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Effect of Traffic Loading on Flexible Pavement Distresses for Main Roadways in Hilla City

A Thesis

Submitted to the College of Engineering/ University of Babylon in Partial Fulfillment of the Requirements for the Degree of Master of Science in Engineering/ Civil Engineering/ Transportation

By

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بسم الله الرحمن الرحيم

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And I dedicate this thesis to my father's soul...

Sally Mowaffaq

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Abstract

Asphalt pavement is influenced by many traffic factors that affect its performance and serviceability. It is usually designed based on certain limits for axle loads and the State Commission for Roads and Bridges (SCRB 2009) has specified the permissible limits for each type of truck axle, but many heavy trucks violate and carry extra weights, which leads to the development of pavement distresses and the lack of maintenance management plans, make the pavement deteriorate rapidly over time thus reduce its design life.

The study aims to investigate the traffic factors that affect the pavement distresses in the selected study sections as well as to evaluate the effect of axle loads on the asphalt pavement layers to propose a design commensurate with the axle loads that use the road using the concept of equivalent load according to the American Association of State Highways and Transportation Officials (AASHTO 1993) method to design the required thickness of the pavement layers.

The study was conducted in the city of Hilla on two sections Hilla-Najaf roadway and road no. (80) due to the presence of many failure areas, based upon a preliminary survey that included the areas of failure, type of traffic used the road, as well as the effects on the road; then engineering survey and traffic study included a traffic situation where classify the traffic volumes of the road based on peak hour volume with the aided of SCRB. The Highway Capacity Software (HCS 2010) was used to analyze the current level of service (LOS) for the selected sections, so the two sections occur with LOS D. A visual inspection survey is conducted on pavement distresses that included the type, severity level, and quantity of failure at sample units of the selected roads. The collected data for each study section are evaluated using Micro PAVER 5.2.3 software to predict the Pavement Condition Index (PCI).

The study calculated that the proposed thickness of the asphalt and subbase layers for the Hilla-Najaf section is (33, 34) cm respectively, where it implements under the technical specifications of the SCRB by following steps:-

- Brushes asphalt surface layer with a thickness of 6 cm.
- A binder course with a thickness of 7 cm and a Tack Coat material is sprayed before the brush.
- A base course with a total thickness of 20 cm brushes in two layers 10 cm for each layer and a Prime Coat material is sprayed before the brush.
- The thickness of the subbase layer is 34 cm it implements in the form of two layers.

While for the road no. 80 section, the asphalt and subbase layers thickness is (33, 32) cm respectively where it is implemented under the technical specifications according to SCRB by following steps:-

- Brushes asphalt surface layer with a thickness of 6 cm.
- A binder course with a thickness of 7 cm and a Tack Coat material is sprayed before the brush.
- A base course with a total thickness of 20 cm brushes in two layers 10 cm for each layer and a Prime Coat material is sprayed before the brush.
- The thickness of the subbase layer is 32 cm it implements in the form of two layers.

For the Hilla-Najaf section, the resulting PCI indicated that 50% of the pavement surface area have good condition, 25% have a fair condition, 14% have very good condition, and 11% have a poor condition. The resulting PCI of the road no. 80 section indicated that 46% of the pavement surface area have good condition, 27% have a fair condition, and 27% have a poor condition. The study recommended adoption of the legal limits of axle loads, the necessity of installing weighing stations at the entrances of the cities to control the axle loads as well as evaluation of the road condition and setting standards for the approval of maintenance types by specialized departments at specific times with documentation.

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List of Abbreviations

Symbols	Details
AASHTO	American Association of State Highways and Transportation Officials
ASTM	American Society for Testing Materials
AC	Asphalt Concrete
ESAL	Equivalent Single Axle Load
CBR	California Bearing Ratio
LEFs	Load Equivalency Factors
M.S	Marshall Stability
M_R	Modulus of Resilience
SN	Structural Number
SCRB	State Commission for Roads and Bridges
NCHRP	National Cooperative Highway Research Program
FHA	Federal Highway Administration
LOS	Level of Service
PSI	Present Serviceability Index
ADT	Average Daily Traffic
PCI	Pavement Condition Index
CDV	Corrected Deduct Value
EALFs	Equivalent Axle Load Factors
P_T	Percentage of Trucks
PMS	Pavement Management System
WB	Wheel Base

CHAPTER ONE

INTRODUCTION

CHAPTER ONE

INTRODUCTION

1.1 Introduction

All infrastructures have a specific period and benefit, they work within a certain time frame, after which they begin to collapse. Roads are an important infrastructure that requires great care through periodic evaluation and timely maintenance to keep the network operating at an acceptable LOS. In order to avoid deterioration of the road and the increased distresses that may lead to functional or structural failure, then in this case it becomes necessary to rehabilitate or re-construct therefore requires a high cost. The study attempts to investigate the traffic characteristics that affect road distresses, through the axle loads of vehicles in general and heavy vehicles in particular, if we take into account the illegal loads. Trucks are characterized by different axle configurations that cause different levels of pavement damage due to their direct effect on the flexible pavement layers. As a result, many failures appear on the asphalt layers, and consequently, the LOS decreases. Therefore, truck traffic is a major factor in pavement design.

Using the concept of load equivalency factors, the AASHTO Pavement Design Guide converts various axle load combinations to standard axle load where an ESAL is 18 kips to conclude an engineering design commensurate with the axle loads used for the road section. As well as, proposing economic treatments that reduce the effect of distresses thus raising the LOS.

1.2 Problem Statement

- As most roads in Hilla City lack analytical studies when designing paving layers, failures and distortions have spread widely across most road networks.
- The appearance of some asphalt layer defects as a result of the absence of road alignment survey, lack of information about the water table, and its contact with the roadway pavement layers.
- lack of use of engineering software based on traffic surveys and roadway characteristics to determine the roadway cross-section and analysis contributes greatly to the asphalt layer failure.
- Lack of availability of asphalt layer designs that adopt the legal limits of axle loads in terms of type and number of axles as well as weights and emergency impact loads.
- Some roads are constructed with specific traffic loads then turn into receiving high traffic loads as a result of functional changes, so they will be exposed to two types of failure functional failure and structural failure.

1.3 The Importance of the Study

This study deals with a problem prevalent in most of the important vital roads responsible for eliminating traffic congestion in Hilla city represented by illegal and repeated traffic loads, various traffic characteristics, and analyzing their effects on pavement layers and road distresses in the absence of maintenance.

The importance of the study is summarized in several points:

- Traffic and engineering analysis studies of current and future paving layers, on the one hand, effects of traffic volumes, and geometric characteristics of roadways, on the other hand, are among the most important tools that should be used in the process of evaluating and developing current roadways of all types.

- Considers the structural design of the road in terms of adopting legal limits of axle loads commensurate with the traffic loads used for the road so that it improves the LOS, saves economic, and facilitates the transportation of traffic volumes safely.

1.4 Objectives of the Study

- The study aims to find the effect of axle loads on asphalt layers then examine the condition of it, as well as the distortions obtained through a scientific consideration based on the traffic characteristics and geometric census for the study area sections.
- The conclusion of a structural design based on AASHTO 1993 design method appropriate with the traffic volumes and axle loads that the roadway carries contributes mainly to maintaining its design speed across all sections.
- Assist the beneficiaries and decision-makers in proposing the implementation of pavement layers and soil stratifications appropriate with the axle loads to avoid failure cases, as well as conclude of a fit economic design while enhancing the factors of safety, efficiency, and convenience for the roadway users.
- Determining the relationship between the proposed engineering analysis of layers and the actual analysis implemented to show the effect of axle loads on asphalt layers, taking into account the traffic characteristics for the studied roadway section length.

1.5 Study Layout

Chapter one presents the context and importance of this thesis, as well as a brief overview of the flexible pavement distress related to the study's problems and objectives. **Chapter two** includes a literature review performed before beginning this thesis, related to its approach by consisting of information needed to provide a detailed knowledge about the subject. **Chapter three** presents a brief description and information about the study area, and what the data are required to evaluate the

LOS of study sections by HCS 2010, as well as census the defects and showing the data needed to evaluate them using the PAVER method. **Chapter four** presents the flexible pavement thickness design according to axle loads used in the study sections, evaluation of asphalt pavement defects by PCI calculation, using PAVER software based on inspection data, and the analysis of the results with necessary discussion. **Chapter five** presents the conclusions and recommendations for future study works. There are three Appendices:

Appendix A presents traffic volumes of the study area sections during the data collection period. **Appendix B** presents pavement distress data collection. **Appendix C** presents the design requirements of flexible pavement such as structural layer coefficients charts.

1.6 Study Methodology

The Figure (1-1) shows the stages of preparation of the study from the point of starting to conduct traffic and engineering surveys of the study sections, namely the preparation which depends mainly on the objectives of the study and the next stage is the stage of data collection, which includes a study of variables that contribute a large role to the completion of the work plan, then the stage of data analysis that depends on the study the nature of the engineering and economic standards adopted in the evaluation, and that the analysis of data is carried out through the approved software for the forms and Tables and to evaluate the LOS and distresses of the road sections of the study area, we rely on engineering programs such as the (HCS 2010) and PAVER 5.2.3 software, respectively. Then, we study the effect of different traffic characteristics, the most important of which is the axle loads because they have a direct effect on the layers of flexible pavement and the deterioration of the roadway using the AASHTO 1993 method by converting vehicle loads into equivalent standard loads, thus concluding the thickness of the road layers according to the legal axle load and technical specifications. Or suggest alternatives and economic solutions that are possible for the purpose.

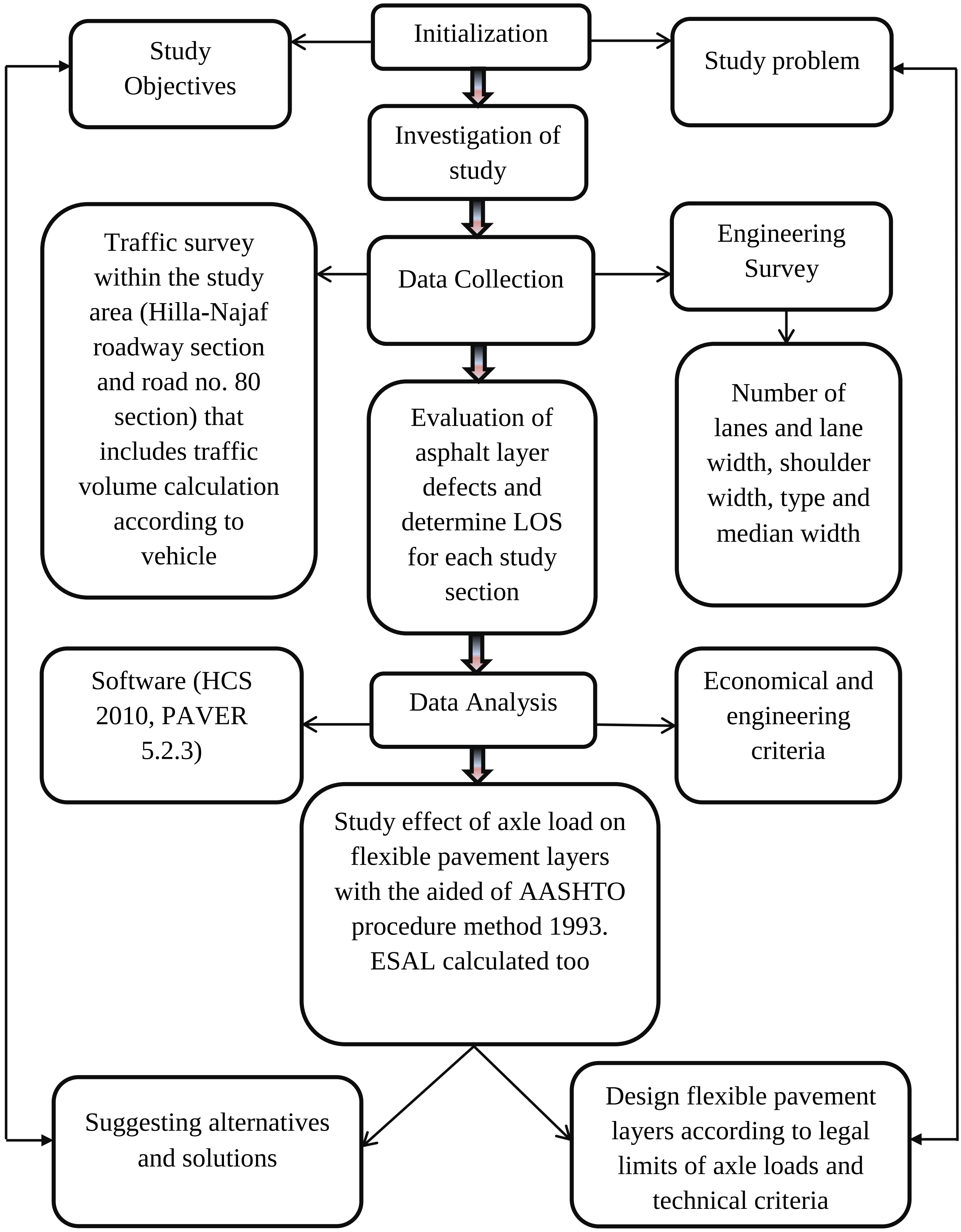

Figure (1-1): Flow Chart for the Methodology of the Study.

CHAPTER TWO

LITERATURE REVIEW

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

The pavement is one of the essential features of the roadway transport system. It is primarily constructed to ensure pedestrian, road user's safety, and support the traffic-induced loads. Traffic is the most important factor affecting the performance of the pavement as well as, the key parameter in road deterioration. Traffic load repetitions, environmental and operational factors within the pavement system contribute to the development of distresses with the absence of maintenance. This chapter presents the literature related to the study, and a description of similar previous studies, in addition to the necessity of examining the traffic characteristics that control pavement performance.

2.2 Overview of the Flexible Pavement

Flexible pavement is a multi-layered system comprising of a bituminous surface course over base course and sub-base course, as well as a mixture of bitumen and aggregates. A pavement structure is a soil-connected system that distributes the load to the subgrade and its stability depends on **[NCHRP, 2004]**:

- Interference between aggregates.
- Intermolecular friction.
- Cohesion strength.

These pavements have a low flexural strength, therefore undergo deformation under load action. The structural capability of flexible pavements is achieved through the combined action of the different pavement layers **[Chandra, 2017]**. Figure (2-1) shows a typical cross-section of a flexible pavement that consists of surface course, tack coat, binder course, prime coat, base course, sub-base course, and natural subgrade.

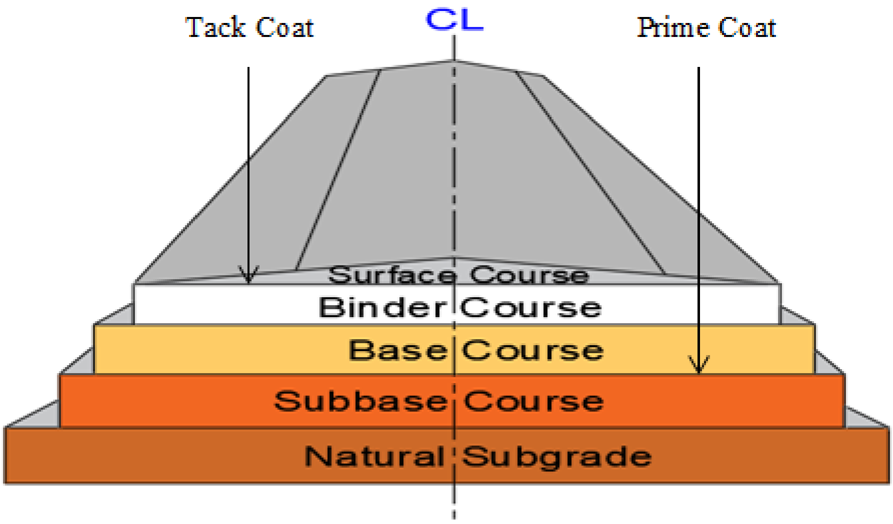

Figure (2-1): Typical Cross-Section of the Flexible Pavement Layers.

Strong materials with maximum stiffness are used in the surface layer because the load distribution area is small, generating high stress levels that decrease with depth, surface layer makes the greatest contribution to pavement strength. Weaker materials that have lesser stiffness are used in the bottom layers because the load distribution area is large. The subgrade layer is equally important in the composition of pavement and is responsible for transferring the load from the upper layers to the ground **[Sharad and Gupta, 2015]**.

The pattern of load distribution varies according to the strength of the layers as well as the flexible pavement is designed in a way that load should not exceed the bearing strength of the layer. When the load is removed, the pavement layers rebound therefore it is referred to as “flexible”, as a result of repeated loads, distresses accumulate and are constantly magnified throughout the years such as fatigue cracking, rutting..etc. The pavement fails when one or more of these distresses exceed an unacceptable level **[Fwa, 2006]**. Failure of flexible pavement may be categorized as follows **[Woods & Adcox, 2002]**:

1. **Functional Failure:** it is the failure of the top layer of the pavement in most sometimes, which could relate to the loss of any flexible pavement function such as the passenger comfort, skid resistance, and safety of road users. It can be controlled with routine maintenance.
2. **Structural Failure:** it is the most dangerous form of failure that affects one or more of the pavement layers in which the pavement becomes unable to withstand the traffic loads that pass on its surface and can only be treated by road rehabilitation.

2.3 Traffic Characteristics Affecting Flexible Pavement

Traffic characteristics effects study is that the most essential for any development of traffic facilities, traffic controls, and design of roadway systems to provide traffic transportation that is both efficient and safe. Traffic characteristics are classified into two types as **[Garber and Hoel, 2010]** & **[Khanna and Justo, 2011]**:

2.3.1- Road User Characteristics: Such as (drivers and pedestrians).

The human element is complex and involved in all road user behavior. Road users behavior varies depending on the class of the vehicle they drive and is influenced by a variety of characteristics that affect driving and the flow of traffic, as well as by internal and external factors such as:

- The environmental factors are considered external.
- The internal factors are classified as follows:

- Physical includes (vision, hearing, perception of reaction time, and strength) as permanent characteristics and (fatigue or illness, and alcohol) as temporary physical characteristics.
- Mental includes (knowledge, skill, experience, and intelligence).
- Psychological or Emotional includes (anger, fear, and impatience).

2.3.2- Vehicular Characteristics: Geometric design criteria of roadways must take into account the characteristics of different types of vehicles, such as static and dynamic properties. The road design is based on the choice of a design vehicle

whose characteristics will include the characteristics of all vehicles that are expected to use the road soon or in the future.
Vehicular characteristics that influence the design and traffic performance may be classified as **[Patel, 2016]**:

- Static Characteristics: include (vehicle dimensions, turning radius in terms of the roadway geometric design, and axle loading in terms of structural design).
- Dynamic Characteristics: these are critical vehicle properties for the design of roadways and traffic control. Include (speed, acceleration, distance, power of vehicle, and braking characteristics).

2.4 Vehicle Classification

Vehicles can be identified and classified according to AASHTO as follows:

- Passenger Car P.C: vehicles with four tires in contact with the pavement.
- Heavy Vehicles H.V: vehicles with more than four tires in contact with the pavement. Figure (2-2) shows the classification of heavy vehicles.

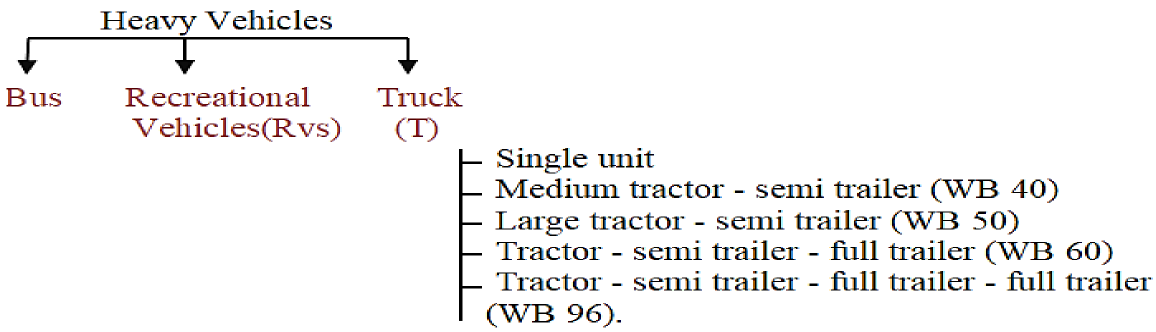

Figure (2-2): Heavy Vehicles Classification According to AASHTO. **[AASHTO, 2011]**.

Heavy vehicles affect traffic and pavement performance in two ways they occupy more roadway space because they are larger than P.C, therefore when designing a road facility or evaluating its performance, it should be carefully considered. As well as have poorer operating capabilities concerning acceleration and deceleration **[HCM, 2010]**.

2.5 Effect of Heavy Vehicle Characteristics on Pavement Damage

Heavy vehicles are a significant source of road damage due to the stresses exerted by heavy axle loads. The mechanics of truck-pavement interaction are investigated to determine which truck properties are most directly and strongly related to road damage **[Gillespie and Karamihas, 1994]**.

The characteristics of a vehicle are an essential component of any transportation system. As a result the vehicle's size and weight, as well as its engine characteristics, affect the vehicle's acceleration mechanism, which affects the vehicle's speed. Another set of important characteristics for a vehicle is its length and trailer coupling, which influences the amount of space it occupies as well as its turning power. Depending on the truck type, different variations of axle configurations are used to move truck loads to pavements **[Richard W. Lyles et al., 2006]** & **[Lily Elefteriadou, 2013]**.

All heavy trucks do not cause equal damage due to variations in axle load, axles number and location, suspensions type, wheels number, tire type, and inflation pressure. The relative damage to a pavement caused by heavy trucks is determined by the vehicle, tire, and pavement characteristics **[NCHRP, 1992]**.

2.5.1 Axle Loads

The axle load has the most significant influence on the structural nature of a pavement. It is defined as "total weight bearing on the roadway for all wheels connected to a given axle".

When a loaded axle travels over a roadway, a load of a vehicle is distributed on the pavement structure by each axle. The pavement is deflected downward the deflection causes short-term stresses and strains that fatigue the pavement structure. Each vehicle type has a different payload capacity and the number of axles **[Gillespie et al., 1992]** & **[Hadiwardoyo et al., 2012]**.

In which the amount of damage caused by vehicles to a road structure is highly dependent on the magnitude of the axle loads, the number of load repetitions, load distribution, and their location on different axles. Axle loads have the greatest influence on fatigue and rutting damage of flexible pavements compared with the other vehicle factors such as tire type and inflation pressure. Since axle load has a significant impact on pavement structural design, axle loads should not exceed the allowable limits. According to AASHTO the most common legal axle limit was 18-kips this axle was used as a reference when measuring the damaging effects of different axle configurations with varying axle loads **[M. T. Keganne et al., 2000]**.

2.5.1.1 Illegal Axle Loads

Is one of the most important problems facing road networks. Overloading occurs when the load on at least one axle reaches the axle's maximum allowable load **[J. C. Pais et.al, 2013]**.

An overloaded axle decreases vehicle steering and increases decelerating or braking time, posing a significant risk to the driver and other road users. One of the key causes of axle overloading is an improper arrangement of goods on the semi-trailer. To achieve optimum vehicle stability, the load should be mounted so that the vehicle's center of gravity is as low as possible and as close to the vehicle's centerline; the load should be distributed so that the weight is distributed evenly over the entire floor space **[D.T.L.R, 2002]**.

Every developed country faces the problem of overloading before its economic system evolves properly. Since the issue of overloading cannot be entirely removed, surveillance, legislation, and education are the only ways to keep it under control. Damages of excess loads lead to results including high costs of maintenance, accelerated vehicle wear, the spread of traffic accidents, and a shorter lifetime of the roadway **[Ying C. Chan, 2008]**.

2.5.1.2 Types of Axles for Heavy Vehicles

They are three types **[Sumati Saxena, 2014]**:

1) **Front axle** → Single axle with a single tire on each side.
2) **Rear axle** →
   - Single axle with a dual tire on each side.
   - Tandem axle with a dual tire on each side.
   - Triple axle with a dual tire on each side.

2.5.2 Tire Configuration

The heavily loaded traditional tire on steer axles is the most damaging tire configuration used on trucks. At their rated load capacity wide-base single tires than dual tires produce greater fatigue and rutting in the flexible pavement for the steer axle **[Hassan Salama et al., 2012]**. Axle Configurations that are considered in this study are 1- Single, 2- Tandem, and 3- Triple.

2.5.3 Axle Spacing

The close spacing of axles does not lead to pavement damage. Damage on flexible pavements is essentially unaffected by axle spacing up to the limits imposed by current tire diameters. As a consequence, the axle spacing is not a significant truck characteristic influencing pavement damage **[David Cebon et al., 1992]**.

2.5.4 Tire Pressure

The increased truck tire pressure has a significant impact on asphalt pavement and depends on the axle load. High tire pressure can cause a significant increase in EALFs at low to moderate axle loads. The difference of EALFs with tire pressure becomes negligible at high axle loads **[M.E. Abdel-Motaleb, 2007]**.

The most obvious effect of higher tire pressure would be a reduction in the tire-pavement contact area, which might lead to an increase in tire-pavement contact stress and greater damaging effects to the pavement. Contact pressure resulting from tire pressure is assumed to be uniformly distributed over the contact area.

Tire-pavement contact pressure is critical in the evolution of defects in flexible pavements; might cause more fatigue and rutting damage to thin pavements than to thick pavements **[S. Weissman, 1999]** & **[Feng Wang, 2005]**.

2.6 Effect of Axle Load Distribution on Pavement Layers

The heavy truck's wheels apply direct pressure on the contact area between the road surface and their tires, when the vehicle is moving, additional pressure is produced due to the slight unevenness in the road surface. Stresses occur and are distributed directly under the centerline of vehicle wheel load applied through the thickness of the road structure layers and the soil subgrade on a pyramidal shape, as shown in Figure (2-3) flexible pavement loading begins at the asphalt layer and continues down and outward through each layer until it reaches the subgrade support **[Keganne and Overby, 2000]** & **[Dana M. Dietz, 2018]**.

The stress at any depth is depending on total axle load, the number of axles, and tire configuration. The loads in a flexible pavement are transmitted through the tiling layers depending on the points of contact between the grains. The more the layers are compacted, the greater their ability to distribute the stresses over a larger horizontal area, and thus the stresses decrease according to the depth. As the asphalt layer thickness increases, the impact of vehicle loads on it decreases with speed increases. Since it carries the most stresses, as well as climate changes, the surface layer is the strongest. As a result, we use quality materials to ensure comfort for the roadway user by giving him a flat surface free of cracks. The effect of axle loads results in stresses and strains, horizontal tensile stress in the asphalt layer from the bottom, and when loads increase or repeat, fatigue cracks, rutting or deep depression appear as symptoms **[Muhammad A. al-Karim et al., 2015].**

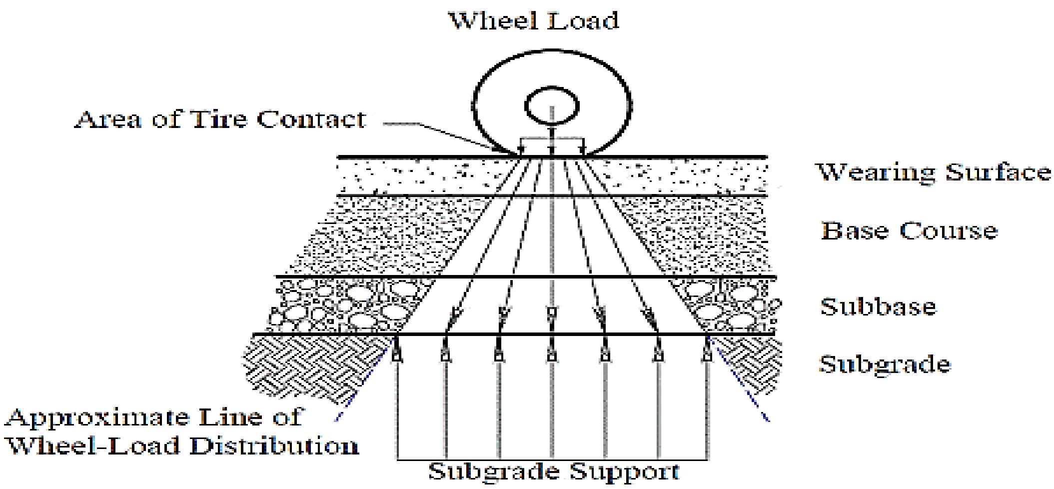

Figure (2-3): The Distribution of Loads According to Layer Thickness. **[Dana M. Dietz, 2018]**.

At the top of the subgrade, a vertical compressive strain is generated and increases in a linear function as the axle load is increased which leads to permanent deformation when overloaded **[Ahmed E. Behiry, 2012]**.

Figure (2-4) shows the more interesting pavement layers responses to evaluate axle load effects. Excessive stresses on the pavement can result in fatigue cracking and/or surface rutting. This may result in structural and functional failure posing a safety risk to drivers **[L. Walubita et al., 2000]** & **[R. Ashtiani, 2018]**.

