and costs	Actual traffic 10% lower than forecasted considering effect on operating revenues only
2021	1	-	-	-
2022	2	-	-	-
2023	3	-	-	-
2024	4	-57.10%	-57.10%	-57.10%

2025	5	-39.00%	-39.00%	-39.00%
2026	6	-24.30%	-26.95%	-30.01%
2027	7	-13.03%	-15.61%	-18.40%
2028	8	-5.64%	-8.12%	-10.70%
2029	9	-0.42%	-2.79%	-5.16%
2030	10	3.42%	1.16%	-1.02%
2031	11	8.02%	6.16%	4.44%
2032	12	11.02%	9.36%	7.87%
2033	13	13.15%	11.61%	10.27%
2034	14	**14.72%**	13.27%	12.03%
2035	15	15.92%	14.54%	13.38%
2036	16	16.85%	**15.53%**	14.43%
2037	17	17.46%	16.19%	**15.15%**
2038	18	17.97%	16.72%	15.70%
2039	19	18.38%	17.16%	16.17%
2040	20	18.73%	17.52%	16.57%
2041	21	19.02%	17.84%	16.90%
2042	22	19.27%	18.10%	17.19%
2043	23	19.48%	18.32%	17.43%
2044	24	19.65%	18.51%	17.64%
2045	25	19.80%	18.68%	17.82%
2046	26	19.93%	18.82%	17.97%
2047	27	20.04%	18.94%	18.11%
2048	28	20.13%	19.04%	18.22%
2049	29	20.22%	19.14%	18.33%
2050	30	20.29%	19.22%	18.42%
2051	31	20.34%	19.28%	18.49%

As per Table 41, a 14-year concession period is required for the concessionaire to achieve the target return on equity (equity IRR), if actual traffic levels are equal to forecasted ones. If a 10% shortage in traffic levels is encountered, an extension by approximately 1.5 years is required for the concessionaire to achieve the target IRR (total concession period of 15.5 years), if the effect on the lower traffic levels on cash inflow and cash outflow is considered. However, if the effect of lower traffic levels on maintenance expenditures is ignored, as observed in current practices of the LPVR mechanism, then the required extension of the concession period will increase to 3 years (total concession period of 17 years). Accordingly, the highway agency will be losing the operation rights of the toll road for 1.5 years. This observation emphasizes on the necessity of assessing the effect of lower traffic levels on the operating costs as well as the operating revenues when providing the concessionaire with any type of guarantee or compensation for lower-than-forecasted traffic levels.

8.4.2.3.3. Observations Regarding the Project's Cash Flow

Note that, in this section, the observations are based on a comparison between the results of 1) the reference case where actual traffic levels are equal to forecasted ones and 2) the case of a 10% lower traffic levels considering the resulting effect on operating costs and revenues.

It seems that a 10% lower-than-forecasted traffic levels scenario is a lose-lose situation for both PPP partners.

From the highway agency's perspective, the subsidy necessary to cover debt service increases from 31.7 for the reference case to 41.9 million USD when a 10% lower traffic volume is encountered. The total highway agency's income (taxes – subsidy) significantly decreases from 403 to 352.6 million USD (Table 38 and Table 39). This corresponds to a 12.5% loss in the highway agency's revenues.

From the concessionaire's perspective, a decrease is observed in the project IRR in nominal terms (from 15.44 to 14.51%), equity IRR in nominal terms (from 20.34 to 19.28%), project NPV (from 145 to 104 million USD), and dividends (from 1912 to 1736 million USD) between the reference case and the case where actual traffic volumes are 10% lower-than-forecasted. The same 8-year pay-back period is observed for both cases (Table 38 and Table 39).

8.4.2.4. Financial Analysis for a 20% Lower-than-Forecasted Traffic Levels

For this scenario, the initial number of cars and trucks are respectively 12,800 and 3,200 (Table 34) and the frequency of the heavy maintenance, corresponding to a 20% shortage in traffic levels, is 9 years (Table 37).

Similarly to section 8.3.2.3, two different analyses are conducted: 1) the effect of the shortage in traffic levels on both the cash inflow and the cash outflow is considered, meaning that the initial traffic count is changed from 16,000 cars and 4,000 trucks to 12,800 cars and 3,200 trucks and the frequency of the heavy maintenance changed from 5 years to 9 years and 2) the effect of shortage in traffic levels on the cash outflow is ignored, as to imitate current practices in the application of different risk sharing mechanisms; in other words, the initial traffic count is changed from 16,000 cars and 4,000 trucks to 12,800 cars and 3,200 trucks but the frequency of the heavy maintenance will be left as 5 years. The corresponding results are shown in Table 42.

Table 42 Financial Analysis Results for the Case where Actual Traffic Levels are 20% Lower than Forecasted

Category	**Output**	**Value considering the effect on cash inflow and cash outflow**	**Value ignoring the effect on cash outflow**
Concessionaire's return	Project IRR after tax (nominal terms) %	13.90%	12.96%
	Project IRR after tax (real terms) %	11.67%	10.74%
	Payback period (years into operating period)	9	9
	Project NPV (million USD)	78	39
	Equity IRR after tax (nominal terms) %	18.58%	17.61%

	Equity IRR after tax (real terms) %	16.25%	15.30%
	Sum dividends in real terms (million USD)	1,632	1,516
Highway Agency's financial flow	Sum subsidies in real terms (million USD)	67.5	92
	PV on subsidy at 8% in real terms (million USD)	49.2	66.8
	Sum VAT and other taxes in real terms (million USD)	681	681
	PV on VAT and other taxes in real terms (million USD)	199.9	199.9
	Sum corporate taxes in real terms (million USD)	692.2	643.8
	PV on corporate taxes in real terms (million USD)	172.7	160.1
	Sum state revenues (-subsidy + VAT + corporate tax)	1305.8	1232.9
	PV on state revenues in real terms	323.4	293.2

Similar conclusions to those observed for the case of a 10% lower-than-forecasted traffic levels can be drawn: if the effect of the lower traffic levels on operating costs are ignored, the estimated losses encountered by the concessionaire are exaggerated, in terms of the project's NPV, project's IRR, equity IRR and shareholder's dividends.

Based on the operating revenues and operating costs presented in Table 43, a 20% lower traffic levels result in 20% lower operating revenues and 23% lower operating costs. Figure 85, showing the cumulated net profit of the concessionaire for 1) the reference case (actual traffic = forecasted), 2) the case where actual traffic levels are 20% lower than forecasted and the resulting effect on cash inflow and outflow is considered and 3) the case where actual traffic levels are 20% lower than forecasted and the resulting effect on cash outflow is ignored, proves that the reduced operating costs, caused by the lower traffic levels, narrowed the difference between the concessionaire's expected net profit based on initial traffic forecasts, and the actual profits estimated based on the updated traffic levels, operating revenues and operating costs.

Table 43 Operating Revenues and Operating Costs for the Cases where Actual Traffic Levels are 1) Equal to Forecasted and 2) 20% Lower-than-Forecasted

Year	Operation Year	Operating/Toll Revenues (million USD)		Operating costs (million USD)	
		Actual traffic = forecasted	Actual traffic 20% lower than forecasted	Actual traffic = forecasted	Actual traffic 20% lower than forecasted
2021	-	-	-	-	-
2022	-	-	-	-	-
2023	1	101.05	80.84	-36.88	-28.39
2024	2	106.16	84.93	-37.61	-28.96
2025	3	111.53	89.22	-38.37	-29.53
2026	4	117.17	93.74	-39.13	-30.12
2027	5	123.10	98.48	-39.92	-30.73
2028	6	129.33	103.47	-40.72	-31.34
2029	7	135.88	108.70	-41.53	-31.97
2030	8	142.75	114.20	-42.36	-32.61
2031	9	149.97	119.98	-43.21	-33.26
2032	10	157.56	126.05	-44.07	-33.93
2033	11	165.54	132.43	-44.95	-34.60
2034	12	173.91	139.13	-45.85	-35.30
2035	13	182.71	146.17	-46.77	-36.00
2036	14	191.96	153.57	-47.70	-36.72
2037	15	201.67	161.34	-48.66	-37.46
2038	16	211.87	169.50	-49.63	-38.21
2039	17	222.59	178.08	-50.62	-38.97
2040	18	233.86	187.09	-51.64	-39.75
2041	19	245.69	196.55	-52.67	-40.54
2042	20	258.12	206.50	-53.72	-41.35
2043	21	271.18	216.95	-54.80	-42.18
2044	22	284.91	227.93	-55.89	-43.03
2045	23	299.32	239.46	-57.01	-43.89
2046	24	314.47	251.57	-58.15	-44.76
2047	25	330.38	264.30	-59.31	-45.66
2048	26	347.10	277.68	-60.50	-46.57
2049	27	364.66	291.73	-61.71	-47.50

2050	28	383.11	306.49	-62.94	-48.45
Present value to the first year of the concession		**1,213.16**	**970.53**	**-341.89**	**-263.18**

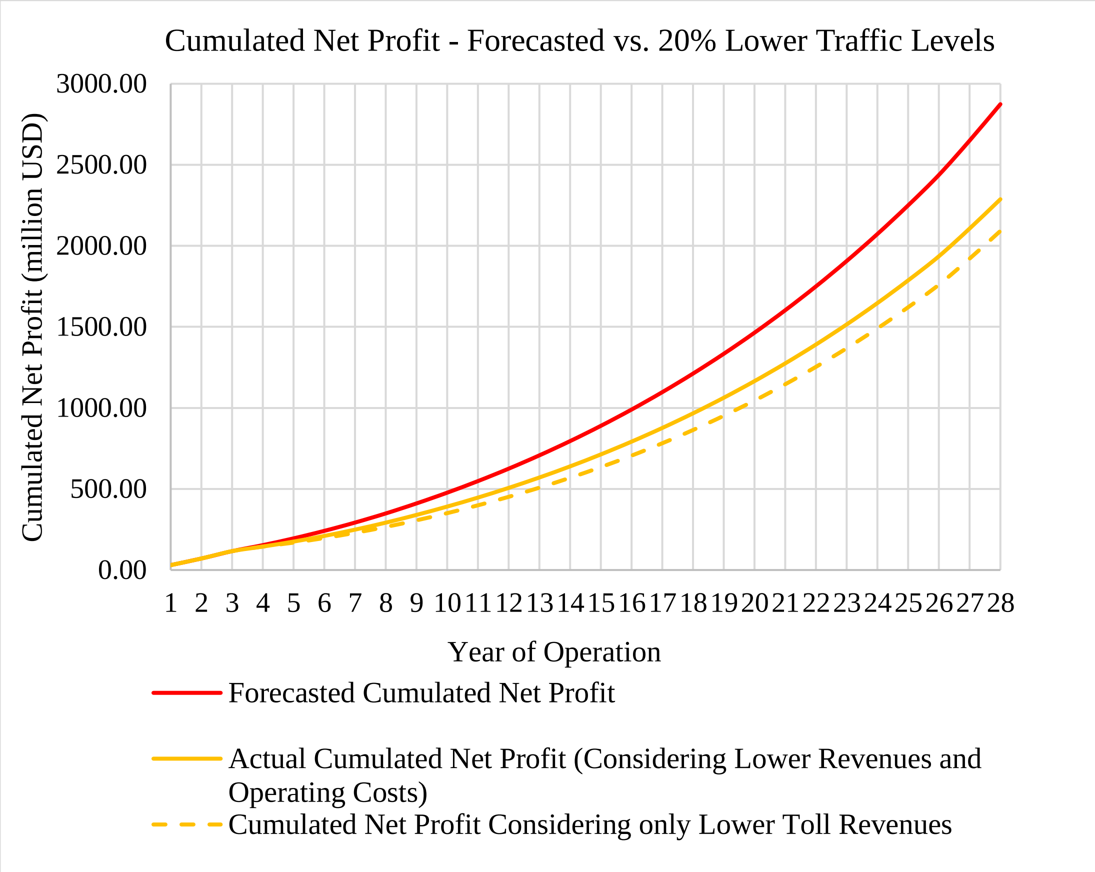

Figure 85 Cumulated Net Profit for the Cases where Actual Traffic Levels are 1) Equal to Forecasted and 2) 20% Lower-than-Forecasted

8.4.2.4.1. Adjusted MRG Mechanism

Considering the reference case where actual traffic levels are equal to forecasted, the needed subsidy, in present value, is 31.7 million USD (Table 38). In case the actual traffic levels turn out to be 20% lower-than-forecasted, if the resulting effect on both the operating revenues and operating costs is considered, then the needed subsidy increases to 49.2 million USD. However, if the effect of lower traffic levels on maintenance expenditures is ignored, as observed in current practices of the MRG mechanism, the estimated subsidy is 66.8 million USD (Table 42), which is 36% higher than the actually needed subsidy (49.2 million USD) to achieve the desired ADSCR. The obtained results emphasize the need for updating the operating revenues and operating costs based on actual traffic before estimating the value of the subsidy to be offered to the concessionaire, as to protect the highway agency's interest, without compromising the concessionaire's profit.

8.4.2.4.2. Adjusted LPVR Mechanism

The evolution of the equity IRR in nominal terms for the cases where actual traffic levels are 1) equal to forecasted, 2) 20% lower than forecasted considering the resulting effect on both the operating revenues and operating costs and 3) 20% lower than forecasted considering the resulting effect on the operating revenues only, are provided in Table 44.

Table 44 Equity IRR in Nominal Terms for the Cases where Actual Traffic Levels are 1) Equal to Forecasted and 2) 20% Lower-than-Forecasted

Year	Concession year	Equity IRR in nominal terms		
		Actual traffic = forecasted	Actual traffic 20% lower than forecasted considering effect on operating revenues and costs	Actual traffic 20% lower than forecasted considering effect on operating revenues only
2021	1	-	-	-
2022	2	-	-	-
2023	3	-	-	-
2024	4	-57.10%	-57.10%	-57.10%
2025	5	-39.00%	-39.00%	-39.00%
2026	6	-24.30%	-30.63%	-30.63%
2027	7	-13.03%	-19.69%	-23.55%
2028	8	-5.64%	-12.06%	-16.08%
2029	9	-0.42%	-6.53%	-10.42%

2030	10	3.42%	-2.37%	-6.02%
2031	11	8.02%	3.37%	0.69%
2032	12	11.02%	6.91%	4.64%
2033	13	13.15%	9.37%	7.34%
2034	14	**14.72%**	11.18%	9.32%
2035	15	15.92%	12.56%	10.83%
2036	16	16.85%	13.64%	12.00%
2037	17	17.46%	14.39%	12.85%
2038	18	17.97%	**14.95%**	13.45%
2039	19	18.38%	15.42%	13.97%
2040	20	18.73%	15.83%	14.41%
2041	21	19.02%	16.17%	14.79%
2042	22	19.27%	16.46%	**15.12%**
2043	23	19.48%	16.71%	15.40%
2044	24	19.65%	16.93%	15.64%
2045	25	19.80%	17.11%	15.85%
2046	26	19.93%	17.27%	16.04%
2047	27	20.04%	17.41%	16.20%
2048	28	20.13%	17.53%	16.34%
2049	29	20.22%	17.65%	16.47%
2050	30	20.29%	17.75%	16.59%
2051	31	20.34%	17.83%	16.70%

If a 20% shortage in traffic levels is encountered, a 4 year extension of the concession period is required for the concessionaire to achieve the target IRR (total concession period of 18 years), if the effect on the lower traffic levels on cash inflow and cash outflow is considered. However, if the effect of lower traffic levels on maintenance expenditures is ignored, as observed in current practices of the LPVR mechanism, then the required extension of the concession period will increase to 8 years (total concession period of 22 years); accordingly, the highway agency will be losing the operation rights of the toll road for 4 years.

8.4.2.4.3. Observations Regarding the Project's Cash Flow

If the effect of a 20% lower-than-forecasted traffic levels on the generated toll revenues and pavement maintenance costs is considered, both PPP partners seem to encounter some losses.

From the perspective of the highway agency, the subsidy necessary to cover debt service increases from 31.7 for the reference case to 58.2 million USD when a 20% lower traffic volume is encountered. The total highway agency's income significantly decreases from 403 to 292 million USD (Table 38 and Table 42). This corresponds to a 27.5% loss in the highway agency's revenues.

From the concessionaire's perspective, a decrease is observed in the project IRR in nominal terms (from 15.44 to 13.23%), equity IRR in nominal terms (from 20.34 to 17.83%), project NPV (from 145 to 50 million USD), and dividends (from 1912 to 1521 million USD) between the reference case and the case where actual traffic volumes are 20% lower-than-forecasted. Furthermore, the pay-back period increase from 8 to 9 years when actual traffic levels are 20% lower than forecasted (Table 38 and Table 42).

8.4.2.5. Financial Analysis for a 30% Lower-than-Forecasted Traffic Levels

For this case, the initial number of cars and trucks are respectively 11,200 and 2,800 (Table 34) and the frequency of the heavy maintenance, corresponding to a 30% shortage in traffic levels, is 11 years (Table 37). However, the maximum frequency of heavy maintenance that the model allows to input is 10 years. Accordingly, a 10 year frequency is selected. Table 45 provides the results of the financial analysis when the effect of the shortage in traffic levels on the maintenance costs is ignored versus the case where both the maintenance costs as well as the generated toll revenues are updated corresponding to the observed shortage in traffic volumes.

Table 45 Financial Analysis Results for the Case where Actual Traffic Levels are 30% Lower than Forecasted

Category	Output	Value considering the effect on cash inflow and cash outflow	Value ignoring the effect on cash outflow
Concessionaire's return	Project IRR after tax (nominal terms) %	11.60%	10.26%
	Project IRR after tax (real terms) %	9.41%	8.10%
	Payback period (years into operating period)	10	11
	Project NPV (million USD)	-16	-67
	Equity IRR after tax (nominal terms) %	16.14%	15.03%
	Equity IRR after tax (real terms) %	13.86%	12.78%
	Sum dividends in real terms (million USD)	1,280	1,140
Highway Agency’s financial flow	Sum subsidies in real terms (million USD)	116.9	169.3
	PV on subsidy at 8% in real terms (million USD)	84.3	119
	Sum VAT and other taxes in real terms (million USD)	560.8	560.8
	PV on VAT and other taxes in real terms (million USD)	164.6	164.6
	Sum corporate taxes in real terms (million USD)	545	486.2
	PV on corporate taxes in real terms (million USD)	139.1	125.3
	Sum state revenues (-subsidy + VAT + corporate tax)	988.9	877.8
	PV on state revenues in real terms	219.4	170.9

Similar conclusions to those observed for the cases of a 10% and 20% lower-than-forecasted traffic levels can be drawn: if the effect of the lower traffic levels on operating costs are ignored, the estimated losses encountered by the concessionaire, in terms of the project's NPV, project's IRR, equity IRR and shareholder's dividends, are exaggerated.

Based on the operating revenues and operating costs presented in Table 46, a 30% lower traffic levels result in 30% lower operating revenues and 26% lower operating costs. Figure 86 shows the cumulated net profit of the concessionaire for 1) the reference case (actual traffic = forecasted), 2) the case where actual traffic levels are 30% lower than forecasted and the resulting effect on cash inflow and outflow is considered and 3) the case where actual traffic levels are 30% lower than forecasted and the resulting effect on cash outflow is ignored.

Table 46 Operating Revenues and Operating Costs for the Cases where Actual Traffic Levels are 1) Equal to Forecasted and 2) 30% Lower-than-Forecasted

Year	Operation Year	Operating/Toll Revenues (million USD)		Operating costs (million USD)	
		Actual traffic = forecasted	Actual traffic 30% lower than forecasted	Actual traffic = forecasted	Actual traffic 30% lower than forecasted
2021	-	-	-	-	-
2022	-	-	-	-	-
2023	1	101.05	70.73	-36.88	-27.33
2024	2	106.16	74.31	-37.61	-27.87
2025	3	111.53	78.07	-38.37	-28.43
2026	4	117.17	82.02	-39.13	-29.00
2027	5	123.10	86.17	-39.92	-29.58
2028	6	129.33	90.53	-40.72	-30.17
2029	7	135.88	95.11	-41.53	-30.77
2030	8	142.75	99.93	-42.36	-31.39
2031	9	149.97	104.98	-43.21	-32.02
2032	10	157.56	110.29	-44.07	-32.66
2033	11	165.54	115.87	-44.95	-33.31
2034	12	173.91	121.74	-45.85	-33.98
2035	13	182.71	127.90	-46.77	-34.66
2036	14	191.96	134.37	-47.70	-35.35
2037	15	201.67	141.17	-48.66	-36.06

2038	16	211.87	148.31	-49.63	-36.78
2039	17	222.59	155.82	-50.62	-37.51
2040	18	233.86	163.70	-51.64	-38.26
2041	19	245.69	171.98	-52.67	-39.03
2042	20	258.12	180.69	-53.72	-39.81
2043	21	271.18	189.83	-54.80	-40.61
2044	22	284.91	199.43	-55.89	-41.42
2045	23	299.32	209.53	-57.01	-42.25
2046	24	314.47	220.13	-58.15	-43.09
2047	25	330.38	231.27	-59.31	-43.95
2048	26	347.10	242.97	-60.50	-44.83
2049	27	364.66	255.26	-61.71	-45.73
2050	28	383.11	268.18	-62.94	-46.64
Present value to the first year of the concession		**1,213.16**	**849.21**	**-341.89**	**-253.34**

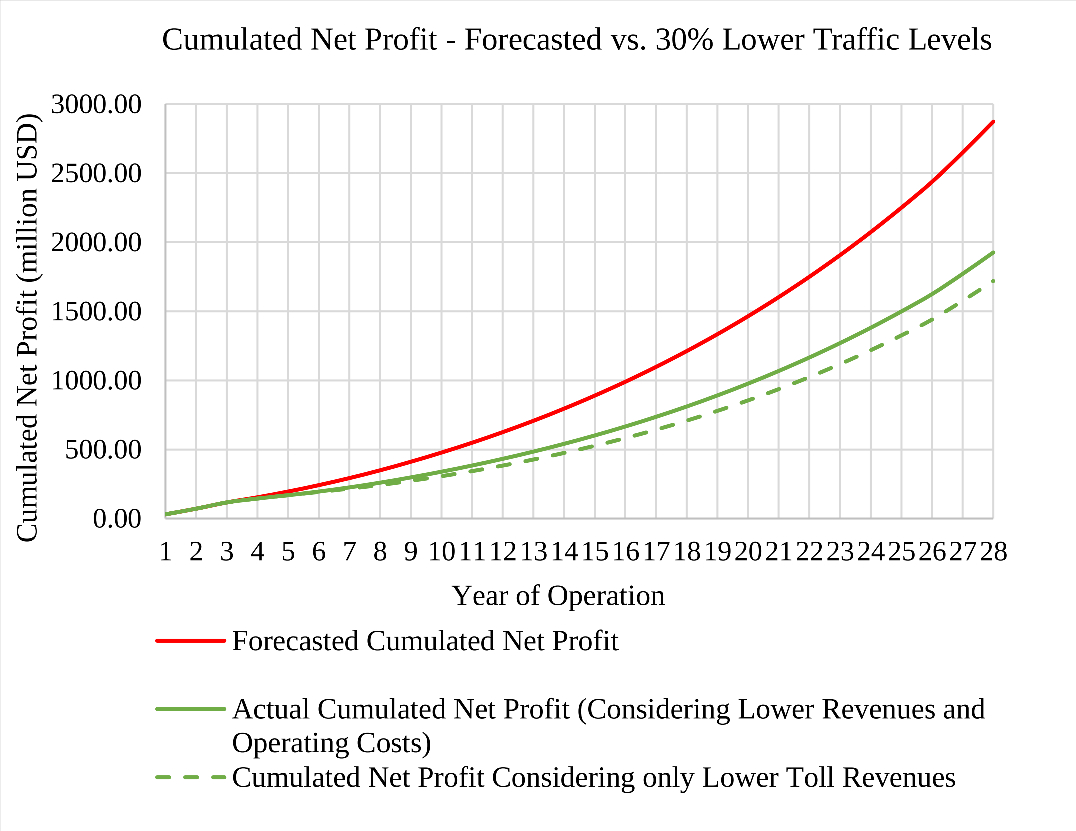

Figure 86 Cumulated Net Profit for the Cases where Actual Traffic Levels are 1) Equal to Forecasted and 2) 30% Lower-than-Forecasted

8.4.2.5.1. Adjusted MRG Mechanism

Considering the reference case where actual traffic levels are equal to forecasted, the needed subsidy, in present value, is 31.7 million USD (Table 38). In case the actual traffic levels turn out to be 30% lower-than-forecasted, if the resulting effect on both the operating revenues and operating costs is considered, then the needed subsidy increases to 84.3 million USD. However, if the effect of lower traffic levels on maintenance expenditures is ignored, as observed in current practices of the MRG mechanism, the estimated subsidy is 119 million USD (Table 45), which is 41% higher than the actually needed subsidy (84.3 million USD) to achieve the desired ADSCR.