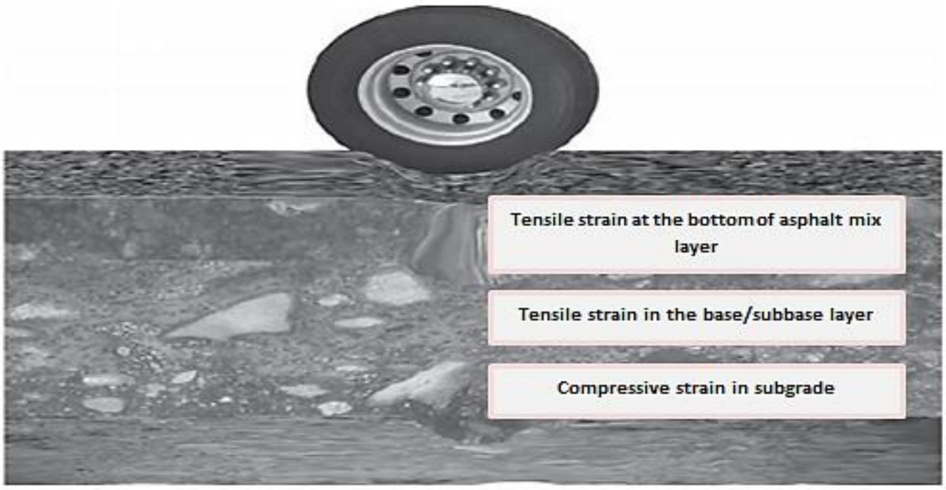

Figure (2-4): Main Responses of the Flexible Pavement Due to Axle Load Effect. **[Noor Moutaz, 2016]**.

The design of flexible pavement is usually dictated by axle load constraints and climatic variables. However, many trucks exceed these weight restrictions to reduce transportation costs. These overweighted trucks deteriorate the pavement, as well as the exhausting of road networks early and rapidly, thus shortening its life **[H.M.A. Salem, 2008]**.

2.7 Flexible Pavement Distresses

Road networks are exposed to many defects due to high stress on the pavement and for other different reasons that reduce their efficiency. These defects vary in their types from one roadway to another, grow in size, and develop under the combined effects of traffic loads and environmental conditions with an increase in the road lifetime. The defects cause a lot of problems for road users such as discomfort and the road will not be safe, the condition of the road may reach bad stages leading to its collapse if there is no follow-up and periodic maintenance. The flexible pavement defects and their causes are defined in terms of decrease in serviceability which was caused by consistence of cracks, ruts, potholes, etc. The flexible pavement deterioration subject is considered to be complicated as several factors participate in its failure and deterioration **[K. H. Hassan, 2013]** & **[N. G. Sorum et al., 2014]**.

There are four major common types of deterioration in flexible pavement **[Shamil A. Al-Arkawazi, 2017]**:

- Cracking
- Surface deformation
- Disintegration
- Surface defects

Minor distresses will be prevented from developing into pavement failure if pavement defects are detected and repaired early. In all pavement maintenance cases, it is best to determine the cause of the defect, it allows the pavement maintenance personnel to determine what type of remedial action is necessary and prevention of recurrence **[Patrick G. Lavin, 2003]**.

2.7.1 Causes of Distresses

The main causes of asphalt pavement distresses are shown as follows **[Patrick G. Lavin, 2003]**, **[Hassan H. Johnny, 2010]**, & **[Sharad & Gupta, 2015]**:

1) Structural Factors

- Excessive axle load.
- The number of axle loads repetitions.

2) Environmental Factors

- Weathering.
- Volume change of soil due to increasing and decreasing of moisture or poor drainage system.
- Aging.
- Temperature varieties.

3) Operational Factors

- Poor asphalt mixing design or the use of asphalt mixtures with conditions and properties not conforming to the Iraqi or other global specifications.
- Subgrade weakness.
- Use dirty aggregate, the disintegration of the paving materials.
- Inefficiency structural design.

4) Lack of maintenance.

2.8 Aging of Asphalt Pavement

Asphalt aging is a complex phenomenon that impacts the effectiveness of asphalt pavements. It is commonly defined as a change in the rheological properties of asphalt binders mixtures as a result of chemical composition changes during construction and service life, it happens during the production of asphalt mixes and when exposed to the immediate environment while in service **[Okan Sirin et al., 2018]**.

Aging causes the asphalt to harden and become brittle as well as a decrease in its ability to relax stress, Under loading, aged asphalt will maintain stress for a longer time, and that stress will be greater than in unaged asphalt. Aging can eventually cause cracking and failure of the asphalt pavement due to a combination of thermal and traffic-induced stresses and other types of deformations that require expensive repairs, and eventually replacement. This process can be documented over time as the color of the pavement gradually changes. The color of the new asphalt pavement is dark black. As a result of oxidation, asphalt becomes a lighter shade of black, eventually transforming into a black-grey hue **[Samer Muayad and Saad Sarsam, 2014], [Golalipour et al., 2018] & [P.L.S, 2019]**.

2.9 Road Condition Assessment Methods

The methods used to assess the pavement condition for proper maintenance are as follows **[Jasim A. Alwan, 2013]**:

1. Deflection Method
2. Pavement Unevenness Index (PUI)
3. Paver Method
4. Present Serviceability Rating (PSR) Method
5. Pavement Roughness Measure Device
6. Falling Weight Deflecto meter

The paver method has recently been considered an accurate and objective method for assessing the condition of road pavement. So this method was used in this study.

2.9.1 Pavement Condition Index

PCI is one of the foremost wide utilized pavements measurements for performance with a rating system to state the actual pavement conditions with reliable and objective data. The PCI method was developed in the United States by the U.S Corps of Engineers because this method obtained accurate data and estimated conditions according to conditions in the field. This procedure is employed worldwide to supply the activity of the pavement condition, taking into consideration the useful performance with implications of structural performance. The PCI level is written on a scale of (0-100) **[F.M.A. Karim et al., 2016]** & **[Ibnu Sholichin and Nugroho Utomo, 2018]**.

2.9.2 Micro PAVER Software

PAVER inventory management stands on a hierarchical structure of networks, branches, and sections, with the section acting as the lowest managed unit. This form makes it simple for users to organize their inventory while also giving a lot of fields and levels for storing pavement data. It is a decision-making tool for developing effective maintenance and repair solutions for highways, streets, parking lots, and airports. PAVER offers a wide range of useful skills **[Mohammed A. Al-Neami et al., 2017; U.S Army Corps of Engineers, 2011; Norlela, et al., 2009]**.

2.10 Flexible Pavement Thickness Design

The AASHTO 1993 method can be considered the most widespread method in the world because of its dependence on the results of the widest program of roads tests and the continuous development of this method in addition to the introduction of new concepts to evaluate the performance effectiveness such as the concept of serviceability effectiveness and the concept of reliability so that it offers several solutions which allows good economic study for paving layers.

Steps for designing flexible pavement layers according to AASHTO:

1. Determining the Effective Soil Resilient Modulus (M_R).

2. Selecting Serviceability Index Change (ΔPSI).

3. Determining the Reliability Level (R-value) and Overall Standard Deviation (S_o).

4. Determining the Total Cumulative Equivalent Single Axle Load (ESAL).

5. Using the previous four values, the Structural Number (SN) is determined.

6. Calculating the pavement layer thickness by using the resulting SN.

The AASHTO method is used to estimate the required structural number. This is the strength of the pavement that must be designed to handle mixed vehicle loads over the roadbed soil while being serviceable during the design period. Knowing the SN the pavement layer thickness can be calculated **[AASHTO, 1993]** & **[F.D.O.T, 2018]**.

2.10.1 Equivalent Single Axle Load (ESAL)

The types of traffic loads that are applied to the pavement surface range from light passenger cars to heavy trucks. Heavy traffic loads are more detrimental to the pavement than moderate traffic loads. Furthermore, as the number of repetitions of the same load increases, so does the effect on the pavement **[Michael S. Mamlouk, 2006]**.

The traffic loads that are applied to the pavement system are normally a different mix of axle loads and configurations, each with its specific damage impact. For pavement design purposes, these mixed axles can be equated to a preferred reference single-axle load. As well as substitute traffic loads with a simple loading system that can be used in pavement design. In several design procedures, a standard load is chosen for the design. The standard load is an 18,000 Ib (18 kips) single axle with dual wheels on each side **[Kawa I et al., 1998]** & **[SCRB, 2005]**. ESAL Definition: "One ESAL reflects the loading that causes an amount of damage to the pavement structure equivalent to one pass of a single 18,000-pound, dual-tire axle with all four tires inflated to 110 psi". The total number of ESAL values for that truck's axles and axle groups is the load factor or complete ESAL value. Each truck category's load factor is calculated by averaging the total ESAL values for all trucks in that category. The primary goal of the AASHTO road test was to notice a relationship between the number of axle load repetitions and the performance of the flexible pavement **[Ashraf A. Aguib, 2013]** & **[A.F.P.D.M, 2020]**.

Equivalent Axle Load Factors (EALF) were introduced by the AASHTO guide 1993 to relate the damage caused by various load magnitudes and axle configurations to the regular axle load. In pavement design determining load equivalency factors (LEFs) is crucial. A poor assessment of the damage caused by axle loads on pavements will result in costly early failure. Overestimating equal single axle loads (ESALs) would result in wasteful spending on over-designed pavements, diverting funds away from other projects **[AASHTO, 1993]** & **[R Hudson et al., 1998]**.

2.10.2 Load Equivalency Factor (LEF) Definition

Load equivalency is defined as the ratio of repetitions assigned to a certain level of serviceability caused by one 18-kip (80-kN) axle load to repetitions assigned to the same level of serviceability produced by another axle load **[Herbert F. Southgate, 1993].** Equation (2.1) is used to determine AASHTO LEFs **[Kawa I et al., 1998]**:

$$LEF_{WC} = N_{18S} \setminus N_{WC} \qquad (2.1)$$

Where:

LEFwc = load equivalency factor of an axle of weight "w" and configuration "c".

N_{18s} = the number of repetitions of an 18 kips single-axle load.

N_{wc} = the number of repetitions of an axle of weight "w" and configuration "c".

In flexible pavement, the LEF for a given axle is a complex function of many variables. Based on the type of trucks and according to SCRB, the limitations of AASHTO 18-kip Load Equivalency Factors including **[Zhang Z et al., 1998]**:

- Axle load.
- Axle configuration (single, tandem, triple).
- Structural Number SN.
- Terminal serviceability level P_t.

2.10.3 ESAL Calculation

To convert mixed axle loads to ESALs, the LEF for each configuration and weight category is employed. The ESALs generated by axles of each axle arrangement in each weight category are then added together to produce a cumulative ESAL for use in pavement layers design, as shown in the equation (2.2) **[AASHTO, 1993]**:

$$W_{18} = D_D \times D_L \times \hat{W}_{18} \qquad (2.2)$$

Where:

$\hat{W}_{18}$ = the total two-way 18 kips ESAL for a particular roadway segment over the analysis period.

D_D = a directional distribution factor, 0.5 typically.

D_L = a lane distribution factor, its value is determined by the number of lanes in each direction, as shown in Table (2-1).

Table (2-1): Suggested Percent of D_L for Various No. of Lanes in Design Lane. **[AASHTO, 1993]**.

Number of Lanes in Each Direction	Percent of 18-kip ESAL in Design Lane
1	100
2	80-100
3	60-80
4	50-75

2.11 Traffic Maintenance Management

Road maintenance is an important and integral part of the overall road system. Even if the roads are adequately designed and built, they may need to be maintained. Road maintenance is essential to keep the road in its original condition, safeguard surrounding resources and user safety, and ensure efficient and convenient travel along the route. Unfortunately maintenance is frequently neglected or conducted incorrectly, resulting in rapid deterioration of the road and eventual breakdown due to both climatic and vehicle use effects. As a result it is impossible to construct and use a road that does not require maintenance. Maintenance does not include reconstruction and rehabilitation activities. Rather, it is the process of repairing the defects that appear on the roadway surface and its other facilities **[Alaa M. Koya et al., 2017]**.

The objectives of road maintenance **[Ian Van Wijk, 2006]**:

- The repair of functional pavement defects.
- The extension of the functional and structural life of the pavement.
- The maintenance of roadway protection and signs.
- The preservation of the road reserve.

Experts have suggested several methods to indicate maintenance type:

- AASHTO method.
- PAVER.
- California method.
- Modified method.

Maintenance expenses can be reduced through proper planning, design, construction, and monitoring. If the causes of potential problems are removed and carefully taken care of when designing, such as (the drainage system or the prevention of overloading), the maintenance costs during service are reduced. It is advisable to implement maintenance measures in the early stages to avoid road distresses because the rate of deterioration increases with time **[A. Das and P. Chakroborty, 2012]**. Figure (2-5) shows the behavior of the Pavement under traffic during its life using Present Serviceability Index.

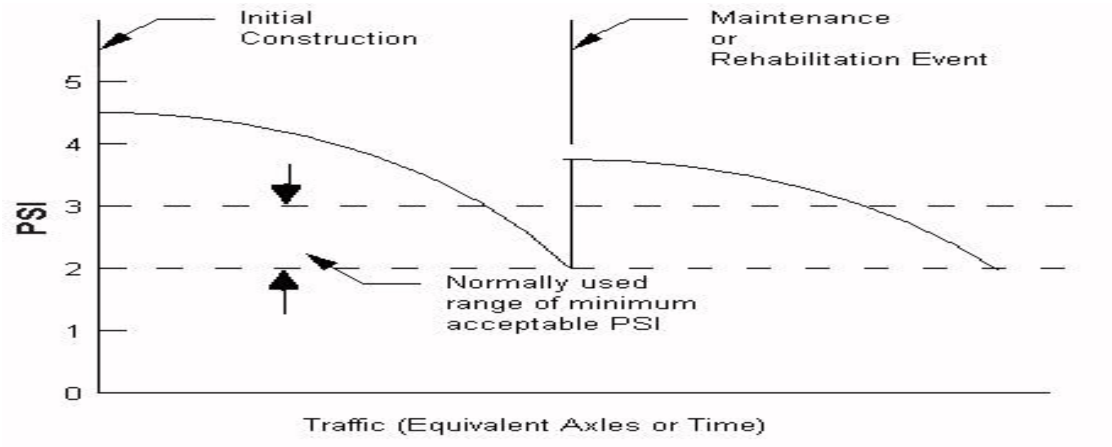

Figure (2-5): Concept of pavement performance using Present Serviceability Index (PSI).

There are three types of visual road maintenance **[H. Khaing & T. Htwe, 2014]** & **[Shakti Singh and Devander Kumar, 2021]**:

- **Remedial / Routine Maintenance**: any type of roadway needs routine maintenance. Repairs are performed regularly, such as day to day and seasonally, including patching, repairing potholes, maintaining cross slopes and shoulders, and maintaining drainage works such as side drains, culverts, road signs, etc.

- **Emergency / Urgent Maintenance**: included earth slips, overturned trees, and other emergency repairs.
- **Preventative / Periodic Maintenance**: include the replacement of the pavement's wearing path.

2.12 Previous Studies

Hassan Salama et al. (2012) the effect of roadway structure and traffic characteristics on flexible pavement damage is investigated in this report. Field surveys were carried out on 115 pavement sections that have variations in traffic characteristics and pavement conditions with unique geometric features. To assess the condition of the pavement, PCI was used.

The study concluded:

- The higher the traffic volume and repetition of ESALs of heavy traffic, the higher the rate of deterioration; thus lower PCI.
- The PCI rises in direct proportion to traffic speed. Reduced speeds at special geometric sections increase the pavement response, resulting in rapid pavement deterioration.
- Pavement with poor structural integrity deteriorates more quickly, and vice versa. The PCI increases as the structural number increases, in other words.
- Pavement deteriorates over time, resulting in a decline in PCI.

J. C. Pais et al. (2013) in this study, the effect of all vehicles on pavement performance was calculated to examine the effects of excessive loads. The effect of vehicle types with different axle loads and axle configurations was expressed by converting all vehicles to a representative vehicle, which is referred to as the standard axle in pavement design 18-kip (ESAL). The study concluded that:

- The effect of heavy vehicle loads is reduced by increasing the thickness of the asphalt pavement layer.

- If vehicles are assumed to be at their full legal weights for consideration in pavement design, the impact of overloaded vehicles on pavement performance is reduced.
- The presence of overloaded vehicles will increase pavement costs by more than 100% as compared to the same vehicles with legal loads.

Khawla. H. Hassan (2013) this study concluded that the construction of roads without adopting engineering design accelerates the appearance of defects, which was evidenced from the analysis of the pavement layers. There is an urgent need to develop a work structure to inspect, evaluate roads, and document maintenance work. The absence of an Iraqi standard specification for maintenance work created a gap between the measures to be taken to improve the level of service for the roads and what is done.

Bharath Boyapati and R. Prasanna Kumar (2015) the main objective of this study is to determine the Pavement Condition Index by collecting and analyzing field data. Traffic, pavement, climatic and environmental conditions will all cause pavement damage and deterioration; these factors contribute to surface distress and the development of shear in the subgrade, subbase, or surface. The PCI is determined by the type, severity, quantity, and density of the distress. The severity levels of all distress are classified. PCI is intended to provide a basis for identifying pavement maintenance and rehabilitation needs and priorities based on the PCI results for the selected study section.

Magdi M. E. Zumrawi (2015) this article will visually inspect and assess flexible pavement failures for maintenance planning. It's important to evaluate and identify the causes of the failed pavement to choose the best treatment method. Systematic recommendations for evaluating damaged pavement are proposed based on literature reviews to provide helpful information for maintenance operations. This study had two tasks: the first was to conduct a visual investigation of existing pavement distresses, and the second was to determine the causes of these failures. Obeid Khatam Road in Khartoum was chosen for investigation as a case study. The existing pavement condition of this roadway was subjected to extensive fieldwork. The majority of the damaged pavement sections were found to have serious cracking and rutting failures. These failures could have been caused by fatigue failure on the pavement structure as a result of the movement of heavily loaded truck trailers. Poor drainage, insufficient design, and the use of inappropriate pavement materials could also be attributed to the damage.

The method developed in this paper for the investigation of pavement failures has been tested in Obeid Khatam road pavement failures to evaluate the effectiveness of the method for real use. He found that the method was good as a general guide, especially for novice highway engineers. However, the engineer's experience is also an important factor in correctly diagnosing the causes of pavement failure and determining the best maintenance option.

Surajo A. Wada (2016) this study found some basic requirements of a flexible pavement; it should be structurally sound enough to resist the pressure imposed on it. The thickness of the pavement should be sufficient to distribute the stresses and axle loads to a safe value on the subgrade soil. As well as the pavement should have a long life and the cost of maintaining it annually should be low.

2.13 Summary

The Previous literature on the subject was discussed in this chapter. It described a flexible pavement structure, traffic characteristics that affect the flexible pavement damage, the most important of which is the effect of axle loads and their distribution pattern on the asphalt layers, pavement defects, their causes, and strategies required for the treatment of specific defects were also assessed. Also reviewed the basic requirements of a flexible pavement design according to AASHTO 1993 method. The research methodology which is the next chapter, adopted some of the appropriate methods used in the reviewed literature.

CHAPTER THREE

METHODOLOGY and DATA COLLECTION

CHAPTER THREE

METHODOLOGY AND DATA COLLECTION

3.1 Introduction

This chapter describes the research methodology to analyze the flexible pavement, as well as determine the effect of traffic characteristics on pavement responses and its design life. It presents a description of the study area in terms of traffic, and geometric characteristics; the methods utilized to collect data then evaluate the road sections for the study area by adopting the HCS 2010 software to determine the current LOS. And collect all other data needed to identify PCI using Micro PAVER software after dividing the network into manageable units, to find out the causes of the distresses of the study area.

3.2 Overview of the Hilla City

Hilla is a historic Iraqi city and the center of Babylon's Governorate. It is located between the cities of Baghdad and Najaf, about 100 km from Baghdad and about 60 km from Najaf. Hilla city is an economic, religious, and tourist destination because it contains many archaeological and religious sites. Figure (3-1) shows the city of Hilla master plan, illustrating the sections selected for study on it. Transportation is one of the factors that increase the link and interaction between places, as any city depends on the conduct of its residents' lives on the transportation systems in it. The transportation system in the city of Hilla deteriorated in the last stages due to the great urban growth witnessed by the city, the increase in the percentage of population and vehicles, which led to significant changes in functional uses and their distribution over the city area. And the consequent difficulties due to congestion and the large disparity in the distribution of vehicles on the city streets.

3.3 Traffic Data Definitions

Average Daily Traffic (ADT): ″The total volume in whole days more than one day, but less than one year, divided by the number of days in that period, expressed in vpd (vehicles per day)″.

Design Hourly Volume (DHV): It is the hourly volume that exceeded by 29 hr, HV used in the roadway design. As well, it is an hourly volume that occurs during traffic peaks. The DHV is normally expressed as a percent (K) of the ADT, as shown in equation (3.1) **[SCRB, 2005]**:

$$DHV = K * ADT \qquad (3.1)$$

K = Percentage of DVH against ADT varies from (0.10 to 0.17) for two-way traffic volume, and from (0.07 to 0.18) for one-way traffic volume.

Directional Distribution (D_D): D_D indicates the percentage of traffic volumes per direction.

Percentage of Trucks (P_T): P_T is the percentage of trucks within peak hour traffic.

Peak Hour Volume (PHV): Number of vehicles that pass a point on a highway during peak period intervals (Veh/hr).

3.4 Study Area Description

The study area was chosen in Hilla city and includes two sections:

3.4.1 (Hilla – Najaf) Roadway Section

A major roadway of economic, social, and tourist importance, leads to the holy shrines in both Babylon and Najaf provinces; contains many universities, notably Babylon University, Al-mostaqbel university, and many schools, making traffic volumes diverse and dense during working days.

The study was conducted on a section of the roadway 1.95 km length (starting from a Nader bridge) because it contains many failures determined during field surveys. Figure (3-2) shows the location of this study section on the master plan of Hilla city.

Hilla-Najaf is a multilane two direction section, with 5 lanes in each direction of 3.65 m wide per lane, divided by a median of 6.0 m wide. The one-direction width of the section is 18.25 m and is characterized by sidewalks in both directions with a width of 3.0 m for each direction. All the dimensions and geometric characteristics of the Hilla-Najaf roadway section are listed in Table (3-1).

Figure (3-3) shows the typical cross-section of the Hilla-Najaf roadway where the dimensions of the section appeared more clearly, the current implemented pavement layers of three layers: binder coarse, base coarse, and Subbase with a thickness of (6,10, and 25) cm respectively, as well as the implemented sidewalk layers are interlocked brick, clean sand, and subbase layer with a thickness of (8, 5-10, 15) cm respectively (Hilla Municipality).

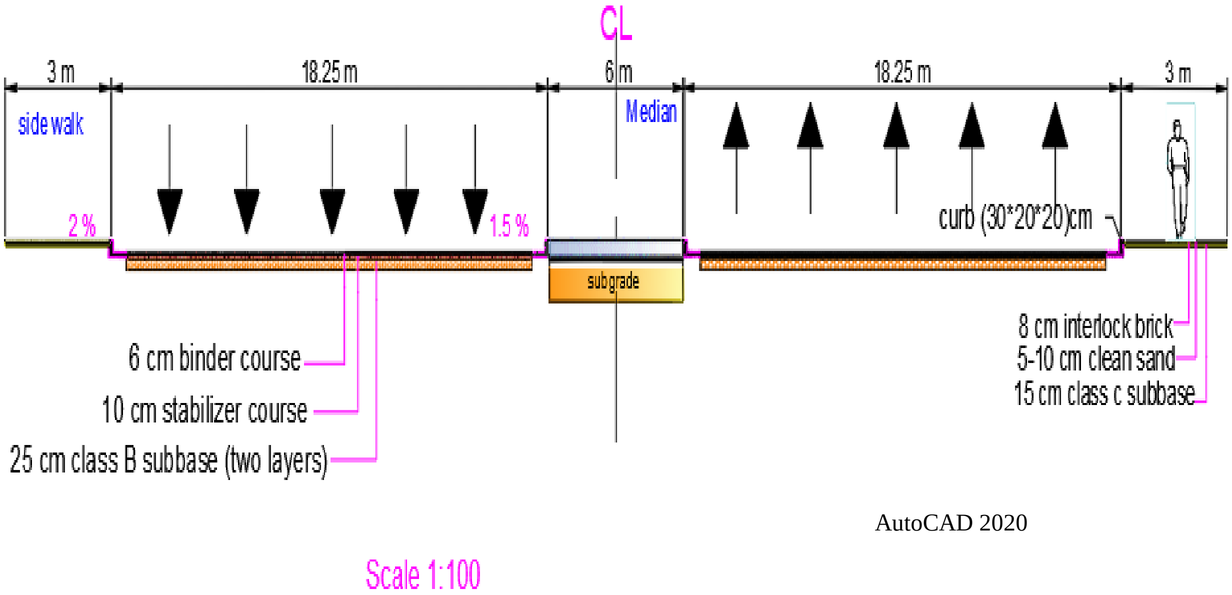

Figure (3-3): Typical Cross-Section in Hilla-Najaf Roadway within the Study Area.

Table (3-1): Geometric Design Characteristics of the Hilla-Najaf Roadway Section.

Design Elements	Characteristics
Classification	Multilane
Service Type	Principal Arterial
Road Type	Divided by Median
Movement Direction	Two Direction
The Number of Lanes / Direction	5
Lane Width	3.65 m
Median Width	6 m
Road Width / Direction	18.25 m
Sidewalk Width / Direction	3 m
Total Width	60 m

3.4.1.1 Data Collection

The collection of field data was carried out through an extensive traffic study preceded by a preliminary study that included the type of traffic used for the roadway, the traffic factors affecting it, failure areas, as well as the condition of the roadway. The traffic study adopted the video camera technique with analysis of Photography clips of this study section cameras using manual count method in calculating traffic volumes; the focus is on collecting data during working days according to the AASHTO guide and based on a.m and p.m peak hour. The study classified the traffic volumes according to the State Commission of Road and Bridge **(SCRB, 2005)**, then represent traffic and geometric data using Tables and Figures aided of Microsoft Excel 2019. The roadway condition was surveyed for a week and of the period from (11/11/2020 to 26/3/2021) including all other administrative and technical matters for the requirements of the study. The environmental conditions were taken into consideration.

Tables (3-2), (3-3), and (3-4) show the traffic volumes variations of different types of vehicles used for the roadway section during the data collection period in working days (Monday 18/1/21, Tuesday 19/1/21, and Wednesday 20/1/21) based on the traffic peak hours (7:30 A.M – 3:30 P.M).

Figures (3-4), (3-5), and (3-6) show the traffic volumes variations during working days of different types of vehicles used for the Hilla-Najaf roadway section over time using a chart with aided of (Microsoft Excel 2019) through which it is possible to easily determine the total traffic volume for each hour quarter and to know the peak hour quarter for this section.

Table (3-2): Traffic Volumes Data Collection for the Hilla-Najaf Roadway Section on (18/1/21).

Time	PC	Bus	Heavy Vehicles							
			Type 2	Type 3	Type 2-S2	Type 3-S3	Type 3-S2	Type 3-3	Type 3-S1-2	Type 2-3
7:30 - 7:45	881	4	138	12	3	6				
7:45 - 8:00	1102	5	172	10		9	1			
8:00 - 8:15	1224	14	189	21	6	11		2	2	
8:15 - 8:30	1192	9	177	17	4	5				3
8:30 - 8:45	1143	6	166	13	1	3		1		
8:45 - 9:00	1105	4	154	7		3	2			
9:00 - 9:15	997	3	183	11	2					1
9:15 - 9:30	989	10	106	8		7			1	
9:30 - 9:45	991	2	199	6	1	5				2
9:45 - 10:00	965	3	182	7	2	6		1		
10:00 - 10:15	937	2	211	4		9	2		1	
10:15 - 10:30	926	4	141	11		12	4			
10:30 - 10:45	893	2	169	9	1	4				3
10:45 - 11:00	882	3	124	8		6			1	
11:00 -11:15	871	5	112	5	4	10		1		1
11:15 - 11:30	867	3	105	7	2	8			2	
11:30 - 11:45	855	6	96	4	1	12				3
11:45 - 12:00	891	5	67	9		4	2			
12:00 - 12:15	838	7	93	8	3	6		1	1	
12:15 - 12:30	887	6	103	9	1	10	1			2
12:30- 12:45	878	8	89	7		4				1

12:45 - 1:00	913	9	78	11	2	1		1		2
1:00 - 1:15	940	12	91	8		7			2	
1:15 - 1:30	966	10	104	5	1	9	1			
1:30 - 1:45	1132	11	113	10	8	12	2			3
1:45 - 2:00	1039	7	119	11	2	8				1
2:00 - 2:15	1106	11	102	9	3	13	1		2	2
2:15 -2:30	1158	8	146	16	12	11	1		1	1
2:30 -2:45	1026	8	122	14		4			1	
2:45 -3:00	1101	7	106	10		15	1		2	
3:00 - 3:15	1056	3	112	17	1	3		1		2
3:15 - 3:30	981	6	96	20	2	9	1			

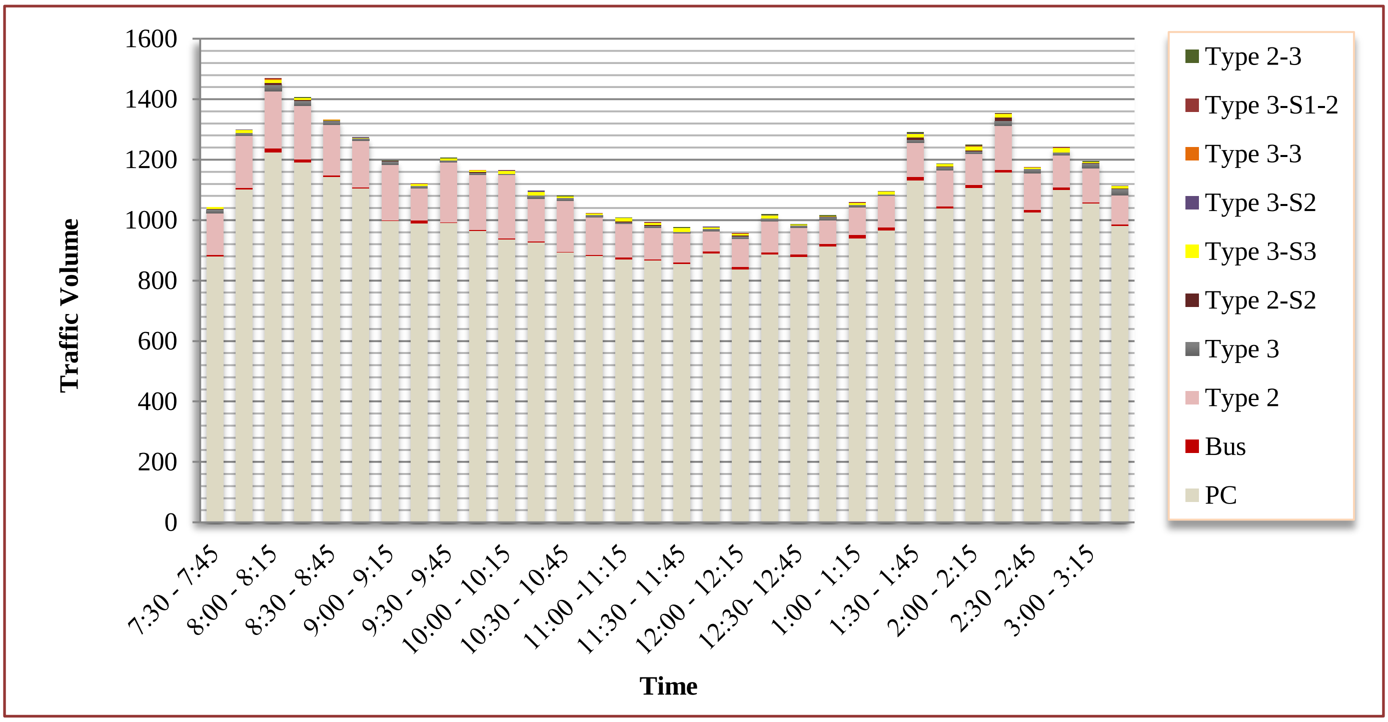

Figure (3-4): Variations of the Traffic Volume in the Hilla-Najaf Roadway Section on (18/1/21).

Table (3-3): Traffic Volumes Data Collection for the Hilla-Najaf Roadway Section on (19/1/21).

Time	PC	Bus	Heavy Vehicles							
			Type 2	Type 3	Type 2-S2	Type 3-S3	Type 3-S2	Type 3-3	Type 3-S1-2	Type 2-3
7:30 - 7:45	812	3	103	8	1	4				2
7:45 - 8:00	1013	5	142	6	2	7	1		1	
8:00 - 8:15	1107	9	176	12	4	18		1		1
8:15 - 8:30	1126	15	216	16	9	13	3		2	2
8:30 - 8:45	1061	9	197	12	3	8	1			2
8:45 - 9:00	997	6	175	8	3	7	2		1	
9:00 - 9:15	1074	5	161	10		6			2	3
9:15 - 9:30	983	7	203	9	8		2			
9:30 - 9:45	949	4	198	6	3	11	1		1	
9:45 - 10:00	903	5	172	8	1	9	1		2	
10:00 - 10:15	911	3	147	11	2		2		1	
10:15 - 10:30	877	4	125	7	2	13				4
10:30 - 10:45	819		113	6		8		1	1	
10:45 - 11:00	691	3	98	2	4	10	1		1	
11:00 -11:15	652	4	87	8	3	13				3
11:15 - 11:30	587	2	74	4	8		2			1
11:30 - 11:45	566	5	69	7	10	7	3		1	
11:45 - 12:00	607	3	81	6	5	10		2		
12:00 - 12:15	641	1	76	3	7	4	1			2
12:15 - 12:30	713	6	103	11	2	8	2			

12:30- 12:45	734	4	114	9		7		2		1
12:45 - 1:00	693	6	108	7		6	1			3
1:00 - 1:15	997	7	99	6	5	13	2	1		
1:15 - 1:30	1094	8	106	13	5	9		2	1	1
1:30 - 1:45	1203	9	141	11	9	7		2		
1:45 - 2:00	1015	12	127	7	3	8			1	2
2:00 - 2:15	1003	7	104	8	6	5			1	1
2:15 -2:30	1071	9	98	3	4		3		1	2
2:30 -2:45	1014	11	79	9	6			1	1	3
2:45 -3:00	982	6	88	12	2	13	1			
3:00 - 3:15	924	4	95	8		2	1		2	2
3:15 - 3:30	867	9	71	10	1	7	3		1	

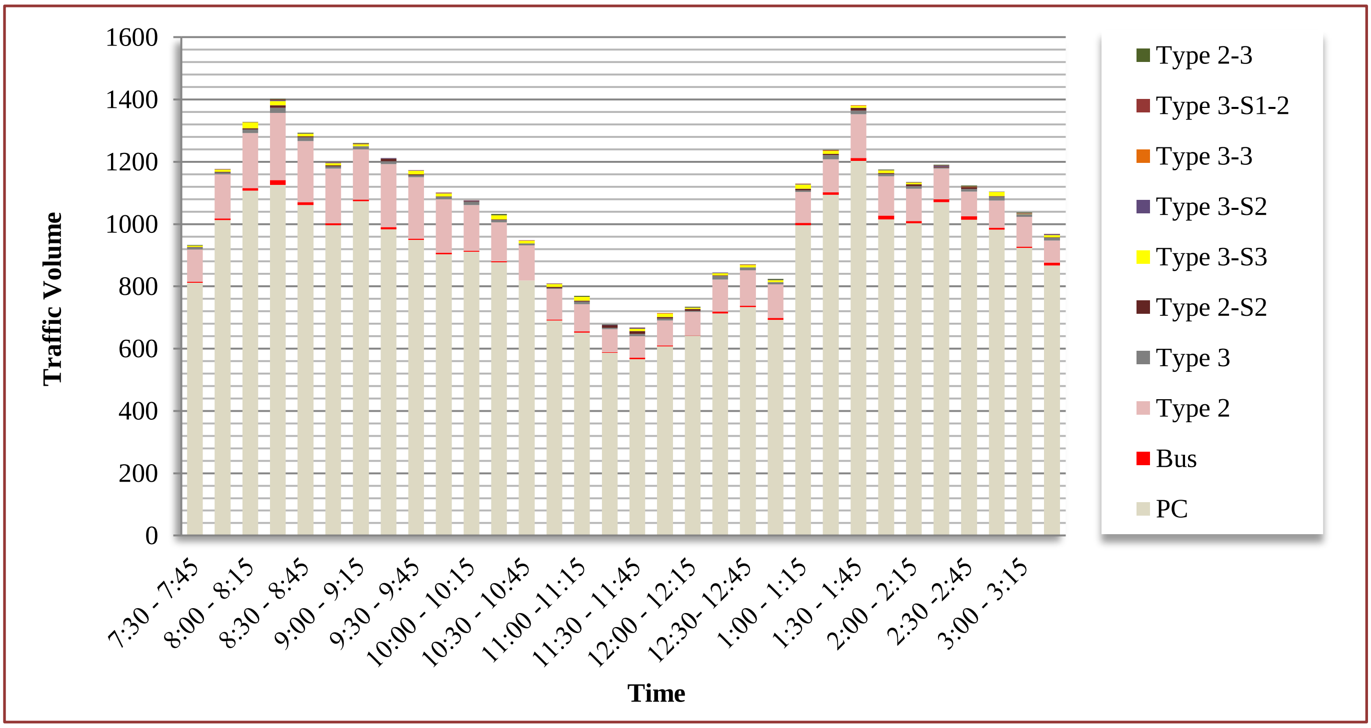

Figure (3-5): Variations of the Traffic Volume in the Hilla-Najaf Roadway Section on (19/1/21).

Table (3-4): Traffic Volumes Data Collection for the Hilla-Najaf Roadway Section on (20/1/21).

Time	PC	Bus	Heavy Vehicles							
			Type 2	Type 3	Type 2-S2	Type 3-S3	Type 3-S2	Type 3-3	Type 3-S1-2	Type 2-3
7:30 - 7:45	719	3	76	10	2	4	1			
7:45 - 8:00	865	6	68	7	1	8			1	
8:00 - 8:15	1034	12	97	26	6	12		1		2
8:15 - 8:30	1126	16	185	17	9	14	2		1	1
8:30 - 8:45	1002	13	166	9	4	10	1	1		
8:45 - 9:00	998	9	134	8	3	7	2			2
9:00 - 9:15	981	5	111	14	5	11		1		
9:15 - 9:30	943	10	98	8		9	3		2	
9:30 - 9:45	952	3	80	6	2		4	2		1
9:45 - 10:00	937	2	56	7	3	8		1	1	
10:00 - 10:15	817	1	45	2		7	2		1	
10:15 - 10:30	798	6	70	11	6	8	4			
10:30 - 10:45	786		86	9	1	4	1		2	3
10:45 - 11:00	801	2	99	2		11	2		1	
11:00 -11:15	776	4	82	5	4	9		1		2
11:15 - 11:30	749	3	98	1	5	7			5	3
11:30 - 11:45	697	5	102	4	1	4			2	3
11:45 - 12:00	715	2	73	2		8	4			1
12:00 - 12:15	758	4	88	9	6			2	2	
12:15 - 12:30	908	1	113	3	2	4	3		2	
12:30- 12:45	810	9	59	7	1	9		2		1

12:45 - 1:00	879	7	69	6	2	3	3	1		2
1:00 - 1:15	944	6	86	11		9	2		2	1
1:15 - 1:30	1099	8	110	9	5	8		2		1
1:30 - 1:45	1164	7	131	14	9	12	2		2	4
1:45 - 2:00	1105	5	116	11		8	3	1	1	
2:00 - 2:15	1120	9	124	6	3	11			2	3
2:15 -2:30	1003	11	28	17	7	13	5	2	2	1
2:30 -2:45	994	7	49	10	4		4		2	3
2:45 -3:00	981		60	9		9		1	3	4
3:00 - 3:15	900		54	4	1	3	2	1		
3:15 - 3:30	867	2	33	6	3	7	1			2

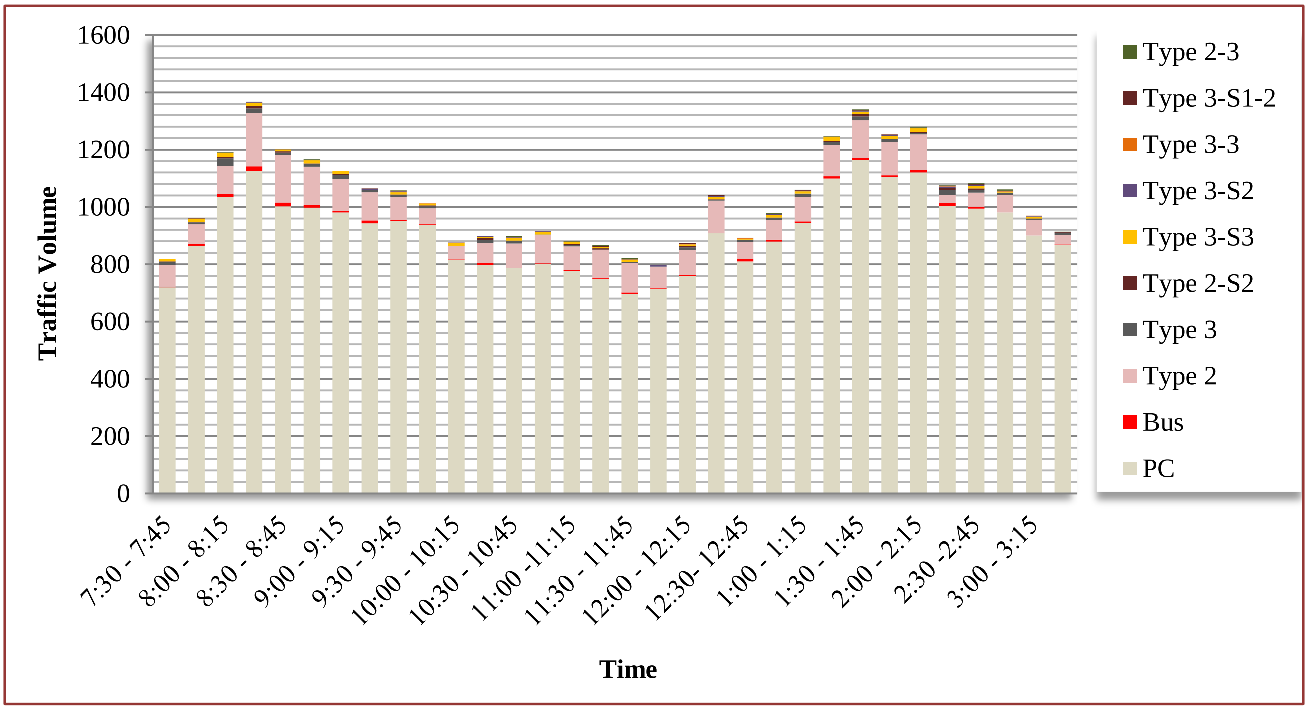

Figure (3-6): Variations of the Traffic Volume in the Hilla-Najaf Roadway Section on (20/1/21).

The traffic volumes for study sections in another direction are shown in Appendix A.

Tables (3-5), (3-6), and (3-7) show the a.m and p.m peak hour volumes during working days for the Hilla-Najaf roadway section. The ADT was adopted based on vehicles classification according to (SCRB, 2005), by using equation 3.1 (K = 0.15). Also, the percentage of heavy trucks P_T was calculated.

Table (3-5): Calculation of ADT According to Vehicle Classification for the Hilla-Najaf Roadway Section on (18/1/21).

Day/ Monday Date 18/1/21											
peak hour / 7:45 - 8:45 A.M											
	PC	Bus	Type 2	Type 3	Type 2-S2	Type 3-S3	Type 3-S2	Type 3-3	Type 3-S1-2	Type 2-3	**Total**
HV	4661	34	704	61	11	28	1	3	3	3	5509
K	0.15										
ADT= $\frac{HV}{K}$	31073	227	4693	407	73	187	7	20	20	20	
P_T	15 %										
peak hour / 1:30 - 2:30 P.M											
	PC	Bus	Type 2	Type 3	Type 2-S2	Type 3-S3	Type 3-S2	Type 3-3	Type 3-S1-2	Type 2-3	**Total**
HV	4435	37	480	46	25	44	4	–	3	7	5081
K	0.15										
ADT= $\frac{HV}{K}$	29567	247	3200	307	167	293	27	–	20	47	
P_T	12 %										

Table (3-6): Calculation of ADT According to Vehicle Classification for the Hilla-Najaf Roadway Section on (19/1/21).

Day/ Tuesday Date 19/1/21											
peak hour / 8:00 - 9:00 A.M											
	PC	Bus	Type 2	Type 3	Type 2-S2	Type 3-S3	Type 3-S2	Type 3-3	Type 3-S1-2	Type 2-3	**Total**
HV	4291	39	749	48	19	46	6	1	3	5	5207
ADT	28607	260	4993	320	127	307	40	7	20	33	
P_T	17 %										
peak hour / 1:15 - 2:15 P.M											
	PC	Bus	Type 2	Type 3	Type 2-S2	Type 3-S3	Type 3-S2	Type 3-3	Type 3-S1-2	Type 2-3	**Total**
HV	4315	36	478	39	23	29	–	4	3	4	4931
ADT	28767	240	3187	260	153	193	–	27	20	27	
P_T	12 %										

Table (3-7): Calculation of ADT According to Vehicle Classification for the Hilla-Najaf Roadway Section on (20/1/21).

Day/ Wednesday Date 20/1/21											
peak hour / 8:00 - 9:00 A.M											
	PC	Bus	Type 2	Type 3	Type 2-S2	Type 3-S3	Type 3-S2	Type 3-3	Type 3-S1-2	Type 2-3	**Total**
HV	4160	50	582	60	22	43	5	2	1	5	4930
ADT	27733	333	3880	400	147	287	–	13	7	33	
P_T	15 %										
peak hour / 1:15 - 2:15 P.M											
	PC	Bus	Type 2	Type 3	Type 2-S2	Type 3-S3	Type 3-S2	Type 3-3	Type 3-S1-2	Type 2-3	**Total**

HV	4488	29	481	40	17	39	5	3	5	8	5115
ADT	29920	193	3207	267	113	260	–	20	33	53	
P_T	12 %										

- From the previous Tables, we find that the highest traffic volume was on Monday (7:45 - 8:45 A.M), Direction/ (Hilla - Najaf) and equal to 5509.

3.4.2 Road no. (80) Section

A ring road in the city of Hilla that serves the main traffic paths in it, a multi-lane two-way with 3 lanes in each direction of 3.75 m wide per lane and divided by a median of 6.0 m width. The one direction width of the pavement is 11.25 m, shoulder width is 2.0 m for each direction. All the dimensions and geometric characteristics of the road 80 are listed in Table (3-8). The implemented roadway section consists of four layers (surface, binder, base, and subbase) with a thickness of (5, 5, 10, and 25) cm respectively (Hilla Municipality). The study was conducted on a section of the roadway 400 m length that begins from the intersection of road no. 80 with the Hilla-Najaf roadway, then towards it; due to the spread of failure areas along this section. Figure (3-7) shows the location of this study section on the master plan of Hilla City.

Figure (3-8) represents the cross section of this roadway within the study area and currently implemented design, in terms of the number of implemented pavement layers, their thickness, as well as the median and shoulders.

Table (3-8): Geometric Design Characteristics of the Road no. 80 Section.

Design Elements	Characteristics
Road Classification	Multilane
Service Type	Principal Arterial
Road Type	Divided by Median
Movement Direction	Two Direction
The Number of Lanes / Direction	3
Lane Width	3.75 m
Median Width	6 m
Road Width / Direction	11.25 m
Shoulder Width / Direction	2 m
Total Width	60 m
Section Length	400 m

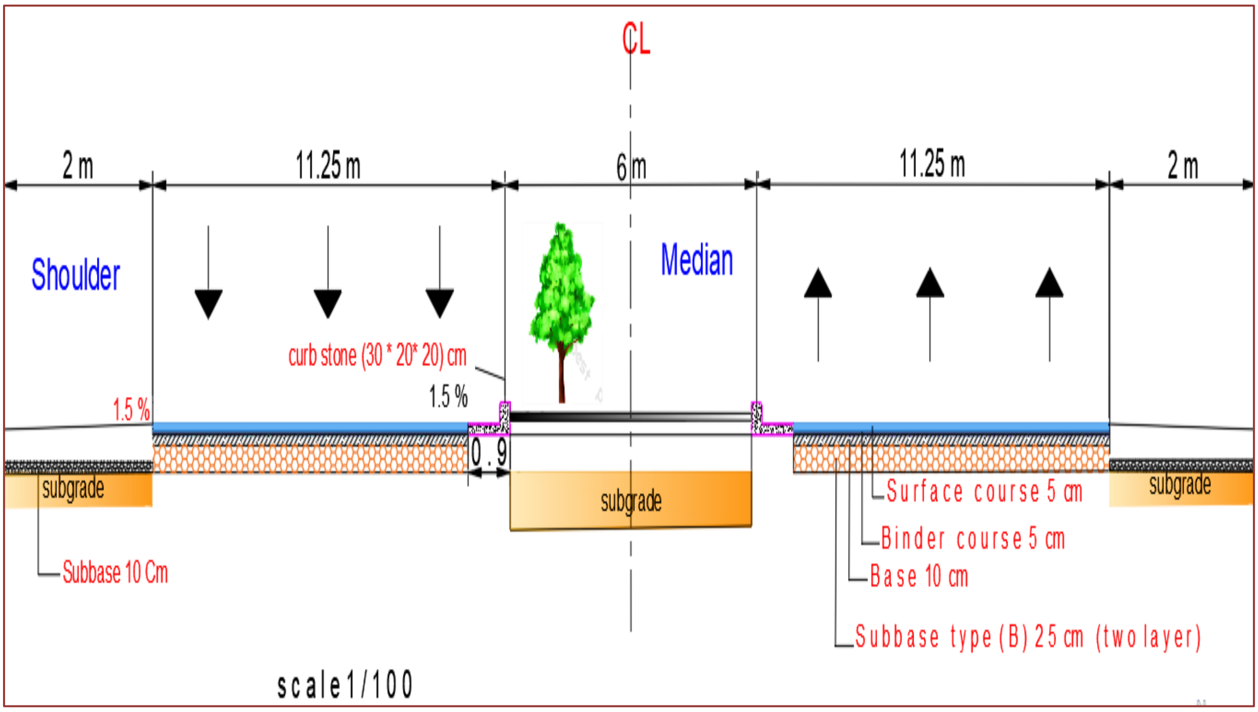

Figure (3-8): Typical Cross Section in the Road no. 80 Section within the Study Area.

3.4.2.1 Traffic Data Survey

A comprehensive traffic study was conducted to collect field data preceded by a preliminary study that examined the condition of the road, failure areas, the type of traffic used, and the affecting traffic factors. For calculating traffic volumes, the study used the video camera technique, film analysis of this study section cameras by using manual count method; the emphasis is on collecting data during working days according to the AASHTO guide and based on a.m and p.m peak hour volume. The study classified the traffic volumes according to the State Commission for Roads and Bridges **(SCRB, 2005)**, then represent traffic and geometric data using Tables and Figures with aided of (Microsoft Excel 2019). The road condition was observed for a week of the period from (8/3/2021 to 26/4/2021), including all other administrative and technical matters for the requirements of the study.

Tables (3-9), (3-10), and (3-11) show the traffic volumes data collection of different types of vehicles used for the road 80 section during working days based on the peak hours. Figures (3-9), (3-10), and (3-11) show the variations of traffic volumes for the road no. 80 section over time based on these Tables with aided of Microsoft Excel 2019.

Table (3-9): Traffic Volumes Data Collection for Najaf-Road no. 80 Section on (29/3/21).

Time	PC	Bus	Heavy Vehicles							
			Type 2	Type 3	Type 2-S2	Type 3-S3	Type 3-S2	Type 3-3	Type 3-S1-2	Type 2-3
7:30 - 7:45	633	1	9	4	1	6	1			1
7:45 - 8:00	761	2	14	3		4			1	1
8:00 - 8:15	789	3	19	6	2	6			2	
8:15 - 8:30	812	8	16	10	6	11	2	1		4
8:30 - 8:45	803	3	19	4	1	3			2	

8:45 - 9:00	756	2	8	6	2	4			1	
9:00-9:15	741	3	14	3		2	1			1
9:15-9:30	768	1	7	2	1	5			1	
9:30 - 9:45	671	6	10	4	3	3				2
9:45 - 10:00	659	2	13	6		6		1	2	
10:00-10:15	638	3	9	4	3	7			3	1
10:15 - 10:30	718	4	10	8	1	9	1	2		
10:30 - 10:45	664	3	5	6	2	3			1	1
10:45-11:00	696	2	15	8	1	7	1		2	
11:00-11:15	597	8	10	4	6	9	2		2	
11:15-11:30	614	2	8	1	3		2		1	1
11:30-11:45	542	3	13	4	2	6	2	1	1	
11:45-12:00	568	5	9	5	3	7			2	3
12:00-12:15	602	6	7	4	1	4				1
12:15 - 12:30	583	4	11	5		8			2	
12:30- 12:45	540	3	10	3	4	9	2			1
12:45 - 1:00	578	4	9	5	1	8	1	1	2	
1:00-1:15	594	7	14	3	2	6				1
1:15-1:30	625	6	20	3		6	1			
1:30 - 1:45	672	7	23	8	2	5	2		1	
1:45 - 2:00	726	5	9	4		9	2			1
2:00 - 2:15	758	8	13	4	1	12	2		2	1
2:15 -2:30	713	3	10	4	4	7		1	1	
2:30 -2:45	669	6	19	5		7	1		4	2
2:45 -3:00	648	4	16	8	2	6	2		1	
3:00 - 3:15	657	3	9	5		4				2
3:15-3:30	624	3	10	6	2	9	2		1	1

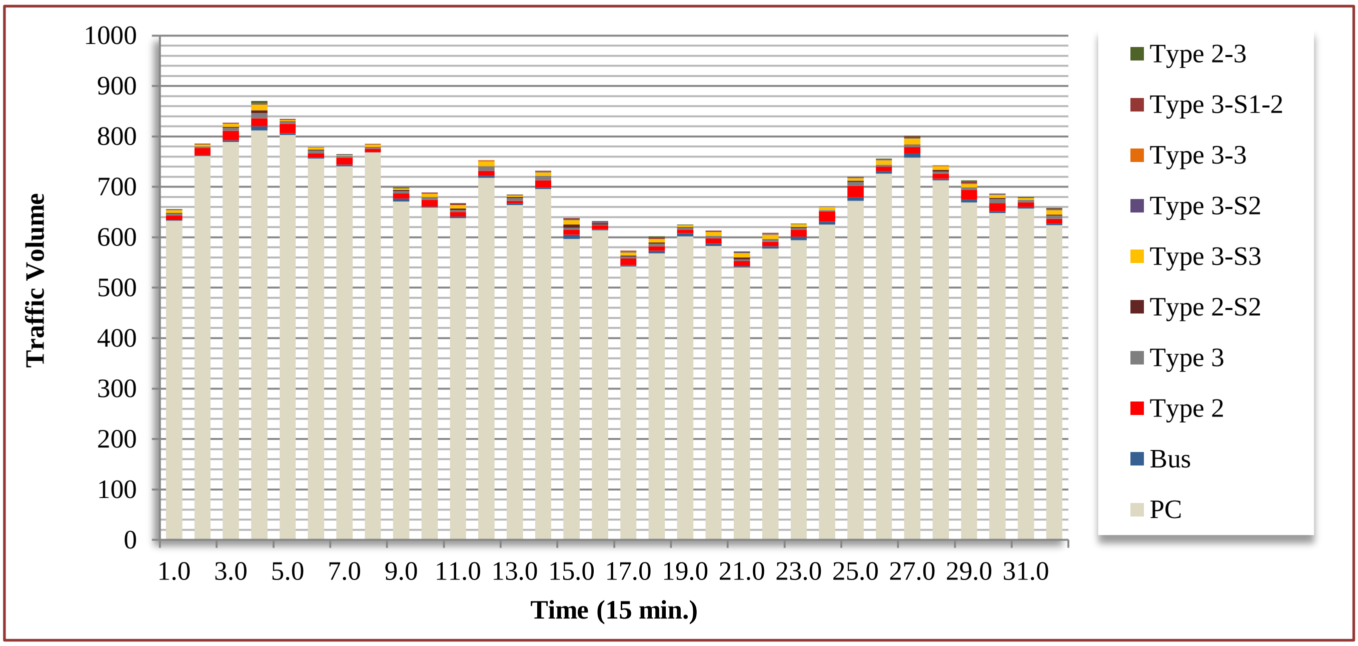

Figure (3-9): Variations of Traffic Volume for the (Najaf-Road no. 80) Section on (29/3/21).

Table (3-10): Traffic Volumes Data Collection for Najaf-Road no. 80 Section on (30/3/21).

Time	PC	Bus	Heavy Vehicles							
			Type 2	Type 3	Type 2-S2	Type 3-S3	Type 3-S2	Type 3-3	Type 3-S1-2	Type 2-3
7:30 - 7:45	541	3	10	3		3	2			
7:45 - 8:00	695	6	12	4	1	9		1		
8:00 - 8:15	843	4	9	1		14	1		1	2
8:15 - 8:30	824	9	32	6	2	11	3			3
8:30 - 8:45	897	8	20	2		3				1
8:45 - 9:00	871	7	15	4	6	12	1		2	
9:00 - 9:15	734	11	26	9	4	3	1			
9:15 - 9:30	816	5	15	4	3	7			2	
9:30 - 9:45	762	6	13	6		3		2		1
9:45 - 10:00	675	5	9	7	1	4			3	1
10:00 - 10:15	648	3	11	3	3	10	1		1	2

10:15 - 10:30	683	4	19	8		12	2		1	1
10:30 - 10:45	594	6	9	4	1	5		2		3
10:45 - 11:00	679	4	11	8	2	4			2	
11:00 -11:15	599	6	21	7	2	8	3		1	
11:15 - 11:30	684	4	10		4	9	1		2	
11:30 - 11:45	632	5	23	9	2	7	3		1	2
11:45 - 12:00	688	6	9	7	1	6	1		1	1
12:00 - 12:15	627	4	14	5	3	11		2		
12:15 - 12:30	658	7	19	8	1	6			3	1
12:30- 12:45	640	7	9	5	2	6	1			1
12:45 - 1:00	672	4	16	7	1	11	3			2
1:00 - 1:15	694	9	24	8	1	9			2	1
1:15 - 1:30	713	10	19	5	3	7	1			3
1:30 - 1:45	755	12	10	6		8	3		2	
1:45 - 2:00	787	7	13	4	1	9	1		1	1
2:00 - 2:15	802	6	9	5	1	10		1		4
2:15 -2:30	853	7	15	4	1	8			1	1
2:30 -2:45	841	3	23	6		7	1		2	1
2:45 -3:00	778	5	12	4	2	8	1		1	
3:00 - 3:15	750	2	9	6		9				2
3:15 - 3:30	677	3	10	5	1	7	1		1	

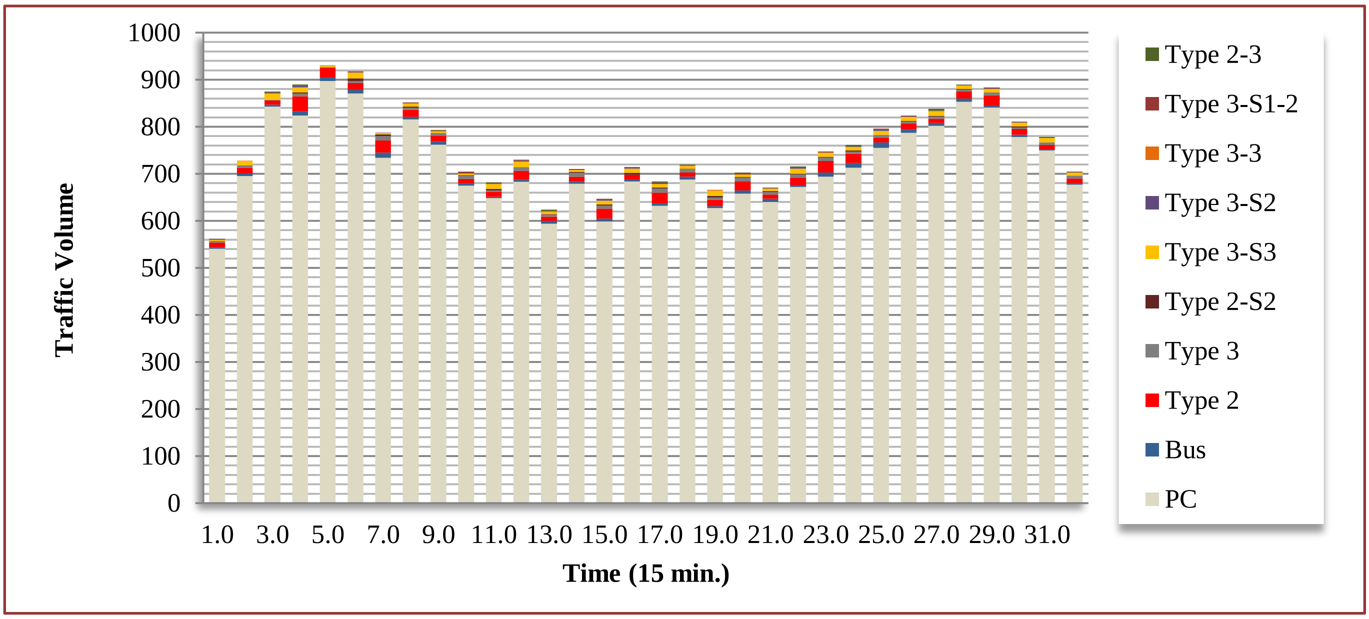

Figure (3-10): Variations of Traffic Volume for the (Najaf-Road no. 80) Section on (30/3/21).