8.4.2.5.2. Adjusted LPVR Mechanism

The evolution of the equity IRR in nominal terms for the cases where actual traffic levels are 1) equal to forecasted, 2) 30% lower than forecasted considering the resulting effect on both the operating revenues and operating costs and 3) 30% lower than forecasted considering the resulting effect on the operating revenues only, are provided in Table 47.

Table 47 Equity IRR in Nominal Terms for the Cases where Actual Traffic Levels are 1) Equal to Forecasted and 2) 30% Lower-than-Forecasted

Year	Concession year	Equity IRR in nominal terms		
		Actual traffic = forecasted	Actual traffic 30% lower than forecasted considering effect on operating revenues and costs	Actual traffic 30% lower than forecasted considering effect on operating revenues only
2021	1	-	-	-
2022	2	-	-	-
2023	3	-	-	-
2024	4	-57.10%	-57.10%	-57.10%
2025	5	-39.00%	-39.00%	-39.00%
2026	6	-24.30%	-30.63%	-30.63%

2027	7	-13.03%	-23.84%	-23.84%
2028	8	-5.64%	-16.99%	-18.56%
2029	9	-0.42%	-11.47%	-14.45%
2030	10	3.42%	-7.14%	-10.90%
2031	11	8.02%	-0.14%	-2.71%
2032	12	11.02%	3.90%	1.70%
2033	13	13.15%	6.64%	4.66%
2034	14	**14.72%**	8.65%	6.82%
2035	15	15.92%	10.18%	8.46%
2036	16	16.85%	11.37%	9.75%
2037	17	17.46%	12.24%	10.73%
2038	18	17.97%	12.85%	11.37%
2039	19	18.38%	13.36%	11.91%
2040	20	18.73%	13.80%	12.39%
2041	21	19.02%	14.18%	12.80%
2042	22	19.27%	14.51%	13.17%
2043	23	19.48%	14.80%	13.48%
2044	24	19.65%	**15.04%**	13.76%
2045	25	19.80%	15.26%	14.00%
2046	26	19.93%	15.45%	14.22%
2047	27	20.04%	15.61%	14.40%
2048	28	20.13%	15.76%	14.57%
2049	29	20.22%	15.89%	14.73%
2050	30	20.29%	16.02%	14.88%
2051	31	20.34%	16.14%	**15.03%**

For a 30% shortage in traffic levels, the needed concession period is 24 years, meaning that a 10 year extension is required to achieve the targeted equity IRR. However, if the reduction if maintenance costs resulting from the lower traffic levels is not considered, a 31-year concession period will be estimated enough to achieve the desired IRR, corresponding to a 17-year extension. Finally, by disregarding the devaluation in maintenance costs resulting from the shortage in traffic counts, the highway agency will be losing 7 years of operation of the toll road.

8.4.2.5.3. Observations Regarding the Project’s Cash Flow

It seems that a 30% lower-than-forecasted traffic levels scenario is a lose-lose situation for both PPP partners, considering the resulting effect on the pavement maintenance cost as well as the generated toll revenues.

For the highway agency, the subsidy necessary to cover debt service increases from 31.7 for the reference case to 84.3 million USD when a 30% lower traffic volume is encountered. The total highway agency's income (taxes – subsidy) significantly decreases from 403 to 219.4 million USD (Table 38 and Table 45). This corresponds to a 45.5% loss in the highway agency's revenues.

From the concessionaire's perspective, a decrease is observed in the project IRR in nominal terms (from 15.44 to 11.60%), equity IRR in nominal terms (from 20.34 to 16.14%), project NPV (from 145 to -16 million USD), and dividends (from 1912 to 1280 million USD) between the reference case and the case where actual traffic volumes are 30% lower-than-forecasted. Furthermore, the pay-back period increase from 8 to 10 years when actual traffic levels are 30% lower than forecasted (Table 38 and Table 45).

8.4.2.6. Financial Analysis for a 10% Higher-than-Forecasted Traffic Levels

For this scenario, the initial number of cars and trucks are respectively 17,600 and 4,400 (Table 34) and the frequency of the heavy maintenance, corresponding to a 10% increase in traffic levels, is 4 years (Table 37).

Two different analyses are conducted: 1) the effect of the increase in traffic levels on both the cash inflow and the cash outflow is considered, meaning that the initial traffic count is increased from 16,000 cars and 4,000 trucks to 17,600 cars and 4,400 trucks and the frequency of the heavy maintenance changed from 5 years to 4 years and 2) the effect of the increase in traffic levels on the cash outflow is ignored, as to imitate current practices in the application of different risk sharing mechanisms; in other words, the initial traffic count is changed from 16,000 cars and 4,000 trucks to 17,600 cars and 4,400 trucks but the frequency of the heavy maintenance will be left as 5 years. The corresponding results are shown in Table 48.

Table 48 Financial Analysis Results for the Case where Actual Traffic Levels are 10% Higher than Forecasted

Category	**Output**	**Value considering the effect on cash inflow and cash outflow**	**Value ignoring the effect on cash outflow**
Concessionaire's return	Project IRR after tax (nominal terms) %	16.41%	17.01%
	Project IRR after tax (real terms) %	14.13%	14.72%
	Payback period (years into operating period)	7	7
	Project NPV (million USD)	190	216
	Equity IRR after tax (nominal terms) %	21.43%	22.06%
	Equity IRR after tax (real terms) %	19.05%	19.66%
	Sum dividends in real terms (million USD)	2,100	2,179
Highway Agency’s financial flow	Sum subsidies in real terms (million USD)	27.6	14.2
	PV on subsidy at 8% in real terms (million USD)	20	10.1
	Sum VAT and other taxes in real terms (million USD)	881.3	881.3
	PV on VAT and other taxes in real terms (million USD)	258.7	258.7
	Sum corporate taxes in real terms (million USD)	888.4	921.5
	PV on corporate taxes in real terms (million USD)	217.4	226.3
	Sum state revenues (-subsidy + VAT + corporate tax)	1742.1	1788.7

	PV on state revenues in real terms	456.1	474.9

As opposed to the conclusions drawn from the financial analysis conducted for lower-than-forecasted traffic levels, in the case of a sudden increase in traffic levels, if the resulting increase in maintenance costs (caused by the accelerated deterioration of the pavement) is ignored, the evaluated extra profits gained by the concessionaire are likely to be over-estimated.

In fact, for a 10% higher-than-forecasted traffic levels, if both the operating revenues and operating costs are increased in compliance with the increase in traffic counts, then the estimated project's NPV is 190 million USD (Table 48), which is higher than the initially assessed NPV (145 million USD), based on the forecasted traffic levels (Table 38). This implies that the concessionaire is achieving a certain extra profit. However, if the increase in operating costs is ignored, then the project's NPV is substantially higher than its actual value, reaching up to 216 million USD (Table 48).

Based on the operating revenues and operating costs presented in Table 49, a 10% higher traffic levels result in 10% higher operating revenues and 13% higher operating costs. Figure 87 illustrates the cumulated net profit of the concessionaire for 1) the reference case (actual traffic = forecasted), 2) the case where actual traffic levels are 10% higher than forecasted and the resulting effect on operating revenues and operating costs is considered and 3) the case where actual traffic levels are 10% higher than forecasted and the resulting effect on operating costs is ignored. The observed cumulated net profits proves the fact that ignoring the additional maintenance expenditures borne by the concessionaire due to the increase in traffic levels leads to an overestimation of the latter's extra profits, to be shared with the highway agency, based on the concept of the MRG mechanism.

Table 49 Operating Revenues and Operating Costs for the Cases where Actual Traffic Levels are 1) Equal to Forecasted and 2) 10% Higher-than-Forecasted

Year	Operation Year	Operating/Toll Revenues (million USD)		Operating costs (million USD)	
		Actual traffic = forecasted	Actual traffic 10% higher than forecasted	Actual traffic = forecasted	Actual traffic 10% higher than forecasted
2021	-	-	-	-	-
2022	-	-	-	-	-
2023	1	101.05	111.15	-36.88	-41.65
2024	2	106.16	116.77	-37.61	-42.49
2025	3	111.53	122.68	-38.37	-43.34
2026	4	117.17	128.89	-39.13	-44.20
2027	5	123.10	135.41	-39.92	-45.09
2028	6	129.33	142.26	-40.72	-45.99
2029	7	135.88	149.46	-41.53	-46.91
2030	8	142.75	157.03	-42.36	-47.85
2031	9	149.97	164.97	-43.21	-48.80
2032	10	157.56	173.32	-44.07	-49.78
2033	11	165.54	182.09	-44.95	-50.77
2034	12	173.91	191.30	-45.85	-51.79
2035	13	182.71	200.98	-46.77	-52.83
2036	14	191.96	211.15	-47.70	-53.88
2037	15	201.67	221.84	-48.66	-54.96
2038	16	211.87	233.06	-49.63	-56.06
2039	17	222.59	244.85	-50.62	-57.18
2040	18	233.86	257.24	-51.64	-58.32
2041	19	245.69	270.26	-52.67	-59.49
2042	20	258.12	283.94	-53.72	-60.68
2043	21	271.18	298.30	-54.80	-61.89
2044	22	284.91	313.40	-55.89	-63.13
2045	23	299.32	329.25	-57.01	-64.39
2046	24	314.47	345.92	-58.15	-65.68
2047	25	330.38	363.42	-59.31	-67.00
2048	26	347.10	381.81	-60.50	-68.34
2049	27	364.66	401.13	-61.71	-69.70

2050	28	383.11	421.42	-62.94	-71.10
Present value to the first year of the concession		**1,213.16**	**1,334.47**	**-341.89**	**-386.16**

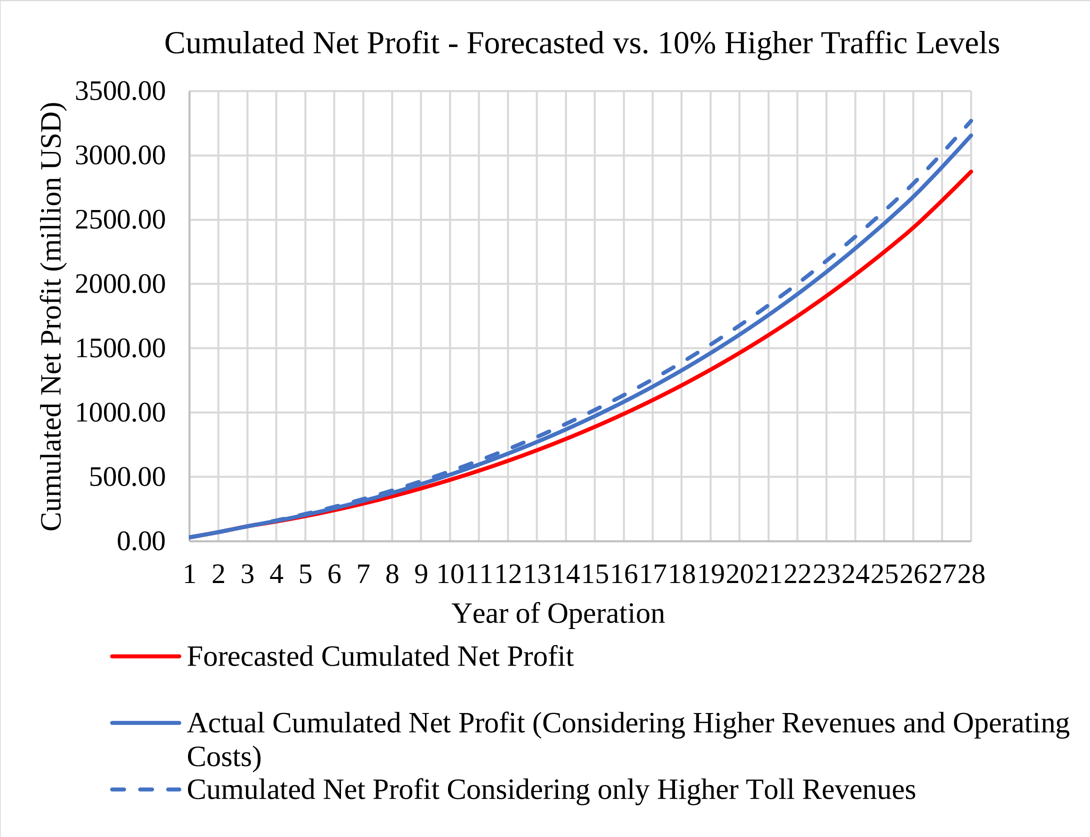

Figure 87 Cumulated Net Profit for the Cases where Actual Traffic Levels are 1) Equal to Forecasted and 2) 10% Higher-than-Forecasted

8.4.2.6.1. Adjusted MRG Mechanism

The MRG mechanism requires that the concessionaire equally shares the extra revenues resulting from any increase in traffic levels with the highway agency. However, based on the observations of the previous section, a sharing mechanism based on gross revenues is not fair to the concessionaire who will endure additional maintenance expenses caused by increased traffic levels. Accordingly, a sharing mechanism based on profit represents a better approach. The cumulated net profit at the end of the concession period is 2873.86, 3154.95 and 3268.61 million USD respectively for 1) the reference case where actual traffic levels are equal to forecasted, 2) the case where actual traffic levels are 10% higher than forecasted and the resulting effect on operating revenues and operating costs is considered and 3) the case where actual traffic levels are 10% higher than forecasted and the resulting effect on operating costs is ignored (Figure 87).

Accordingly, the extra profit, calculated relative to the reference case, gained by the concessionaire from a 10% increase in traffic levels is 3154.95 - 2873.86 = 281.09 million USD, if the effects of the higher traffic levels on the operating revenues and costs are considered. Nevertheless, if the higher maintenance costs are not taken into consideration, the concessionaire's extra profit is over estimated, as it would be valued at 3268.61 – 2873.86 = 394.75 million USD. Consequently, the highway agency's share of the extra profit would be 281.09/2 = 140.54 million USD instead of 394.75/2 = 197.37 million USD. Finally, a fair estimation of the highway agency's share of the extra profit requires an accurate estimation of the effect of the increase in traffic levels on operating costs as well as revenues.

8.4.2.6.2. Adjusted LPVR Mechanism

The evolution of the equity IRR in nominal terms for the cases where actual traffic levels are 1) equal to forecasted, 2) 10% higher than forecasted considering the resulting effect on both the operating revenues and operating costs and 3) 10% higher than forecasted considering the resulting effect on the operating revenues only, are provided in Table 50.

Table 50 Equity IRR in Nominal Terms for the Cases where Actual Traffic Levels are 1) Equal to Forecasted and 2) 10% Higher-than-Forecasted

Year	Concession year	Equity IRR in nominal terms		
		Actual traffic = forecasted	Actual traffic 10% higher than forecasted considering effect on operating revenues and costs	Actual traffic 10% higher than forecasted considering effect on operating revenues only
2021	1	-	-	-
2022	2	-	-	-
2023	3	-	-	-
2024	4	-57.10%	-57.10%	-57.09%
2025	5	-39.00%	-39.00%	-39.00%
2026	6	-24.30%	-21.73%	-19.97%
2027	7	-13.03%	-10.50%	-8.81%
2028	8	-5.64%	-3.19%	-1.60%
2029	9	-0.42%	1.92%	3.41%
2030	10	3.42%	5.64%	7.03%
2031	11	8.02%	9.90%	11.07%
2032	12	11.02%	12.71%	**13.77%**
2033	13	13.15%	**14.72%**	**15.69%**
2034	14	**14.72%**	**16.21%**	17.11%
2035	15	15.92%	17.34%	18.20%
2036	16	16.85%	18.19%	19.00%
2037	17	17.46%	18.77%	19.55%
2038	18	17.97%	19.25%	20.01%
2039	19	18.38%	19.64%	20.39%
2040	20	18.73%	19.97%	20.70%
2041	21	19.02%	20.24%	20.95%
2042	22	19.27%	20.47%	21.17%
2043	23	19.48%	20.66%	21.35%
2044	24	19.65%	20.82%	21.50%
2045	25	19.80%	20.96%	21.62%
2046	26	19.93%	21.07%	21.73%
2047	27	20.04%	21.17%	21.82%
2048	28	20.13%	21.25%	21.90%
2049	29	20.22%	21.33%	21.96%
2050	30	20.29%	21.39%	22.02%
2051	31	20.34%	21.43%	22.06%

To achieve an equity IRR of 15%, a 14-year concession period is need if actual traffic levels are equal to forecasted. If actual traffic levels are 10% higher-than-forecasted, the targeted IRR is reached at year 13.5 if the resulting effect on operating costs as well as operating revenues is considered. However, if the effect on operating revenues is not taken into consideration, the concession term will end after 12.5 years, resulting in some losses to the concessionaire.

8.4.2.6.3. Observations Regarding the Project's Cash Flow

The following observations are based on a comparison between the results of 1) the reference case where actual traffic levels are equal to forecasted ones and 2) the case of a 10% higher traffic levels considering the resulting effect on operating costs and revenues.

Apart from the MRG and LPVR mechanisms, the subsidy necessary for the concessionaire to cover debt service decreases from 31.7 million USD (Table 38) to 20 million USD (Table 48) as estimated respectively for traffic levels equal to forecast and 10% higher than forecasted. This corresponds to a 37% decrease in the provided subsidy. Furthermore, the highway agency's income, in terms of the collected taxes, is higher than the initially estimated income based on forecasted traffic.

In total, the present value of the highway agency's revenues (taxes – subsidy) for the reference case is 403 million USD (Table 38), while for the case where actual traffic levels are 10% higher than the forecasted numbers, the collected taxes, in present value, increase to 456.1 million USD (Table 48), if the effect of the increase in traffic levels on the operating revenues and costs taken into account. This corresponds to a 13% increase in the highway agency's revenues.

In summary, for a 10% increase in traffic levels (and considering the resulting effect on cash inflow and cash outflow), the highway agency's revenues are 13% higher than the reference case. Furthermore, if a MRG mechanism is applied, the highway agency shall be entitled to 140.54 million USD as a shared profit with the concessionaire, compared to no profit shared in the case of actual traffic levels that meet the forecasted numbers. This implies that a 10% increase in traffic counts would be beneficial to the highway agency in terms of increasing the latter's cash inflow.

On the other side, from a concessionaire's perspective, a 10% higher-than-forecasted traffic levels is a winning scenario for the concessionaire, based on the following findings: for a 30-year concession period, compared to the reference case scenario, for a 10% increase in traffic levels, and considering the resulting effect on operating revenues and costs 1) the project IRR in nominal terms increased from 15.44 to 16.41%, 2) the equity IRR in nominal terms increased from 20.34% to 21.43%, 3) the project's NPV increase from 145 to 190 million USD, 4) the sum dividends in real terms increase from 1912 to 2100 million USD and 5) the pay-back period decreased from 8 to 7 years into operating period (Table 38 and Table 48).

8.4.2.7. Financial Analysis for a 20% Higher-than-Forecasted Traffic Levels

The initial number of cars and trucks are respectively 19,200 and 4,800 (Table 34) and the frequency of the heavy maintenance, corresponding to a 20% increase in traffic levels, is 2 years (Table 37). Table 51 shows the output of financial analysis corresponding to the different scenarios considered.

Table 51 Financial Analysis Results for the Case where Actual Traffic Levels are 20% Higher than Forecasted

Category	Output	Value considering the effect on cash inflow and cash outflow	Value ignoring the effect on cash outflow
Concessionaire's return	Project IRR after tax (nominal terms) %	15.00%	18.54%
	Project IRR after tax (real terms) %	12.74%	16.22%
	Payback period (years into operating period)	8	6
	Project NPV (million USD)	132	287
	Equity IRR after tax (nominal terms) %	19.98%	24.26%
	Equity IRR after tax (real terms) %	17.62%	21.83%
	Sum dividends in real terms (million USD)	1,971	2,456
Highway Agency's financial flow	Sum subsidies in real terms (million USD)	65.7	0.5
	PV on subsidy at 8% in real terms (million USD)	48	0.3
	Sum VAT and other taxes in real terms (million USD)	961.4	961.4
	PV on VAT and other taxes in real terms (million USD)	282.2	282.2
	Sum corporate taxes in real terms (million USD)	834.6	1037.7
	PV on corporate taxes in real terms (million USD)	199.7	256.4
	Sum state revenues (-subsidy + VAT + corporate tax)	1730.3	1998.7
	PV on state revenues in real terms	433.8	538.2

Similarly to the case of a 10% higher traffic levels, it is observed that in the case of a sudden increase in traffic levels, if the resulting increase in maintenance costs (caused by the accelerated deterioration of the pavement) is ignored, the evaluated extra profits gained by the concessionaire are over-estimated.

Based on the operating revenues and operating costs presented in Table 52, a 20% higher traffic levels result in 20% higher operating revenues and 77.7% higher operating costs. These values indicate that, for a 20% higher traffic levels, the increase in the operating costs is much higher than the corresponding increase in the revenues.

To better analyze the obtained results, the cumulated net profit of the concessionaire for 1) the reference case (actual traffic = forecasted), 2) the case where actual traffic levels are 20% higher than forecasted and the resulting effect on operating revenues and operating costs is considered and 3) the case where actual traffic levels are 20% higher than forecasted and the resulting effect on operating costs is ignored, are illustrated in Figure 88. It can be inferred that the cumulated net profit is almost unchanged between the reference case and the case of a 20% higher traffic levels if the resulting effect on cash inflow and outflow is considered, meaning that the generated extra revenues were cancelled out by the increased operating costs. On the other side, if the increased operating costs are ignored, the concessionaire's profit is over-estimated.

Table 52 Operating Revenues and Operating Costs for the Cases where Actual Traffic Levels are 1) Equal to Forecasted and 2) 20% Higher-than-Forecasted

Year	Operation Year	Operating/Toll Revenues (million USD)		Operating costs (million USD)	
		Actual traffic = forecasted	Actual traffic 20% higher than forecasted	Actual traffic = forecasted	Actual traffic 20% higher than forecasted
2021	-	-	-	-	-
2022	-	-	-	-	-
2023	1	101.05	121.25	-36.88	-65.53
2024	2	106.16	127.39	-37.61	-66.84
2025	3	111.53	133.84	-38.37	-68.18
2026	4	117.17	140.61	-39.13	-69.54
2027	5	123.10	147.72	-39.92	-70.93
2028	6	129.33	155.20	-40.72	-72.35

2029	7	135.88	163.05	-41.53	-73.80
2030	8	142.75	171.30	-42.36	-75.27
2031	9	149.97	179.97	-43.21	-76.78
2032	10	157.56	189.08	-44.07	-78.31
2033	11	165.54	198.64	-44.95	-79.88
2034	12	173.91	208.69	-45.85	-81.48
2035	13	182.71	219.25	-46.77	-83.11
2036	14	191.96	230.35	-47.70	-84.77
2037	15	201.67	242.00	-48.66	-86.46
2038	16	211.87	254.25	-49.63	-88.19
2039	17	222.59	267.11	-50.62	-89.96
2040	18	233.86	280.63	-51.64	-91.76
2041	19	245.69	294.83	-52.67	-93.59
2042	20	258.12	309.75	-53.72	-95.46
2043	21	271.18	325.42	-54.80	-97.37
2044	22	284.91	341.89	-55.89	-99.32
2045	23	299.32	359.19	-57.01	-101.31
2046	24	314.47	377.36	-58.15	-103.33
2047	25	330.38	396.46	-59.31	-105.40
2048	26	347.10	416.52	-60.50	-107.51
2049	27	364.66	437.59	-61.71	-109.66
2050	28	383.11	459.74	-62.94	-111.85
Present value to the first year of the concession		**1,213.16**	**1,455.79**	**-341.89**	**-607.53**

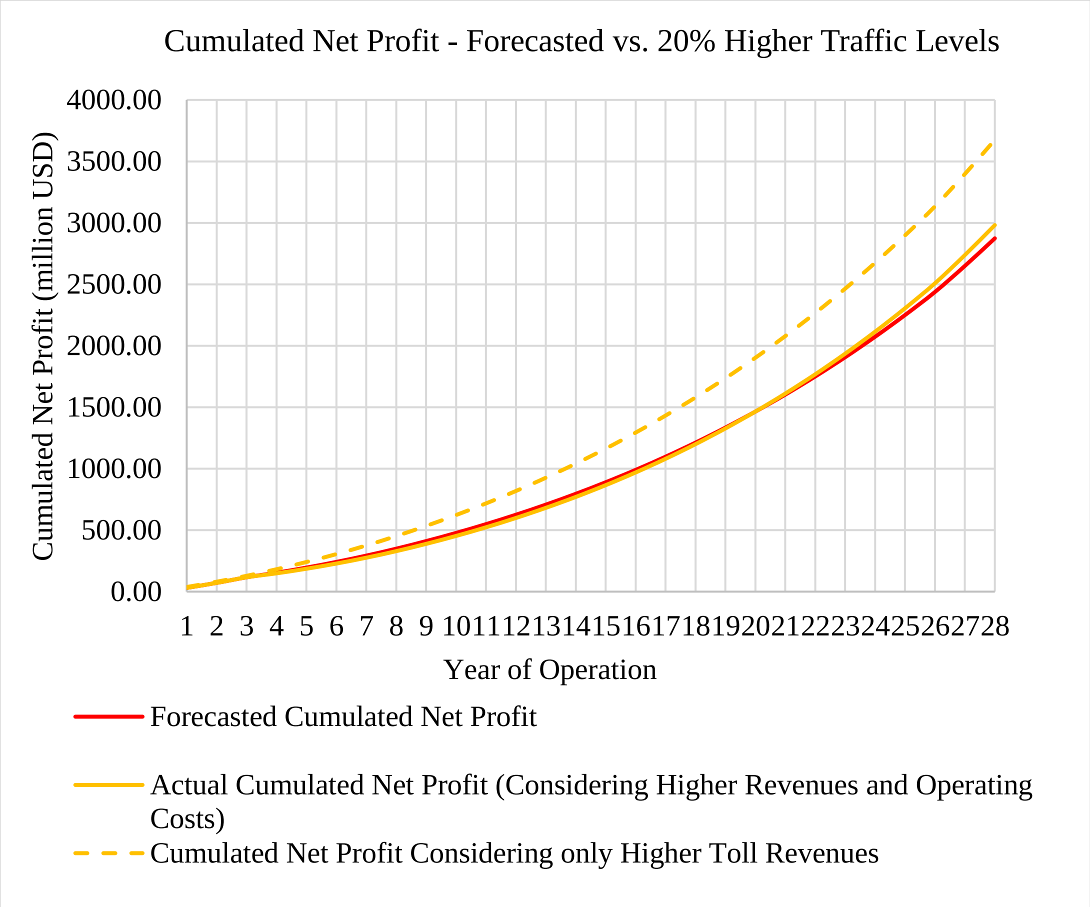

Figure 88 Cumulated Net Profit for the Cases where Actual Traffic Levels are 1) Equal to Forecasted and 2) 20% Higher-than-Forecasted

8.4.2.7.1. Adjusted MRG Mechanism

As previously stated a MRG sharing mechanism based on profit is proposed. The cumulated net profit at the end of the concession period is 2873.86, 2981.55 and 3675.14 million USD respectively for 1) the reference case where actual traffic levels are equal to forecasted, 2) the case where actual traffic levels are 20% higher than forecasted and the resulting effect on operating revenues and operating costs is considered and 3) the case where actual traffic levels are 20% higher than forecasted and the resulting effect on operating costs is ignored (Figure 88).