Table (3-11): Traffic Volumes Data Collection for Najaf-Road no. 80 Section on (31/3/21).

Time	PC	Bus	Heavy Vehicles							
			Type 2	Type 3	Type 2-S2	Type 3-S3	Type 3-S2	Type 3-3	Type 3-S1-2	Type 2-3
7:30 - 7:45	563	3	11	4	2	6				
7:45 - 8:00	741	5	19	3		4	1			1
8:00 - 8:15	956	3	16	7	2	8				
8:15 - 8:30	989	10	48	18	6	15		1		2
8:30 - 8:45	1003	4	21	3	1	2	1		1	
8:45 - 9:00	971	6	15	7	2	3			1	
9:00-9:15	904	4	24	2		2				1
9:15-9:30	868	5	17	4	2	9			1	
9:30 - 9:45	871	7	12	3	3	1				2
9:45 - 10:00	859	2	15	6		5		1	2	

10:00-10:15	828	4	9	4	2	8	1		3	
10:15 - 10:30	786	6	13	11	1	10	1			2
10:30 - 10:45	764	3	6	5	3	4		1		1
10:45-11:00	699	2	18	12	3	1			2	
11:00-11:15	597	9	15	4	6	11	2		1	
11:15-11:30	674	4	10		3	9	1			1
11:30-11:45	532	8	20	9	2	7	3		1	3
11:45-12:00	688	6	9	7	1	6	1		1	1
12:00-12:15	602	4	14	6	3	2				
12:15 - 12:30	586	5	11	4		7			2	
12:30- 12:45	640	7	9	5	1	6				1
12:45 - 1:00	679	6	12	7	2	10		1		2
1:00-1:15	694	9	14	4		7			2	1
1:15-1:30	711	10	19	5	2	10	1			
1:30 - 1:45	765	8	23	9	1	6	2		1	
1:45 - 2:00	797	7	13	6		11	1		2	1
2:00 - 2:15	820	10	16	3	2	14	3		2	2
2:15 -2:30	853	9	22	4	1	11		1	1	1
2:30 -2:45	891	6	29	6		8	2		1	3
2:45 -3:00	778	7	13	8	1	7	1		1	
3:00 - 3:15	760	3	9	5		4				2
3:15-3:30	678	2	7	5	1	9	1		1	1

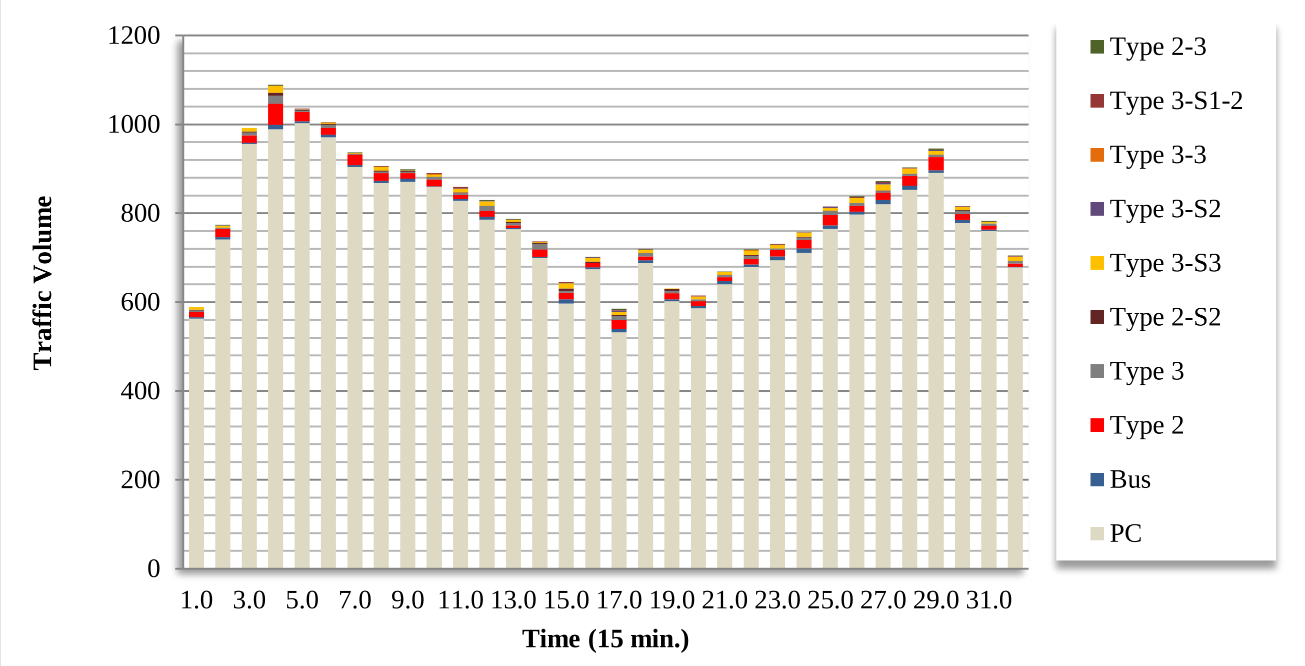

Figure (3-11): Variations of Traffic Volume for the (Najaf-Road no. 80) Section on (31/3/21).

Tables (3-12), (3-13), and (3-14) show the calculation of ADT values and percentage of heavy trucks P_T for the (Najaf-Road no. 80) section based on vehicle classification and according to SCRB, 2005 using equation (3.1), (K value = 0.15).

Table (3-12): Calculation of ADT According to Vehicle Classification for the (Najaf-Road no. 80) Section on (29/3/21).

Day/ Monday Date 29/3/21											
peak hour / 7:45 - 8:45 A.M											
	PC	Bus	Type 2	Type 3	Type 2-S2	Type 3-S3	Type 3-S2	Type 3-3	Type 3-S1-2	Type 2-3	**Total**
HV	3165	16	68	23	9	24	2	1	5	5	3318
K	0.15										
ADT= $\frac{HV}{K}$	21100	107	453	153	60	160	13	7	33	33	
P_T	4 %										
peak hour / 1:30 - 2:30 P.M											
	PC	Bus	Type 2	Type 3	Type 2-S2	Type 3-S3	Type 3-S2	Type 3-3	Type 3-S1-2	Type 2-3	**Total**

HV	2869	23	55	20	7	33	6	1	4	2	3020
K	0.15										
ADT= $\frac{HV}{K}$	19127	153	367	133	47	220	40	7	27	13	
P_T	4 %										

Table (3-13): Calculation of ADT According to Vehicle Classification for the (Najaf-Road no. 80) Section on (30/3/21).

Day/ Tuesday Date 30/3/21											
peak hour / 8:00 - 9:00 A.M											
	PC	Bus	Type 2	Type 3	Type 2-S2	Type 3-S3	Type 3-S2	Type 3-3	Type 3-S1-2	Type 2-3	**Total**
HV	3435	28	76	13	8	40	5	–	3	6	3614
ADT	22900	187	507	87	53	267	33	–	20	40	
P_T	4 %										
peak hour / 1:45 - 2:45 P.M											
	PC	Bus	Type 2	Type 3	Type 2-S2	Type 3-S3	Type 3-S2	Type 3-3	Type 3-S1-2	Type 2-3	**Total**
HV	3283	23	60	19	3	34	2	1	4	7	3436
ADT	21887	153	400	127	20	227	13	7	27	47	
P_T	4 %										

Table (3-14): Calculation of ADT According to Vehicle Classification for the (Najaf-Road no. 80) Section on (31/3/21).

Day/ Wednesday Date 31/3/21											
peak hour / 8:00 - 9:00 A.M											
	PC	Bus	Type 2	Type 3	Type 2-S2	Type 3-S3	Type 3-S2	Type 3-3	Type 3-S1-2	Type 2-3	**Total**
HV	3919	23	100	35	11	28	1	1	2	2	4122
ADT	26127	153	667	233	73	187	7	7	13	13	
P_T	4 %										

peak hour / 1:45 - 2:45 P.M											
	PC	Bus	Type 2	Type 3	Type 2-S2	Type 3-S3	Type 3-S2	Type 3-3	Type 3-S1-2	Type 2-3	**Total**
HV	3361	32	80	19	3	44	6	1	6	7	3559
ADT	22407	213	533	127	20	293	40	7	40	47	
P_T	5 %										

From previous Tables, we find that the highest traffic volume was on wednesday (8:00 - 9:00 A.M), direction/ (Najaf-Road no.80) and equal to 4122.

3.5 Evaluation of the Level of Service using HCS 2010 Software

The Highway Capacity Software HCS was founded by the FHWA in 1986 as the center for Microcomputer in Transportation (McTrans) Moving Technology at the University of Florida, published by the Transportation Research Board (TRB). The main aim of the software is to analyze the capacity, determine the LOS, and used it to model intersections, roundabouts, freeways, two and multilane highways according to procedures defined in the highway capacity manual 2010 (HCM 2010). This software is in US units **[Mohammad Obadat et al., 2013]**.

We adopt operational analysis in the road sections for a study area to calculate the LOS for existing conditions. The data used contained traffic volume data, roadway geometric data, and vehicle speed data.

For study area sections in both directions, the traffic and geometric data that are required to evaluate the LOS using HCS 2010 software, are shown in Plates (3-1) and (3-2).

For any data that cannot be collected, the default values recommended by HCM were used, for example, driver population factor FP **[Majed Msallam, 2019]**.

FREE-FLOW SPEED

Direction	1		2	
Lane width	11.9	ft	11.9	ft
Lateral clearance:				
Right edge	6.0	ft	6.0	ft
Left edge	6.0	ft	6.0	ft
Total lateral clearance	12.0	ft	12.0	ft
Access points per mile	8		7	
Median type	Divided		Divided	
Free-flow speed:	Base		Base	
FFS or BFFS	47.0	mph	47.0	mph
Lane width adjustment, FLW	0.0	mph	0.0	mph
Lateral clearance adjustment, FLC	0.0	mph	0.0	mph
Median type adjustment, FM	0.0	mph	0.0	mph
Access points adjustment, FA	2.0	mph	1.8	mph
Free-flow speed	45.0	mph	45.3	mph

VOLUME

Direction	1		2	
Volume, V	3306	vph	2077	vph
Peak-hour factor, PHF	0.90		0.86	
Peak 15-minute volume, v15	918		604	
Trucks and buses	15	%	10	%
Recreational vehicles	0	%	0	%
Terrain type	Level		Level	
Grade	1.50	%	1.50	%
Segment length	1.21	mi	1.21	mi
Number of lanes	3		3	
Driver population adjustment, fP	1.00		1.00	
Trucks and buses PCE, ET	1.5		1.5	
Recreational vehicles PCE, ER	1.2		1.2	
Heavy vehicle adjustment, fHV	0.930		0.952	
Flow rate, vp	1316	pcphpl	845	pcphpl

Plate (3-1): Traffic and Geometric Data of Hilla-Najaf Roadway Section in Both Directions (for Existing Conditions).

FREE-FLOW SPEED

Direction	1		2	
Lane width	12.0	ft	12.0	ft
Lateral clearance:				
Right edge	6.0	ft	6.0	ft
Left edge	6.0	ft	6.0	ft
Total lateral clearance	12.0	ft	12.0	ft
Access points per mile	3		7	
Median type	Divided		Divided	
Free-flow speed:	Base		Base	
FFS or BFFS	52.0	mph	52.0	mph
Lane width adjustment, FLW	0.0	mph	0.0	mph
Lateral clearance adjustment, FLC	0.0	mph	0.0	mph
Median type adjustment, FM	0.0	mph	0.0	mph
Access points adjustment, FA	0.8	mph	1.8	mph
Free-flow speed	51.3	mph	50.3	mph

VOLUME

Direction	1		2	
Volume, V	4122	vph	3588	vph
Peak-hour factor, PHF	0.95		0.98	
Peak 15-minute volume, v15	1085		915	
Trucks and buses	4	%	5	%
Recreational vehicles	0	%	0	%
Terrain type	Level		Level	
Grade	1.50	%	1.50	%
Segment length	0.25	mi	0.25	mi
Number of lanes	3		3	
Driver population adjustment, fP	1.00		1.00	
Trucks and buses PCE, ET	1.5		1.5	
Recreational vehicles PCE, ER	1.2		1.2	
Heavy vehicle adjustment, fHV	0.980		0.976	
Flow rate, vp	1475	pcphpl	1250	pcphpl

Plate (3-2): Traffic and Geometric Data of Road no. 80 Section in Both Directions (for Existing Conditions).

3.6 Evaluation of Flexible Pavement Distress using PCI

This section reviews the forms of defects found during the field survey of the study sections then evaluated using the PCI index. All the inspection data are shown in Appendix B.

3.6.1 Inspection of Failure Patterns in the Study Area Sections

The failure patterns such as alligator cracking, potholes, patching, bleeding, rutting, transverse cracking, and raveling, shown in Plates (3-3) to (3-10), are classified by visual inspection along the study road sections.

- Alligator / Fatigue Cracking: It is a series of interconnected cracks that begin at the bottom of the asphalt surface or the base layer when the highest loads are applied on the road, and by load repetitions the cracks connect, forming irregular longitudinal cracks. Plate (3-3).

Plate (3-3) a.

Plate (3-3) b.

Plate (3-3) c.

Plate (3-3): Existing Alligator Cracking.

- Potholes: They are holes or gaps of various shapes and sizes that appear on the pavement surface. Plate (3-4).

Plate (3-4) a.

Plate (3-4) b.

Plate (3-4): Potholes.

- Transverse Cracks: These are perpendicular to the centerline of the roadway, its appearance is not related to the load. Plate (3-5).

Plate (3-5) a.

Plate (3-5) b.

Plate (3-5): Existing Pavement of Transverse Cracking.

- Patching: It is an area of tiling that is replaced with new material for maintenance or repair, and referred to it as a defect in case it was not executed as well the original road section. Plate (3-6).

Plate (3-6): Patching.

- Bleeding: It forms a smooth, shiny, slippery layer on the road surface. Plate (3-7).

Plate (3-7): Bleeding.

- Raveling/Weathering: The study noted the presence of weathering processes, the gradual disintegration of the surface asphalt layer. These defects refer to certain types of traffic loads or poor quality of the mixture, so that the asphalt materials turn into scattered materials and the aggregate is isolated, then volatilizes from the pavement surface with the movement of vehicles and the road surface becomes rough. Plate (3-8).

Plate (3-8) a.

Plate (3-8) b.

Plate(3-8): Raveling.

- Ruts: They are depressions in the road surface observed especially after a rainfall due to repeated traffic loads.

Plate(3-9): Oxidation.

3.6.2 Pavement Condition Index PCI

The PAVER method is one of the advanced and accurate methods for assessing the condition of road pavements, driving safety, and detecting defects in them, contains 19 distress, which is called the pavement condition index. The PCI provides a numerical rating, starting from zero for poor/failed pavements to one hundred for pavements being excellent developed by the (U.S. Army Corps of Engineers) to supply an index of the pavement structural integrity and surface operational condition. As well as to evaluate paved surface situations to validate or improve current pavement design, acknowledge maintenance needs, and rehabilitation works to prevent deterioration **[ASTM D6433, 2011]**.

A correlation is used to determine the pavement condition rating, which shows the pavement condition rating as a function of the PCI value. When interpreting the visual condition data collected, three different aspects of the collected data are of interest: the type of the distress, the amount, and the severity level. Pavements at the upper end of the scale (PCI = 40-100) are more likely to be candidates for simple rehabilitation and maintenance, whereas those at the lower end of the scale (PCI= 0-40) are more likely to require structural rehabilitation or reconstruction **[Fareed M. A. Karim et al., 2016]**.

To meet this challenge, deduct values have been introduced as a type of weighting factor to indicate the degree of influence that each combination of damage type, severity, and quantity has on the condition of the road surface. To accurately verify PCI, the road network must be divided into measurable sections **[M.Y. Shahin, 2005]**.

3.6.2.1 Sampling and Sample Units

The road network must be divided into branches (such as streets, parking lots, etc). Each branch should be divided into sections that have specific characteristics over its entire area, such as structural composition, traffic, and road condition.

The road section should be divided into several segments which represent “sample unit” with a defined area range (2500 ft^2) ± 1000 or (225 m^2) ± 90 for Asphalt Concrete (AC) pavements.

Determine the total sample units (N) in the study area sections using equation (3.2):

$$N = \frac{Area\ of\ the\ Section}{Area\ of\ the\ Sample} \qquad (3.2)$$

A specimen plan for PAVER software is used, so that a reasonably accurate PCI may be calculated based on the number of specimen units in a segment of pavement. For instance, the pavement could be separated into specimen units to the road 80 section at any direction as follows:

$$N = \frac{4500}{300} = 15$$

Calculate the minimum number of sample units (n) to be inspected within a given section using equation (3.3) below, to obtain a reasonable estimate (95% confidence), that the error is within ± 5 points of the true mean PCI of the section **[M.Y. Shahin, 2005]** & **[ASTM D6433, 2011]**.

$$n = \frac{N * S^2}{\left(\frac{e^2}{4}\right)(N-1) + S^2} \qquad (3.3)$$

Where:

N= number of all specimen units.

S= standard deviation of PCI (assumed ten).

e= suitable error in PCI (e=5 fixed).

$$n = \frac{15 * 100}{\left(\frac{25}{4}\right) * 14 + 100} = 8$$

The sampling interval (i) of the units to be sampled is computed using the equation (3.4) **[M.Y. Shahin, 2005]** & **[Fareed. M.A. Karim et al., 2016]**, and rounded to the lowest whole number:

$$i = \frac{N}{n} \qquad (3.4)$$

Interval (i) = $\frac{N}{n}$ = 1.88 ≈1

Random sampling can be used to acquire the spacing interval of units as shown in Figure (3-12).

Random Start (S) = 2 , S + i = 3, S + 2i = 4, etc..

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15

Figure (3-12): Example of Systematic Random Sampling.

For each study section, the total sample units and inspected units are shown in Table (3-15).

Table (3-15): Total Sample Units N and Inspected Units n for Each Study Road Sections Inspection.

Section Name	N	n
Hilla-Najaf section	122	15
Road no. (80) section	15	8

3.6.2.2 Calculation of the PCI Manually

PCI is determined utilizing detailed data from pavement surface distresses that were identified during pavement condition surveys. A condition survey identifies the distress type, extent, and severity within a section of pavement. The PCI calculation steps are summarized as follows **[M.Y. Shahin, 2005]** & **[Bindiya Patel and Ashraf Mathakiya, 2018]**:

Step 1: Add up the total amount of each distress at each severity level and record them in the "Total Severity" section.

Step 2: To obtain the percent density, divide the total quantity of each distress type at each severity level by the total area of the sample unit and multiply by 100.

Step 3: From the distress deduct value curves, calculate the deduct value (DV) for each distress type and severity level combination.

Step 4: Determine the maximum allowable number of deducts (m). The deduct values included in the calculation of the maximum correction for the deduct values are determined according to the following equation (3.5) or from Figure (3-13):

$$m_i = 1 + (9/98)(100 - HDV_i) \leq 10 \qquad (3.5)$$

Where:

m_i = allowable number of deducts for sample unit i.

HDV_i = Highest Individual Deduct Value for sample unit i.

The individual deducts values should be reduced to (m). If fewer than (m) are available. All of the deduct values are used.

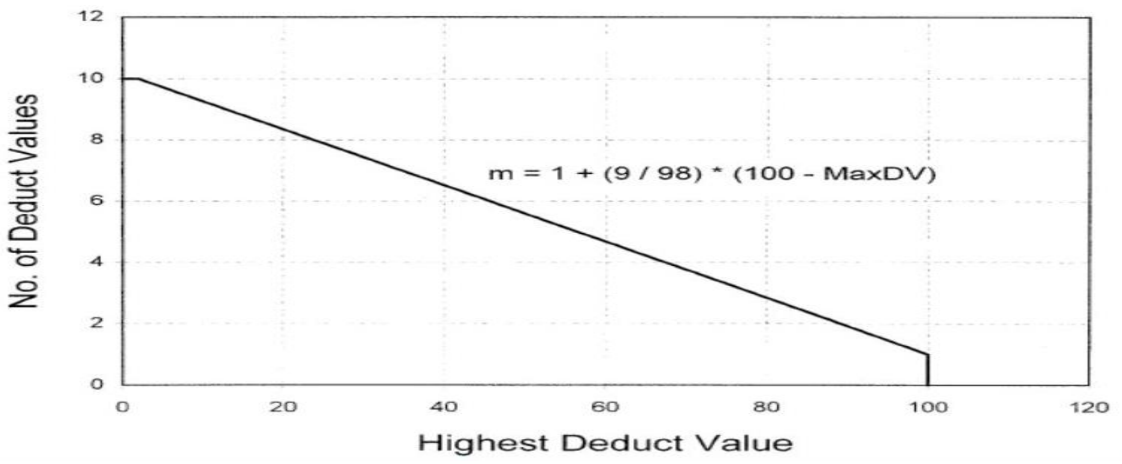

Figure (3-13): Adjustment of Number of Deduct values. **[ASTM D6433, 2011]**.

Step 5: Determine the maximum Corrected Deduct Value (CDV).

Step 6: Calculate PCI by deducting the highest CDV from equation (3.6) **[M.Y. Shahin**, **2005]** & **[Bindiya Patel & Ashraf Mathakiya, 2018]**:

$$PCI = 100 - \text{maximum } CDV \qquad (3.6)$$

3.6.2.3 Data Inspection

The deterioration of the road surface is measured with the PCI, developed the methodology for testing PCI. It is important to note that the American Society for Testing Materials (ASTM) has implemented the PCI as the basis for assessing the quality of road surfaces. The survey data includes distress type, severity level, and density or quantity for each sample unit in a road section. Table (3-16) shows Paver 5.2.3 classification distress for asphalt surfaced roads and parking. A section sample of the distressed inspection data in the (Road no. 80-Najaf) pavement sample is shown in Table (3-17). The inspection data of all sections in the study area are shown in Appendix B **[ASTM D6433, 2011]**.

Table (3-16): PAVER 5.2.3 Classification Distress for Asphalt-Surfaced Roads and Parking. (M.Y. Shahin-2005, Kirbas, and Gursoy-2010, Raid R. Almuhanna et al- 2018, PAVER 5.2.3 index).

Code	Distress	Unit of measure	Defined severity levels?	Cause
01	Alligator cracking	m^2	Yes	Load
02	Bleeding	m^2	Yes	Other
03	Block cracking	m^2	Yes	Climate
04	Bumps and sags	m	Yes	Other
05	Corrugation	m^2	Yes	Other
06	Depression	m^2	Yes	Other
07	Edge cracking	m	Yes	Load
08	Joint reflection	m	Yes	Climate
09	Lane/shoulder drop-off	m	Yes	Other
10	Longitudinal and transverse cracking	m	Yes	Climate
11	Patching and utility cut patching	m^2	Yes	Other
12	Polished aggregate	m^2	No	Other
13	Potholes	number	Yes	Load
14	Railroad crossings	m^2	Yes	Other
15	Rutting	m^2	Yes	Load
16	Shoving	m^2	Yes	Load
17	Slippage cracking	m^2	Yes	Other
18	Swell	m^2	Yes	Other
19	Weathering and Raveling	m^2	Yes	Climate

Table (3-17): The Inspection Data for the Section of (Road no. 80-Najaf).

Sample Unit No.	Distress Severity	Level of Severity			Quantity
		L	M	H	
2	Raveling	√			286 m^2
	Longitudinal Cracking		√		78 m
3	Patching			√	10.5 m^2
4	Alligator Cracking		√		16.7 m^2
	Potholes	√			4
	Weathering		√		86.45 m^2
5	Edge Cracking			√	59.54 m
	Transverse Cracking	√			127 m
6	Shoving		√		5 m^2
	Polished Aggregate	N/A			64 m^2
	Raveling		√		212 m^2
7	Rutting		√		43 m^2
	Potholes			√	1
8	Patching		√		6.5 m^2
	Weathering			√	33 m^2
	Transverse Cracking	√			99 m
	Block Cracking	√			51 m^2
9	Alligator Cracking			√	9.5 m^2
	Rutting	√			21 m^2
	Raveling		√		146.4 m^2

The levels of Severity L, M & H which represent low, medium, and high respectively.

3.6.3 Micro PAVER 5.2.3 Software Program

Micro PAVER is a computerized Pavement Management System created by the United States Army Corps of Engineers. It was first released in 1981 and was sponsored by numerous organizations in the United States. PAVER 5.2.3 software system has been utilized to see current PCI and to predict future pavement condition **[Elfadil A. A. Ahmed, 2014]** & **[Raid R. Almuhanna et al., 2018]**.

PAVERTM provides pavement management capabilities to **[US Army Corps of Engineers, 2004]**:

- Develop and organize the pavement inventory.
- Evaluate the current state of pavements.
- Develop models to anticipate future conditions.
- Report on past and future pavement performance.
- Develop situations for M&R supported budget or condition requirements and arrange projects.

According to PAVER 5.2.3 the pavement condition index has rated as the guide shows present condition of pavement as compared to standard PCI uses a scale of 7 different kinds started from excellent, to good, to satisfactory...etc until reach to failed to facilitate discrimination of these categories they use different colors assigned by the PAVER 5.2.3 program. The PAVER software is intriguing and offers user assistance. Positive program performance feedback was one of the most essential factors that aided Pavement Management System (PMS) in modifying and improving the program. **[Shahn & Smith, 2005]** & **[Khawla H. Shubber & Mohammed Mahdi, 2020; APWA, 2012]**.

PAVER menus that used when calculating the PCI :

- **Preferences Menu:** Through this menu, the units used in the entered data are selected.

- **Inventory Menu:** It contains three adjustable menus:

1. Network: It is a menu in which network data is entered and contains two types of input:

- Network Name: The name of the network is entered and it is an alphabetical descriptive name.
- Network ID: Network ID preferably a digital ID.

2. Branch: It is a menu in which branch data is entered and contains:

- Branch Name: The name of the branch is entered and it is an alphabetical descriptive name.
- Branch ID: Branch ID preferably a digital ID.
- Branch Use: The type of use of the branch is selected.

3. Section: It is a menu in which section data is entered and contains:

- Section ID: Section ID preferably a digital ID.
- Surface Type: It contains three types (Asphalt Overlay over Asphalt Concrete (AAC), Asphalt Concrete (AC), and Surface Treatment (ST).

- **PCI Menu:** Through this menu, the value of the pavement condition index is calculated. When you click on it, a window will open containing three commands:

  - Edit Inspections: The total number of samples is determined.
  - Edit Sample Units: The units of the inspection samples are modified by pressing Edit Sample Units where the sample unit and its area are specified.
  - Calculate Condition: After entering all the sample units in the section, it becomes possible to use the command Calculate Condition to calculate the pavement condition index for a section.

CHAPTER FOUR

Analysis, Results, and Discussion

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Analysis, Results, and Discussion

4.1 Introduction

This chapter presents the flexible pavement thickness design according to axle loads used for the study sections, evaluation of asphalt pavement defects by PCI calculation, using Micro PAVER 5.2.3 software based on inspection data, and the analysis of the results with necessary discussion. The AASHTO 1993 design procedures is the design method adopted for flexible pavement in this thesis, it provides typical design values for layers thickness according to traffic loading and different material properties.

4.2 AASHTO 1993 Design Guide

4.2.1 Method Description

AASHTO published an interim design guide in 1961 based on the results of the AASHO Road Test which was conducted in Ottawa, Illinois. The primary goal of the test was to determine if there was a link between the number of axle load repetitions and the performance of the flexible and rigid pavements. It was updated multiple times before being published in 1986 and 1993. The empirical performance equations were derived using a specific set of pavement materials and subgrade soils in a specific climatic condition. **[AASHTO, 1993]** & **[Ashraf A. Aguib, 2013]**.

4.2.2 Flexible Pavement Design Requirements

The main requirement is to calculate the thicknesses of different pavement layers to achieve design objectives. Assuming that the pavement section consists of surface, binder, base, and subbase, four thicknesses D_1, D_2, D_3, and D_4 are required for the four layers, respectively. The design procedure steps are presented below.

Many other elements must be taken into account when designing: cost, construction method, and maintenance **[AASHTO, 1993]**, **[Michael S. Mamlouk, 2006]**, **[F.D.O.T, 2018]**, **and [SUDAS, 2019]**:

4.2.2.1- Performance Criteria: The PSI is a roadway's ability to serve the traffic that uses the facility. Condition of pavements is rated with a PSI ranging from 0 to 5 and decreases due to deterioration.

- **Initial Serviceability Index (P_o)**: It gives an indication of the LOS provided by the road at the beginning of its design life. A value of (4.2) is assumed for flexible pavement according to the AASHTO guide.
- **Terminal Serviceability Index (P_t)**: This is the roadway condition that has reached the point when rehabilitation or reconstruction is required. A value of (2.5) is assumed generally for major arterial roads.
- **Serviceability Change (ΔPSI)**: This is the difference between initial serviceability and terminal serviceability. A value of (1.7) is used. The pavement design is based on the ΔPSI.

$$\Delta PSI = P_o - P_t \qquad (4.1)$$

4.2.2.2- Design Variables

- **Analysis Period (n)**: This refers to the time for which the analysis will be carried out. For flexible pavement, the recommended analysis period is (20 years).
- **Design Traffic ESAL**: Based on the equality of the stresses and deformations caused by a group of wheels with the stresses resulting from the equivalent wheel load, the ESALs are estimated during the required analysis period and depend on vehicle classes, Annual Average Daily Traffic (AADT), Annual traffic growth rate (% g), Percentage of Trucks (P_T), and Analysis period (n).

The cumulative expected W_{18} during the design life in the design lane is then determined, as stated in section 2.10.3. To get the ESAL in any dir. the cumulative two-directional ($\hat{W}_{18}$) must be factored by directions By multiplying the design traffic by the Directional Distribution (D_D) then the design traffic in direction is multiplied by the Lane Distribution (D_L). The total load determines the thickness of the pavement layer.

State Commission of Roads and Bridges (SCRB, 2009) determined the legal axle load limit as 7 tons for single-axle single tire, 13 tons for single-axle double tires, 20 tons for tandem axles, and 27 tons for triple axles, as shown in Plate (4-1). Types of heavy vehicles used for the study area sections, the number of their axles, and the permissible axle load are shown in Table (4-1). The values of total ESAL for heavy-loaded and empty trucks are calculated by multiplying the number of axles/trucks by the number of trucks. These data are used in pavement analysis and design.

Plate (4-1): Gross Weights and Legal Axle Loads on Vehicles in Regular Operation in Iraq. (Ministry of Housing and Construction - State Commission of Roads and Bridges SCRB, Statement No. (1) 2009).

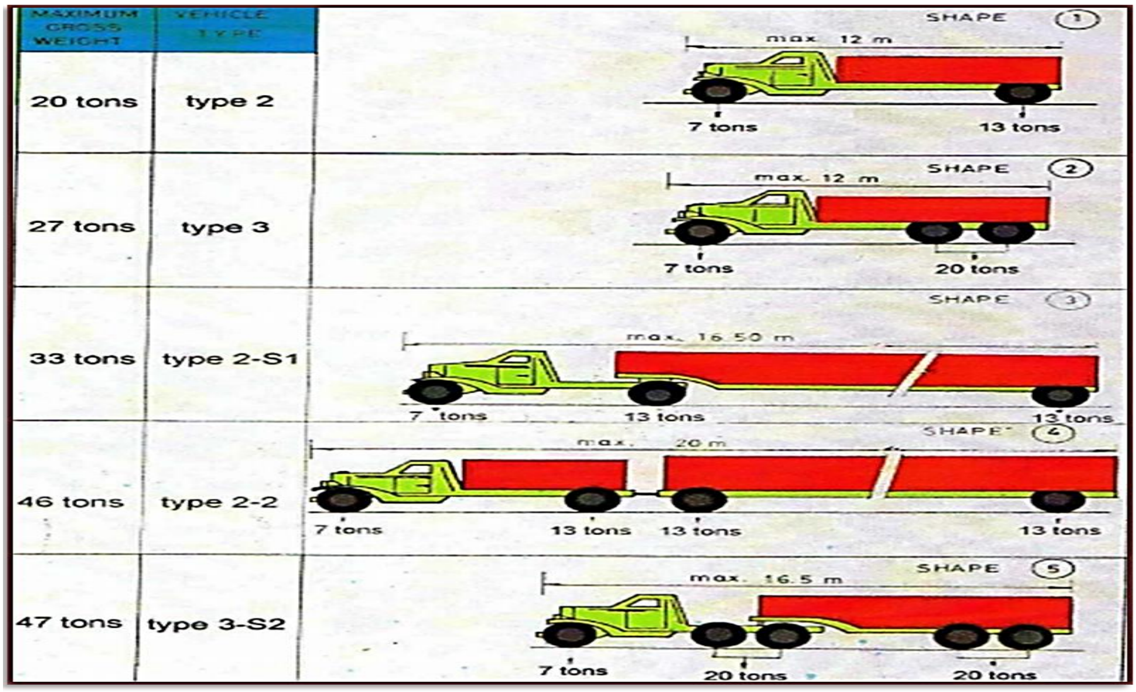

Plate (4-1): Gross Weights and Legal Axle Loads on Vehicles in Regular Operation in Iraq. (Ministry of Housing and Construction - State Commission of Roads and Bridges SCRB, Statement No. (1) 2009). (continued)

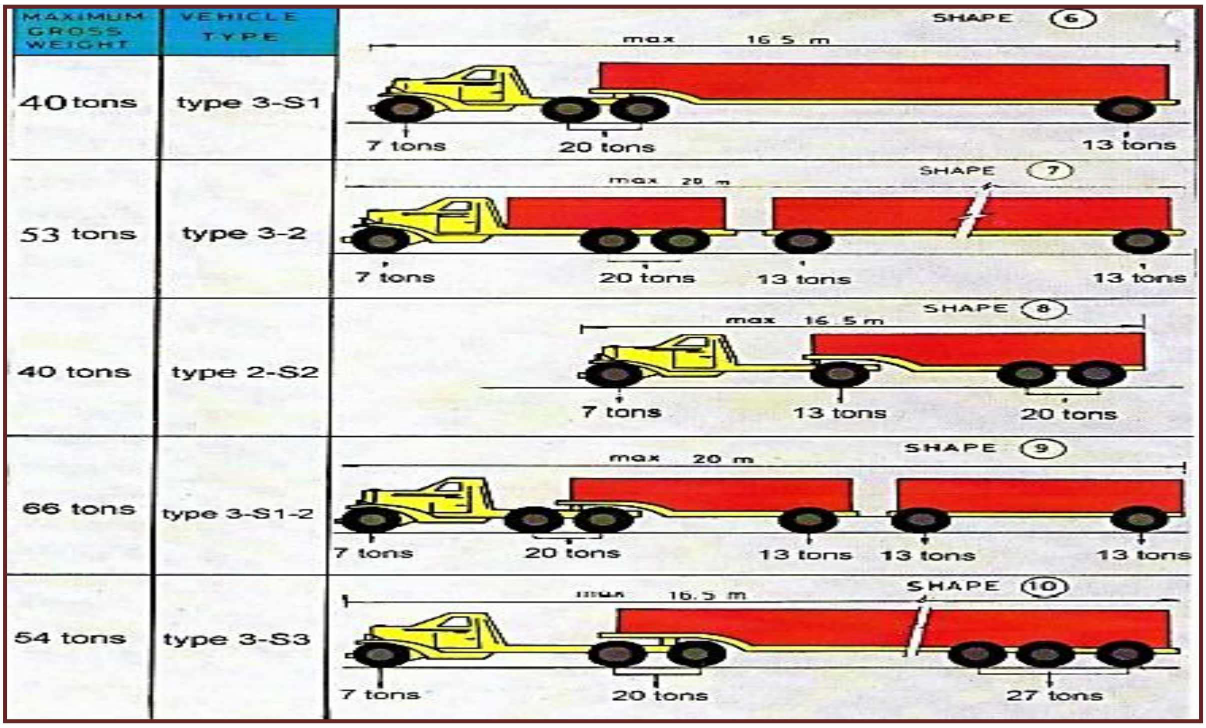

Table (4-1): Types of Heavy Vehicles in the Study Area Sections, the Number of Axles, and the Permissible Axle Load According to SCRB 2009.

Heavy Truck Type	**The highest permissible load (ton)**				
	Number of Axles				
	1	**2**	**3**	**4**	**5**
Type 2	7 •S	13 •S			
Type 3	7 •S	20 ••Ta			
Type 2-S2	7 •S	13 •S	20 ••Ta		
Type 3-S3	7 •S	20 ••Ta	27 •••Tr		
Type 3-S2	7 •S	20 ••Ta	20 ••Ta		
Type 3-3	7 •S	20 ••Ta	13 •S	20 ••Ta	
Type 3-S1-2	7 •S	20 ••Ta	13 •S	13 •S	13 •S
Type 2-3	7 •S	13 •S	13 •S	20 ••Ta	

•S = Single axle type.

••Ta= Tandem axle type.

•••Tr = Triple axle type.

- **Reliability (R-Value %)**: The level of reliability (R) is influenced by the road's functional classification and whether it is located in an urban or rural environment. The probability that the pavement will last throughout the design life is referred to as reliability without decreasing level of service, i.e. without failure. Better performance is ensured by a higher reliability value, but it needs a thicker layer. Table (4-2) shows reliability levels recommended by the AASHTO 1993 design guide.

Table (4-2): Recommended Levels of Reliability for Different Functional Classifications. **[AASHTO, 1993]**.

Functional Classification	Recommended Level of Reliability	
	Urban	Rural
Interstate and other freeways	85-99.9	80-99.9
Principal arterials	80-99	75-95
Collecters	80-95	75-95
Local	50-80	50-80

- **Normal Deviation (Z_R)**: Z_R is dependent on the used R-value, as shown in Table (4-3) according to AASHTO 1993 guide.
- **Overall Standard Deviation (S_o)**: This is a coefficient that indicates how closely the AASHO road test data matches the AASHTO design equations. For flexible pavements, this range is suggested (0.4-0.5). A value of 0.45 is used.

Table (4-3): Z_R Values Corresponding to Selected Levels of Reliability. [AASHTO, 1993].

Reliability (R percent)	Standard Normal Deviate (Z_R)
50	0 000
60	0 253
70	0 524
75	0 674
80	0 841
85	1 037

90	1 282
91	1 340
92	1 405
93	1 476
94	1 555
95	1 645
96	1 751
97	1 881
98	2 054
99	2 327
99 9	3 090
99 99	3 750

4.2.2.3- Material Properties

Good design requires knowledge and understanding of the important properties of the materials used in tiling work, as well as the soil on which the road is based. The properties of the materials are different, but the most important thing is that all the materials of the pavement layers share the characteristics of strength, stability, properties of repeated loads, and resistance to bending. The geometric properties of a pavement material depend on the relative composition of its constituents. The composition is finalized through an appropriate mix design so that the desired levels of various engineering properties of the material are achieved. These materials illustrate complex responses when subjected to temperature, moisture, and load variations **[Animesh Das, 2015]**.

- **Soil Resilient Modulus (M_R)**: The most significant factor to consider while describing the basis for pavement design. MR is a soil property that indicates the soil's stiffness or elasticity under dynamic loading. In the case of a dynamically loaded test specimen. The term "resilience" refers to the amount of energy that material may absorb and still return to its original state. Pavement performance can be influenced by the environment in a variety of ways. Temperature and moisture variations can affect the pavement and roadbed materials' strength, durability, and load-carrying capacity, as well as the direct effect of different deformations that can have on loss of riding quality and serviceability level.

AASHTO 1993 suggested a relationship between the resilient modulus and soil properties, the most important of which is the value of California Bearing Ratio (CBR) to calculate M_R value, and this relationship was adopted in this study:

When CBR value $\leq$ 10 %

$$\mathbf{M_R\ (psi)} = 1500 \times \text{CBR} \qquad (4.2)$$

When CBR value > 10%

$$\mathbf{M_R\ (psi)} = 500 \times \text{CBR} \qquad (4.3)$$

- **Structural Layer Coefficients (a_i)**: For each pavement layer, a coefficient value is set for converting the real layer thickness into a structural number (SN) in the tiling system. It is a measure of the relative ability of layer materials to act as a structural component of paving layers, and this relationship was inferred based on tests of AASHTO methods. It is obtained depending on: 1) Type of material and its properties 2) Layer thickness and its location 3) Failure pattern 4) level of the applied load.

4.2.2.4- Pavement Structural Characteristics

- **Coefficient of Drainage (m_i)**: This is a coefficient that is used to modify layer coefficients. Which allows inserting the effects of drainage on the base and sub-base layers within the relationship of calculating the SN and depend on drainage quality, period of water removed, and time moisture approach saturation.
- **Structural Number (SN)**: SN is an index value that incorporates the thicknesses of the layers, the structural layer coefficients, and the drainage coefficients. Figure (4-1) shows the SN calculation for each pavement layer.

  The required SN is determined using either equation (4.4) below or from Figure (4-3) **[AASHTO, 1993]**.

$$\log W_{18}=Z_R S_o+9.36\log(SN+1)-0.2+\log[\Delta PSI/(4.2-1.5)]/[0.4+1094/(SN+1)^{5.19}]+2.32\log M_R-8.07 \quad (4.4)$$

This process is repeated two or more times to obtain the required SN on each pavement layer, then obtain the thickness of the pavement layers.

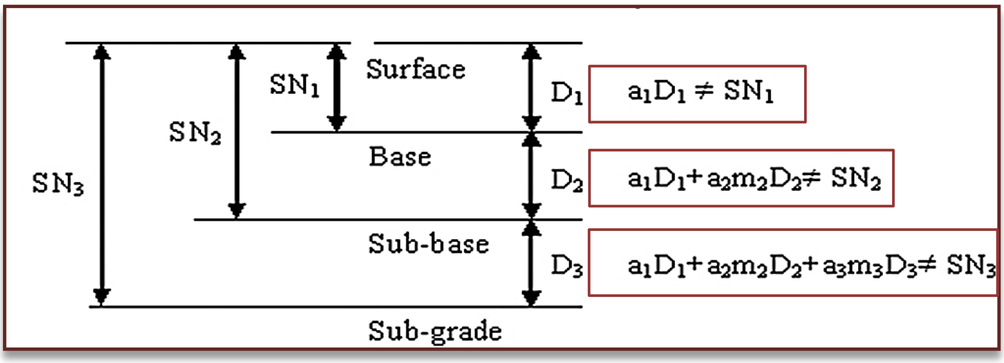

Figure (4-1): Structural Number for Pavement Layers.

5. Flexible Design Determinants

Economy, safety & service level during the design period, the ability to withstand repeated stresses and resist deformations, and reduce inconvenience and reduce air pollution during implementation.

4.3 Traffic Loading Computations

4.3.1 For Hilla-Najaf Roadway Section

There are many different types of heavy vehicles that were surveyed in this study section, and the variation of these vehicles in terms of weights, number of axles has a significant impact on bearing the roadway for the axle loads. And depending on the peak traffic volumes that used this road, which amount to (5509 veh/hr) as showed in Table (3-5), were on monday (18/1/21) at (7:45-8:45) a.m. The annual traffic volume was estimated based on the next 20 years, while the growth rate was calculated based on (6%).

The ADT value is adopted according to (Highway Design Manual SCRB, 2005). Factor (K= 0.15). The percentage of heavily loaded vehicles that were monitored using this roadway section is 66% and it is loaded with different loads, while the percentage of empty heavy vehicles is 34%.

The two Tables (4-4), (4-5) show the calculation of ESAL for heavy vehicles according to their classification when they are loaded and empty respectively. By using LEFs Tables are shown in Appendix C or using equation (4.5) below, and assumed (SN=5) **[AASHTO, 1993]**.

$$e = \frac{(L_x+L_2)^{4.79}}{(18+1)^{4.79}} * \frac{10^{G`/B18}}{10^{G`/B_x} * L_2{}^{4.331}} \qquad (4.5)$$

$$G` = log_{10}\ [\frac{(4.2-Pt)}{(4.2-1.5)}] \qquad (4.6)$$

$$B_X = 0.4 + \frac{0.081\ (L_x+L_2)^{3.23}}{(SN+1)^{5.19} * L_2{}^{3.23}} \qquad (4.7)$$

Where:

L_X = Load on each axle type (Kips).

L_2 = Axle Code: (1 for single axle, 2 for tandem axle, 3 for triple axle).

B_{18} = Value of B_X when L_X= 18, L_2 =1.

Table (4-4): The ESAL of Loaded Heavy Vehicles for the Hilla-Najaf Roadway Section.

Truck Type	Weight	Axle Load *	LEFs	Equivalent No. of Axles/ Truck	Number of Trucks	ESAL
	ton	ton				
Type 2	20	7 S	0.544	6.417	704	4517.568
		13 S	5.873			
Type 3	27	7 S	0.544	3.544	61	216.184
		20 Ta	3			
Type 2-S2	40	7 S	0.544	9.417	11	103.587
		13 S	5.873			
		20 Ta	3			
Type 3-S2	47	7 S	0.544	6.544	1	6.544
		20 Ta	3			
		20Ta	3			
Type 2-3	53	7 S	0.544	15.29	3	45.87
		13 S	5.873			
		13 S	5.873			
		20 Ta	3			
Type 3-S3	54	7 S	0.544	5.961	28	784
		20 Ta	3			
		27 Tr	2.417			

Type 3-3	60	7 S	0.544	12.417	3	37.251
		20 Ta	3			
		13 S	5.873			
		20 Ta	3			
Type 3-S1-2	66	7 S	0.544	21.163	3	63.489
		20 Ta	3			
		13 S	5.873			
		13 S	5.873			
		13 S	5.873			
Total ESAL						**5774.493**

*Plate (4-1)

Table (4-5): The ESAL of Heavy Vehicles, When They are Empty for the Hilla-Najaf Roadway Section.

Truck Type	Weight	Axle Load *	LEFs	Equivalent No. of Axles/ Truck	Number of Trucks	ESAL
	ton	ton				
Type 2	5.5	4 S	0.0556	0.057	704	40.128
		1.5 S	0.0014			
Type 3	7	4 S	0.0556	0.0728	61	4.4408
		3 Ta	0.0172			
Type 2-S2	8.5	4 S	0.0566	0.0752	11	0.8272
		1.5 S	0.0014			
		3 Ta	0.0172			
Type 3-S2	10	4 S	0.0556	0.09	1	0.09
		3 Ta	0.0172			
		3Ta	0.0172			
Type 2-3	10	4 S	0.0556	0.0756	3	0.2268
		1.5 S	0.0014			
		1.5 S	0.0014			
		3 Ta	0.0172			
Type 3-S3	14	4 S	0.0556	0.6169	28	784
		3 Ta	0.0172			
		7 Tr	0.5441			
Type 3-3	11.5	4 S	0.0556	0.0914	3	0.2742
		3 Ta	0.0172			
		1.5 S	0.0014			
		3 Ta	0.0172			
Type 3-S1-2	11.5	4 S	0.0556	0.077	3	0.231
		3 Ta	0.0172			
		1.5 S	0.0014			
		1.5 S	0.0014			
		1.5 S	0.0014			
Total ESAL						**830.218**

⁑ Through the review of the SCRB which supported the use of these variables through several field studies and the report "Baghdad Expressway Design" certified of SCRB/ Planning and Studies district. According to what was previously concluded , 66% of the vehicles that use the roadway are loaded, while 34% of them are empty, so:

ESAL/Day = 5774.493 * 0.66 + 830.218 * 0.34 = 4093.4395

ESAL/Year = 4093.4395 * 365 = 1494105.42

To calculate the ESAL during the design life of the roadway, we determine the Traffic Projection Factor TPF, as shown in Table (4-6).

Table (4-6): Traffic Growth Factors.

Analysis Period Years (n)	No Growth	Annual Growth Rate, Percent (g) 2	4	5	6	7	8	10
1	1 0	1 0	1 0	1 0	1 0	1 0	1 0	1 0
2	2 0	2 02	2 04	2 05	2 06	2 07	2 08	2 10
3	3 0	3 06	3 12	3 15	3 18	3 21	3 25	3 31
4	4 0	4 12	4 25	4 31	4 37	4 44	4 51	4 64
5	5 0	5 20	5 42	5 53	5 64	5 75	5 87	6 11
6	6 0	6 31	6 63	6 80	6 98	7 15	7 34	7 72
7	7 0	7 43	7 90	8 14	8 39	8 65	8 92	9 49
8	8 0	8 58	9 21	9 55	9 90	10 26	10 64	11 44
9	9 0	9 75	10 58	11 03	11 49	11 98	12 49	13 58
10	10 0	10 95	12 01	12 58	13 18	13 82	14 49	15 94
11	11 0	12 17	13 49	14 21	14 97	15 78	16 65	18 53
12	12 0	13 41	15 03	15 92	16 87	17 89	18 98	21 38
13	13 0	14 68	16 63	17 71	18 88	20 14	21 50	24 52
14	14 0	15 97	18 29	19 16	21 01	22 55	24 21	27 97
15	15 0	17 29	20 02	21 58	23 28	25 13	27 15	31 77
16	16 0	18 64	21 82	23 66	25 67	27 89	30 32	35 95
17	17 0	20 01	23 70	25 84	28 21	30 84	33 75	40 55
18	18 0	21 41	25 65	28 13	30 91	34 00	37 45	45 60
19	19 0	22 84	27 67	30 54	33 76	37 38	41 45	51 16
20	20 0	24 30	29 78	33 06	36 79	41 00	45 76	57 28
25	25 0	32 03	41 65	47 73	54 86	63 25	73 11	98 35
30	30 0	40 57	56 08	66 44	79 06	94 46	113 28	164 49
35	35 0	49 99	73 65	90 32	111 43	138 24	172 32	271 02

*Factor $= \frac{(1+g)^n - 1}{g}$, where $g = \frac{\text{rate}}{100}$ and is not zero If annual growth rate is zero, the growth factor is equal to the analysis period

T.P.F = 36.79

ESAL/20 Year = 1494105.42 * 36.79 = 54968138.4

$W_{18} = D_D * D_L * \hat{W}_{18}$

D_D = 0.5 typically, D_L = From Table (2-1) depending on number of lanes/direction.

$W_{18} = 0.5 * 0.5 * 54968138.4 = 13.742 * 10^6$

Figure (4-2) shows the growth of traffic volumes during the analysis period or the design life of the Hilla-Najaf roadway section.

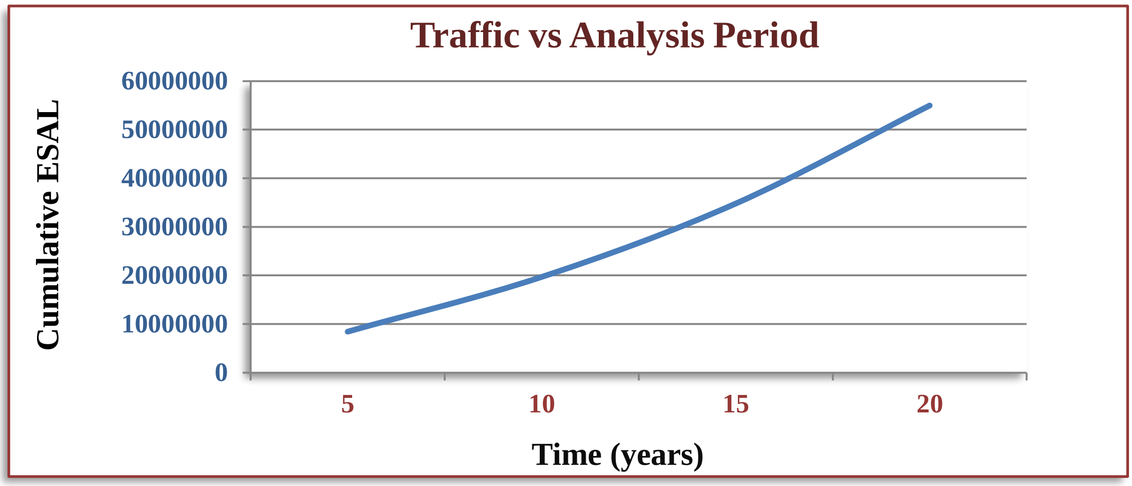

Figure (4-2): A Plot of Cumulative ESAL Traffic Versus Time for the Hilla-Najaf Roadway Section.

Table (4-7) demonstrates the computation of structural layer coefficients for each pavement layer using specific figures from the AASHTO guide depending on the properties of the layers. We got the properties of materials used in pavement layers such as Marshall Stability (M.S) and California Bearing Ratio (CBR) from the results of laboratory tests of this study section with the assistance of the Hilla Municipality/ Projects Department.

Table (4-7): Calculation of Structural Layer Coefficient (a_i) for the Hilla-Najaf Roadway Layers.

Layer	Property	(a_i)
Base Layer	Marshall Stability = 6.4 KN	a_2 = 0.28
Subbase Layer	Subbase CBR value = 40%	a_3 = 0.12

Table (4-8): Design Variables for the Hilla-Najaf Roadway Section.

Variable	Value
ΔPSI	1.7
R	90%
S_o	0.45
M_R (CBR $_{subbase}$ = 40%)	20000 psi
ESAL	13.742 * 10^6

Figure (4-3) shows a design chart of structural number SN for each pavement layer based on design variables are listed in Table (4-8).

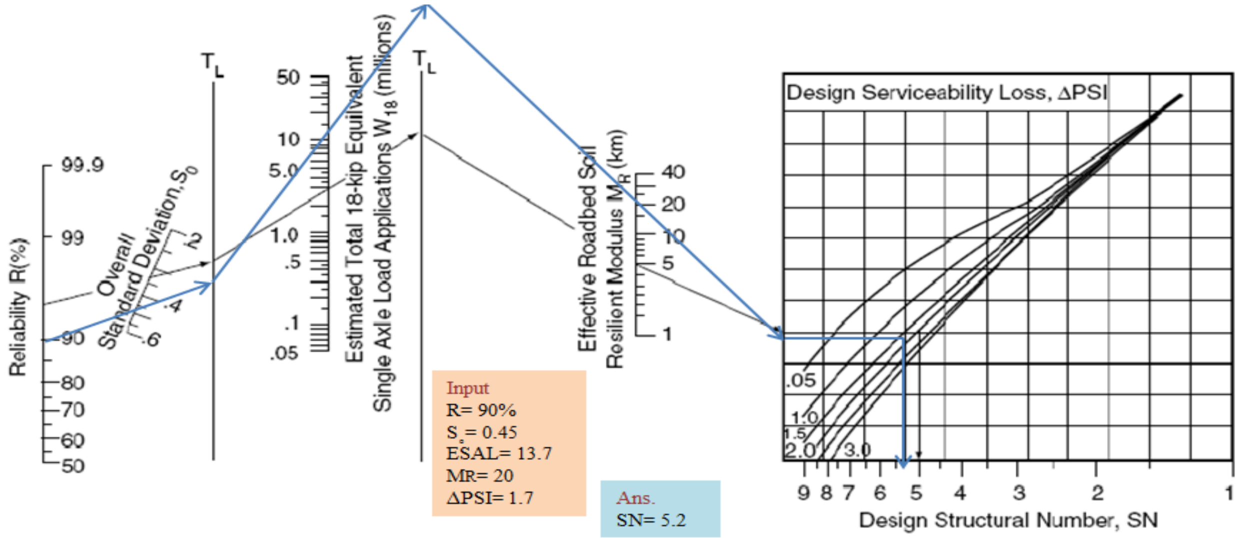

Figure (4-3): Design Chart for Flexible Pavement. **[AASHTO, 1993]**.

→ (SN_2 = 3.7).

$SN_2 = a_2 * D_2$, D_2 = 13 in, Use D_2 = 33 cm.

$SN_2 = 0.28 * 13 = 3.64$

Subgrade CBR value = 5%; M_R = 7500 psi, then

$SN_3 = 5.2$, $D_3 = \frac{5.2-3.64}{0.12} = 13$ in, Use D_3 = 34 cm.

4.3.2 For Road no. (80) Section

Depending on the peak traffic volumes that use this road section, which amount to (4122 veh/hr) as showed previously in Table (3-14) were on Wednesday (31/3/21) at (8:00-9:00) a.m, which include different types of heavy vehicles that affect the bearing capacity of the roadway section, whether due to axle loads, tires pressure, etc. It is detailed and categorized according to SCRB and AASHTO. The ADT values that were calculated with a factor (K=0.15) based on (Highway Design Manual SCRB, 2005).

The percentage of heavily loaded vehicles that were surveyed using the road is 60% and they are loaded with different loads, while the percentage of empty heavy vehicles is 40%.

The two Tables (4-9), (4-10) show the calculation of ESAL for heavy vehicles according to their classification when they are loaded and empty respectively. By using LEFs Tables are shown in Appendix C or equation (4.5) that was mentioned earlier and assumed (SN=5) **[AASHTO, 1993]**.

Table (4-9): The ESAL of Loaded Heavy Vehicles for the Road no. 80 Section.

Truck Type	**Weight**	**Axle Load**	**LEFs**	**Equivalent No. of Axles/ Truck**	**Number of Trucks**	**ESAL**
	ton	**ton**				
Type 2	20	7 S	0.544	6.417	100	641.7
		13 S	5.873			
Type 3	27	7 S	0.544	3.544	35	124.04
		20 Ta	3			
Type 2-S2	40	7 S	0.544	9.417	11	103.587
		13 S	5.873			
		20 Ta	3			
Type 3-S2	47	7 S	0.544	6.544	1	6.544
		20 Ta	3			
		20Ta	3			
Type 2-3	53	7 S	0.544	15.29	2	30.58
		13 S	5.873			
		13 S	5.873			
		20 Ta	3			
Type 3-S3	54	7 S	0.544	5.961	28	166.908
		20 Ta	3			
		27 Tr	2.417			
Type 3-3	60	7 S	0.544	12.417	1	12.417
		20 Ta	3			
		13 S	5.873			
		20 Ta	3			
Type 3-S1-2	66	7 S	0.544	21.163	2	42.326
		20 Ta	3			
		13 S	5.873			
		13 S	5.873			
		13 S	5.873			
Total ESAL						**1128.102**

Table (4-10): The ESAL of Heavy Vehicles, When They are Empty for the Road no. 80 Section.