Accordingly, the extra profit, calculated relative to the reference case, gained by the concessionaire from a 20% increase in traffic levels is 2981.55 - 2873.86 = 107.69

million USD, if the effects of the higher traffic levels on the operating revenues and costs are considered. Nevertheless, if the higher maintenance costs are not taken into consideration, the concessionaire's extra profit is over estimated, as it would be valued at 3675.14 – 2873.86 = 801.29 million USD. Consequently, the highway agency's share of the extra profit would be 107.69/2 = 53.85 million USD instead of 801.29/2 = 400.65 million USD.

8.4.2.7.2. Adjusted LPVR Mechanism

Table 53 shows the evolution of the equity IRR in nominal terms for the cases where actual traffic levels are 1) equal to forecasted, 2) 20% higher than forecasted considering the resulting effect on both the operating revenues and operating costs and 3) 20% higher than forecasted considering the resulting effect on the operating revenues only.

Table 53 Equity IRR in Nominal Terms for the Cases where Actual Traffic Levels are 1) Equal to Forecasted and 2) 20% Higher-than-Forecasted

Year	Concession year	Equity IRR in nominal terms		
		Actual traffic = forecasted	Actual traffic 20% higher than forecasted considering effect on operating revenues and costs	Actual traffic 20% higher than forecasted considering effect on operating revenues only
2021	1	-	-	-
2022	2	-	-	-
2023	3	-	-	-
2024	4	-57.10%	-53.22%	-57.10%
2025	5	-39.00%	-34.69%	-39.00%
2026	6	-24.30%	-14.41%	-27.46%
2027	7	-13.03%	-3.69%	-15.77%
2028	8	-5.64%	3.15%	-8.02%
2029	9	-0.42%	7.84%	-2.48%

2030	10	3.42%	11.18%	1.62%
2031	11	8.02%	**14.71%**	6.64%
2032	12	11.02%	**17.10%**	9.87%
2033	13	13.15%	18.80%	12.16%
2034	14	**14.72%**	20.06%	13.85%
2035	15	15.92%	21.01%	**15.14%**
2036	16	16.85%	21.69%	16.13%
2037	17	17.46%	22.18%	16.79%
2038	18	17.97%	22.58%	17.34%
2039	19	18.38%	22.90%	17.80%
2040	20	18.73%	23.17%	18.18%
2041	21	19.02%	23.38%	18.50%
2042	22	19.27%	23.56%	18.78%
2043	23	19.48%	23.71%	19.01%
2044	24	19.65%	23.83%	19.20%
2045	25	19.80%	23.93%	19.37%
2046	26	19.93%	24.02%	19.52%
2047	27	20.04%	24.09%	19.64%
2048	28	20.13%	24.14%	19.75%
2049	29	20.22%	24.20%	19.84%
2050	30	20.29%	24.24%	19.93%
2051	31	20.34%	24.26%	19.98%

To achieve an equity IRR of 15%, a 14-year concession period is need if actual traffic levels are equal to forecasted. If actual traffic levels are 20% higher-than-forecasted, the concessionaire will need 15 years to reach the targeted IRR, considering the effect of higher traffic levels on cash inflow and cash outflow, instead of an 11.5 year-concession term estimated when higher operating costs are disregarded.

8.4.2.7.3. Observations Regarding the Project's Cash Flow

For the highway agency, the subsidy necessary for the concessionaire to cover debt service increases from 31.7 million USD (Table 38) to 48 million USD (Table 51) as estimated respectively for traffic levels 1) equal to forecast and 2) 20% higher than forecasted, considering the resulting effect on the generated tolls and the operating costs. This corresponds to a 51.4% increase in the provided subsidy. However, this increase in the subsidy is accompanied with an increase in the collected taxes.

In total, the present value of the highway agency's revenues (taxes – subsidy) increases from 403 million USD (Table 38) for the reference case to 433.8 million USD (Table 51) for the case where actual traffic levels are 20% higher than the forecasted numbers. This corresponds to a 7.6% increase in the highway agency's income.

In summary, a 20% increase in traffic levels (and considering the resulting effect on cash inflow and cash outflow) is a winning scenario for the highway agency as the latter's income increased by 7.6% increase. Furthermore, if a MRG mechanism is applied, the highway agency shall be entitled to 53.85 million USD as a shared profit with the concessionaire, compared to no profit shared in the case of actual traffic levels that meet the forecasted numbers.

A 10% higher traffic levels, however, is more favorable, as the highway agency's income was 13% higher than the reference case and, if an MRG mechanism is applied, the corresponding shared profit is 140.54 million USD.

From the concessionaire's perspective, for a 30-year concession period, comparing the reference case scenario to the case of a 20% increase in traffic levels (and considering the resulting effect on operating revenues and costs), the following findings are observed: 1) the project IRR in nominal terms slightly decreased from 15.44 to 15.00%, 2) the equity IRR in nominal terms slightly decreased from 20.34% to 19.98%, 3) the project's NPV decreased from 145 to 132 million USD, 4) the sum dividends in real terms increased from 1912 to 1971 million USD and 5) the same 8 years pay-back period is observed (Table 38 and Table 51).

It can be concluded that, for the considered case study, from the concessionaire's perspective, the scenario considering 20% higher traffic levels along with the corresponding effect on operating revenues and costs is approximately equivalent to the reference scenario where actual traffic levels are equal to forecasted.

8.4.2.8. Financial Analysis for a 30% Higher-than-Forecasted Traffic Levels

For this scenario, the initial number of cars and trucks are respectively 20,800 and 5,200 (Table 34) and the frequency of the heavy maintenance, corresponding to a 30% increase in traffic levels, is 1 year (Table 37).

The following cases are analyzed: 1) the effect of the increase in traffic levels on both the cash inflow and the cash outflow is considered, and 2) the effect of the increase in traffic levels on the cash outflow is ignored, as to imitate current practices in the application of different risk sharing mechanisms. The corresponding results are shown in Table 54.

Table 54 Financial Analysis Results for the Case where Actual Traffic Levels are 30% Higher than Forecasted

Category	**Output**	**Value considering the effect on cash inflow and cash outflow**	**Value ignoring the effect on cash outflow**
Concessionaire's return	Project IRR after tax (nominal terms) %	10.75%	20.04%
	Project IRR after tax (real terms) %	8.58%	17.68%
	Payback period (years into operating period)	12	6
	Project NPV (million USD)	-56	358
	Equity IRR after tax (nominal terms) %	16.26%	26.91%

	Equity IRR after tax (real terms) %	13.98%	24.42%
	Sum dividends in real terms (million USD)	1,493	2,743
Highway Agency's financial flow	Sum subsidies in real terms (million USD)	236.2	0
	PV on subsidy at 8% in real terms (million USD)	164	0
	Sum VAT and other taxes in real terms (million USD)	1041.6	1041.6
	PV on VAT and other taxes in real terms (million USD)	305.7	305.7
	Sum corporate taxes in real terms (million USD)	634.3	1157.8
	PV on corporate taxes in real terms (million USD)	147.8	288.9
	Sum state revenues (-subsidy + VAT + corporate tax)	1439.7	2199.4
	PV on state revenues in real terms	289.5	594.6

The results obtained for a 30% higher traffic levels indicate that the inclusion of the operating costs in the analysis significantly affect the project's cash flow and threatens the project's viability. The operating revenues and operating costs are presented in Table 55. It is noticed that a 30% higher traffic levels result in 30% higher operating revenues and 207.2% higher operating costs. These values indicate that, for a 30% higher traffic levels, the increase in the operating costs is extremely higher than the corresponding increase in the revenues.

The cumulated net profit of the concessionaire for 1) the reference case (actual traffic = forecasted), 2) the case where actual traffic levels are 30% higher than forecasted and the resulting effect on operating revenues and operating costs is considered and 3) the case where actual traffic levels are 30% higher than forecasted and the resulting effect on operating costs is ignored, are illustrated in Figure 89. It can be inferred that the cumulated net profit for a 30% higher traffic levels are significantly lower than the expected profit based on forecasted traffic levels, when the operating costs are updated corresponding to the increase in traffic volumes. However, if the operating costs are considered to be unchanged, the concessionaire's profit is extremely over-estimated.

Table 55 Operating Revenues and Operating Costs for the Cases where Actual Traffic Levels are 1) Equal to Forecasted and 2) 30% Higher-than-Forecasted

Year	Operation Year	Operating/Toll Revenues (million USD)		Operating costs (million USD)	
		Actual traffic = forecasted	Actual traffic 30% higher than forecasted	Actual traffic = forecasted	Actual traffic 30% higher than forecasted
2021	-	-	-	-	-
2022	-	-	-	-	-
2023	1	101.05	131.36	-36.88	-113.28
2024	2	106.16	138.01	-37.61	-115.55
2025	3	111.53	144.99	-38.37	-117.86
2026	4	117.17	152.33	-39.13	-120.22
2027	5	123.10	160.03	-39.92	-122.62
2028	6	129.33	168.13	-40.72	-125.07
2029	7	135.88	176.64	-41.53	-127.58
2030	8	142.75	185.58	-42.36	-130.13
2031	9	149.97	194.97	-43.21	-132.73
2032	10	157.56	204.83	-44.07	-135.38
2033	11	165.54	215.20	-44.95	-138.09
2034	12	173.91	226.08	-45.85	-140.85
2035	13	182.71	237.52	-46.77	-143.67
2036	14	191.96	249.54	-47.70	-146.54
2037	15	201.67	262.17	-48.66	-149.48
2038	16	211.87	275.44	-49.63	-152.47
2039	17	222.59	289.37	-50.62	-155.51
2040	18	233.86	304.02	-51.64	-158.62
2041	19	245.69	319.40	-52.67	-161.80
2042	20	258.12	335.56	-53.72	-165.03
2043	21	271.18	352.54	-54.80	-168.33
2044	22	284.91	370.38	-55.89	-171.70
2045	23	299.32	389.12	-57.01	-175.13

2046	24	314.47	408.81	-58.15	-178.64
2047	25	330.38	429.49	-59.31	-182.21
2048	26	347.10	451.23	-60.50	-185.85
2049	27	364.66	474.06	-61.71	-189.57
2050	28	383.11	498.05	-62.94	-193.36
Present value to the first year of the concession		**1,213.16**	**1,577.11**	**-341.89**	**-1,050.26**

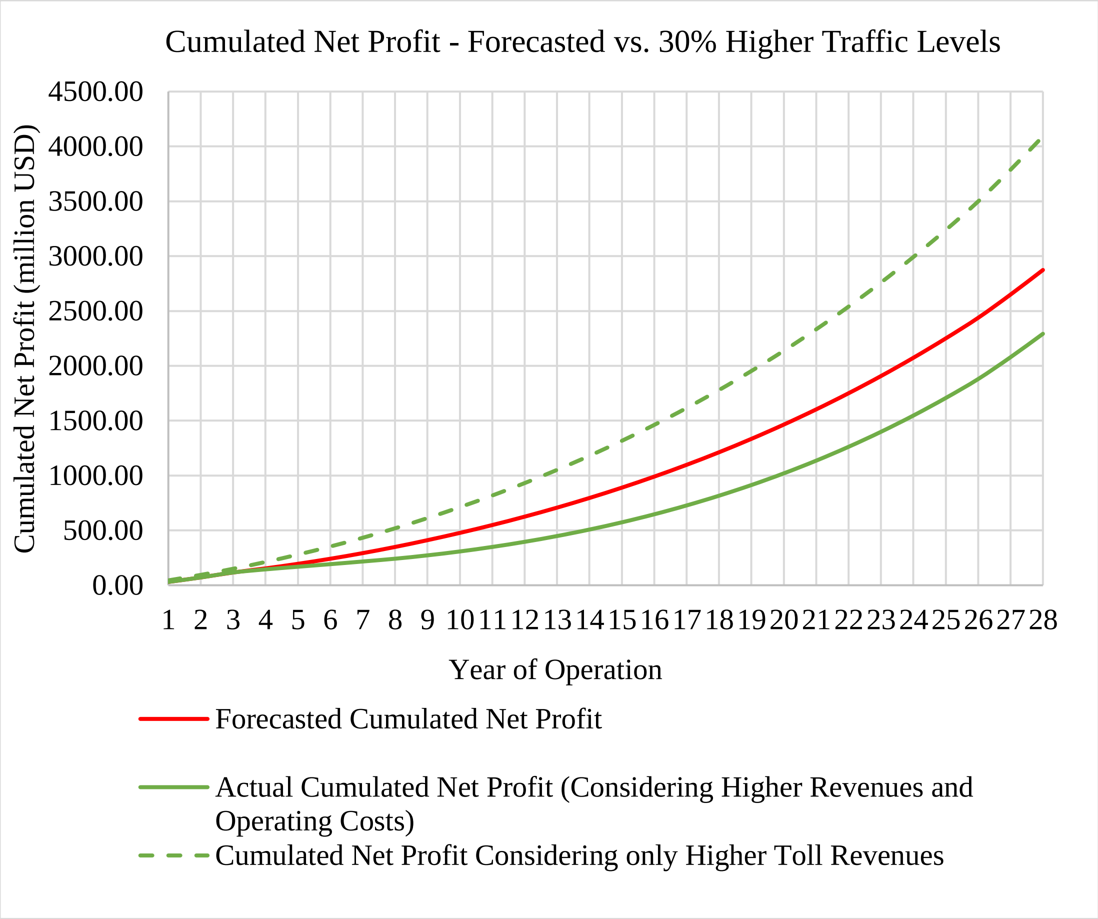

Figure 89 Cumulated Net Profit for the Cases where Actual Traffic Levels are 1) Equal to Forecasted and 2) 30% Higher-than-Forecasted

8.4.2.8.1. Adjusted MRG Mechanism

The cumulated net profit at the end of the concession period is 2873.86, 2292.12 and 4091.82 million USD respectively for 1) the reference case where actual traffic levels are equal to forecasted, 2) the case where actual traffic levels are 30% higher than forecasted and the resulting effect on operating revenues and operating costs is considered and 3) the case where actual traffic levels are 30% higher than forecasted and the resulting effect on operating costs is ignored (Figure 89).

Accordingly, due to the notably high operating costs (207.2% higher than originally estimated values based on forecasted traffic), the concessionaire profit is extremely lower than initially expected, and no extra revenues are generated for sharing with the highway agency. However, if the operating costs are not updated, the obtained results imply that 4091.82 - 2873.86 = 1217.96 million USD extra profit should be shared between PPP partners. This finding accentuates the need for accurately assessing the effect of the increase in traffic levels on the operating costs as well as revenues, to avoid any unfair revenues sharing.

8.4.2.8.2. Adjusted LPVR Mechanism

The evolution of the equity IRR in nominal terms for the cases where actual traffic levels are 1) equal to forecasted, 2) 30% higher than forecasted considering the resulting effect on both the operating revenues and operating costs and 3) 30% higher than forecasted considering the resulting effect on the operating revenues only, are provided in Table 56.

Table 56 Equity IRR in Nominal Terms for the Cases where Actual Traffic Levels are 1) Equal to Forecasted and 2) 30% Higher-than-Forecasted

Year	Concession year	Equity IRR in nominal terms		
		Actual traffic = forecasted	Actual traffic 30% higher than forecasted considering effect on operating revenues and costs	Actual traffic 30% higher than forecasted considering effect on operating revenues only

2021	1	-	-	-
2022	2	-	-	-
2023	3	-	-	-
2024	4	-57.10%	-57.10%	-44.23%
2025	5	-39.00%	-39.00%	-25.56%
2026	6	-24.30%	-30.63%	-7.59%
2027	7	-13.03%	-23.84%	2.27%
2028	8	-5.64%	-18.56%	8.54%
2029	9	-0.42%	-14.45%	12.80%
2030	10	3.42%	-11.23%	**15.81%**
2031	11	8.02%	-2.75%	18.84%
2032	12	11.02%	1.87%	20.91%
2033	13	13.15%	5.00%	22.38%
2034	14	**14.72%**	7.30%	23.47%
2035	15	15.92%	9.06%	24.28%
2036	16	16.85%	10.45%	24.84%
2037	17	17.46%	11.46%	25.26%
2038	18	17.97%	12.18%	25.59%
2039	19	18.38%	12.81%	25.86%
2040	20	18.73%	13.36%	26.08%
2041	21	19.02%	13.84%	26.25%
2042	22	19.27%	14.25%	26.39%
2043	23	19.48%	14.61%	26.50%
2044	24	19.65%	14.92%	26.60%
2045	25	19.80%	**15.19%**	26.67%
2046	26	19.93%	15.43%	26.74%
2047	27	20.04%	15.64%	26.79%
2048	28	20.13%	15.83%	26.83%
2049	29	20.22%	16.00%	26.87%
2050	30	20.29%	16.15%	26.90%
2051	31	20.34%	16.26%	26.91%

For a 30% % higher-than-forecasted traffic volumes, the concessionaire will need 25 years to reach the targeted IRR, considering the effect of higher traffic levels on cash inflow and cash outflow, instead of an 10 year-concession term estimated when higher operating costs are disregarded.

8.4.2.8.3. Observations Regarding the Project's Cash Flow

Comparing the reference case, in which actual traffic levels are equal to forecasted, and the case where actual traffic levels are 30% higher-than-forecasted (considering the resulting effect on cash inflow and cash outflow), it can be stated that both PPP partners are negatively impacted.

From the perspective of the highway agency, the subsidy necessary to cover debt service increases from 31.7 for the reference case to 164 million USD when 30% higher traffic is encountered. The total highway agency's income significantly decreases from 403 to 289.5 million USD (Table 38 and Table 54). This corresponds to a 28.1% loss in the highway agency's revenues. Furthermore, if a MRG mechanism is adopted, no additional revenues, for sharing between PPP partners, are generated.

From the concessionaire's perspective, a significant decrease is observed in the project IRR in nominal terms (from 15.44 to 10.75%), equity IRR in nominal terms (from 20.34 to 16.26%), project NPV (from 145 to -56 million USD), and dividends (from 1912 to 1493 million USD) between the reference case and the case where actual traffic volumes are 30% higher-than-forecasted. Furthermore, a pay-back period of 12 years is needed to repay the concessionaire's investment if actual traffic levels are 30% higher than initially estimated, compared to an 8 year pay-back period estimated for the reference case (Table 38 and Table 54).

8.5. Summary, Findings and Recommendations

This chapter addressed the risk of errors in traffic volume forecasts by enhancing the two most common traffic volume risk sharing mechanisms: the Minimum Revenue Guarantee (MRG) and the Least Present Value of Revenues (LPVR). This is accomplished by assessing the effect of the deviation in traffic levels on two major parameters that affect the project's cash flow: the generated toll revenues and the pavement maintenance costs.

The proposed methodology makes use of pavement performance prediction models and more specifically the AASHTOWare Pavement ME, and a financial model developed by the World Bank. A case study is chosen, and the following scenarios are investigated: actual traffic volumes are 1) equal to forecasted, 2) 10% lower than forecasted, 3) 20% lower than forecasted, 4) 30% lower than forecasted, 5) 10% higher than forecasted, 6) 20% higher than forecasted, 7) 30% higher than forecasted.

The conducted analysis is bi-fold.

First, the importance of assessing the effect of the deviation in traffic levels on maintenance expenses before applying the traffic volume risk sharing mechanism is accentuated by comparing the outcome of a revenues-based MRG mechanism and a profit-based MRG mechanism on one side and a revenues-based LPVR mechanism and a profit-based LPVR mechanism on the other side.

For the MRG mechanism applied when lower traffic levels are encountered, the failure to assess the resulting decrease in maintenance expenditures leads to an over-estimation of the subsidy to be provided by the highway agency to the concessionaire, consequently increasing the agency's contingent liabilities.

For the MRG mechanism applied when higher traffic levels are encountered, it is concluded that updating the maintenance expenses based on the actual traffic levels significantly affect the project's cash flow, as the maintenance costs for relatively high volumes of traffic were extremely high, in some cases threatening the viability of the project by generating a negative NPV. Consequently, the extra profits that the concessionaire has to share with the highway agency is notably exaggerated.

For the LPVR mechanism applied when lower traffic levels are encountered, if no resulting effect on the maintenance expenditures is accounted for in the analysis, the concession term is likely to be over-extended, thus resulting in some losses to the highway agency.

For the LPVR mechanism applied when higher traffic levels are encountered, if the increased maintenance costs are ignored, the estimated length of the concession term will not be sufficient for the concessionaire to achieve the targeted profit.

Second, the effect of the deviation in traffic levels on the profit of each PPP partner is studied in details.

It seems that lower than forecasted traffic levels is a lose-lose scenario for both parties. For the highway agency, lower-than-forecasted traffic levels lead to a decrease in the latter's income (taxes – subsidy), compared to initially estimated profit based on the forecasted traffic volumes. For the concessionaire, a decrease in the project's IRR, equity IRR, project NPV and shareholder's dividends is observed for all lower traffic scenarios, compared to the expected values that were originally assessed based on the forecasted traffic levels.

The effect of higher traffic levels, however, is highly dependent on the traffic count. For the considered case study, a 10% higher-than-forecasted traffic levels represented a win-win situation for both PPP partners. A 20% higher traffic volume produced a scenario that is approximately equivalent to the reference case (actual traffic = forecasted), in terms of the achieved profit of each PPP partner. A 30% higher-than-forecasted traffic level, however, resulted in significant losses to both PPP partners, caused by the extremely high maintenance costs.

Briefly, traffic volume risk is one of the most challenging risks faced in PPP road projects, as it adversely affects the project's cash inflow and cash outflow. Accordingly, a fair risk sharing mechanism cannot ignore the resulting effect of the deviated traffic volume on the cash outflow.

CHAPTER 9

SUMMARY, FINDINGS AND RECOMMENDATIONS

9.1. Summary and Conclusions

This dissertation addresses three major risks encountered in PPP road projects: 1) the non-compliance with the standard construction specifications, 2) the increased legal load limit and 3) the traffic volume risk, which combines 3.a) the risk of a shortage in toll revenues caused by lower-than-forecasted traffic levels and 3.b) the risk of increased operation and maintenance costs caused by higher-than-forecasted traffic levels.