Truck Type	Weight	Axle Load	LEFs	Equivalent No. of Axles/ Truck	Number of Trucks	ESAL
	ton	ton				
Type 2	5.5	4 S	0.0556	0.057	100	5.7
		1.5 S	0.0014			
Type 3	7	4 S	0.0556	0.0728	35	2.548
		3 Ta	0.0172			
Type 2-S2	8.5	4 S	0.0566	0.0752	11	0.8272
		1.5 S	0.0014			
		3 Ta	0.0172			
Type 3-S2	10	4 S	0.0556	0.09	1	0.09
		3 Ta	0.0172			
		3Ta	0.0172			
Type 2-3	10	4 S	0.0556	0.0756	2	0.1512
		1.5 S	0.0014			
		1.5 S	0.0014			
		3 Ta	0.0172			
Type 3-S3	14	4 S	0.0556	0.6169	28	784
		3 Ta	0.0172			
		7 Tr	0.5441			
Type 3-3	11.5	4 S	0.0556	0.0914	1	0.0914
		3 Ta	0.0172			
		1.5 S	0.0014			
		3 Ta	0.0172			
Type 3-S1-2	11.5	4 S	0.0556	0.077	2	0.154
		3 Ta	0.0172			
		1.5 S	0.0014			
		1.5 S	0.0014			
		1.5 S	0.0014			
Total ESAL						**793.5618**

ESAL/Day = 1128.102 * 0.6 + 793.562 * 0.4 = 994.286

ESAL/Year = 994.286 * 365 = 362914.4

T.P.F = 36.79 (Table 4-6)

ESAL/20 Year = 362914.4 * 36.79 = 13351620.4

W_{18} = 13351620.4 * 0.5 * 0.7 = 4673067.14 = 4.673 * 10^6

Table (4-11) shows the structural layer coefficient calculation for each pavement layer according to the AASHTO guide based on the properties of layers. The properties of materials used in pavement layers such as (M.S, CBR), we obtained from the results of the laboratory tests of this study section with aid of the Hilla Municipality . Table (4-12) shows the design variables of this study section.

Table (4-11): Calculation of Structural Layer Coefficient (a_i) for the Road no. 80 Layers.

Layer	Property	(a_i)
Surface Layer	Marshall Stability = 9.6 KN	a_1 = 0.45
Base Layer	Marshall Stability = 6 KN	a_2 = 0.26
Subbase Layer	Subbase CBR value = 35.8 %	a_3 = 0.118

Table (4-12): Design Variables for the Road no. 80 Section.

Variable	Value
ΔPSI	1.7
R	95%
S_o	0.45
M_R ($CBR_{subbase}$ = 35.8%) **M_R ($CBR_{subgrade}$ = 4.6%)**	17900 psi 6900 psi
ESAL	4.673 * 10^6

Based on design variables are listed in Table (4-12), determine the SN using Figure (4-3) → (SN_2= 3.42), D_2 = 13 in, Use D_2 = 33 cm.

SN_2 = 3.38

To calculate SN_3, repeat the above step → (SN_3 = 4.82)

$D_3 = \frac{4.82-3.38}{0.118}$ = 12 in = 30.5 cm, Use D_3 = 32 cm.

4.4 Evaluation Results of LOS

The two Tables (4-13), (4-14) show the LOS evaluation results for study area sections using HCS 2010 software (for existing conditions).

Table (4-13): Evaluation Results of LOS for Hilla-Najaf Roadway Section Using HCS 2010 Software (for Existing Conditions).

Direction	Flow Rate vp (pc/h/ln)	Free Flow Speed FFS (mph)	Travel Speed S (mph)	Density D (pc/mi/ln)	LOS
up stream	1316	45	45	29.2	D
down stream	845	45.3	45.3	18.7	C

Table (4-14): Evaluation Results of LOS for Road no. 80 Section Using HCS 2010 Software (for Existing Conditions).

Direction	Flow Rate vp (pc/h/ln)	Free Flow Speed FFS (mph)	Travel Speed S (mph)	Density D (pc/mi/ln)	LOS
up stream	1475	51.3	51	28.9	D
down stream	1250	50.3	50.3	24.9	C

4.5 Distress Evaluation Results Using the PCI Index

This section reviews the results of distress assessment using the PAVER method manually and the Micro PAVER software for a specific section of the study area as an applied example of the evaluation process steps.

4.5.1 Evaluation Results Using the PAVER Method Manually

The PCI is calculated for the entire section of pavement using the PCI values calculated for each examined sample unit; by deducting weighing factors ranging from 0 to 100, which indicate the effect of each defect on the pavement condition. The (Road no. 80-Najaf) section was taken as an illustrative example to show the method of calculation the PCI manually, as follows:

Total number of sample units in section (N) = 15

Minimum number of units to be inspected (n) = 8

Interval (i) = $\frac{N}{n}$ = ≈ 1

Random Start (S) = 2

inspecting units in this section are (2, 3, 4, 5,6,7,8, 9).

<u>For unit 9 as a detailed example:</u>

The density of the distresses, measured in square meters (m^2) in this section unit.

$$\text{Density \% (for Alligator Cracking H)} = \frac{distressed\ area\ per\ defect}{sample\ unit\ area} * 100 \quad (4.8)$$

$$= \frac{9.5}{300} * 100 = 3.17$$

$$\text{Density \% (for Rutting L)} = \frac{21}{300} * 100 = 7$$

$$\text{Density \% (for Raveling M)} = \frac{146.4}{300} * 100 = 49$$

From deduct value curves are shown in Figure (4-4), for each distress type, calculate the deduct value based on distress density percent and severity level. The calculation steps of PCI manually for this sample unit are shown clearly in Table (4-15).

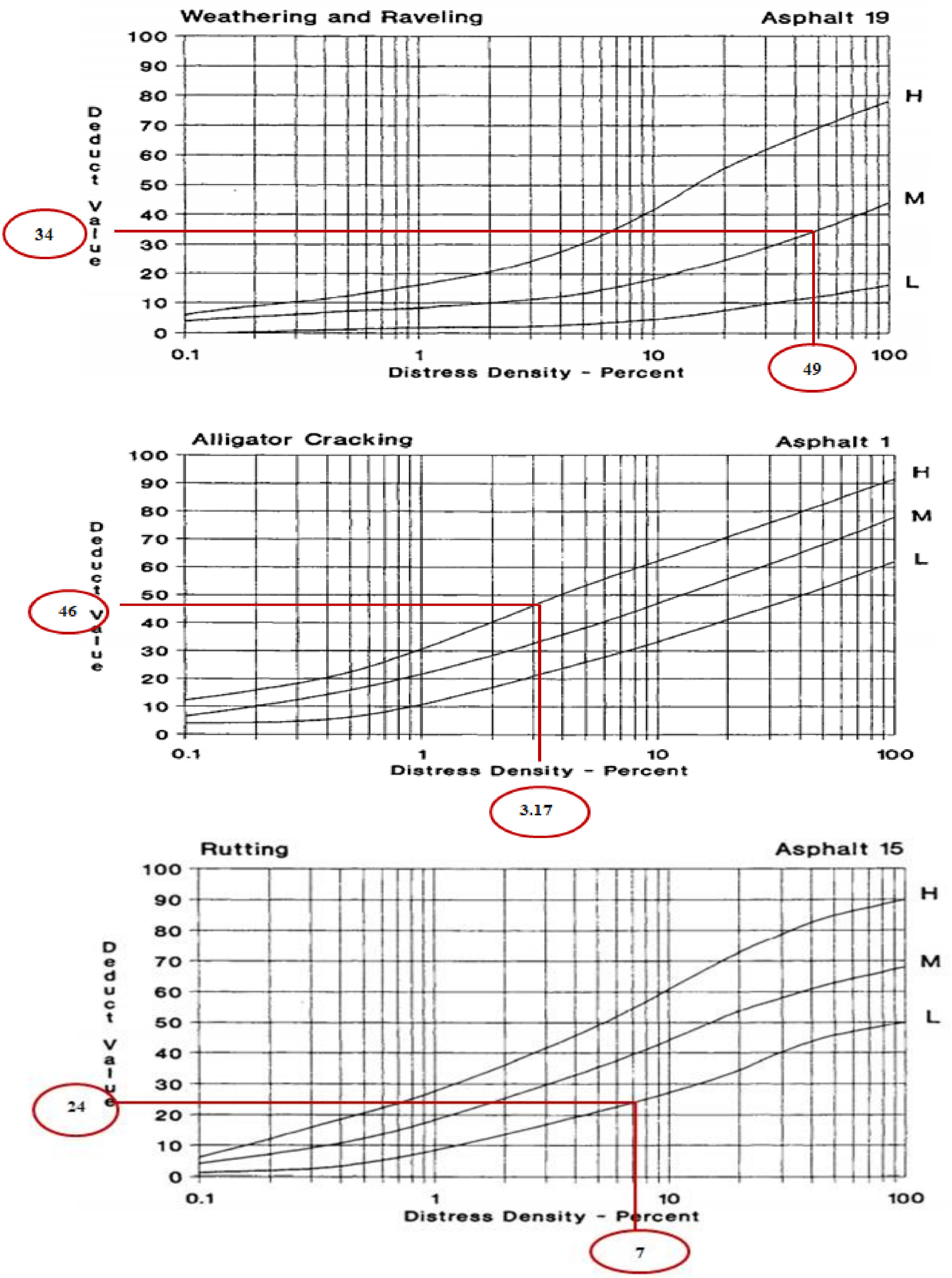

Figure (4-4): Alligator Cracking, Rutting, and Raveling Distress Deduct Value Curves. **[Shahin, 2005] & [ASTM D6433, 2011]**.

Table (4-15): The Procedure of Calculation PCI Manually of Road no. 80-Najaf Section's Unit (No. 9).

AC $m_i = 1 + (\frac{9}{98})(100 - 46) = 5.96 > 3$

#	Deduct Value			TDV	q	CDV
1	46	34	24	104	3	66 Max.
2	46	34	2	82	2	59
3	46	2	2	50	1	50
PCI = 100 – 66 = 34				**Rating**	Poor	

The value of unit's q is equal to 3 < m_i; that have a higher deduct value than 2 (all deducts values are used). Then specify a CDV from the total deduct value and q by looking for the related correction curve, the max. CDV for this unit is 66 as shown in Figure (4-5) which demonstrates the correction curve for asphalt-surfaced road pavements. For all other units, the PCI values were estimated by using hand calculations are shown in Table (4-16).

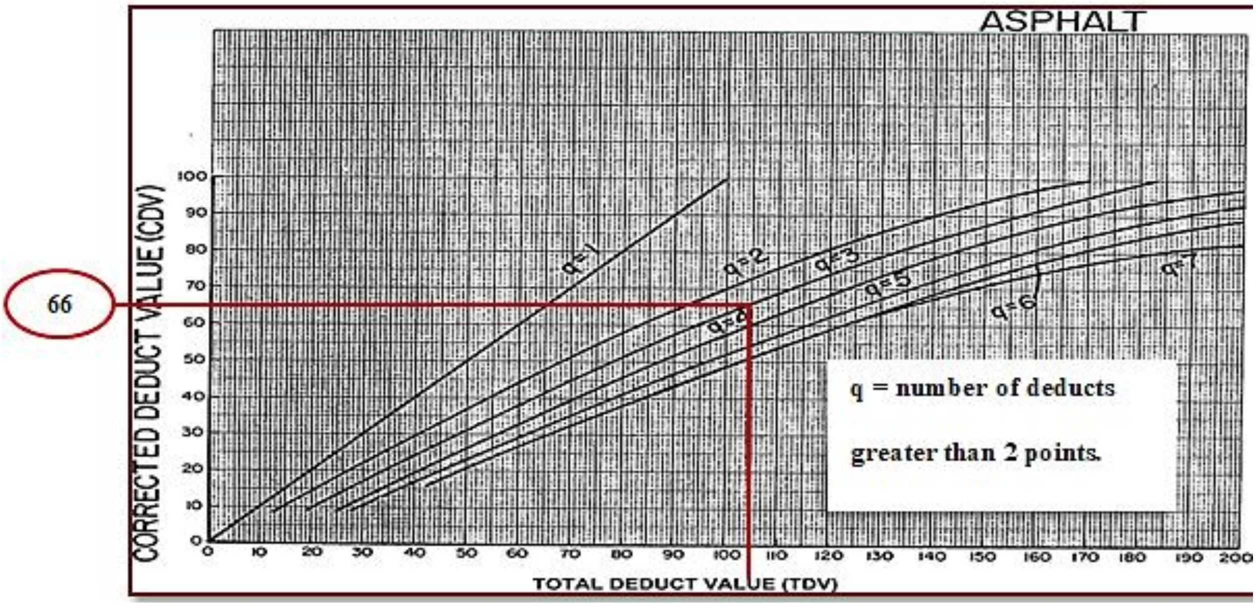

Figure (4-5): Corrected Deduct Value Curves for Asphalt Surfaced Roads. **[Bindiya and Mathakiya, 2018]**.

Table (4-16): The PCI Values Estimation for Each Sample Unit in the (Road no. 80-Najaf) Section in the Study Area.

Unit No.	Distress Severity	Quantity	Density	deduct value	m_i	q	TDV	CDV	PCI
2	Raveling L	286 m^2	95	16	7.43	2	46	34	66
	Longitudinal Cracking M	78 m	26	30		1	32	31	
3	Patching H	10.5 m^2	4	33	7.15	1	33	32	68
4	Alligator Cracking M	16.7 m^2	6	40	6.51	3	84	57.5	42.5
	Potholes L	4	1	18		2	68	50	
	Weathering M	86.45 m^2	29	26		1	44	41	
5	Edge Cracking H	59.54 m	20	32	7.24	2	51	39	61
	Transverse Cracking L	127 m	42	19		1	34	35	
6	Shoving M	5 m^2	2	17	6.69	3	63	39	56
	Polished Aggregate N/A	64 m^2	20	8		2	57	44	
	Raveling M	212 m^2	70	38		1	42	40	
7	Rutting M	43 m^2	14	48	5.78	2	79	58.5	41.5
	Potholes H	1	0.3	31		1	50	50	
8	Patching M	6.5 m^2	2	15	6.42	4	85	48	52
	Weathering H	33 m^2	11	41		3	74	47	
	Transverse Cracking L	99 m	33	16		2	61	45	
	Block Cracking L	51 m^2	17	11		1	47	46.5	
9	Alligator Cracking H	9.5 m^2	3	46	5.96	3	104	66	34
	Rutting L	21 m^2	7	24		2	82	59	
	Raveling M	146.4 m^2	49	34		1	50	50	

The quantity of distress type was measured in square meters, linear meters, or the number of occurrences.

If all surveyed sample units are equal in size, the PCI of this section is calculated by averaging the PCIs of the sample units inspected, as shown in the equation (4.9) **[Shahin, 2005]**:

$$PCI = \frac{PCIs\ for\ all\ sample\ units}{No.of\ sample\ units} \qquad (4.9)$$

PCI = (66+68+42.5+61+56+41.5+52+34) / 8 = 52.63

4.5.2 Distress Evaluation Results Using a Micro PAVER Software

The analysis process was carried out to calculate the PCI as follows:

- Choose the unit of measurement used from the Preferences menu (Metric Units).

- Enter network, branch, and section information using an inventory menu, as shown in Plates (4-2), (4-3), and (4-4) respectively.

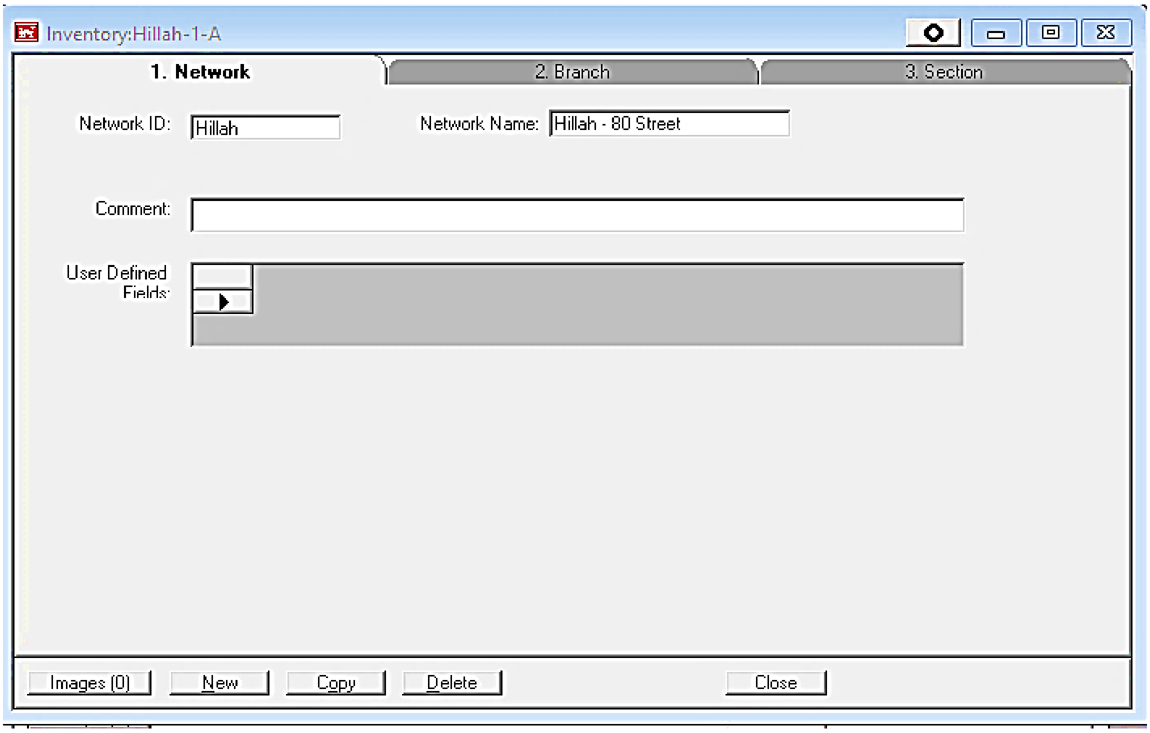

Plate (4-2): Entering Network Data in the Network Menu.

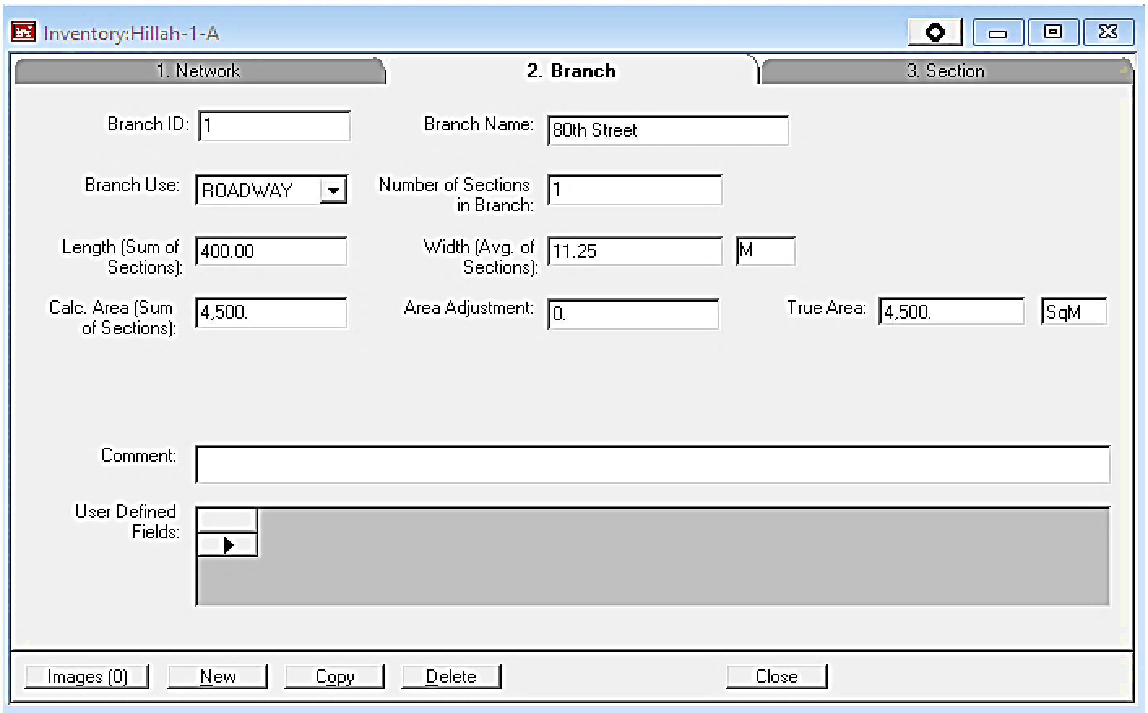

Plate (4-3): Defines Pavement Inventory for the Branch.

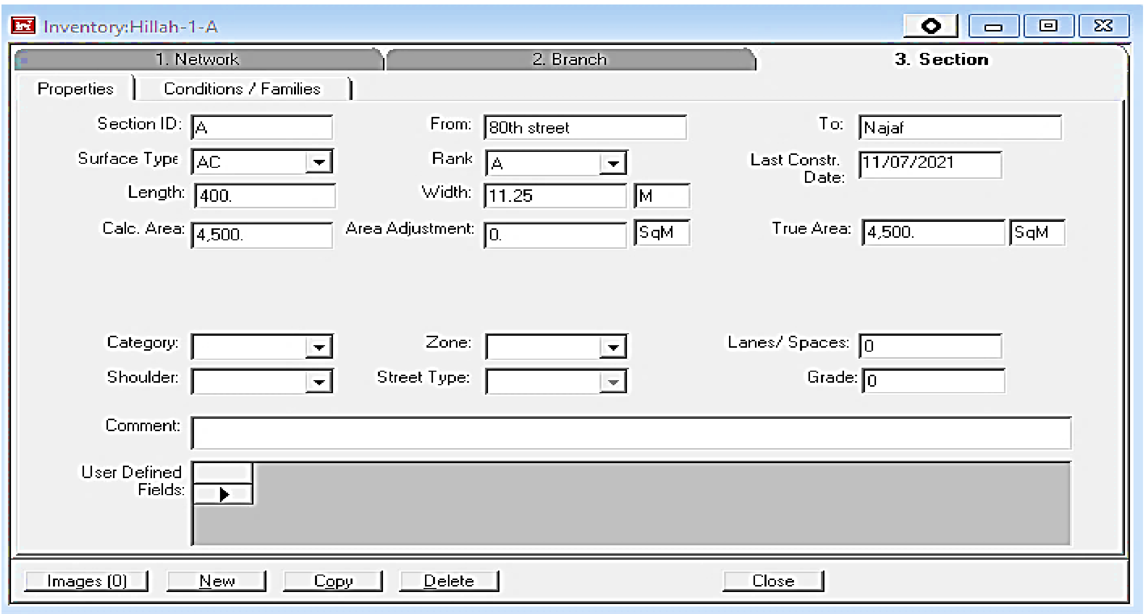

Plate (4-4): Defines Pavement Inventory for the Section.

- Calculating the value of the pavement condition index using the PCI menu:

- **Edit Inspections.** Through this command, you can enter the total number of samples for the examined section, as shown in a Plate (4-5).

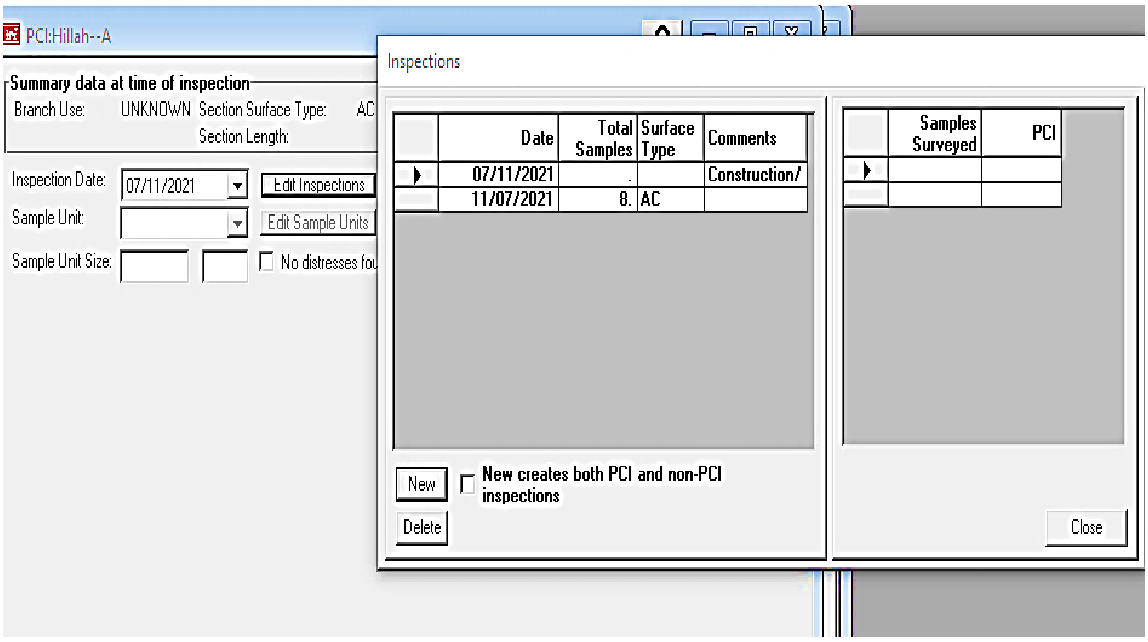

Plate (4-5): The Entry of the Total Number of Inspected Samples in PAVER

5.2.3 Software Using the PCI Menu.

- **Edit Sample Units.** Through this command, the number of inspection samples units is entered with the area of each sample as shown in a Plate (4-6).

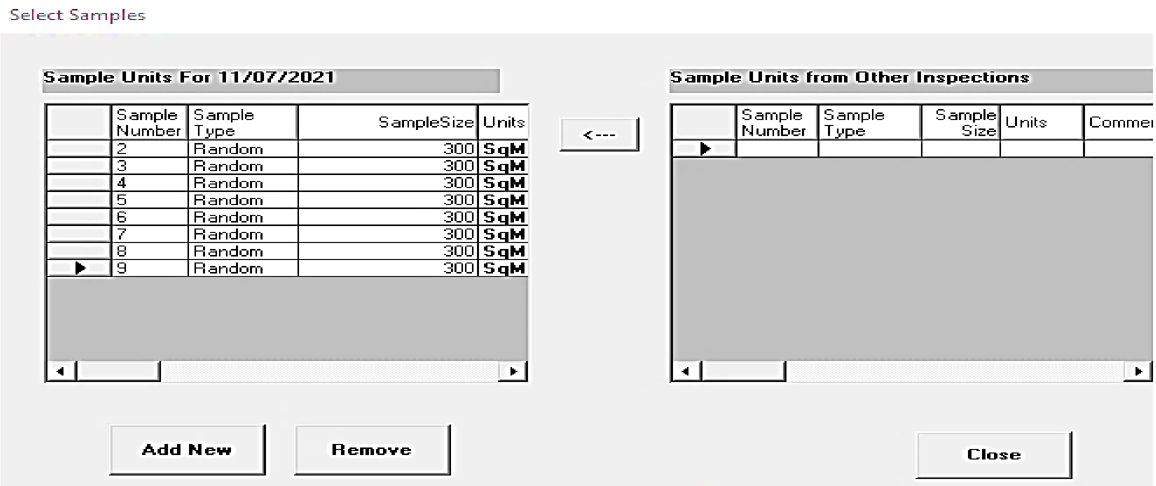

Plate (4-6): The Entry of Inspection Samples Numbers with the Area of Each Sample in PAVER 5.2.3 Software Using the PCI Menu.

- **Calculate Conditions.** From the PCI menu, add distresses type, quantity, and severity for all inspected units as shown in a Plate (4-7), then Calculate Conditions command to determine the PCI scale & rating.

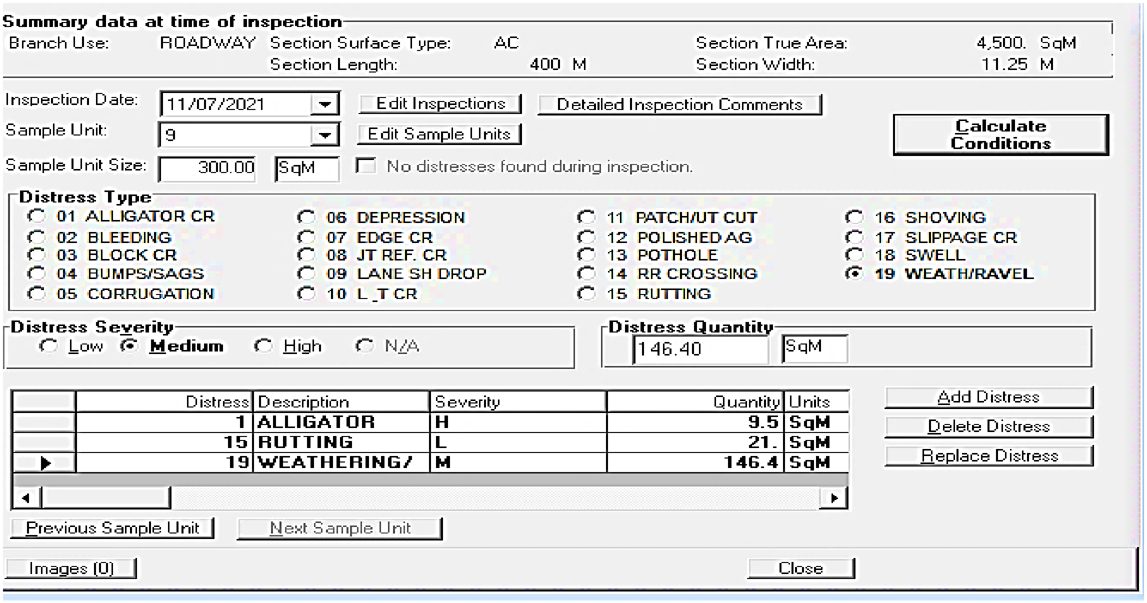

Plate (4-7): The Entry of Distress Type, Quantity, and Severity Level of Inspected Samples Units in PAVER 5.2.3.