A common ground between these risks is their significant effect on the pavement performance throughout the concession period. Accordingly, the effective management of these risks requires an accurate prediction of the change in the pavement performance caused by the change in the following project's characteristics, respectively corresponding to the three aforementioned risks: 1) an out-of-specs pavement construction, in terms of the air-void content in the AC mix, binder content in the AC mix and the AC layer thickness, 2) an increased truck load limit and 3) a deviation in traffic volume (either lower or higher than forecasted). The study utilizes AASHTOWare Pavement ME for the required performance prediction. Furthermore, the RealCost tool is used for conducting a life-cycle cost analysis when required. Finally, in the case of a complex risk, such as traffic volume risk, a detailed financial analysis is conducted, using an Excel-based numerical model, developed by the World Bank, which is specifically designed for the financial analysis of PPP road projects.

A summary of the framework (Figure 90) proposed for addressing each one of the three risks, along with the main findings are provided herein.

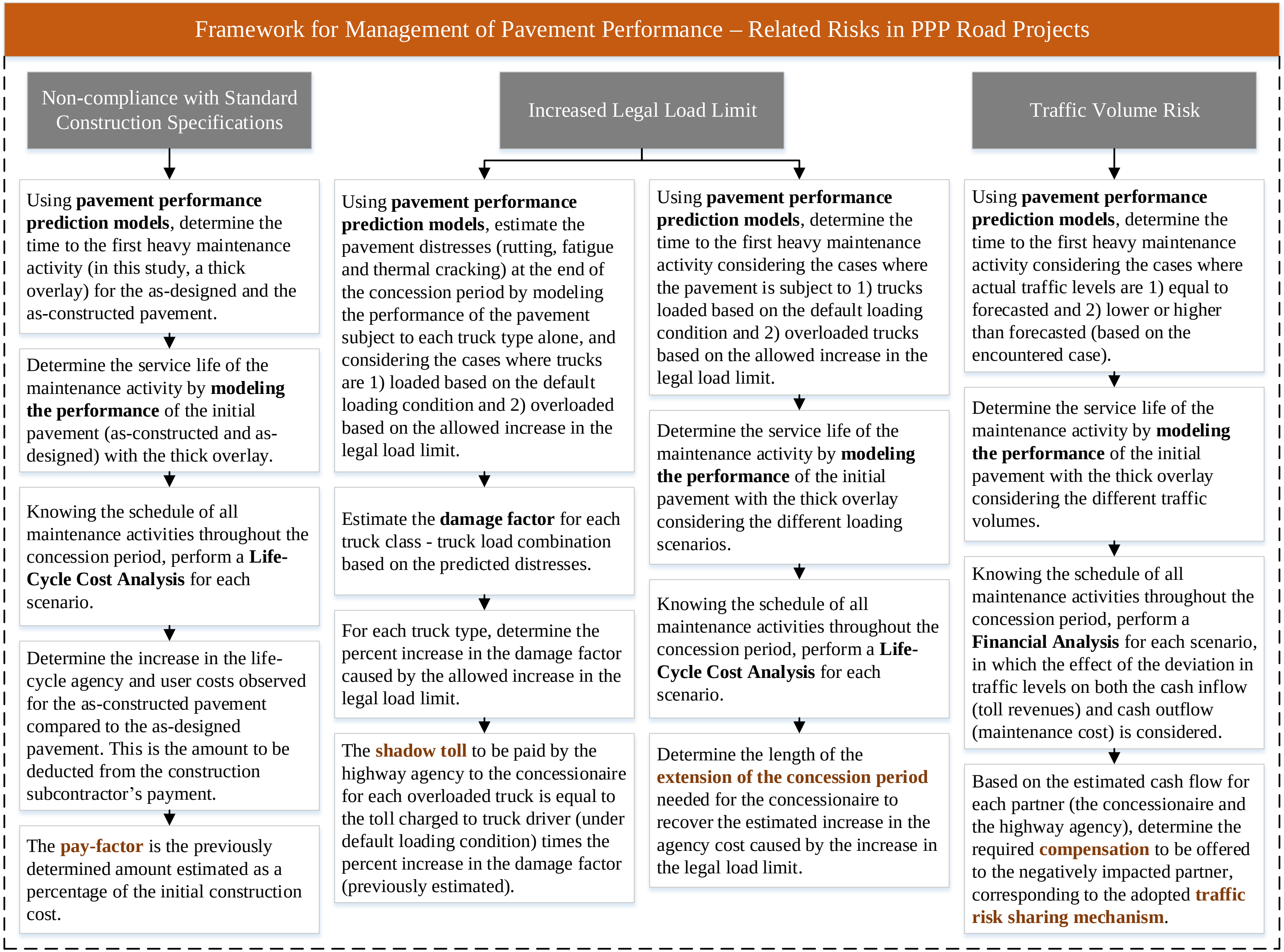

Figure 90 Framework for Management of Risks Affecting the Pavement Performance in PPP Road Projects

The Risk of Non-Compliance with the Standard Construction Specifications.

The delivery of an out-of-specs pavement construction, in terms of the air-void content in the AC mix, binder content in the AC mix and the AC layer thickness, is a common concern among all road projects. In traditional road procurement strategies, a "pay-adjustment factor", representing a deduction from the construction contractor's payment, is applied as a penalty for the non-compliance with the prescribed specifications. Briefly, a higher-than-forecasted air-void content is expected to affect both the fatigue and rutting performance of the pavement. A higher-than-target binder content, even though improves fatigue behavior of the pavement, results in a reduction in rutting resistance, and the pay-factor is determined accordingly. Finally, a thinner AC layer imposes a pay-factor assessed based on the reduction in the pavement's fatigue performance.

Current practices in the assessment of pay-adjustment factors for flexible pavement consider only the time to the first heavy maintenance activity and the resulting increase in agency cost. This study proposes a methodology for the estimation of the pay-adjustment factor, imposed on the construction subcontractor within the private consortium involved in a PPP road project. The proposed methodology considers all maintenance activities performed throughout the concession period and includes both the agency and user costs in the assessment of pay-adjustment factor. These enhancements, when discussed between the involved parties – the construction subcontractor, the concessionaire and the highway agency – and included in the contract shall achieve the following enhancements: 1) the construction subcontractor being incentivized to deliver a construction that is compliant with the construction specifications, 2) the concessionaire securing the needed fund for maintaining the road facility, without compromising their profit and 3) the highway agency being ensured that the concessionaire will be able to adequately maintain the road without delays.

The proposed methodology is implemented as follows: the performance of the pavement is predicted considering the cases where the construction is 1) compliant and 2) non-compliant with the standard construction specifications, using AASHTOWare Pavement ME. Based on the obtained results, the first heavy maintenance activity in terms of a thick overlay is scheduled for each of the considered scenarios. Then, AASHTOWare Pavement ME is used again to model the performance of the pavement with a thick overlay for the considered scenarios; accordingly, the pavement service life for various scenarios is estimated. A LCCA is then conducted, using RealCost, and the increased agency and user costs caused by the non-compliant pavement construction, are assessed. Finally, the pay-adjustment factor is equivalent to the additional total (agency + user) cost, calculated as a percentage of the initial construction cost. Note that different pavement structures, with different material properties, climatic and traffic conditions are included in the analysis.

The obtained results show that the most critical parameter is the thickness of the AC layer, as it yields the highest pay factor values, reaching up to 50% of the construction cost, for a 1 in thinner AC layer. Briefly, a ½ in thinner AC layer resulted in pay-factors ranging between 11.45 and 24.04%, and between 23.18 and 51.72% for a 1 in thinner AC layer. The highest pay-factors are observed for low quality materials, especially used in the base layer, and relatively thin pavements.

The non-compliance with the target air-void content in the AC mix resulted in pay-factors ranging between 6.96 and 11.08% of the initial construction cost for a (target + 1%) air-void content, and between 13.47 and 23.39% of the initial construction cost for a (target + 2%) air-void content in the AC mix. High values of the pay-factor are observed for low quality materials, especially the subgrade, and for high traffic volumes.

Finally, a higher-than-target binder content yielded relatively low values of the pay-factor, given to the fact that PPP road projects are generally constructed using high quality materials, such as PG 76-22 and PG 82-22 binder grade considered in this study, to ensure a long service life compatible with the long-term contract. Accordingly, it can be inferred that for PPP road projects, where high PG grade binders are used in the AC mix, higher than target binder content have relatively low effect on the pavement performance. Nevertheless, the highest values of the pay-factor (approximately 2% of the construction cost) are observed for hot climatic conditions and slow operational speed, conditions favorable for accelerated development of rutting. Note that the same methodology can be applied by PPP partners to determine the pay-factor imposed on the construction subcontractor for a lower-than-target binder content, which, although improves rutting resistant of the pavement, accelerates the development of fatigue cracks.

The Risk of Increased Legal Load Limit

The performance of flexible pavements is highly sensitive to the load carried by trucks. In case the highway agency allows a certain increase in the legal truck load limit, the concessionaire will be negatively impacted due to the resulting accelerated deterioration of the pavement, and consequently, the increased need for maintenance activities. Accordingly, the concessionaire holds the right to claim a compensation from the highway agency to remunerate the incurred losses. This study proposes two concessionaire compensation strategies that can be adopted by the highway agency in case the latter increases the permissible truck load limit.

The first compensation strategy is through a shadow toll paid by the highway agency to the concessionaire for each overloaded truck. The value of the shadow toll is determined as a percentage of the initial toll charged to the truck driver. In such strategy, the performance of the pavement is predicted for different truck class/truck load combinations using AASHTOWare Pavement ME. Alternatively stated, for each class n truck, with n = 5 to 13, the pavement performance is predicted considering the default loading condition, and the cases where truck load limit is increased by 10%, 20% and 30%. Then, a damage factor is estimated based on the predicted distresses for each scenario. Finally, the shadow toll for given truck class/truck load combination is determined as to be proportional to the increase in the estimated damage factor caused by the corresponding increase in the truck load. The work is repeated considering different pavement structures, subject to different climatic and traffic conditions. 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 and 2) the project's characteristics, with a strong influence observed for the climatic conditions and the material properties.

The second compensation strategy is by offering an extension to the concession period, as to allow the concessionaire to recover the incurred losses. The AASHTOWare Pavement ME is used to schedule heavy maintenance activities by modelling the performance of 1) the initial pavement and 2) the pavement with a thick overlay considering different loading conditions. Finally, a LCCA is 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 is estimated as to allow the concessionaire to recover the resulting losses. Note that different pavement structures, with different material properties, climatic and traffic conditions are included in the analysis. For a 10%, 20% and 30% increase in truck load limit, and considering a 30 years initial concession period, the average length of the extension of the concession term is 1.7, 3.9 and 6 years respectively.

Traffic Volume Risk

Traffic volume risk is one of the most challenging risks encountered in PPP road projects, as the deviation in traffic levels adversely affects both the project's cash inflow, in terms of the generated toll revenues, and the cash outflow, in terms of the pavement maintenance costs. In fact, lower traffic levels negatively affect the cash inflow by reducing the generated toll revenues, while positively affecting the cash outflow, given to the resulting reduction in pavement maintenance costs. An opposite scenario is expected for higher traffic levels.

The most common traffic volume risk sharing mechanisms adopted by highway agencies worldwide are the Minimum Revenue Guarantee (MRG) and the Least Present Value of Revenues (LPVR).

The MRG mechanism functions as follows: in case of lower-than-forecasted traffic levels, a subsidy is provided by the highway agency to the concessionaire to compensate the resulting shortage in toll revenues; in case of higher-than-forecasted traffic levels, the concessionaire shared the extra toll revenues with the highway agency. One of the drawbacks of the MRG mechanism is that the highway agencies are unsure of the level of guarantee to be provided to the concessionaire. In fact, based on the reviewed literature, highway agencies have guaranteed up to 90% of the forecasted revenues in some cases, while in others, only 60% of the forecasted revenues had been covered by the MRG. In all cases, the level of the guarantee is not determined based on any technical basis, as they do not account for the actual losses incurred by the concessionaire. Furthermore, current practices in the MRG mechanism adopt a gross revenues threshold, instead of profit, which is equal to the gross revenues minus the expenses. This is justified by the difficulties faced by the highway agency in monitoring the concessionaire's expenses. However, as previously explained, lower traffic levels affect both the revenues and expenses, accordingly a revenues-based MRG leads to an unfair risk sharing.

This study enhances the MRG mechanism for lower-than-forecasted traffic levels by applying the following modifications: 1) the subsidy to be provided to the concessionaire is estimated as to allow the concessionaire cover the debt service and 2) the effect of the shortage in traffic levels on both the generated revenues and the maintenance costs is taken into consideration. The first enhancement aims at avoiding disputes between the highway agency and the concessionaire by setting a clear basis for the subsidy estimation, while the second one ensures a fair risk sharing between PPP partners.

When the MRG mechanism is applied for higher-than-forecasted traffic levels, the proposed enhancement is to assess the extra revenues that the concessionaire is required to share with the highway agency after deducting the additional maintenance expenses (caused by the higher traffic volumes) borne by the concessionaire, as to ensure a fair risk sharing.

On the other side, the LPVR mechanism links the concession term to the traffic volume. In such case, the concession period is not specified in the contract, but delimited by the time a certain IRR is achieved. However, current practices show the tendency to implement LPVR mechanism based on a certain level of revenues or traffic, instead of adopting the actual IRR. This means that the effect of the deviation in traffic levels on the maintenance costs is ignored. Accordingly, this study applies the LPVR based on the IRR, by updating the maintenance expenditures as well as the generated toll revenues according to the actual traffic levels.

To achieve the desired objectives, the AASHTOWare Pavement ME is used to model the performance of the pavement when subject to different traffic levels, equal, lower and higher than forecasted, as well as the performance of a thick overlay placed for each scenario. These runs help in scheduling the heavy maintenance activities for the different traffic levels considered. Then, a detailed financial analysis for each scenario is conducted, with the use of an Excel-based numerical tool developed by the World Bank, specifically designed for PPP toll road projects.

One major conclusion of the study is that an MRG mechanism based on gross-revenues leads to an overestimation of the subsidy to be paid by the highway agency to the concessionaire, to compensate the shortage in the generated toll revenues, caused by the lower-than-forecasted traffic levels. Accordingly, the effect of lower traffic levels on the maintenance costs must be taken into account when assessing the value of the required subsidy, as to avoid any additional increase in the agency's contingent liabilities.

For higher-than-forecasted traffic levels, the results are highly sensitive to the level of increase in traffic levels. For the adopted case study, 10% higher-than-forecasted traffic levels resulted in a win-win scenario for both PPP partners. However, an accurate estimation of the extra profit (instead of extra revenues) that the concessionaire has to share with the highway agency, requires that the increased maintenance costs be taken into account in the analysis. A 20% higher-than-forecasted traffic levels generated a scenario equivalent to the initial one (with actual traffic equal to forecasted), in terms of the generated profit, when the effect of the increase in traffic levels on cash inflow an outflow is considered. A 30% higher traffic levels, however, resulted in a 30% higher tolls generated, and 200% higher maintenance costs. This leaded to a negative project's NPV and significant losses encountered by the concessionaire. Accordingly, no extra revenues are generated for being shared with the highway agency. These observations emphasize on the need to accurately estimate the effect of the increase in traffic levels on the maintenance costs as well as the generated toll revenues before applying the MRG mechanism.

Finally, a LPVR mechanism that ignores the reduction in maintenance costs caused by the shortage in traffic volumes leads to an over extension of the concession term, and consequently, some losses borne by the highway agency. On the opposite side, a LPVR mechanism that ignores the increase in maintenance costs caused by the increase in traffic volumes results in an insufficient concession period for the concessionaire to reach the desired IRR.

9.2. Recommendations and Practical Implications

This dissertation emphasizes on the importance of an accurate pavement performance prediction for the management of risks likely to affect the scheduling of the maintenance activities for PPP road projects, and consequently, leading to disputes between PPP parties. The methodologies proposed throughout the study are believed to facilitate the negotiations between PPP parties, and consequently avoiding disputes, by establishing a clear basis for the assessment of the rights and responsibilities of each party, based on a technical evaluation of the losses incurred by the negatively impacted partner, and the corresponding compensation to be offered by the party to whom the risk is allocated.

9.3. Limitations and Future Work

The presented work used the AASHTOWare Pavement ME for the prediction of pavement performance considering several changes in the project's characteristics, in terms of the AC layer's volumetrics and thickness, the truck loading conditions and the truck volume. One limitation is that all the conducted AASHTOWare Pavement ME runs considered the nationally calibrated factors for all distress prediction models. Therefore, for road projects located in regions were local calibration factors are available, these should be used for the AASHTOWare Pavement ME runs.

Furthermore, for the LCCA and financial analysis, the study adopted a heavy maintenance activity corresponding to a thick AC overlay placed after milling the top 5 in of the existing AC layer, while other minor maintenance works, such as preventive, routine and corrective treatments, were not considered. However, all maintenance activities can be incorporated in the analysis in the case of the availability of the right tools/expertise that can assess the effect of the change in the project's characteristics on the scheduling of these activities. Nevertheless, the construction and maintenance costs should be accurately estimated by the concessionaire and the highway agency, based on local unit prices.

Moreover, the traffic volume risk was addressed based on a hypothetical case study, considering common values of the toll rates, inflation rate, tax rates, among others. These parameters are project specific and have significant influence on the project's cash flow, and consequently the traffic risk sharing mechanisms.

Finally, the importance of the work provided in this dissertation does not reside in the obtained values of the pay-factors, shadow tolls, concession period extension, subsidy or shared revenues, but in the general framework provided for managing the considered risks and avoiding disputes between PPP partners.

Future work could include the analysis of actual PPP road projects using the proposed framework, if all the parameters required for the pavement performance prediction, the LCCA and the financial analysis are made available. Furthermore, a sensitivity analysis in Module 3, considering different economic parameters, such as inflation, tax and discount rates could reveal their corresponding impact on the project's cash flow and consequently, the traffic risk sharing mechanism. Finally, the same methodologies could be applied using other available tools for pavement performance prediction, life-cycle cost analysis and/or financial analysis of PPP road projects.