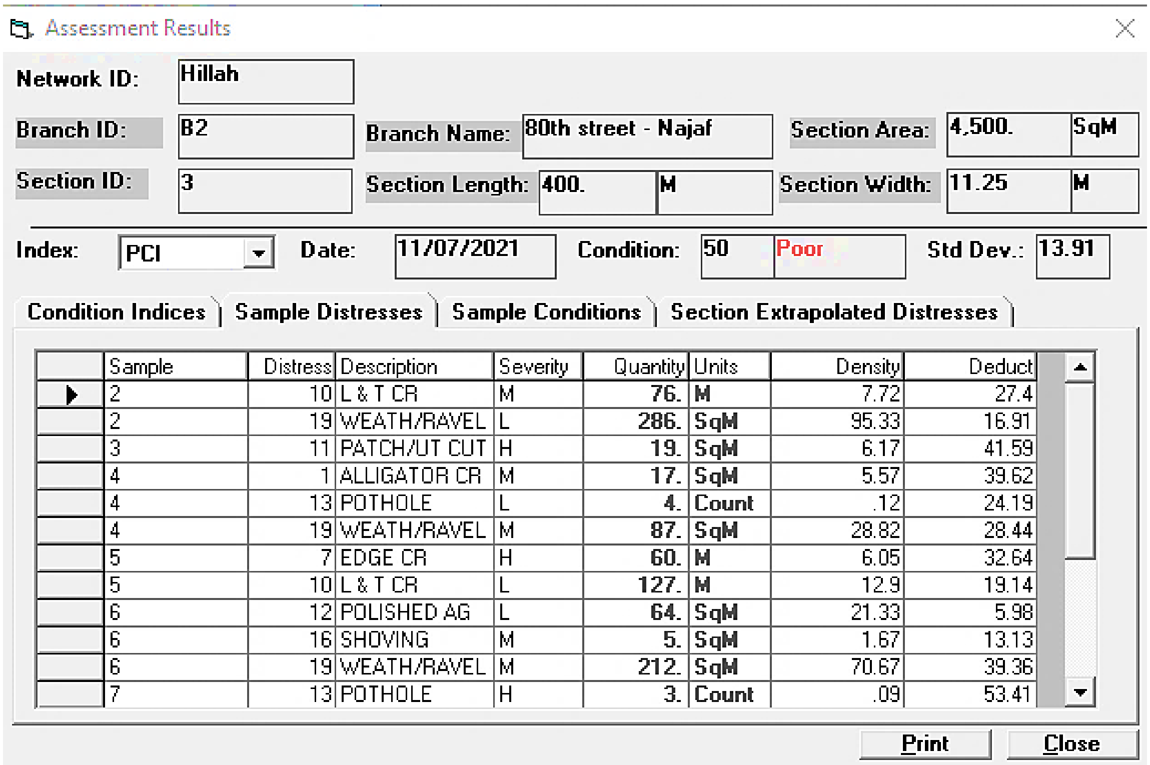

Plate (4-8): The Value of the PCI and the Assessment of Pavement Condition of (Road no. 80-Najaf) Section Using Micro PAVER 5.2.3 Software.

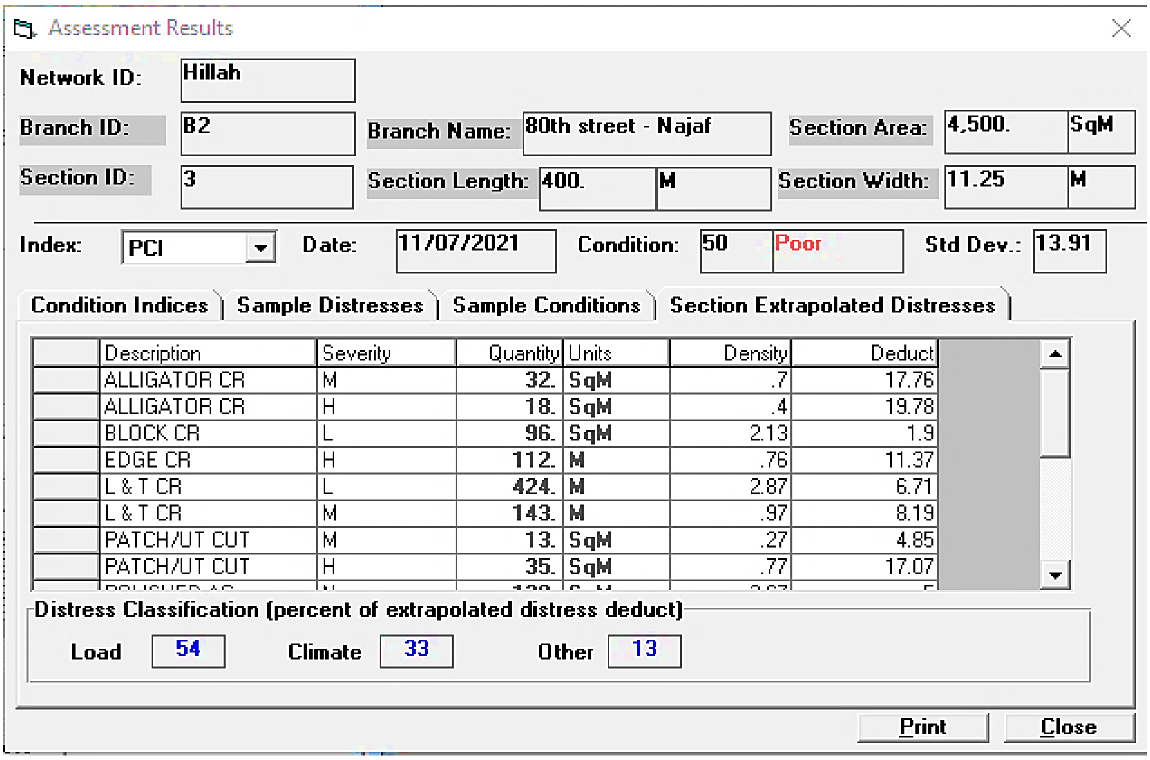

Plate (4-9): The Distress Causes for (Road no. 80-Najaf) Section Using Micro PAVER 5.2.3 Software.

The condition of the road is determined by the value of the PCI, as shown in Figure (4-6) below. The PCI values results were estimated by using Micro PAVER of study area sections for both directions, which are shown clearly in Appendix B. The Micro PAVER software is characterized by ease of handling, saving time and effort, as well as providing results with accuracy and high efficiency. Therefore, it is considered one of the most important modern programs used to develop road management and maintenance systems.

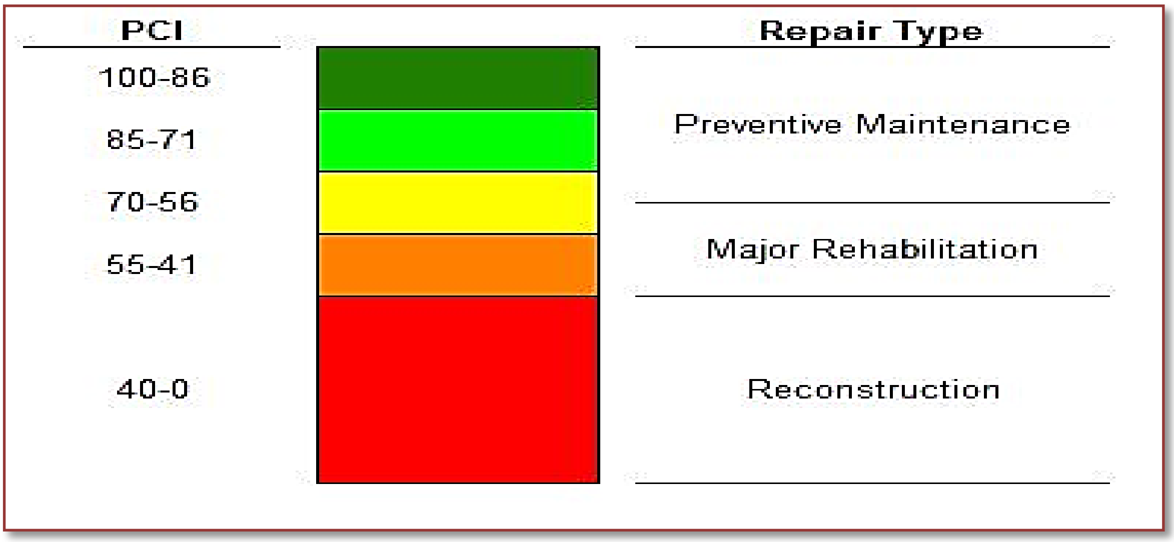

Figure (4-6): PCI Scale Vs M & R. **[Kyle Schauer et al., 2015]** & **[Kırbaş and Karaşahin, 2017]**.

The resulting PCI of (Hilla-Najaf) roadway section indicated that 50% of the pavement surface area have ″Good″ condition, 25% have ″Fair″ condition, 14% have ″Very Good″ condition, and 11% have ″Poor″ condition with an average PCI of 57, as shown in Figure (4-7). For the road no. 80 section, the resulting PCI indicated that 46% of the pavement surface area section have ″Good″ condition, 27% have ″Fair″ condition, and 27% have ″Poor″ condition with an average PCI of 48.5, as shown in Figure (4-8).

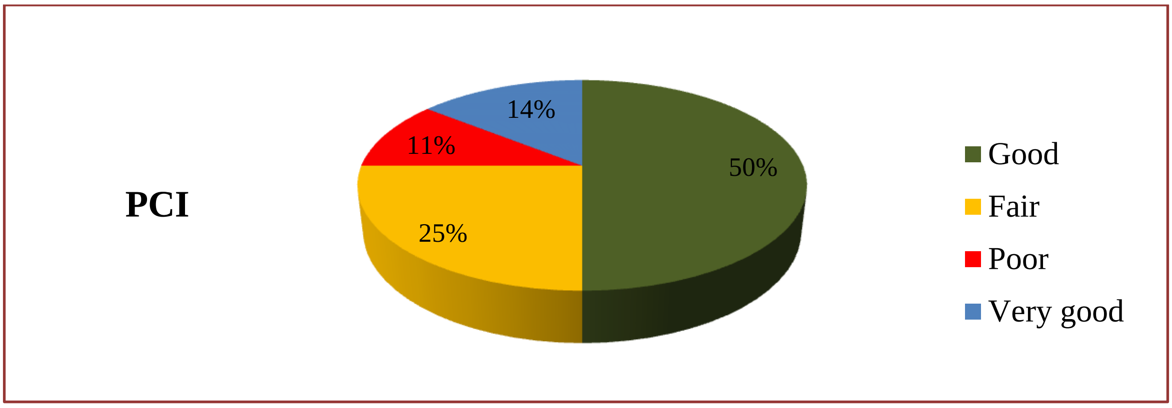

Figure (4-7): PCI Distribution for the (Hilla-Najaf) Roadway Section at Inspection.

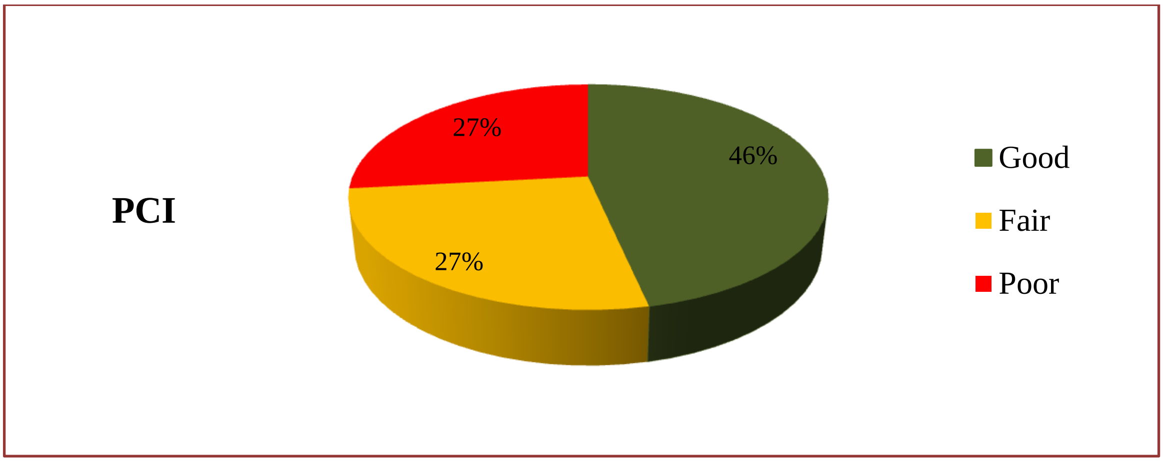

Figure (4-8): PCI Distribution for the Road no. 80 Section at Inspection.

4.6 Results Discussion

In this section, we review the research results and discuss them as possible.

4.6.1- After performing the calculations of the ESAL according to traffic study requirements, the axle loads used for road, and the percentage of heavy trucks P_T, the thickness of pavement layers was determined using the AASHTO 1993 design method for both sections of the study area. The proposed thickness of asphalt and subbase layers for Hilla-Najaf section is (D_2=33 & D_3=34) cm respectively while the implemented thickness is (D_2=16 & D_3=25) cm for asphalt and subbase layers respectively; and this is not commensurate with the axle loads that used this roadway.

For Road no. 80 section the calculated thickness of asphalt and subbase layers is (D_2=33, D_3=32) cm respectively based on axle loads that used this study section; while the implemented thickness is (D2=20 & D3=25) cm for asphalt and subbase layers respectively. So, insufficient thickness to carry the traffic loads used for the road, and this illustrates the appearance of various types of distresses in the asphalt layer and occurrence of failure.

4.6.2- After conducting the evaluation process for the section (Road 80-Najaf), it was found that the value of the PCI using the PAVER method manually is (52.63), while the value calculated using the Micro PAVER software is (50) and accordingly, the two values reflect a poor condition of the pavement. The causes of pavement distresses can be classified into three general categories: (1) Load Related, (2) Climate/Durability Related, and (3) Other. As shown in Plate (4-9) that most of the distress observed on the pavement was due to loads are 54%, 33% are due to the environment, while 13% are due to other reasons according to the Micro PAVER software classification method. Figure (4-9) shows distress classification in this study section.

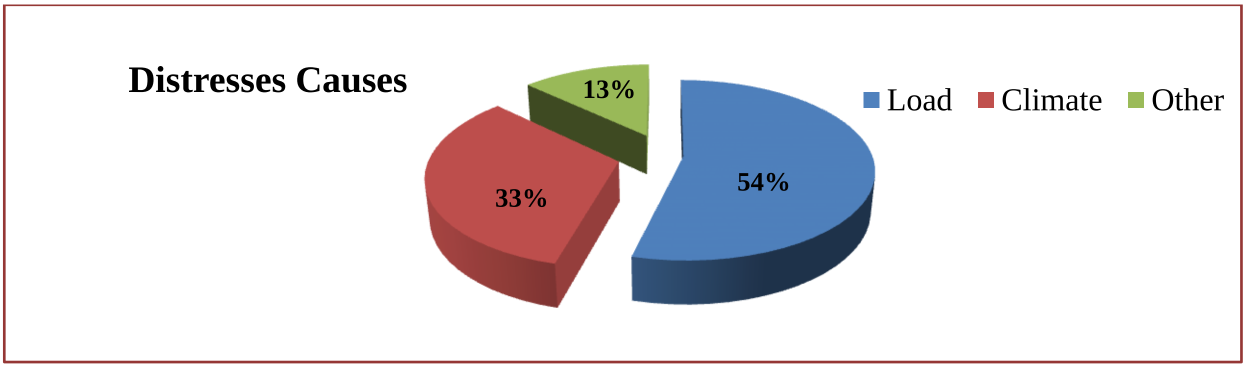

Figure (4-9): Percentage of Pavement Distress Causes for the (Road no. 80-Najaf) Section.

4.6.3- The resulting PCI of (Hilla-Najaf) roadway and road no. 80 is (57 & 48.5) respectively. The two values reflect a fair condition of the pavement. The proposed maintenance type for study sections based on PCI scale is major rehabilitation.

Chapter Five

Conclusions and Recommendations

Chapter Five

Conclusions and Recommendations

5.1 Conclusions

Depending on the current research, the findings were written down:

5.1.1- The study concludes using AASHTO 1993 design method that the proposed thickness of the pavement layers for the Hilla-Najaf roadway section where it implements by following steps under the technical specifications of State Commission of Roads and Bridges SCRB:

- Brushes asphalt surface layer with a thickness of 6 cm, (M.S ≥ 8 KN).
- A binder course with a thickness of 7 cm, (M.S ≥ 7 KN), and a Tack Coat material is sprayed before the brush.
- A base course with a thickness of 20 cm brushes in two layers; 10 cm for each layer, (M.S ≥ 5 KN), and a Prime Coat material is sprayed before the brush.
- Subbase layers with a thickness of 34 cm implement in the form of two layers.

5.1.2- The study determines that the thickness of the pavement layers required for the road no. 80 section implements as follows under SCRB:

- Brushes asphalt surface layer with a thickness of 6 cm, (M.S ≥ 8 KN).
- A binder course with a thickness of 7 cm, (M.S ≥ 7 KN), and a Tack Coat material is sprayed before the brush.
- A base course with a thickness of 20 cm brushes in two layers; 10 cm thickness for each layer, (M.S ≥ 5 KN), and a Prime Coat material is sprayed before the brush.
- Subbase layers with a thickness of 32 cm implement in the form of two layers.

5.1.3- When comparing the thickness of the layers concluded by the study with the thickness of the actually implemented layers , the study found that it is less than the prescribed thickness, which explains the occurrence of different stresses in the pavement layers as well as many different failure distresses.

5.1.4- By using Highway Capacity System (HCS 2010) software the study concludes that the LOS for road no. 80 section, type D. And the Hilla-Najaf section also operates in LOS D for existing conditions for study area sections.

5.1.5- Most of the distresses of different types appeared through studies of pavement surface distress type, amount, and severity so it can be concluded that the Pavement Condition Index. The PCI rate of the inspected samples ranged between poor and very good (37-80) in the Hilla-Najaf section, with an average PCI = 57 which reflects fair condition for this road section in both directions. In the road no. 80 section, the PCI ranged between (28-68) for inspected samples with an average PCI = 48.5 which reflects a poor condition of the pavement.

5.1.6- By comparing the results obtained from the Micro PAVER computer program and the manually PAVER method, they are not very different, but Micro PAVER software prefers because it saves time, effort when performing the analysis, and gives results in a shorter time as it calculates the values from the schemas.

5.2 Recommendations

5.2.1- The study recommends the adoption of the legal axle loads. Surveying the roadway alignment and adopting the results of engineering analysis based on the axle loads used for the road are the most important design requirements, taking into account the growth rates and the increase in the heavy vehicles percentages.

5.2.2- Since the pavement distresses are highly dependent on the axle loads and strain level, the State Commission of Roads and Bridges SCRB in Iraq should install weighing stations at the entrances of the cities to restrict the heavy loads.

5.2.3- The study recommends the application of the Micro PAVER system to manage the maintenance of road networks in Hilla city.

5.2.4- Evaluation of the road condition and setting standards for the approval of maintenance types by specialized departments at specific times with documentation. Because neglecting it leads to great financial losses in the future due to the aggravation of the situation.

5.2.5- The application of intelligent transportation systems in the city of Hilla, in particular, for its urgent need in managing traffic, parking lots, enhancing security and traffic safety, in addition to reducing the level of pollution. The most important technical requirements are high-quality surveillance cameras, electronic meters, sensors, etc.

5.2.6- Activate the shoulders function, especially the paved ones, and prevent traffic from encroaching them because of their additional structural support for the road and increase the life expectancy.

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Appendix A

Traffic Volumes of the Study Sections during Data Collection Period

Traffic Volumes for the Najaf-Hilla Roadway Section

Table (A-1): Traffic Volumes Data Collection for the Najaf-Hilla Roadway Section on (18/1/21).

Time	PC	Bus	Heavy Vehicles							
			Type 2	Type 3	Type 2-S2	Type 3-S3	Type 3-S2	Type 3-3	Type 3-S1-2	Type 2-3
7:30 - 7:45	978	3	55	10	2	4	1			
7:45 - 8:00	1293	7	88	17	14	11		1	2	
8:00 - 8:15	2034	12	97	28	8	12		1		2
8:15 - 8:30	2124	16	184	17	19	13	2		4	1
8:30 - 8:45	2402	13	259	47	14	20	1	1	5	
8:45 - 9:00	2198	9	133	29	13	15	2		1	2
9:00 - 9:15	1979	7	108	19	9	11		1		
9:15 - 9:30	1843	9	99	13		14	3		4	
9:30 - 9:45	1752	8	93	15	2		4	2		1
9:45 - 10:00	1539	7	76	7	11	18		1	5	
10:00 - 10:15	1387	3	45	20	6	16	3		4	
10:15 - 10:30	1298	6	70	11	8	8	4			
10:30 - 10:45	986	2	94	22	17	12	1		4	3
10:45 - 11:00	998	4	101	19	9	11	2		1	
11:00 -11:15	977	5	82	32	4	9		1		2
11:15 - 11:30	949	3	101		5	7			3	3
11:30 - 11:45	997	5	96	4	1	6	1		2	3
11:45 - 12:00	871	2	73	13	7	8	4			1
12:00 - 12:15	858	4	90	24	10			1	2	
12:15 - 12:30	908	1	103	3	2	5	2		2	
12:30- 12:45	810	9	59	7	1	7		1		1
12:45 - 1:00	879	7	78	6	2	3	3	1		2
1:00 - 1:15	944	6	86	13		15	2		2	1
1:15 - 1:30	1364	8	110	9	5	8		2		1
1:30 - 1:45	2056	7	131	20	9	12	2		2	4
1:45 - 2:00	2105	5	116	11		8	3	1	1	
2:00 - 2:15	2120	9	124	6	3	11			2	3
2:15 -2:30	1923	11	28	17	7	13	5	2	2	1
2:30 -2:45	994	7	49	10	4		4		2	3
2:45 -3:00	981	1	60	9		9		1	3	4
3:00 - 3:15	902	2	54	4	1	3	2	1		
3:15 - 3:30	880	2	33	6	3	7	1			2

Table (A-2): Traffic Volumes Data Collection for the Najaf-Hilla Roadway Section on (19/1/21).

Time	PC	Bus	Heavy Vehicles							
			Type 2	Type 3	Type 2-S2	Type 3-S3	Type 3-S2	Type 3-3	Type 3-S1-2	Type 2-3
7:30 - 7:45	481	2	103	11	3	6			1	
7:45 - 8:00	902	3	72	11	9		2			
8:00 - 8:15	1024	12	98	19		11	3	1	1	
8:15 - 8:30	1192	8	79	20	3	7			2	
8:30 - 8:45	1213	4	106	11	4	2				2
8:45 - 9:00	1235	5	124	11	2	5			1	
9:00 - 9:15	999	3	184	11	2		1			1
9:15 - 9:30	989	10	106	8		7			1	
9:30 - 9:45	994	3	199	6	1	5				2
9:45 - 10:00	965	3	182	7	2	6		1		
10:00 - 10:15	937	2	195	4		10	2		1	
10:15 - 10:30	926	4	141	11		12	4			
10:30 - 10:45	889	2	166	9	1	4				3
10:45 - 11:00	882	3	124	8	2	6			1	
11:00 -11:15	869	5	110	5	4	10		1		1
11:15 - 11:30	860	3	105	8	2	8			2	
11:30 - 11:45	855	6	96	4	1	12				3
11:45 - 12:00	891	5	70	9		4	2			
12:00 - 12:15	838	7	93	8	3	6		1	1	
12:15 - 12:30	887	7	101	7	1	9	1			2
12:30- 12:45	890	8	89	7		4				1
12:45 - 1:00	913	9	78	11	2	1		1		2
1:00 - 1:15	940	12	93	8		9			2	
1:15 - 1:30	966	10	104	5	1	9	1			
1:30 - 1:45	1031	11	113	10	8	12	2			3
1:45 - 2:00	1047	7	119	11	3	10				2
2:00 - 2:15	1036	11	121	9	3	13	1		2	2
2:15 -2:30	1158	8	146	16	12	11	1		1	1
2:30 -2:45	1122	8	122	14		4			1	
2:45 -3:00	1101	7	106	10		15	1		2	
3:00 - 3:15	1058	3	112	17	1	3		1		1
3:15 - 3:30	981	6	96	20	2	9	1			

Table (A-3): Traffic Volumes Data Collection for the Najaf-Hilla Roadway Section on (20/1/21).

Time	PC	Bus	Heavy Vehicles							
			Type 2	Type 3	Type 2-S2	Type 3-S3	Type 3-S2	Type 3-3	Type 3-S1-2	Type 2-3
7:30 - 7:45	912	3	103	8	1	4				2
7:45 - 8:00	1127	5	142	6	2	7	1		1	
8:00 - 8:15	1256	15	199	12	4	18		1		1
8:15 - 8:30	1372	14	219	39	15	13	3		4	2
8:30 - 8:45	2294	12	216	43	18	21	2		5	2
8:45 - 9:00	1964	6	175	8	3	7	2		1	
9:00 - 9:15	2074	5	161	10		6			2	3
9:15 - 9:30	1383	7	203	9	8		2			
9:30 - 9:45	1049	4	198	8	3	11	1		1	
9:45 - 10:00	983	5	173	12	10	9	2		3	
10:00 - 10:15	911	3	147	11	2		2		1	
10:15 - 10:30	877	4	125	7	2	13				4
10:30 - 10:45	849		113	14	4	9		1	2	
10:45 - 11:00	891	3	98	2	4	10	1		1	
11:00 -11:15	856	7	87	16	5	15		1	2	3
11:15 - 11:30	787	2	74	8	8		4			1
11:30 - 11:45	766	5	69	7	10	7	3		1	
11:45 - 12:00	699	3	81	6	5	11		2		
12:00 - 12:15	704		77	3	7	4	1			2
12:15 - 12:30	710	8	103	11	2	8	2			
12:30- 12:45	734	4	114	9		9			2	1
12:45 - 1:00	793	6	108	7		6	1			3
1:00 - 1:15	997	7	99	6	5	13	2	1		
1:15 - 1:30	1094	8	106	13	5	9		2	1	1
1:30 - 1:45	1415	9	141	11	9	7		2		
1:45 - 2:00	2375	12	127	7	3	8			1	2
2:00 - 2:15	2103	7	104	8	6	5			1	1
2:15 -2:30	1271	9	98	3	4		3		1	2
2:30 -2:45	1014	11	79	9	6			1	1	3
2:45 -3:00	982	6	88	12	2	13	1			
3:00 - 3:15	924	4	95	8		2	1		2	2
3:15 - 3:30	867	9	71	10	1	7	3		1	

Traffic Volumes for the Road 80-Najaf Section

Table (A-4): Traffic Volumes Data Collection for the Road no. 80-Najaf Section on (29/3/21).

Time	PC	Bus	Heavy Vehicles							
			Type 2	Type 3	Type 2-S2	Type 3-S3	Type 3-S2	Type 3-3	Type 3-S1-2	Type 2-3
7:30 - 7:45	796	3	9	5	2	6	1			1
7:45 - 8:00	1089	4	14	12	7	9		1	2	1
8:00 - 8:15	1812	5	56	24	12	18			4	
8:15 - 8:30	2434	9	97	41	16	22	3	1		5
8:30 - 8:45	2803	11	108	47	18	20	2		3	
8:45 - 9:00	2957	14	112	56	22	14	1		4	
9:00 - 9:15	3271	8	195	54	23	31	3		2	1
9:15 - 9:30	2368	5	96	33	5	16	2		2	
9:30 - 9:45	1967	6	74	24	13	9			4	2
9:45 - 10:00	1659	2	13	6		6		1	2	
10:00 - 10:15	1438	3	9	4	3	7			3	1
10:15 - 10:30	1518	4	10	8	1	9	1	2		
10:30 - 10:45	986	3	25	6	2	3			1	1
10:45 - 11:00	896	2	36	11	1	7	1		2	
11:00 -11:15	859	8	30	14	8	9	2		2	
11:15 - 11:30	914	2	18	3	3		2		1	1
11:30 - 11:45	942	3	13	4	2	6	2	1	1	
11:45 - 12:00	968	5	9	5	3	7			2	3
12:00 - 12:15	902	6	7	4	1	4				1
12:15 - 12:30	983	4	11	5		8			2	
12:30- 12:45	940	3	10	3	4	9	2			1
12:45 - 1:00	878	4	19	8	5	8	1	1	2	
1:00 - 1:15	994	7	14	3	2	6				1
1:15 - 1:30	925	6	20	3		6	1			
1:30 - 1:45	1272	7	23	12	2	5	2		1	
1:45 - 2:00	1726	5	19	9		9	2			1
2:00 - 2:15	2158	8	33	14	3	12	2		2	1
2:15 -2:30	2473	3	30	26	4	7		1	1	
2:30 -2:45	2369	6	19	15		7	1		4	2
2:45 -3:00	1648	4	16	8	2	6	2		1	
3:00 - 3:15	1157	3	9	5		4				2
3:15 - 3:30	962	3	10	6	2	9	2		1	1

Table (A-5): Traffic Volumes Data Collection for the Road no. 80-Najaf Section on (30/3/21).