APPENDIX A

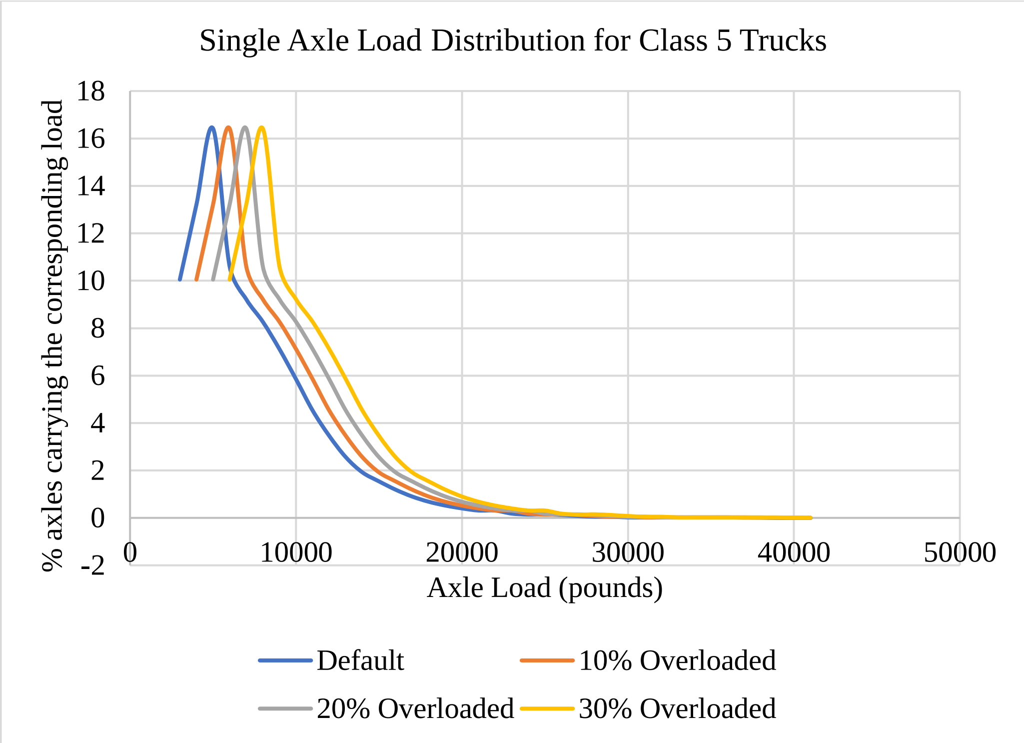

Figure 91 Single Axle Load Distribution for Class 5 Trucks

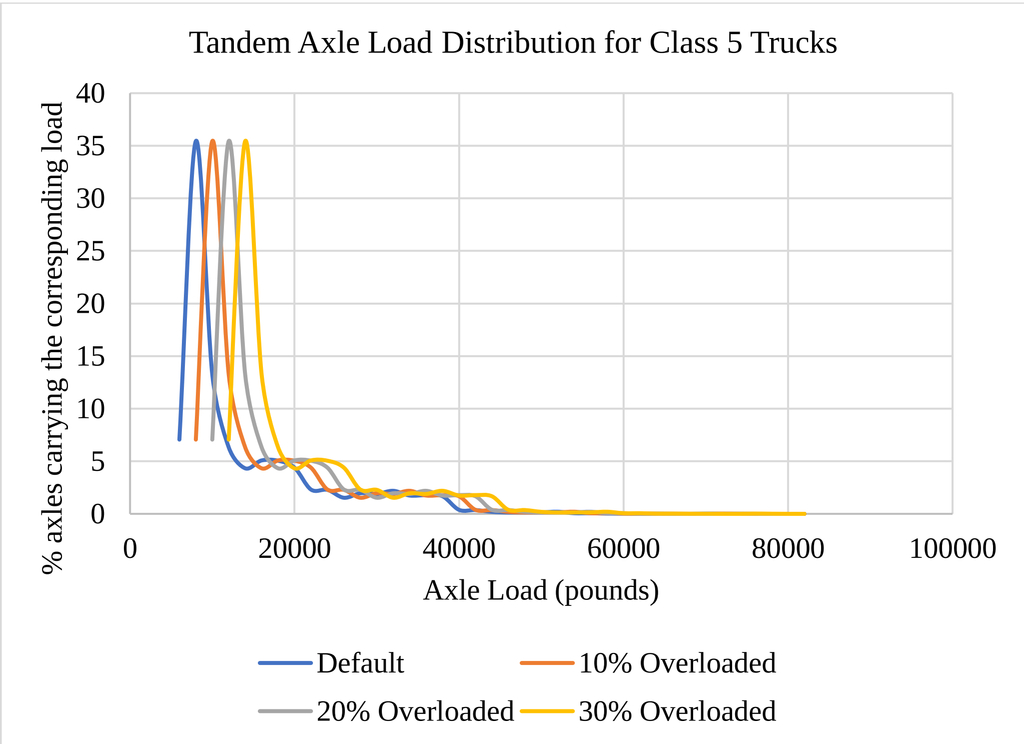

Figure 92 Tandem Axle Load Distribution for Class 5 Trucks

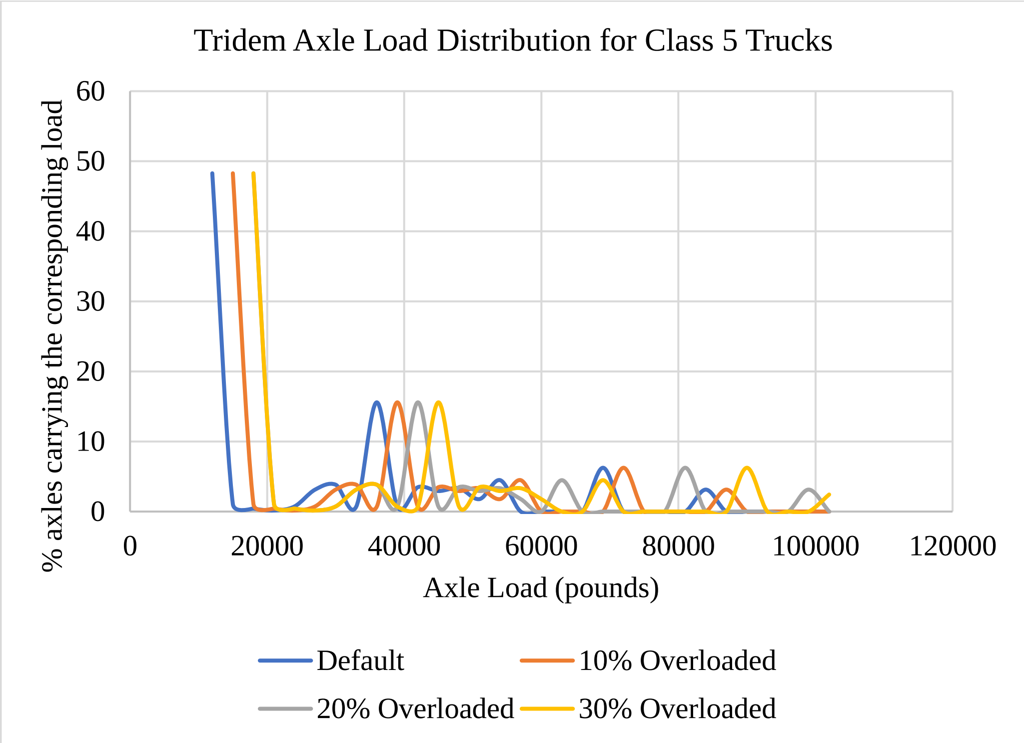

Figure 93 Tridem Axle Load Distribution for Class 5 Trucks

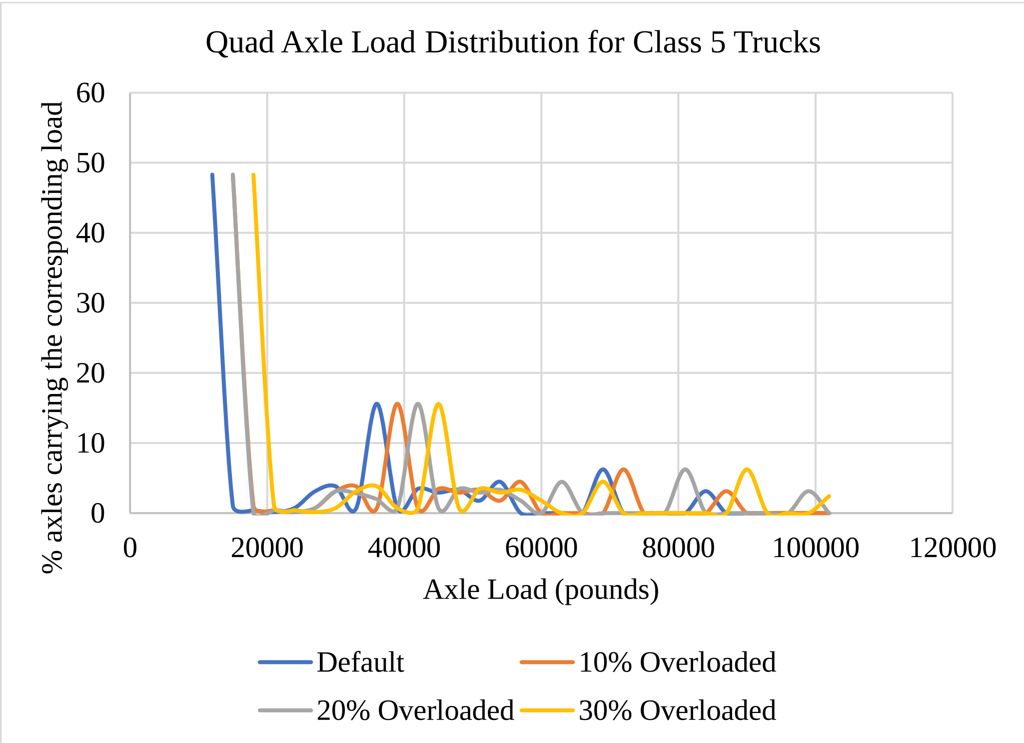

Figure 94 Quad Axle Load Distribution for Class 5 Trucks

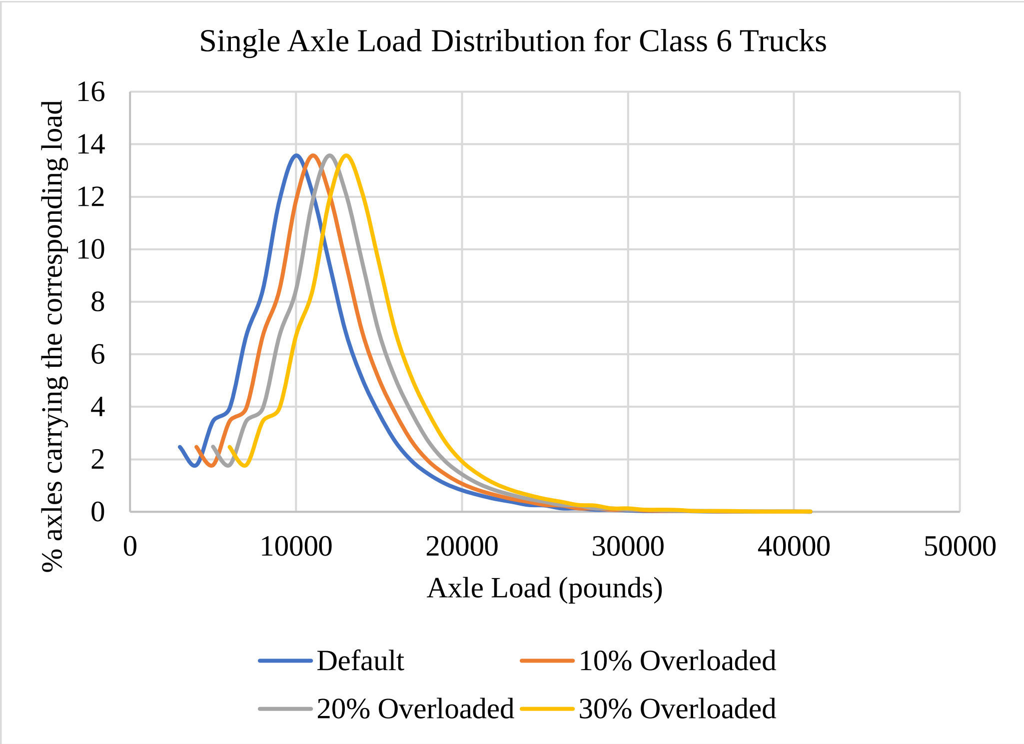

Figure 95 Single Axle Load Distribution for Class 6 Trucks

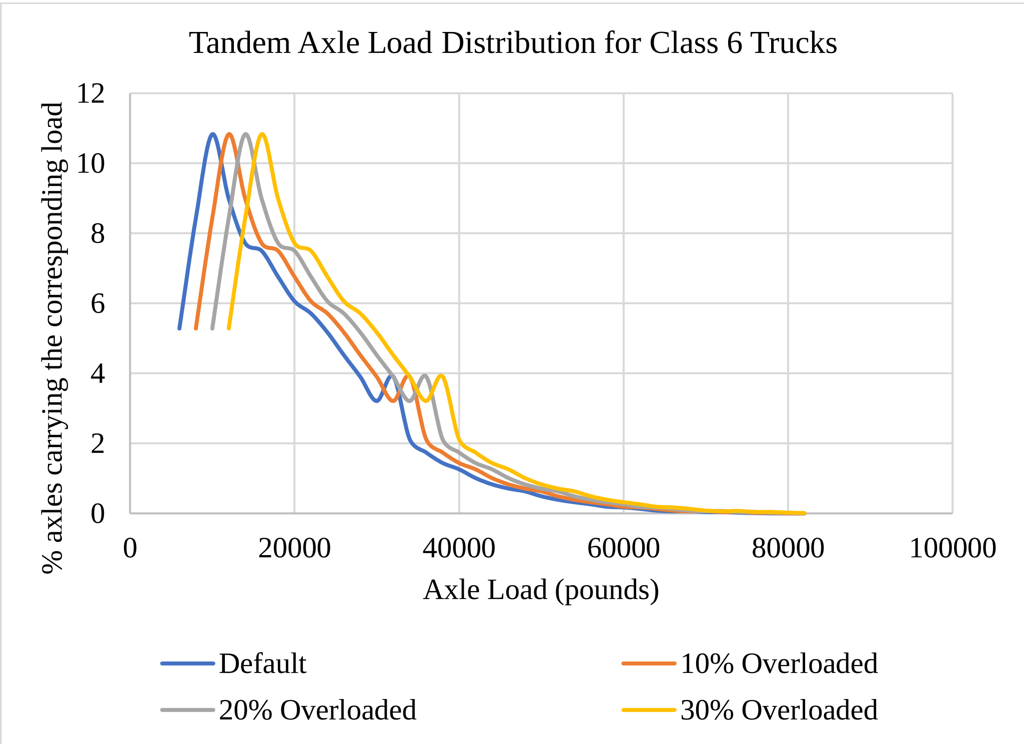

Figure 96 Tandem Axle Load Distribution for Class 6 Trucks

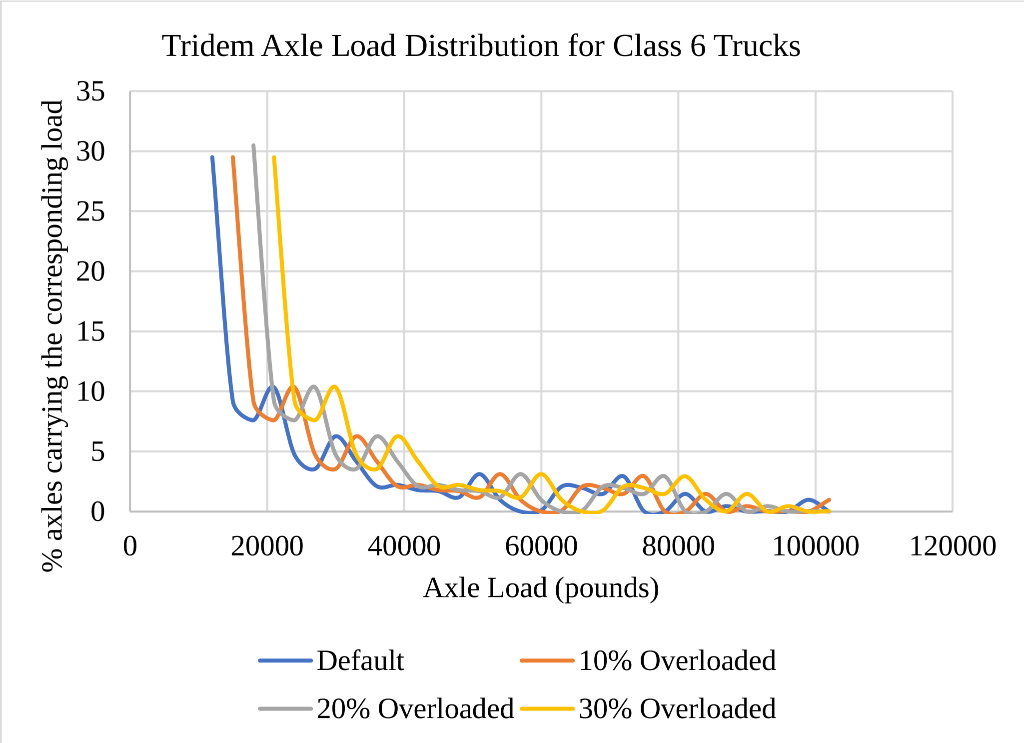

Figure 97 Tridem Axle Load Distribution for Class 6 Trucks

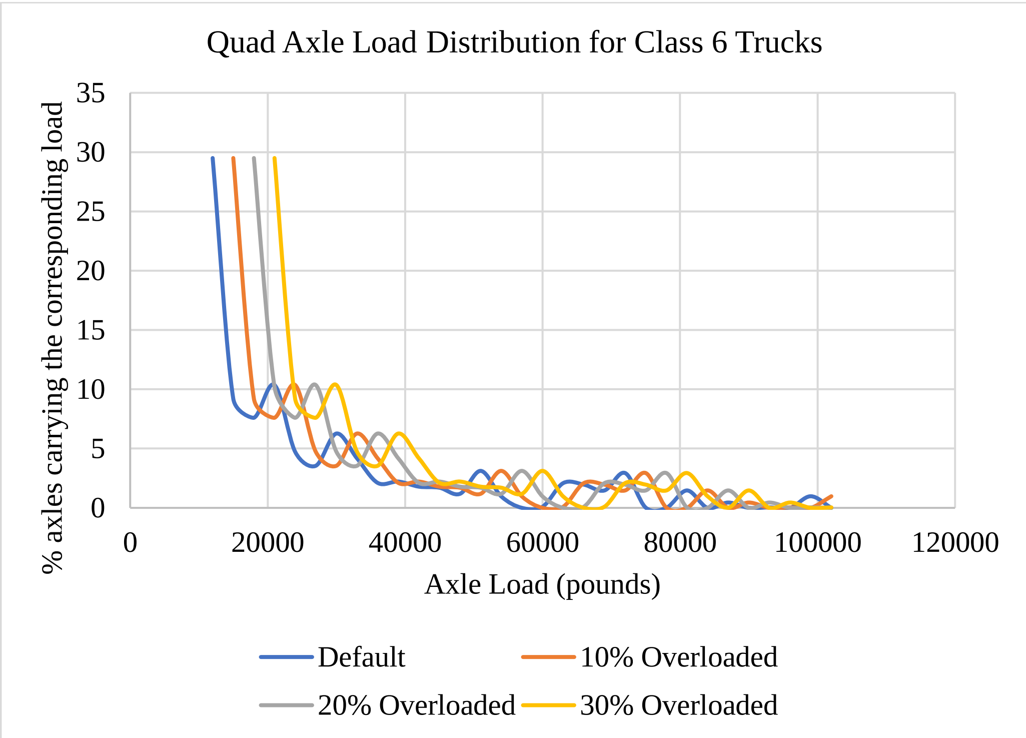

Figure 98 Quad Axle Load Distribution for Class 6 Trucks

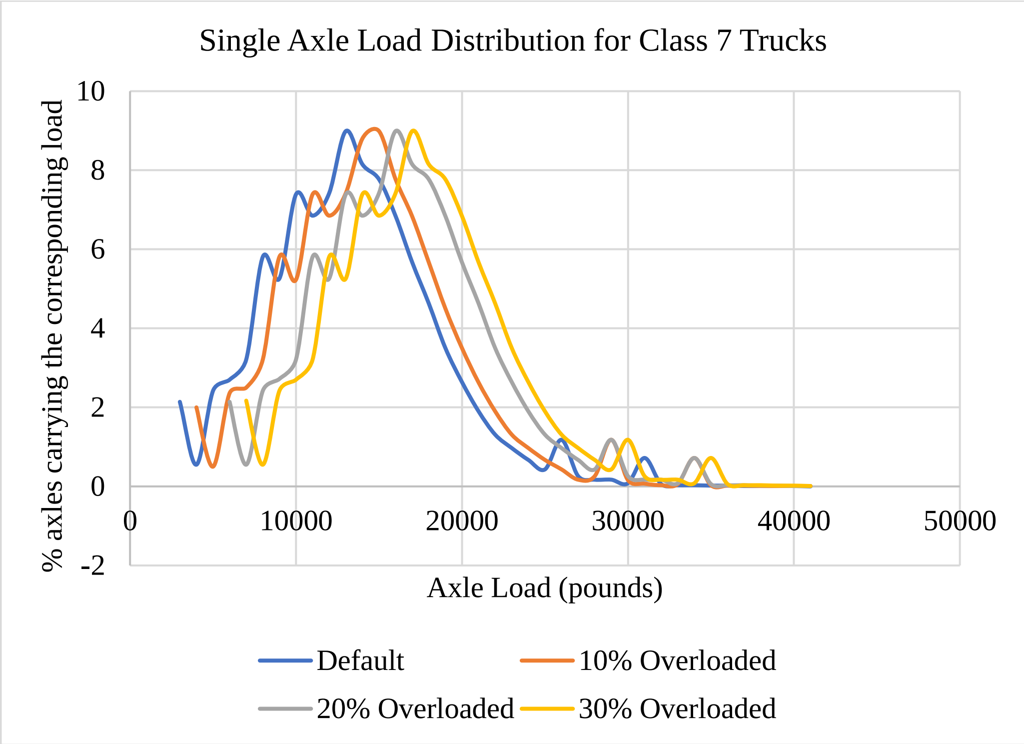

Figure 99 Single Axle Load Distribution for Class 7 Trucks

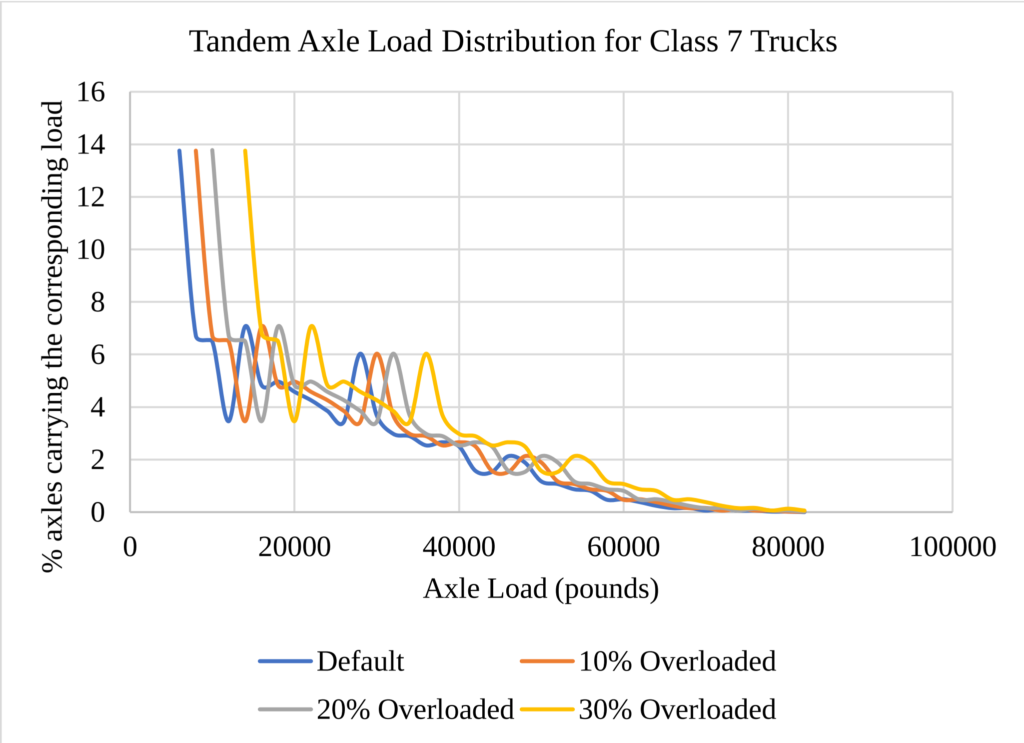

Figure 100 Tandem Axle Load Distribution for Class 7 Trucks

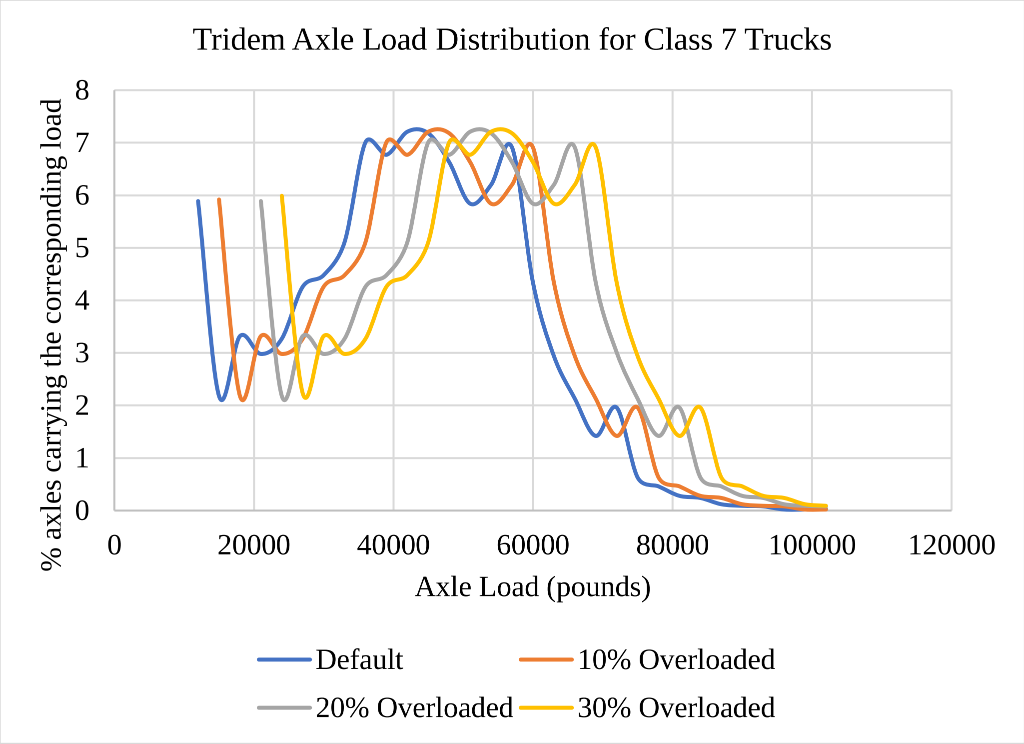

Figure 101 Tridem Axle Load Distribution for Class 7 Trucks

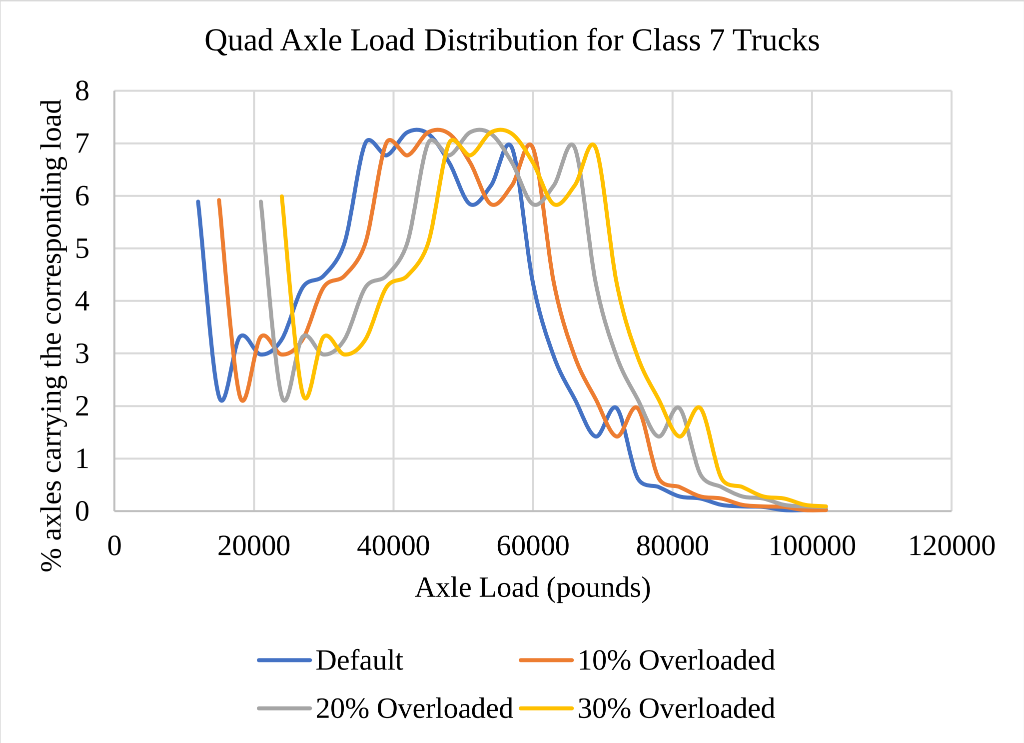

Figure 102 Quad Axle Load Distribution for Class 7 Trucks

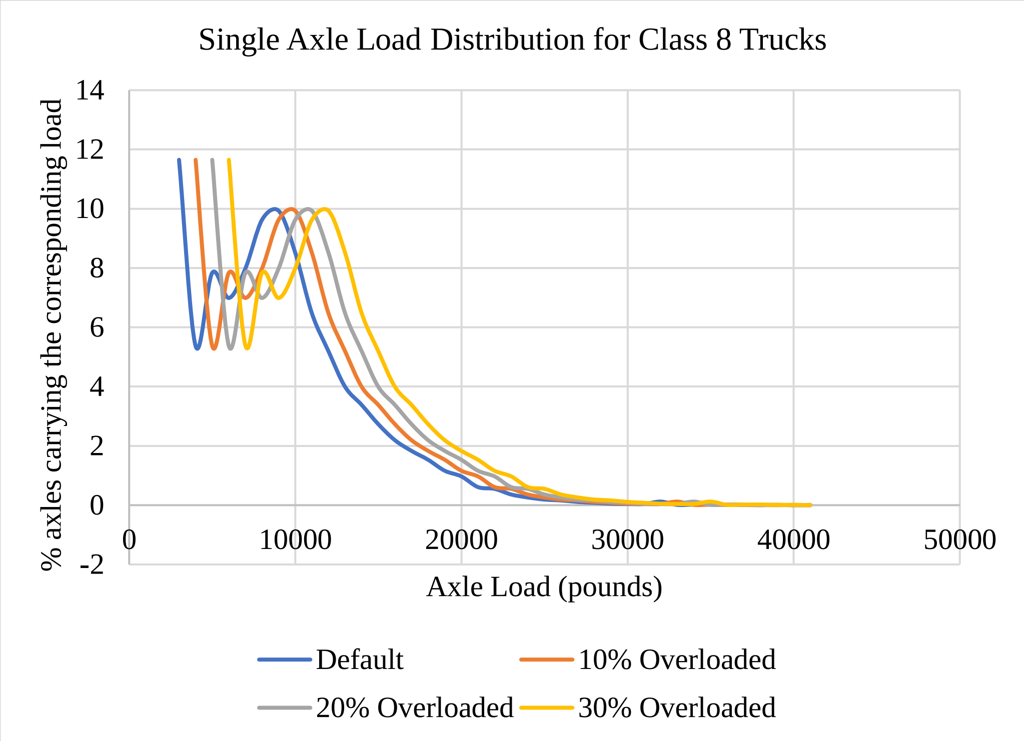

Figure 103 Single Axle Load Distribution for Class 8 Trucks

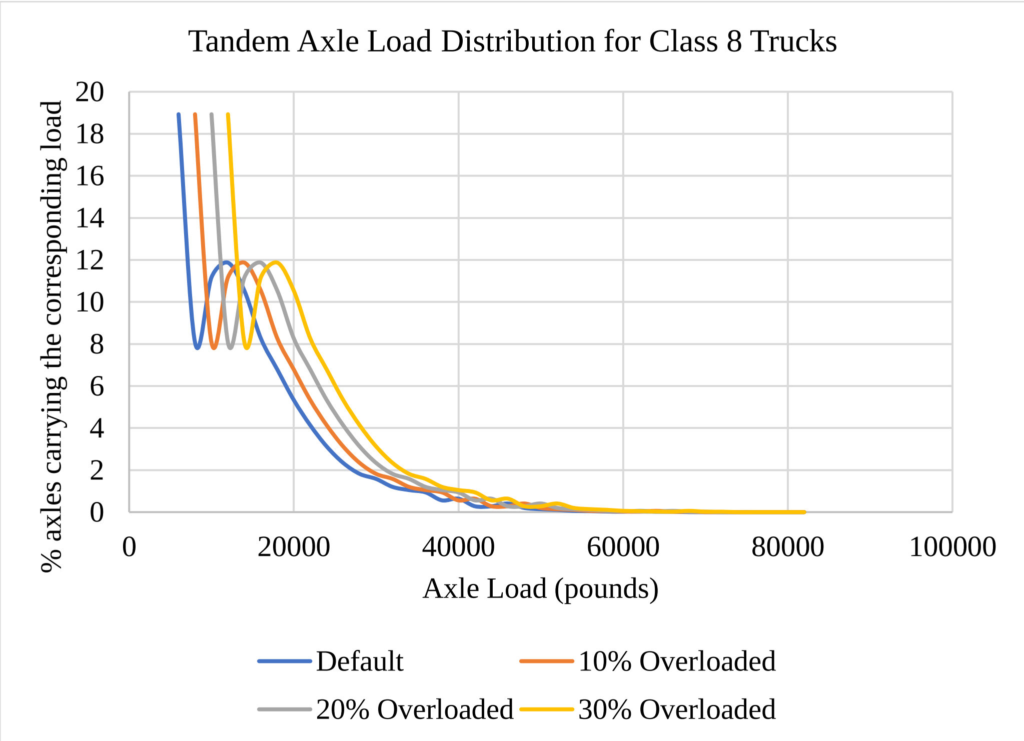

Figure 104 Tandem Axle Load Distribution for Class 8 Trucks

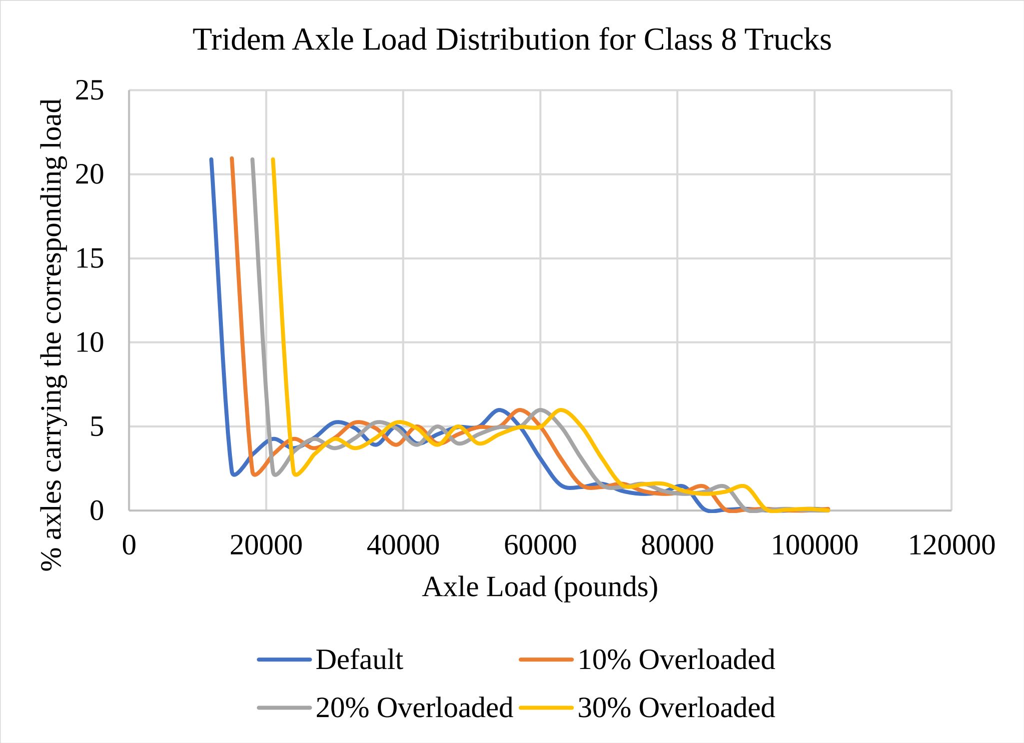

Figure 105 Tridem Axle Load Distribution for Class 8 Trucks

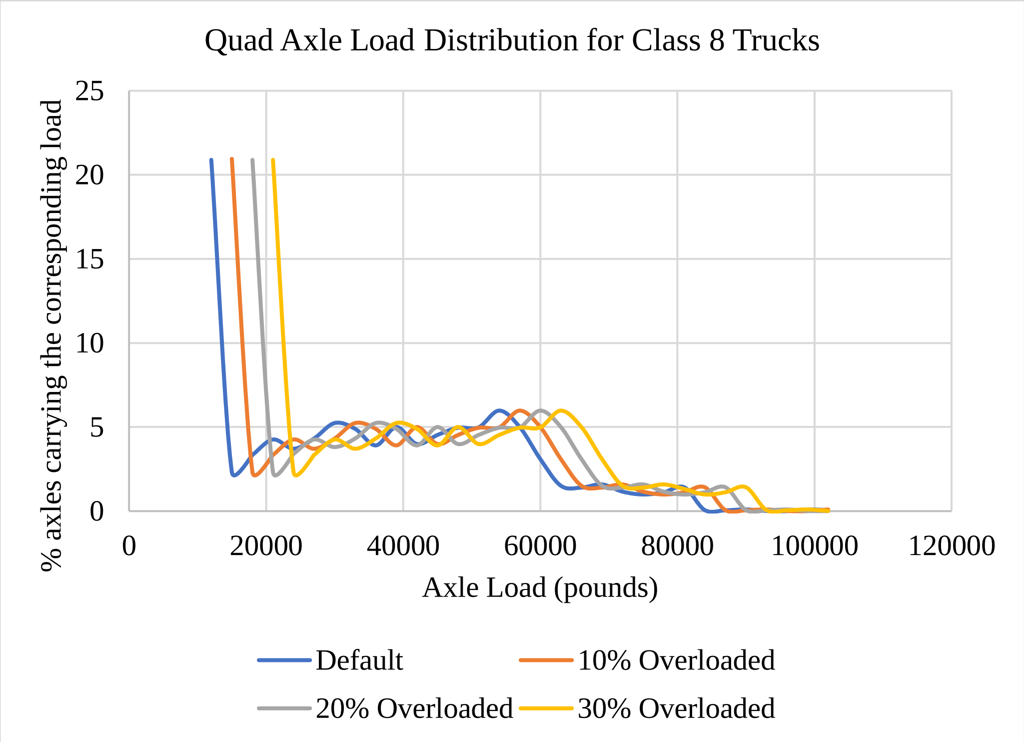

Figure 106 Quad Axle Load Distribution for Class 8 Trucks

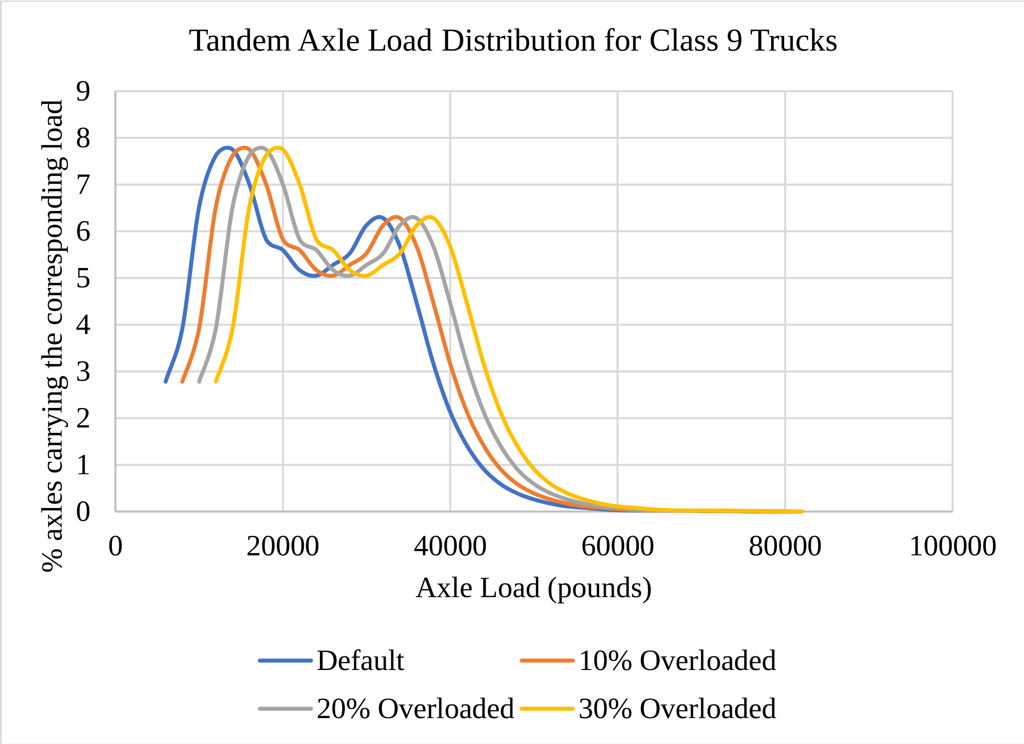

Figure 107 Tandem Axle Load Distribution for Class 9 Trucks

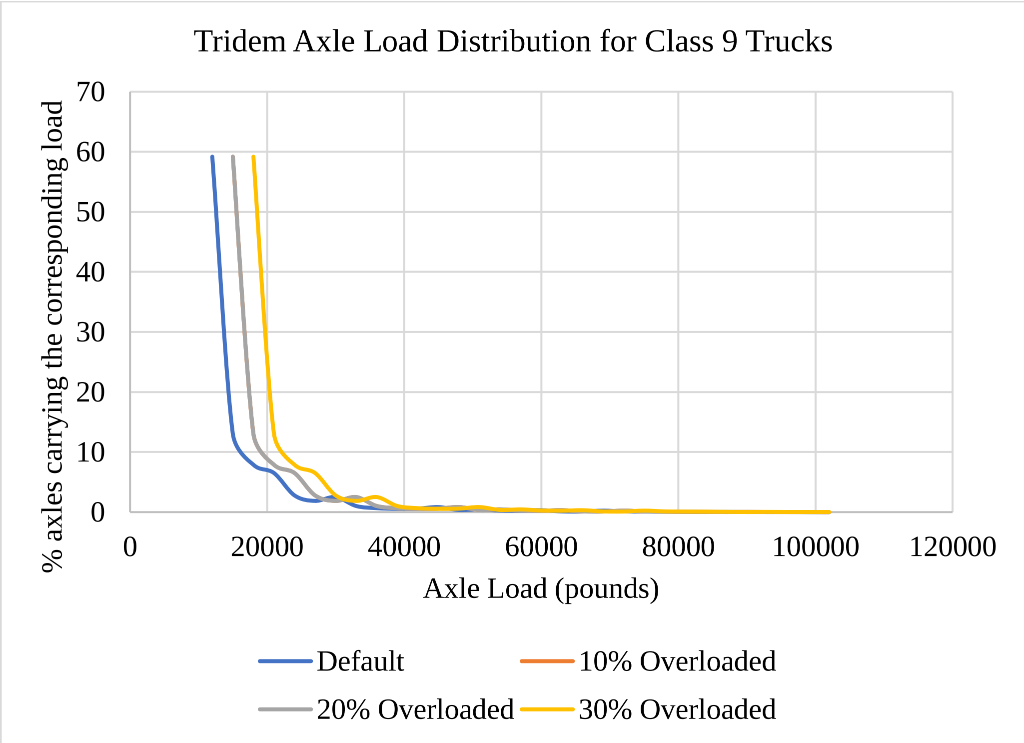

Figure 108 Tridem Axle Load Distribution for Class 9 Trucks

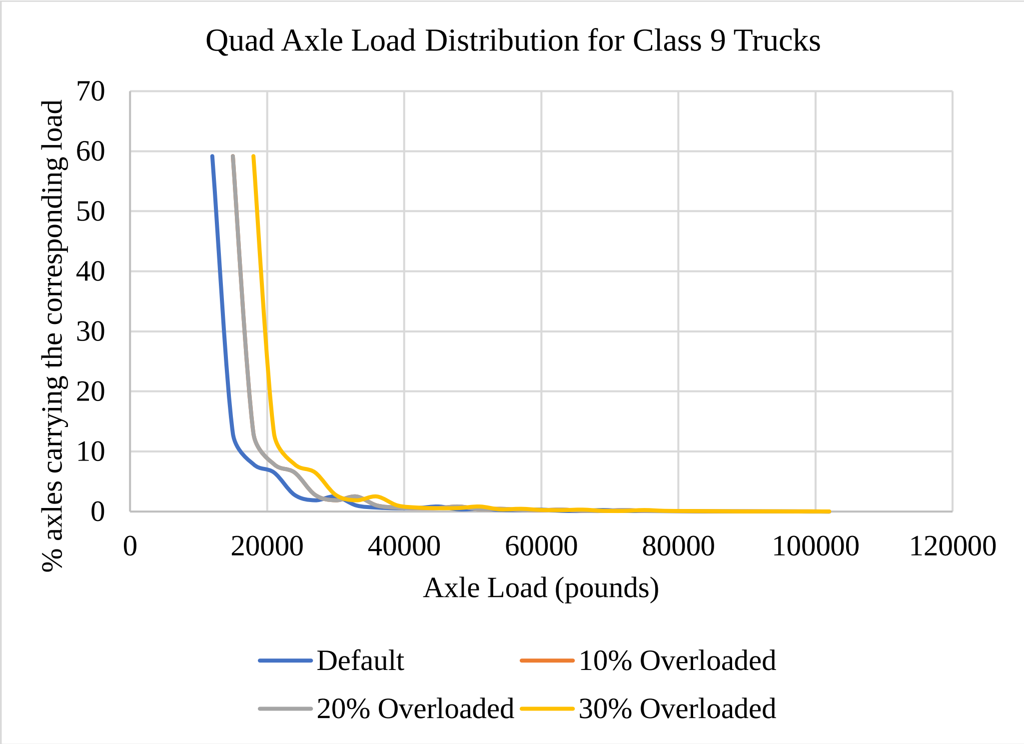

Figure 109 Quad Axle Load Distribution for Class 9 Trucks

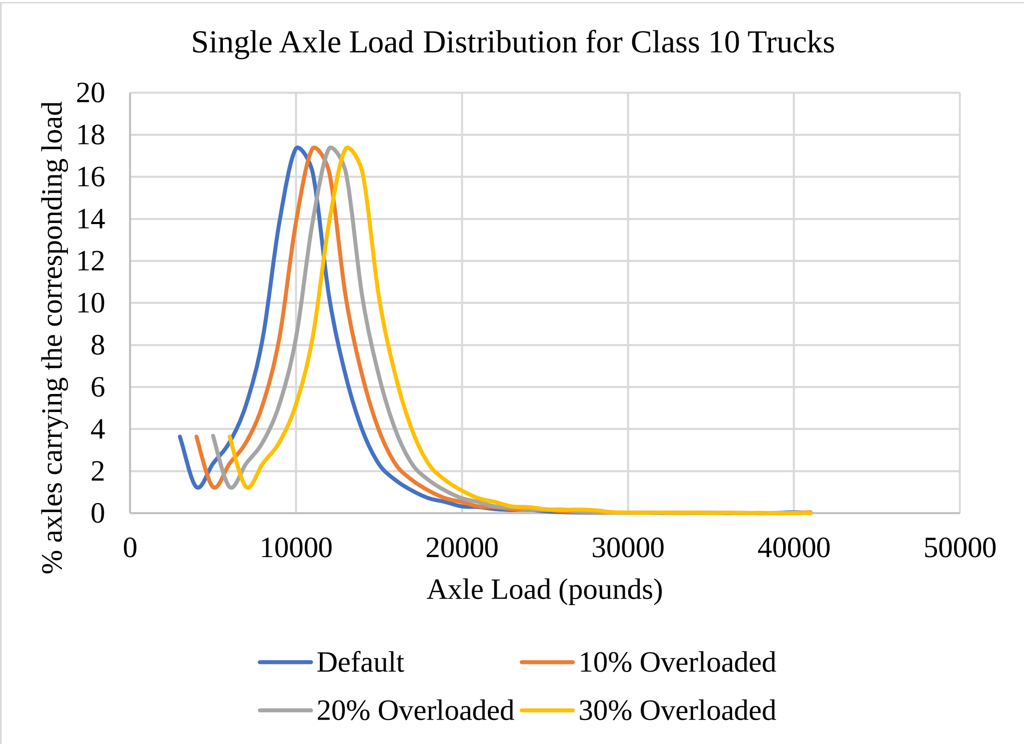

Figure 110 Single Axle Load Distribution for Class 10 Trucks

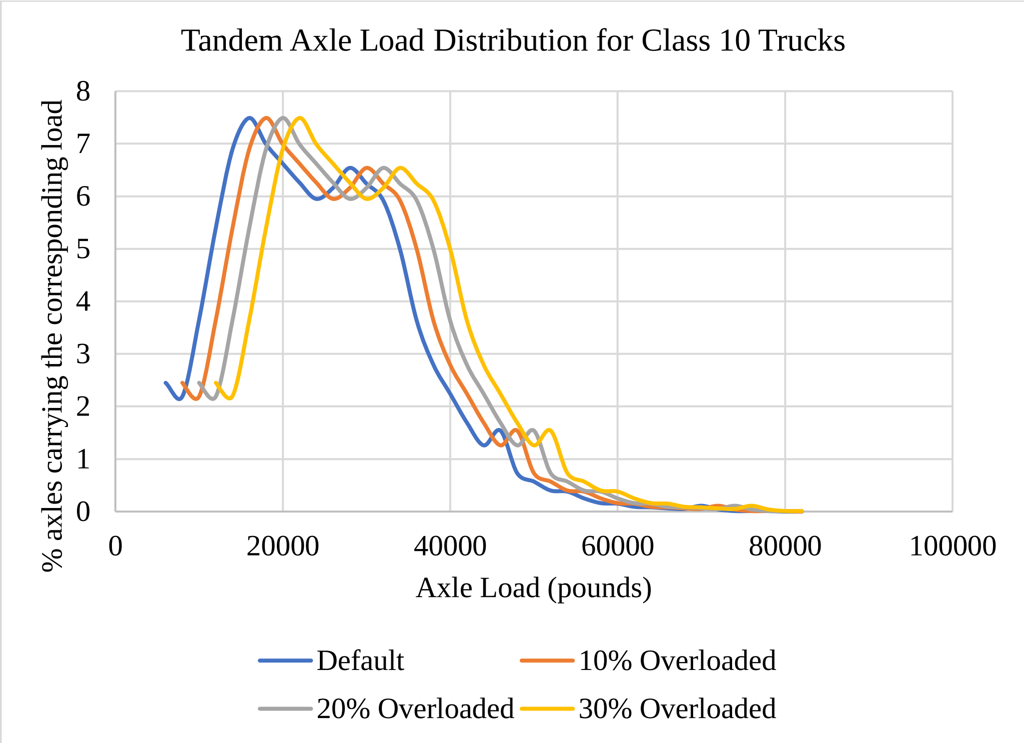

Figure 111 Tandem Axle Load Distribution for Class 10 Trucks

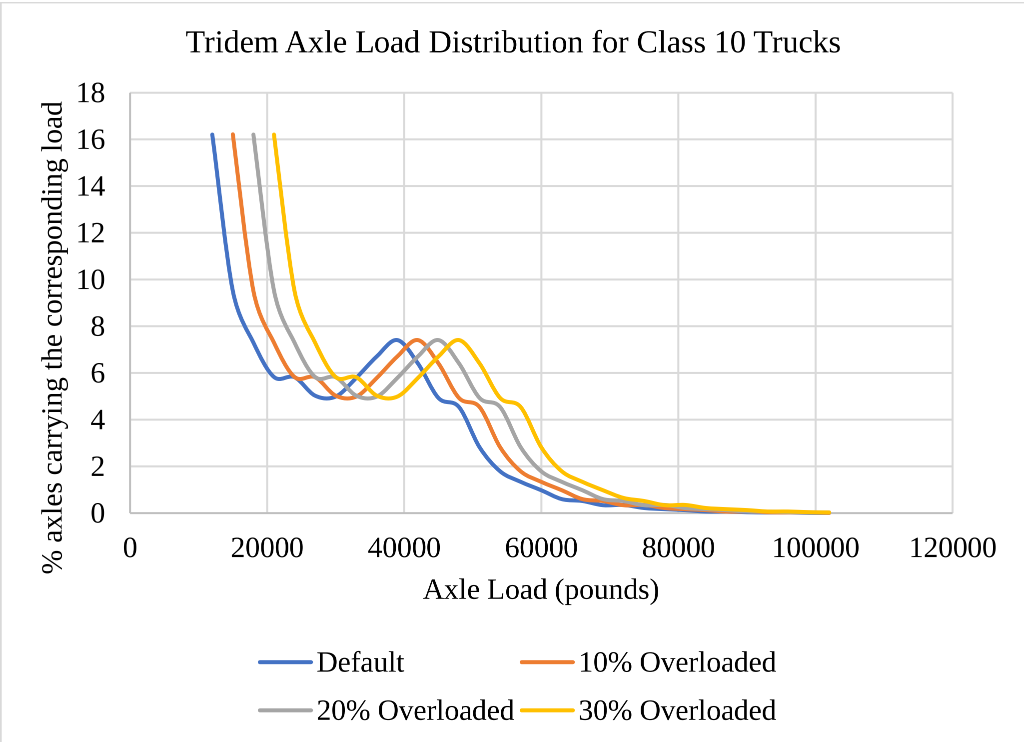

Figure 112 Tridem Axle Load Distribution for Class 10 Trucks

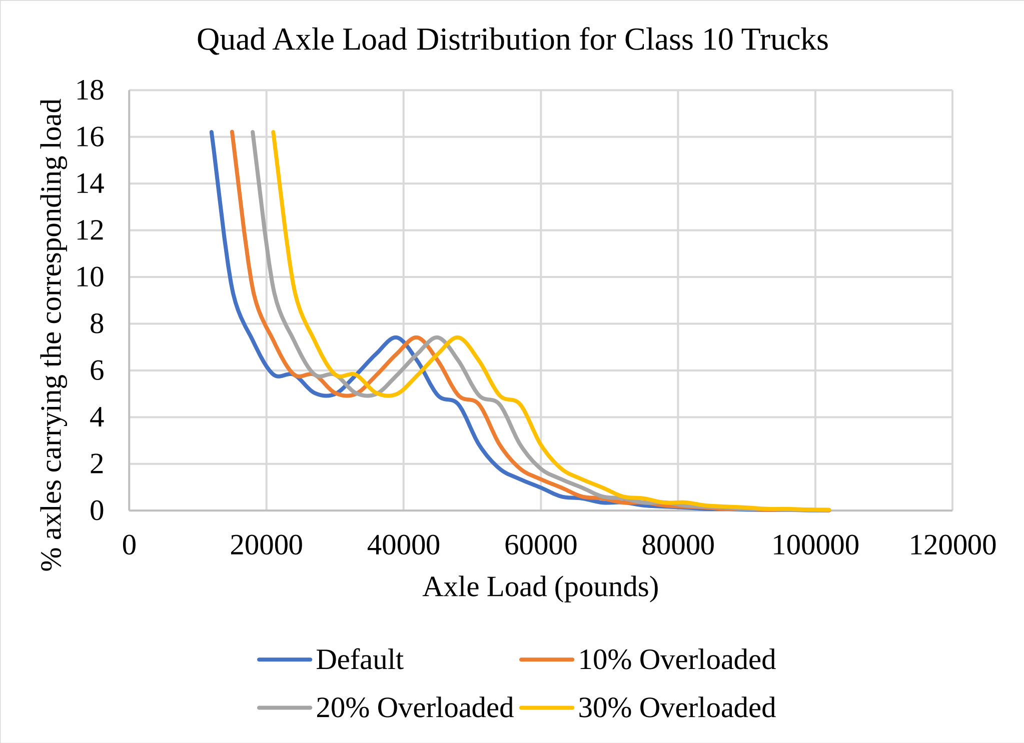

Figure 113 Quad Axle Load Distribution for Class 10 Trucks

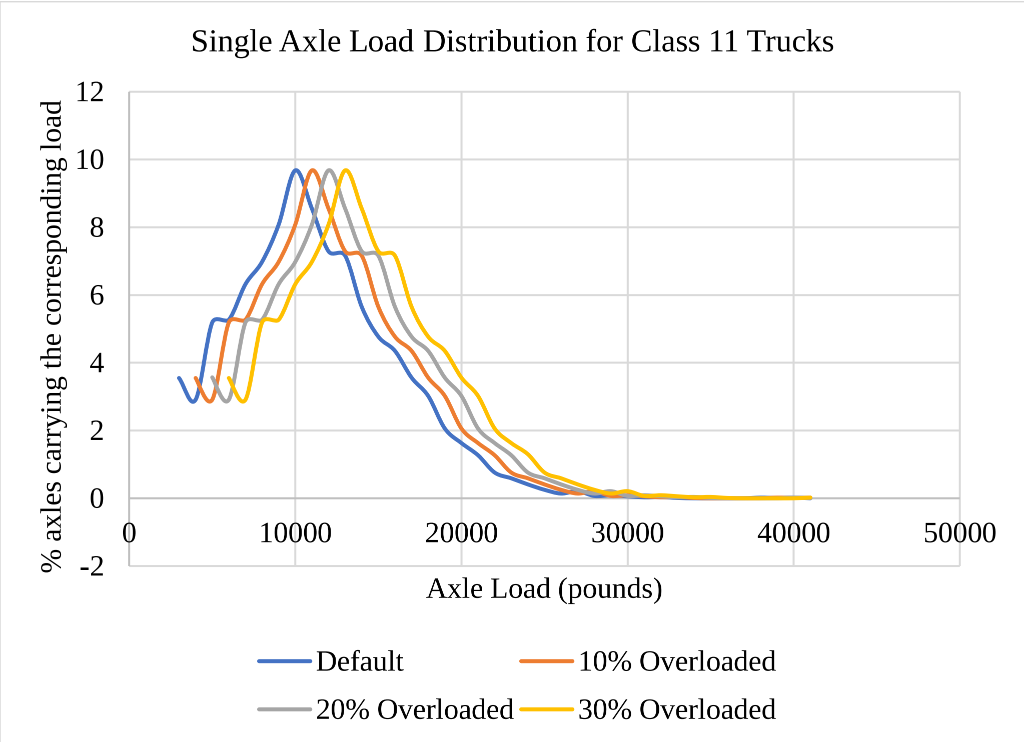

Figure 114 Single Axle Load Distribution for Class 11 Trucks

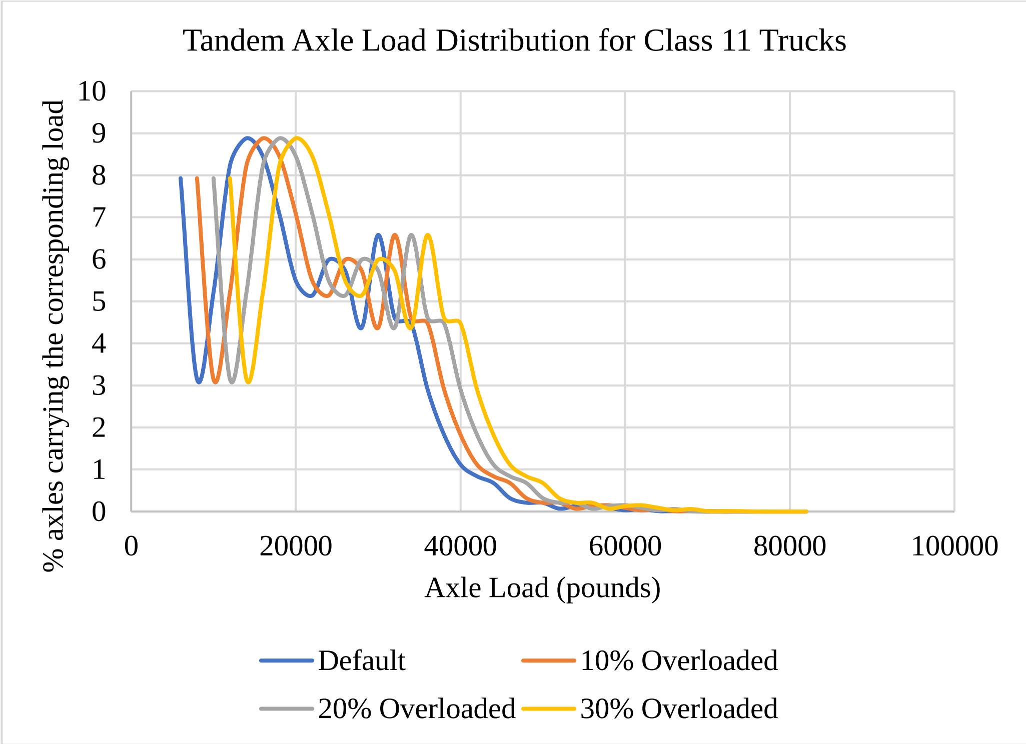

Figure 115 Tandem Axle Load Distribution for Class 11 Trucks

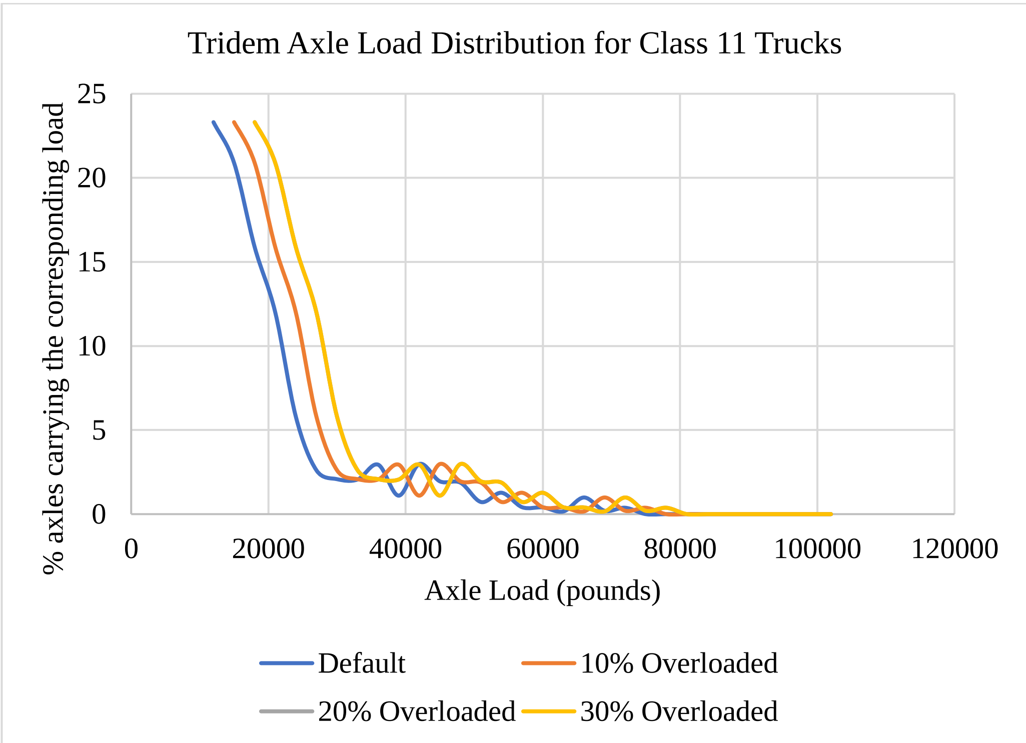

Figure 116 Tridem Axle Load Distribution for Class 11 Trucks

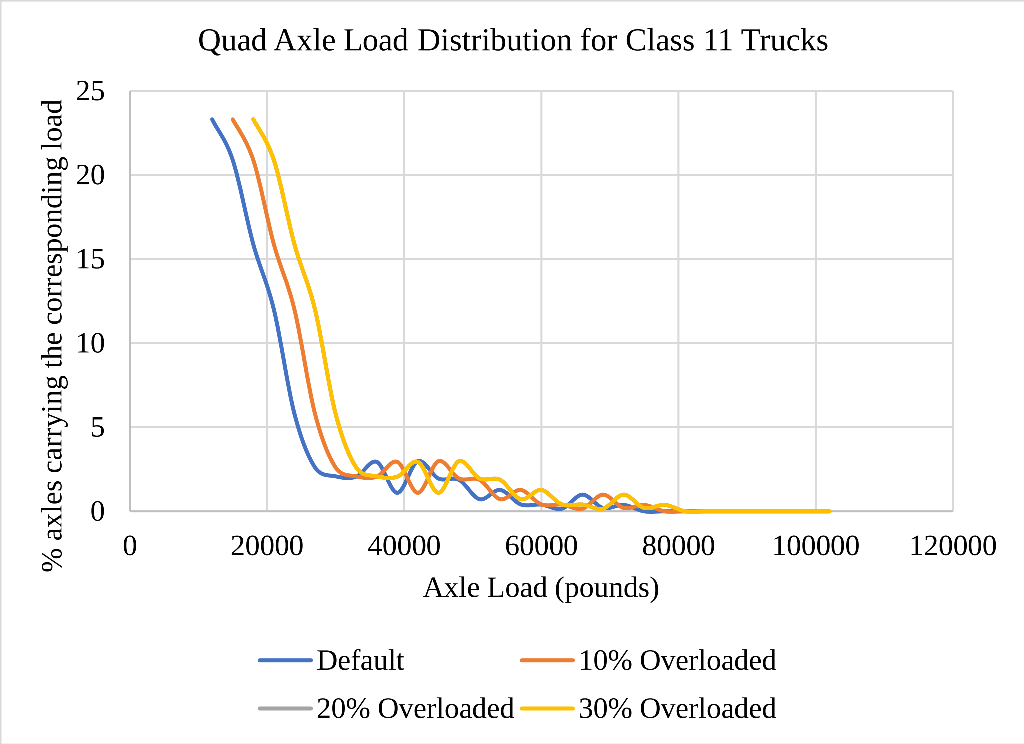

Figure 117 Quad Axle Load Distribution for Class 11 Trucks

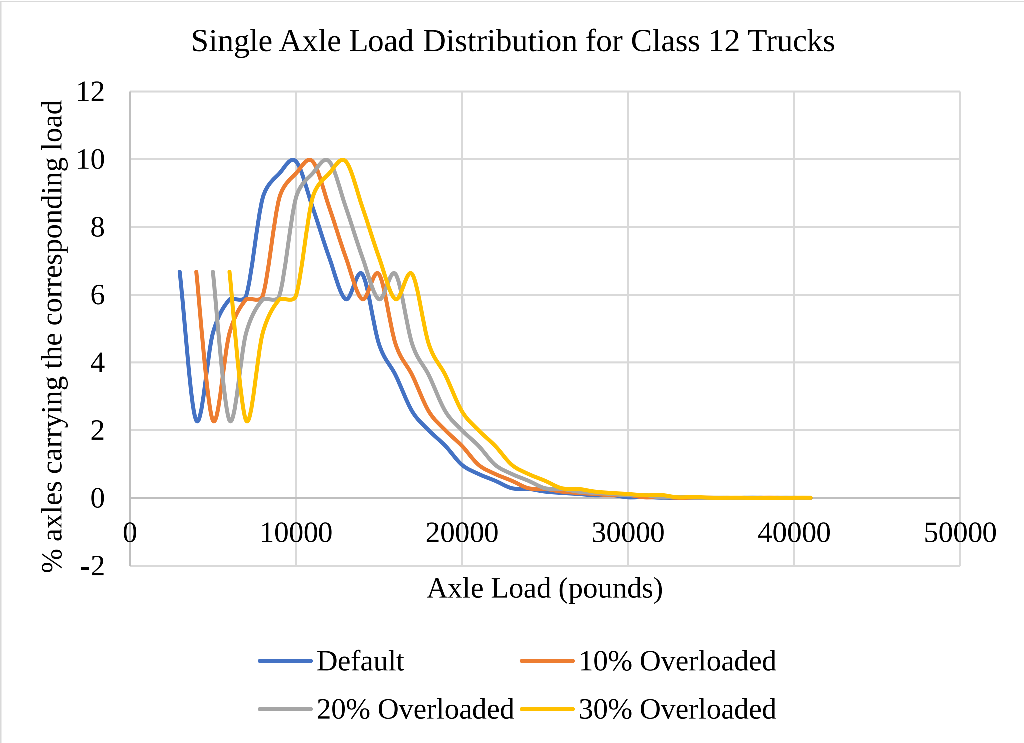

Figure 118 Single Axle Load Distribution for Class 12 Trucks

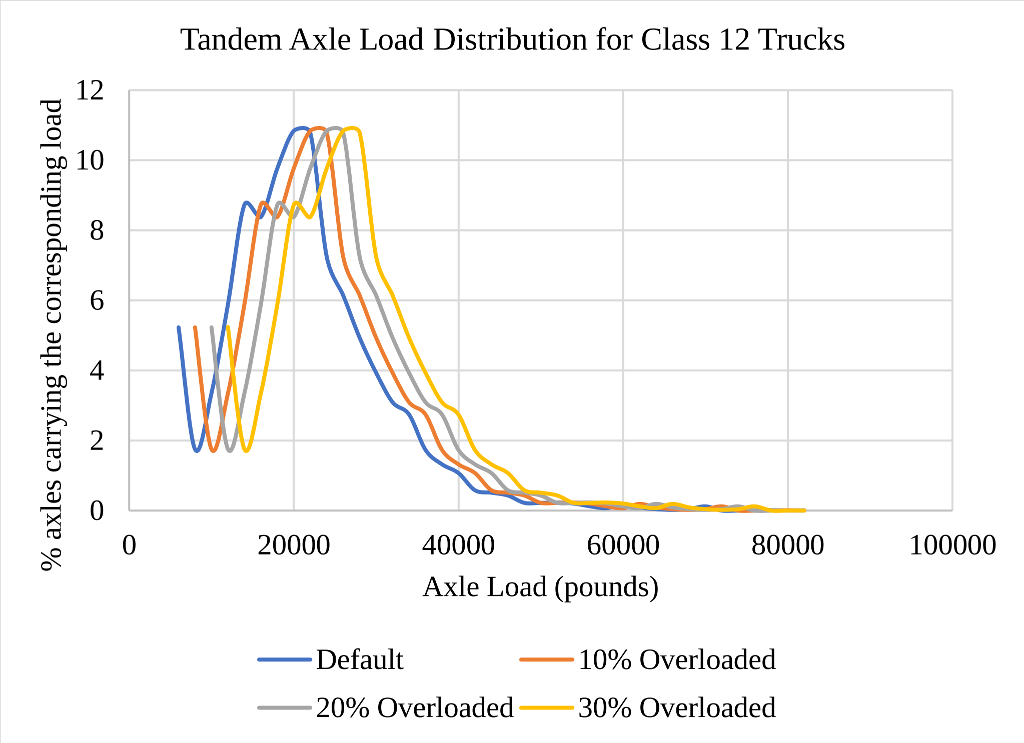

Figure 119 Tandem Axle Load Distribution for Class 12 Trucks

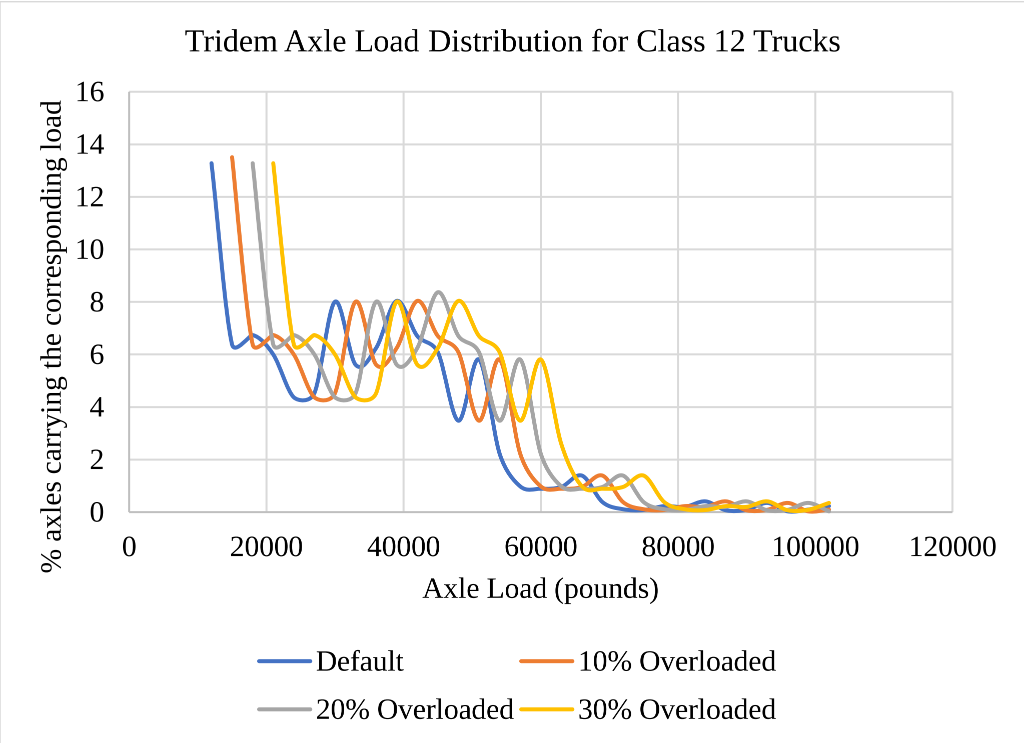

Figure 120 Tridem Axle Load Distribution for Class 12 Trucks

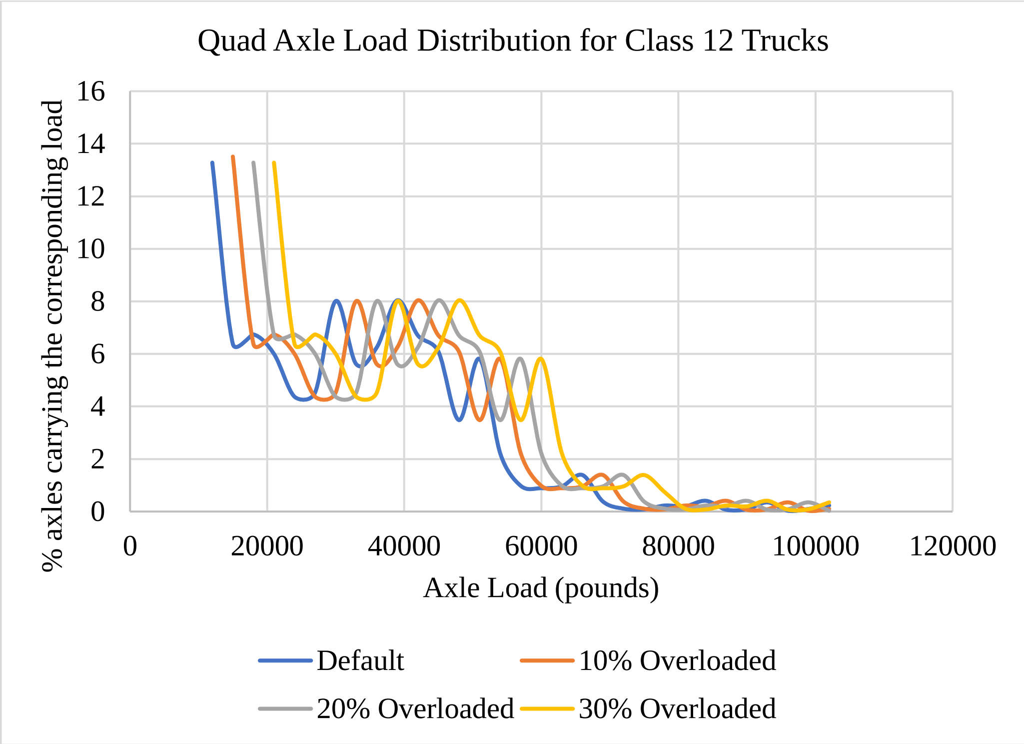

Figure 121 Quad Axle Load Distribution for Class 12 Trucks

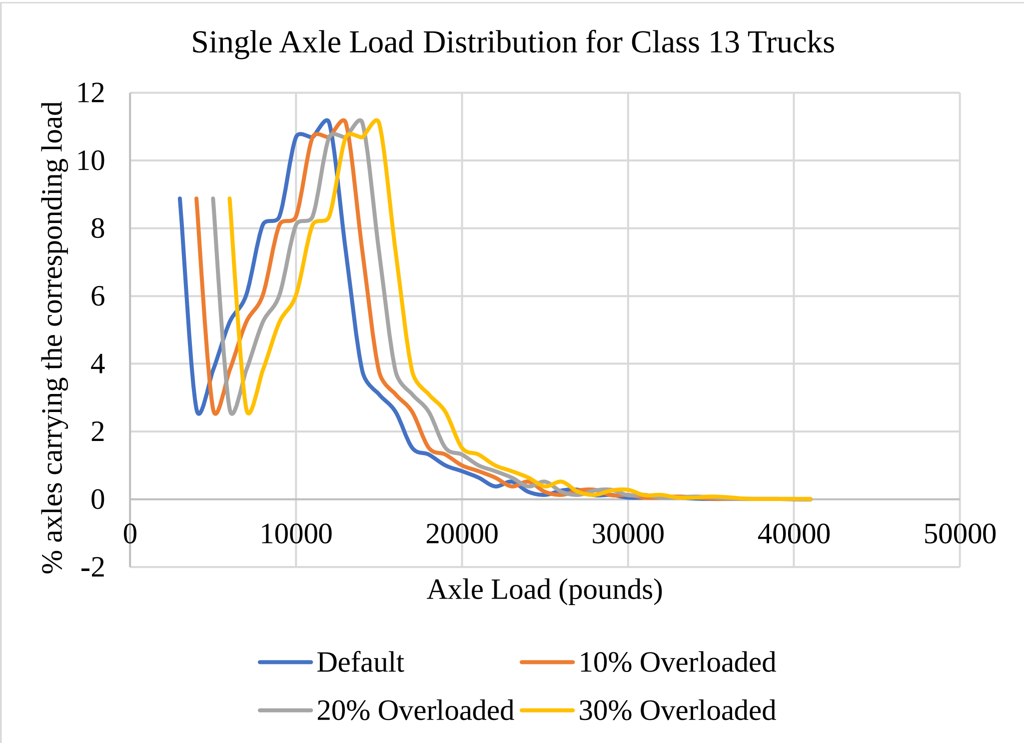

Figure 122 Single Axle Load Distribution for Class 13 Trucks

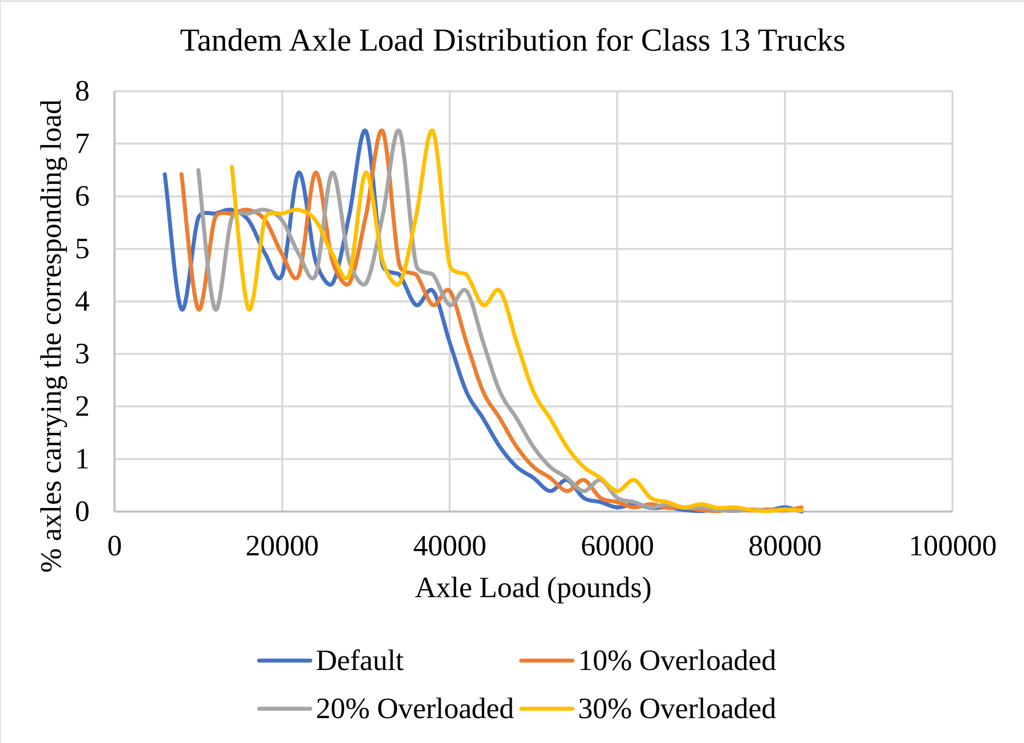

Figure 123 Tandem Axle Load Distribution for Class 13 Trucks

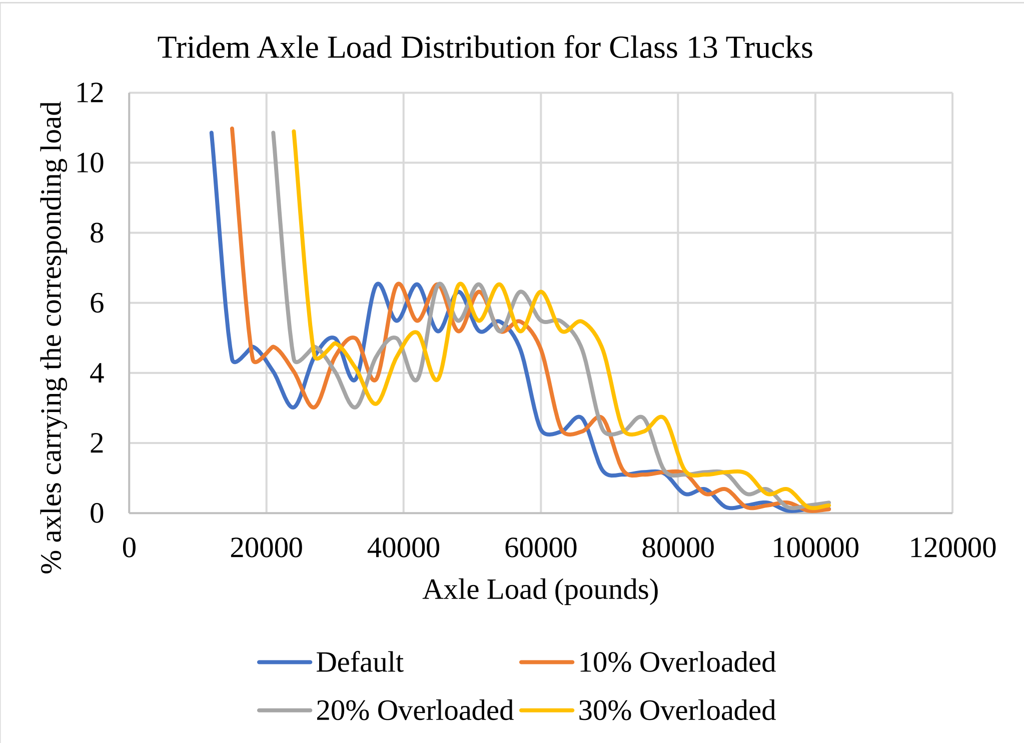

Figure 124 Tridem Axle Load Distribution for Class 13 Trucks

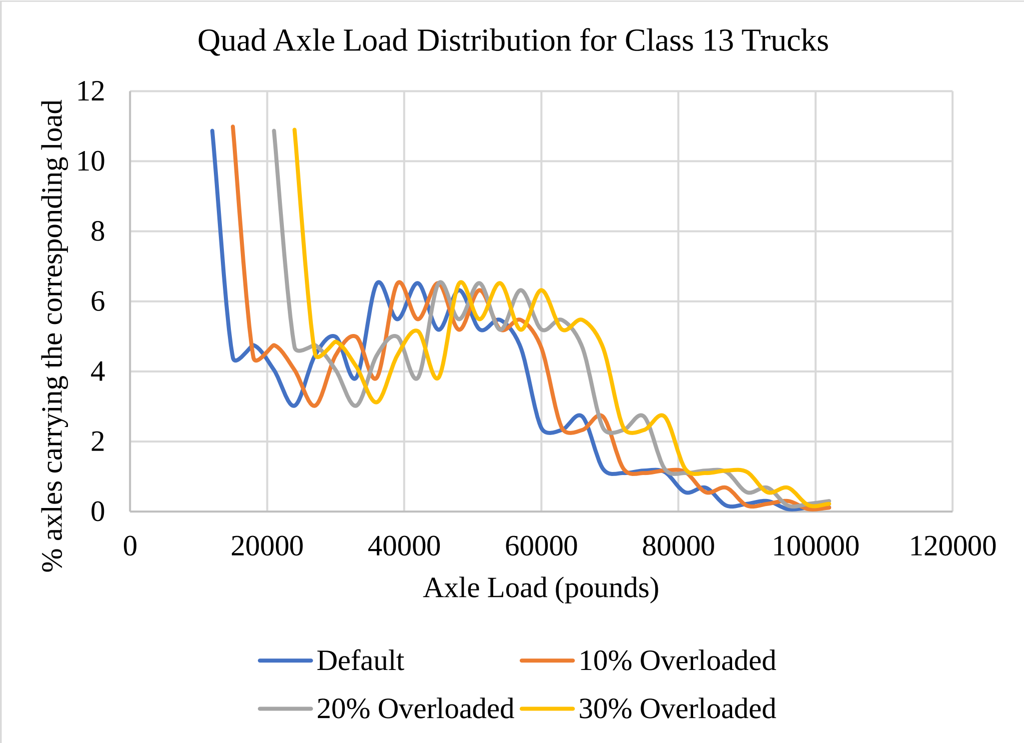

Figure 125 Quad Axle Load Distribution for Class 13 Trucks

APPENDIX B

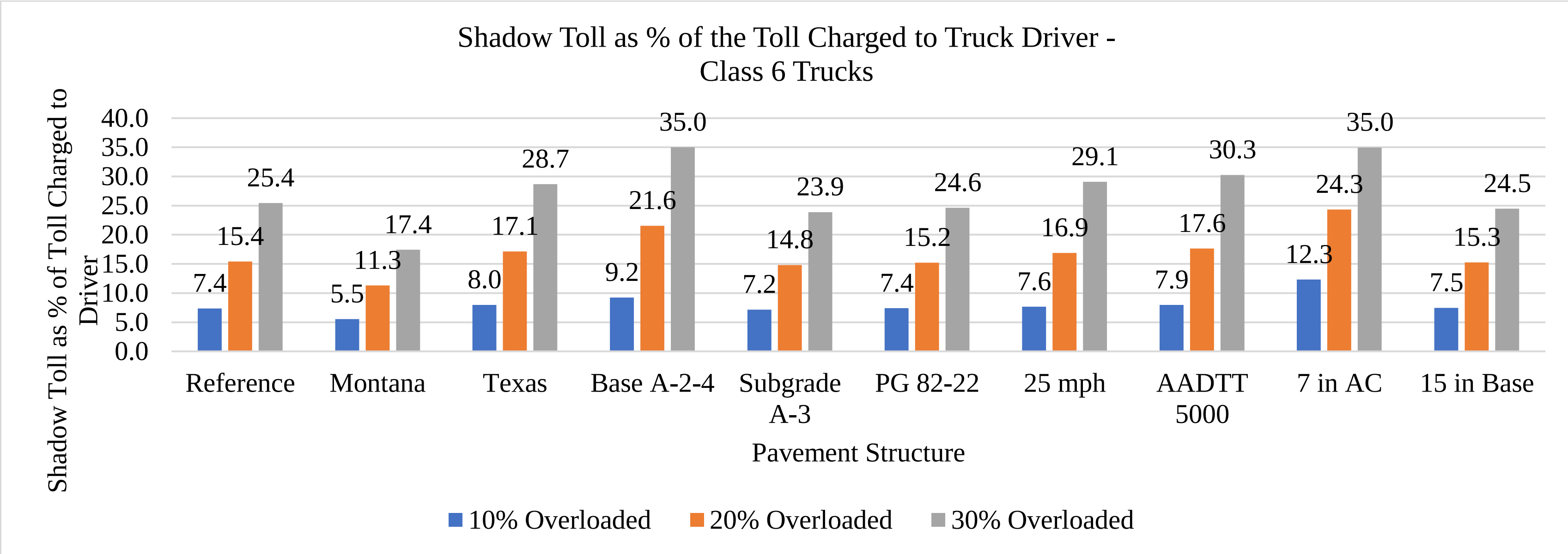

Figure 126 Shadow Toll for 10%, 20% and 30% Overloaded Class 6 Trucks as a Percentage of the Toll Charged to the Truck Driver

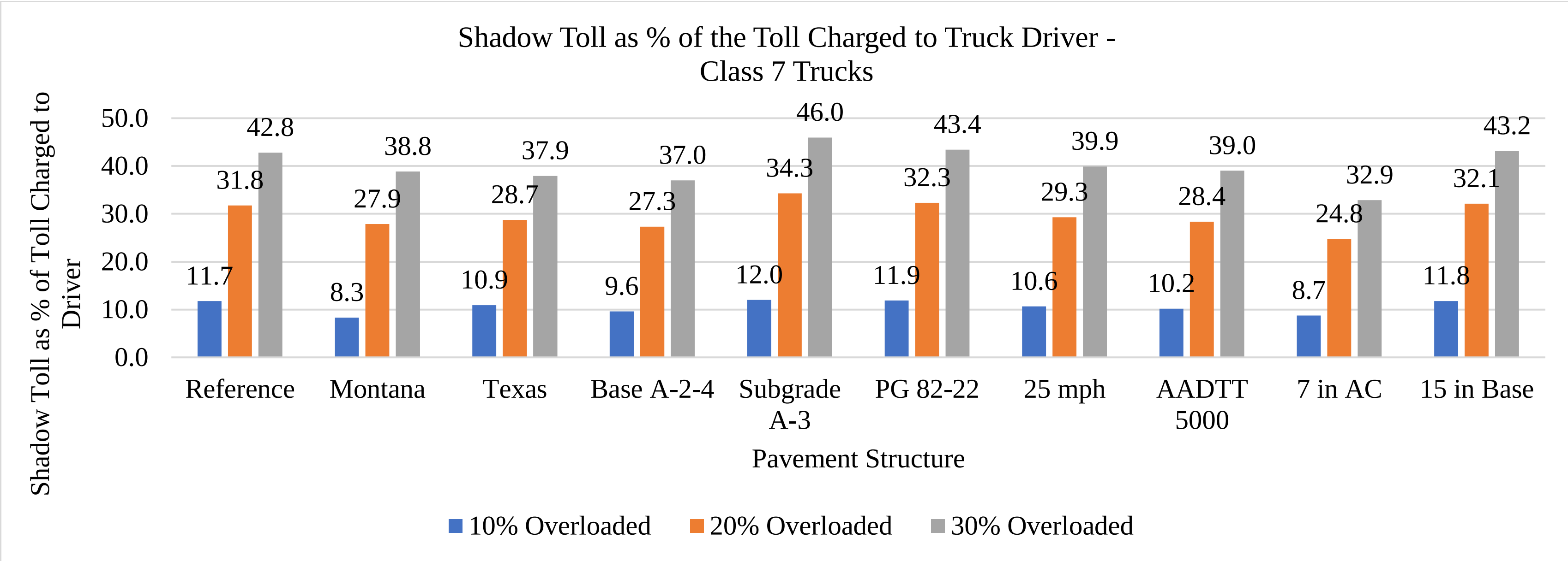

Figure 127 Shadow Toll for 10%, 20% and 30% Overloaded Class 7 Trucks as a Percentage of the Toll Charged to the Truck Driver

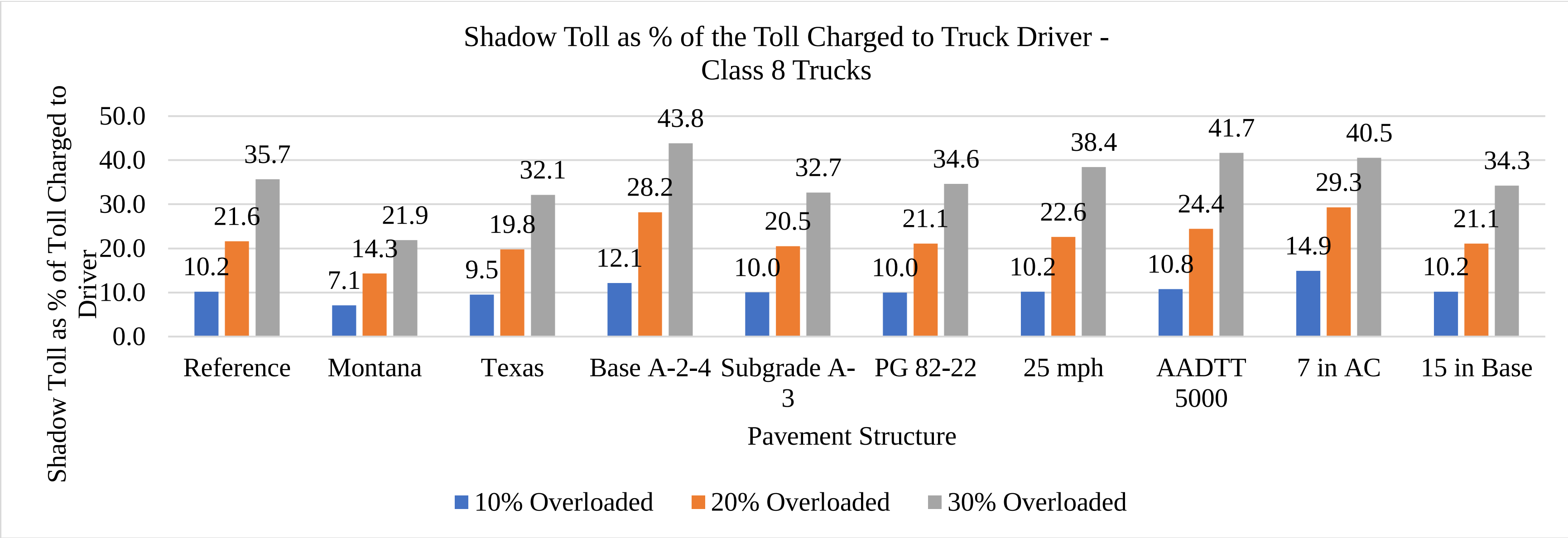

Figure 128 Shadow Toll for 10%, 20% and 30% Overloaded Class 8 Trucks as a Percentage of the Toll Charged to the Truck Driver

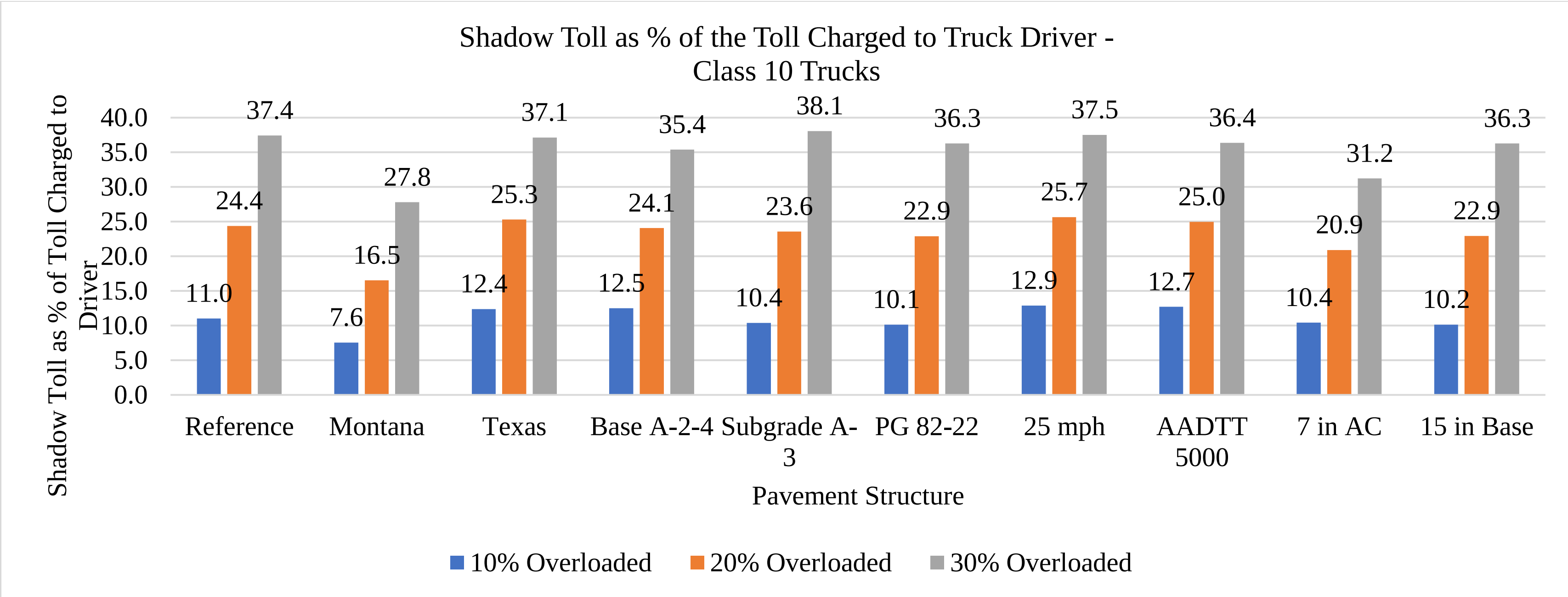

Figure 129 Shadow Toll for 10%, 20% and 30% Overloaded Class 10 Trucks as a Percentage of the Toll Charged to the Truck Driver

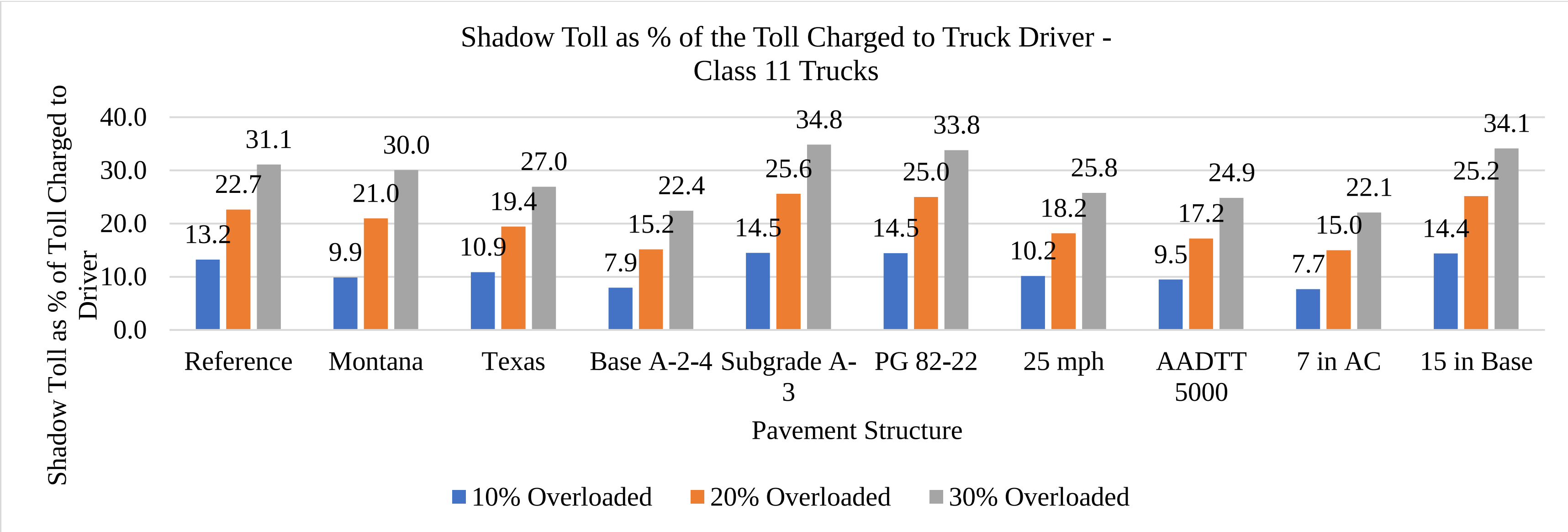

Figure 130 Shadow Toll for 10%, 20% and 30% Overloaded Class 11 Trucks as a Percentage of the Toll Charged to the Truck Driver

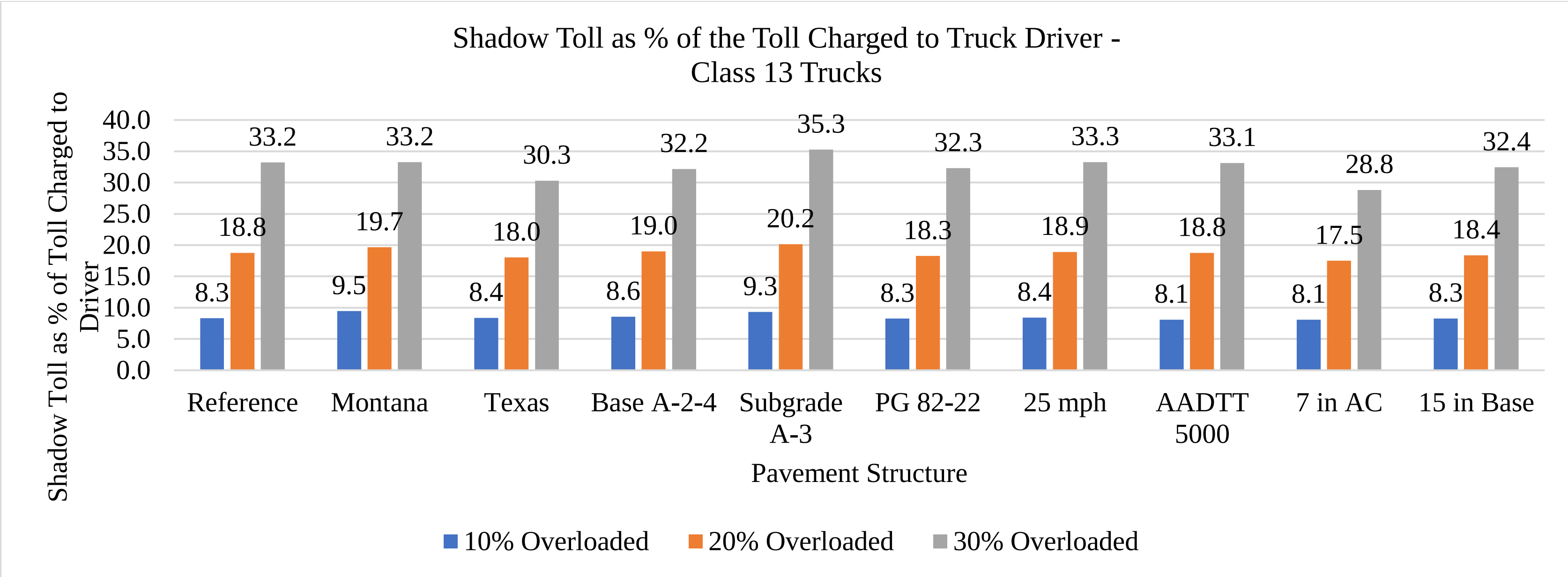

Figure 131 Shadow Toll for 10%, 20% and 30% Overloaded Class 13 Trucks as a Percentage of the Toll Charged to the Truck Driver

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