Time	PC	Bus	Heavy Vehicles							
			Type 2	Type 3	Type 2-S2	Type 3-S3	Type 3-S2	Type 3-3	Type 3-S1-2	Type 2-3
7:30 - 7:45	741	3	10	8	2	6	2			
7:45 - 8:00	895	6	17	20	9	9		1		
8:00 - 8:15	943	4	21	12	6	14	1		1	2
8:15 - 8:30	982	9	32	22	2	18	3			2
8:30 - 8:45	992	8	37	19	7	11			4	1
8:45 - 9:00	971	7	25	14	6	12	1		2	
9:00 - 9:15	934	11	31	9	7	9	1			
9:15 - 9:30	816	5	15	4	3	7			2	
9:30 - 9:45	862	6	13	6		3		2		1
9:45 - 10:00	875	5	9	7	1	4			3	1
10:00 - 10:15	848	3	11	5	3	10	1		1	2
10:15 - 10:30	883	4	19	8		12	2		1	1
10:30 - 10:45	794	6	22	13	3	9		2		3
10:45 - 11:00	879	4	19	8	2	4			2	
11:00 -11:15	799	6	30	17	2	8	3		1	
11:15 - 11:30	784	4	10		4	9	1		2	
11:30 - 11:45	732	5	23	9	2	7	3		1	2
11:45 - 12:00	688	6	12	7	1	6	1		1	1
12:00 - 12:15	827	4	14	5	3	11		2		
12:15 - 12:30	758	7	19	8	1	6			3	1
12:30- 12:45	740	7	9	10	2	6	1			1
12:45 - 1:00	672	4	16	7	1	11	3			2
1:00 - 1:15	894	9	24	8	1	9			2	1
1:15 - 1:30	813	10	33	15	3	7	1			3
1:30 - 1:45	755	12	10	6		8	3		2	
1:45 - 2:00	787	7	13	4	1	9	1		1	1
2:00 - 2:15	822	6	9	5	1	10		1		4
2:15 -2:30	857	7	15	4	1	8			1	1
2:30 -2:45	938	3	23	6		7	1		2	1
2:45 -3:00	776	5	12	14	2	8	1		1	
3:00 - 3:15	763	2	9	6		9				2
3:15 - 3:30	677	3	10	5	1	7	1		1	

Table (A-6): Traffic Volumes Data Collection for the Road no. 80-Najaf Section on (31/3/21).

Time	PC	Bus	Heavy Vehicles							
			Type 2	**Type 3**	**Type 2-S2**	**Type 3-S3**	**Type 3-S2**	**Type 3-3**	**Type 3-S1-2**	**Type 2-3**
7:30 - 7:45	653	3	11	9	4	6			1	
7:45 - 8:00	741	5	19	13	3	9	1			1
8:00 - 8:15	876	3	23	11	5	8			1	
8:15 - 8:30	989	10	38	18	6	13		1		2
8:30 - 8:45	1013	4	27	21	8	10	1		1	
8:45 - 9:00	1197	6	34	16	7	12			1	
9:00 - 9:15	994	4	24	2		2				1
9:15 - 9:30	888	5	27	14	4	11			3	
9:30 - 9:45	896	7	19	12	3	9				2
9:45 - 10:00	879	2	25	16	2	5		1	2	
10:00 - 10:15	858	4	19	17	4	18	1		3	
10:15 - 10:30	826	6	23	12	10	9	1			2
10:30 - 10:45	794	3	31	15	8	14		1		1
10:45 - 11:00	799	2	18	12	3	11			2	
11:00 -11:15	787	9	25	9	6	17	2		1	
11:15 - 11:30	694	4	11	14	9	15	1			1
11:30 - 11:45	732	8	20	17	5	9	3		1	3
11:45 - 12:00	688	6	29	14	4	10	2		1	1
12:00 - 12:15	723	4	14	21	6	12				
12:15 - 12:30	786	5	11	4		7			2	
12:30- 12:45	640	7	9	5	1	6				1
12:45 - 1:00	677	6	12	7	3	10		1		2
1:00 - 1:15	694	9	14	9	4	7			2	1
1:15 - 1:30	711	10	19	5	2	10	1			
1:30 - 1:45	725	8	23	11	1	6	2		1	
1:45 - 2:00	797	7	13	6	3	11	2		2	1
2:00 - 2:15	850	10	16	9	5	14	3		2	2
2:15 -2:30	883	9	22	14	2	11		1	1	1
2:30 -2:45	891	6	29	16	6	8	2		1	3
2:45 -3:00	775	7	13	18	7	12	1		2	
3:00 - 3:15	763	3	11	8		4				2
3:15 - 3:30	678	2	7	5	1	9	1		2	1

Appendix B

Pavement Distress Data Collection

Table (B-1): Distress Inspection for the Hilla-Najaf Roadway Section.

Sample Unit No.	Distress Type	Level of Severity			Quantity
		L	M	H	
2	Raveling		√		83.7 m^2
	Transverse Cracking	√			33 m
10	Raveling		√		184.68 m^2
	Transverse Cracking		√		49 m
18	Potholes		√		3
26	Raveling			√	99.65 m^2
	Bleeding	√			27.6 m^2
34	Edge Cracking		√		64.73 m
42	Transverse Cracking			√	36 m
50	Rutting	√			77.13 m^2
58	Raveling			√	79.33 m^2
	Patching		√		3 m^2
66	Alligator Cracking		√		15.7 m^2
	Raveling		√		68 m^2
	Potholes	√			2
74	Transverse Cracking			√	14 m
	Edge Cracking		√		73 m
82	—				—
90	Raveling		√		218 m^2
	Patching	√			4.2 m^2
98	Transverse Cracking		√		68 m
	Rutting	√			34 m^2
	Alligator Cracking	√			11 m^2
106	Transverse Cracking			√	22 m
	Raveling		√		68 m^2
	Potholes		√		2
114	Alligator Cracking		√		38.4 m^2
	Raveling	√			87.9 m^2

Table (B-2): Distress Inspection for the Najaf-Hilla Roadway Section.

Sample Unit No.	Distress Severity	Level of Severity			Quantity
		L	M	H	
2	Raveling		√		198 m^2
10	Edge Cracking	√			68.85 m
	Transverse Cracking		√		80 m
18	Potholes		√		3
26	Raveling		√		87 m^2
	Rutting	√			41 m^2
34	Transverse Cracking			√	62.7 m
42	—				—
50	Alligator Cracking		√		28.4 m^2
58	Raveling			√	76 m^2
	Patching			√	3 m^2
66	Polished Aggregate	N/A			47 m^2
	Transverse Cracking		√		148.9 m
74	Edge Cracking		√		114 m
82	Patching	√			8.2 m^2
	Raveling			√	86 m^2
90	Depression		√		25.91 m^2
98	Alligator Cracking			√	11 m^2
	Raveling	√			73.8 m^2
106	Transverse Cracking		√		65 m
114	Block Cracking	√			18.4 m^2
	Potholes			√	1

Table (B-3): Distress Inspection for the Section (Road no. 80-Najaf).

Sample Unit No.	Distress Severity	Level of Severity			Quantity
		L	M	H	
2	Raveling	√			286 m^2
	Longitudinal Cracking		√		78 m
3	Patching			√	10.5 m^2
4	Alligator Cracking		√		16.7 m^2
	Potholes	√			4
	Weathering		√		86.45 m^2
5	Edge Cracking			√	59.54 m
	Transverse Cracking	√			127 m
6	Shoving		√		5 m^2
	Polished Aggregate	N/A			64 m^2
	Raveling		√		212 m^2
7	Rutting		√		43 m^2
	Potholes			√	1
8	Patching		√		6.5 m^2
	Weathering			√	33 m^2
	Transverse Cracking	√			99 m
	Block Cracking	√			51 m^2
9	Alligator Cracking			√	9.5 m^2
	Rutting	√			21 m^2
	Raveling		√		146.4 m^2

Table (B-4): Distress Inspection for the Section (Najaf-Road no. 80).

Sample Unit No.	Distress Severity	Level of Severity			Quantity
		L	M	H	
2	Weathering			√	42 m^2
	Alligator Cracking	√			8.8 m^2
3	Transverse Cracking		√		69 m
	Depression	√			33 m^2
4	Patching			√	12.8 m^2
	Shoving		√		4.5 m^2
5	—				—
6	Potholes		√		2
	Raveling		√		124 m^2
7	Rutting	√			26 m^2
	Weathering		√		168 m^2
	Alligator Cracking			√	11.6 m^2
8	Transverse Cracking			√	77 m
	Block Cracking		√		44 m^2
	Bleeding	√			36 m^2
9	Patching		√		9.6 m^2
	Potholes			√	3
	Polished Aggregate	N/A			18 m^2
	Weathering		√		277.9 m^2

PCI Values Results Using PAVER Software

Table (B-5): PCI Values of the Hilla-Najaf Roadway Section.

No.	Sample No.	Sample Unit Area (m^2)	PCI	Rating
1	2	292	70	Good
2	10	292	56	Good
3	18	292	67	Good
4	26	292	46	Fair
5	34	292	80	Very good
6	42	292	62	Good
7	50	292	61	Good
8	58	292	38	Poor
9	66	292	48	Fair
10	74	292	68	Good
11	82	292	—	—
12	90	292	58	Good
13	98	292	50	Fair
14	106	292	49	Fair
15	114	292	57	Good
PCI = 56				

Table (B-6): PCI values of the Najaf-Hilla roadway Section.

No.	Sample No.	Sample Unit Area (m^2)	PCI	Rating
1	2	292	61	Good
2	10	292	70	Good
3	18	292	67	Good
4	26	292	56	Good
5	34	292	44	Fair
6	42	292	—	—
7	50	292	54	Fair
8	58	292	39	Poor
9	66	292	62	Good
10	74	292	75	Very good
11	82	292	37	Poor
12	90	292	71	Very good
13	98	292	50	Fair
14	106	292	74	Very good
15	114	292	64	Good
PCI = 58.86				

Average of PCI = 57

Table (B-7): PCI Values of the Road no. 80-Najaf Section.

No.	Sample No.	Sample Unit Area (m2)	PCI	Rating
1	2	300	66	Good
2	3	300	68	Good
3	4	300	41	Fair
4	5	300	61	Good
5	6	300	56	Good
6	7	300	40	Fair
7	8	300	50	Fair
8	9	300	34	Poor
PCI = 50				

Table (B-8): PCI Values of the Najaf-Road no. 80 Section.

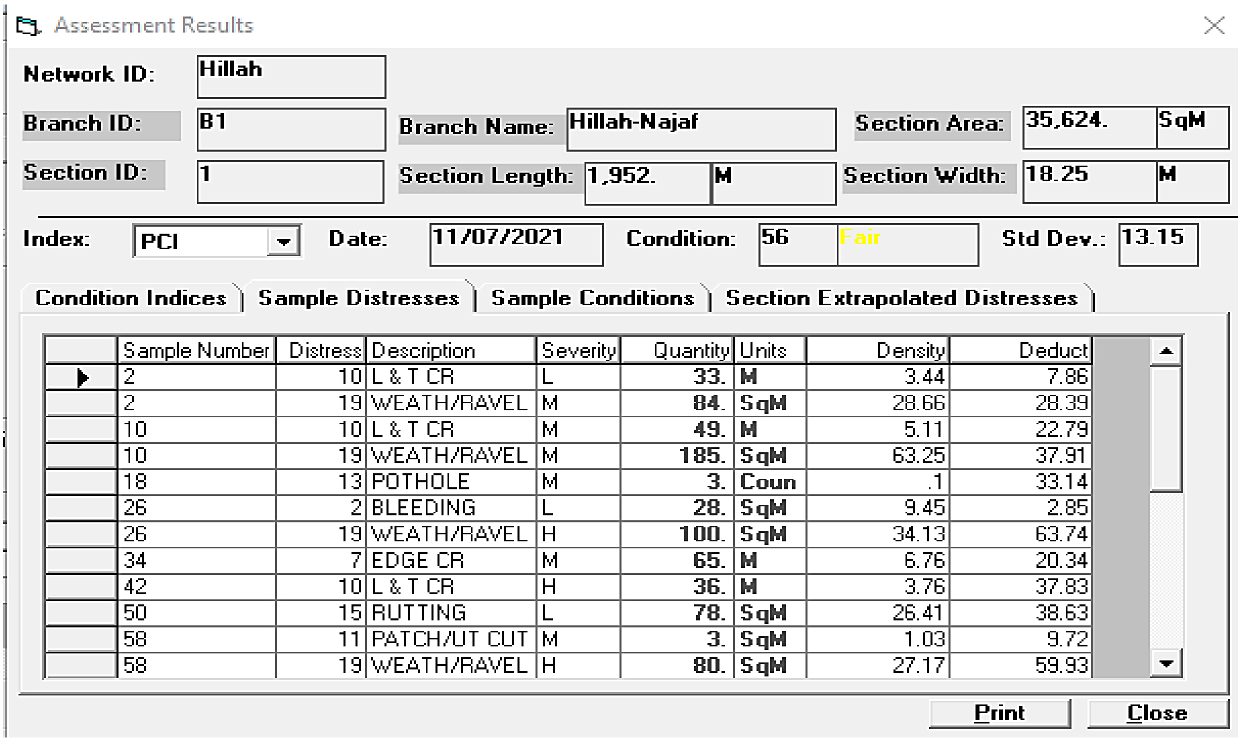
No.	Sample No.	Sample Unit Area (m2)	PCI	Rating
1	2	300	49	Fair
2	3	300	65	Good
3	4	300	63	Good
4	5	300	—	—
5	6	300	57	Good
6	7	300	31	Poor
7	8	300	40	Poor
8	9	300	28	Poor
PCI = 47				

Average of PCI = 48.5

The average of PCI was calculated for both directions, of study area sections by using the following equation:

$$PCI = \sum (PCI) / N$$

Results of PAVER Software for Each Section in Both Directions:



Assessment Results

Network ID: Hillah

Branch ID: B1 | Branch Name: Hillah-Najaf | Section Area: 35,624. SqM

Section ID: 1 | Section Length: 1,952. M | Section Width: 18.25 M

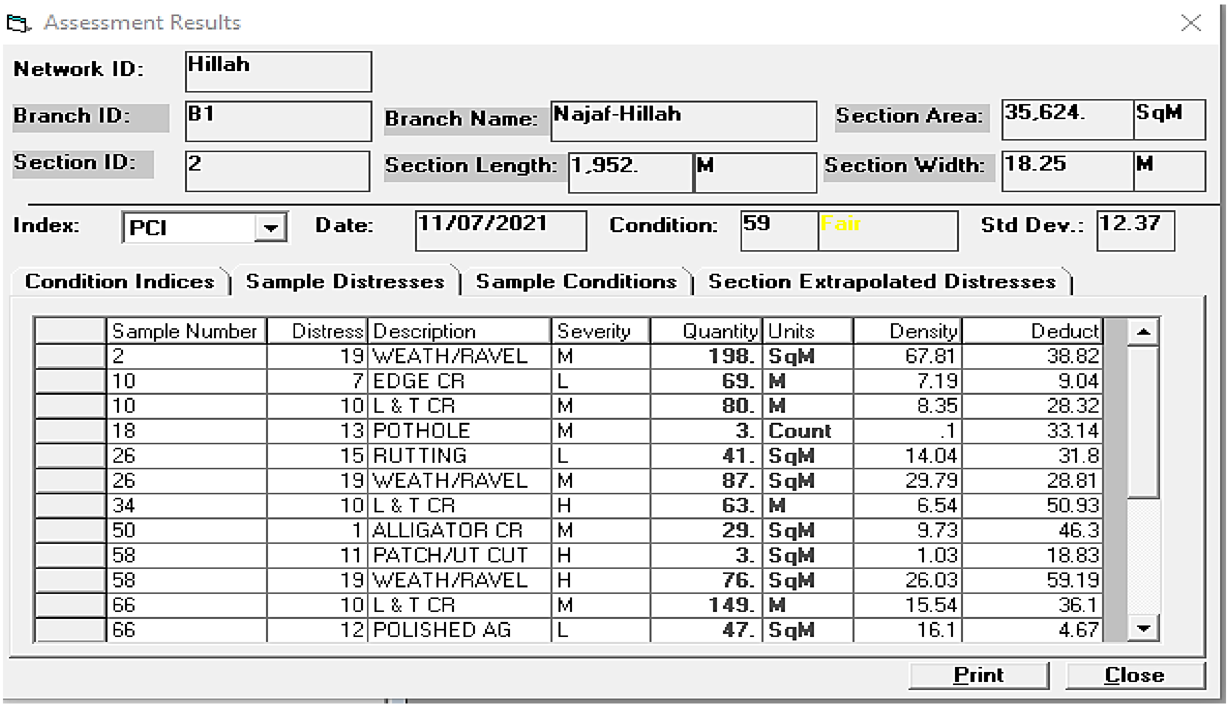
Index: PCI | Date: 11/07/2021 | Condition: 56 Fair | Std Dev.: 13.15

Condition Indices | Sample Distresses | Sample Conditions | Section Extrapolated Distresses

Sample Number	Distress	Description	Severity	Quantity	Units	Density	Deduct
2	10	L & T CR	L	33.	M	3.44	7.86
2	19	WEATH/RAVEL	M	84.	SqM	28.66	28.39
10	10	L & T CR	M	49.	M	5.11	22.79
10	19	WEATH/RAVEL	M	185.	SqM	63.25	37.91
18	13	POTHOLE	M	3.	Coun	.1	33.14
26	2	BLEEDING	L	28.	SqM	9.45	2.85
26	19	WEATH/RAVEL	H	100.	SqM	34.13	63.74
34	7	EDGE CR	M	65.	M	6.76	20.34
42	10	L & T CR	H	36.	M	3.76	37.83
50	15	RUTTING	L	78.	SqM	26.41	38.63
58	11	PATCH/UT CUT	M	3.	SqM	1.03	9.72
58	19	WEATH/RAVEL	H	80.	SqM	27.17	59.93

Print | Close

Plate (B-1): PCI Values of the Hilla-Najaf Roadway Section Using PAVER 5.2.3.



Assessment Results

Network ID: Hillah

Branch ID: B1 | Branch Name: Najaf-Hillah | Section Area: 35,624. SqM

Section ID: 2 | Section Length: 1,952. M | Section Width: 18.25 M

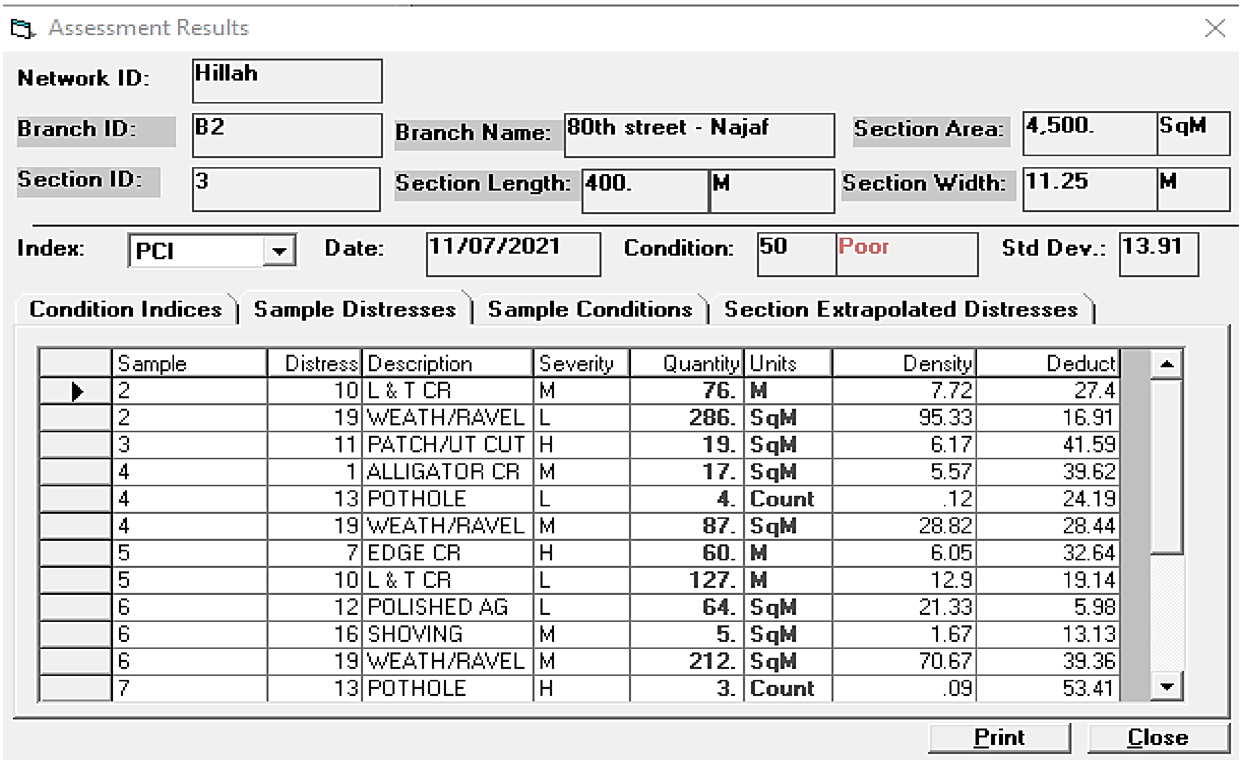
Index: PCI | Date: 11/07/2021 | Condition: 59 Fair | Std Dev.: 12.37

Condition Indices | Sample Distresses | Sample Conditions | Section Extrapolated Distresses

Sample Number	Distress	Description	Severity	Quantity	Units	Density	Deduct
2	19	WEATH/RAVEL	M	198.	SqM	67.81	38.82
10	7	EDGE CR	L	69.	M	7.19	9.04
10	10	L & T CR	M	80.	M	8.35	28.32
18	13	POTHOLE	M	3.	Count	.1	33.14
26	15	RUTTING	L	41.	SqM	14.04	31.8
26	19	WEATH/RAVEL	M	87.	SqM	29.79	28.81
34	10	L & T CR	H	63.	M	6.54	50.93
50	1	ALLIGATOR CR	M	29.	SqM	9.73	46.3
58	11	PATCH/UT CUT	H	3.	SqM	1.03	18.83
58	19	WEATH/RAVEL	H	76.	SqM	26.03	59.19
66	10	L & T CR	M	149.	M	15.54	36.1
66	12	POLISHED AG	L	47.	SqM	16.1	4.67

Print | Close

Plate (B-2): PCI Values of the Najaf-Hilla Roadway Section Using PAVER 5.2.3.



Assessment Results

Network ID: Hillah

Branch ID: B2 Branch Name: 80th street - Najaf Section Area: 4,500. SqM

Section ID: 3 Section Length: 400. M Section Width: 11.25 M

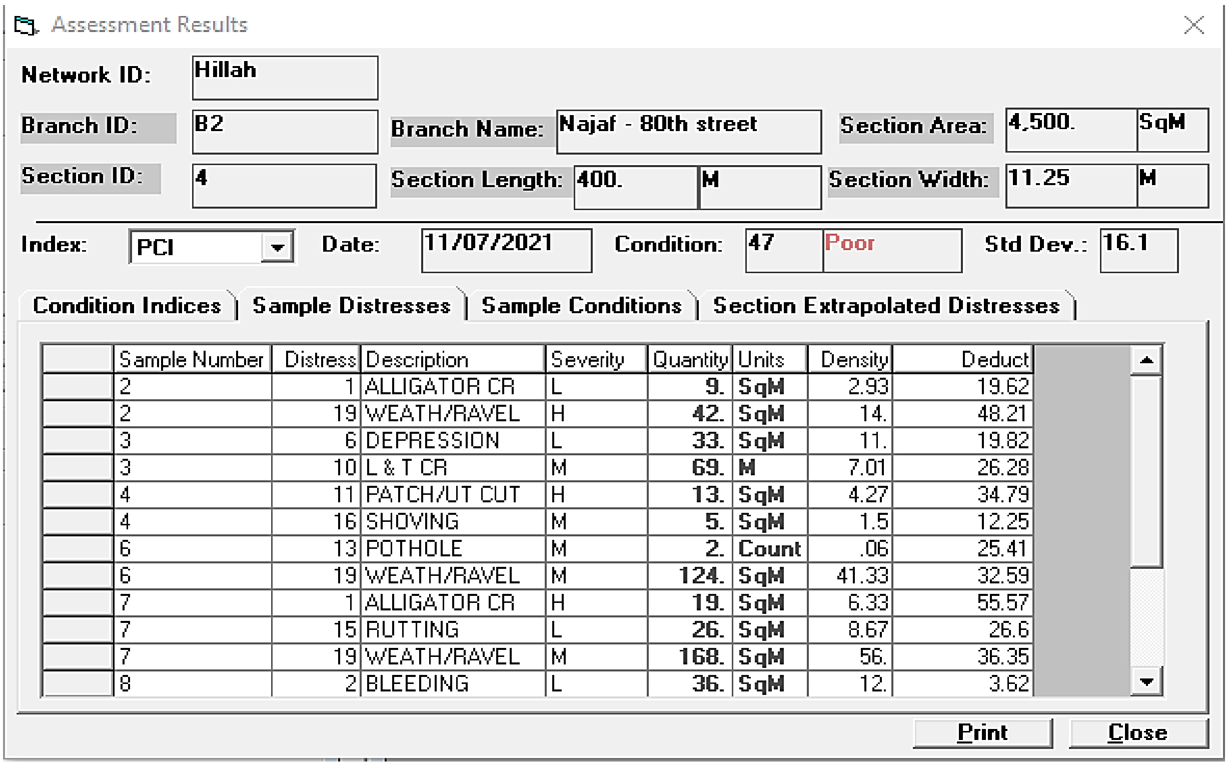
Index: PCI Date: 11/07/2021 Condition: 50 Poor Std Dev.: 13.91

Condition Indices | Sample Distresses | Sample Conditions | Section Extrapolated Distresses

Sample	Distress	Description	Severity	Quantity	Units	Density	Deduct
2	10	L & T CR	M	76.	M	7.72	27.4
2	19	WEATH/RAVEL	L	286.	SqM	95.33	16.91
3	11	PATCH/UT CUT	H	19.	SqM	6.17	41.59
4	1	ALLIGATOR CR	M	17.	SqM	5.57	39.62
4	13	POTHOLE	L	4.	Count	.12	24.19
4	19	WEATH/RAVEL	M	87.	SqM	28.82	28.44
5	7	EDGE CR	H	60.	M	6.05	32.64
5	10	L & T CR	L	127.	M	12.9	19.14
6	12	POLISHED AG	L	64.	SqM	21.33	5.98
6	16	SHOVING	M	5.	SqM	1.67	13.13
6	19	WEATH/RAVEL	M	212.	SqM	70.67	39.36
7	13	POTHOLE	H	3.	Count	.09	53.41

Print Close

Plate (B-3): PCI Values of the Road no. 80-Najaf Section Using PAVER 5.2.3.



Assessment Results

Network ID: Hillah

Branch ID: B2 Branch Name: Najaf - 80th street Section Area: 4,500. SqM

Section ID: 4 Section Length: 400. M Section Width: 11.25 M

Index: PCI Date: 11/07/2021 Condition: 47 Poor Std Dev.: 16.1

Condition Indices | Sample Distresses | Sample Conditions | Section Extrapolated Distresses

Sample Number	Distress	Description	Severity	Quantity	Units	Density	Deduct
2	1	ALLIGATOR CR	L	9.	SqM	2.93	19.62
2	19	WEATH/RAVEL	H	42.	SqM	14.	48.21
3	6	DEPRESSION	L	33.	SqM	11.	19.82
3	10	L & T CR	M	69.	M	7.01	26.28
4	11	PATCH/UT CUT	H	13.	SqM	4.27	34.79
4	16	SHOVING	M	5.	SqM	1.5	12.25
6	13	POTHOLE	M	2.	Count	.06	25.41
6	19	WEATH/RAVEL	M	124.	SqM	41.33	32.59
7	1	ALLIGATOR CR	H	19.	SqM	6.33	55.57
7	15	RUTTING	L	26.	SqM	8.67	26.6
7	19	WEATH/RAVEL	M	168.	SqM	56.	36.35
8	2	BLEEDING	L	36.	SqM	12.	3.62

Print Close

Plate (B-4): PCI Values of the Najaf-Road no. 80 Section Using PAVER 5.2.3.

Appendix C

Design Requirements

AASHTO Equivalency Factors – Flexible Pavement

Table (C-1): Axle LEFs for Flexible Pavements, Single Axles and p_t of 2.5.

Axle Load (kips)	Pavement Structural Number (SN)					
	1	2	3	4	5	6
2	0004	0004	0003	0002	0002	0002
4	003	004	004	003	002	002
6	011	017	017	013	010	009
8	032	047	051	041	034	031
10	078	102	118	102	088	080
12	168	198	229	.213	189	176
14	328	358	399	388	360	342
16	591	613	646	645	623	606
18	1 00	1 00	1 00	1 00	1 00	1 00
20	1 61	1 57	1 49	1 47	1 51	1 55
22	2 48	2 38	2 17	2 09	2 18	2 30
24	3 69	3 49	3 09	2 89	3 03	3 27
26	5 33	4 99	4 31	3 91	4 09	4 48
28	7 49	6 98	5 90	5 21	5 39	5 98
30	10 3	9 5	7 9	6 8	7 0	7 8
32	13 9	12 8	10 5	8 8	8 9	10 0
34	18 4	16 9	13 7	11 3	11 2	12 5
36	24 0	22 0	17 7	14 4	13 9	15 5
38	30 9	28 3	22 6	18 1	17 2	19 0
40	39 3	35 9	28 5	22 5	21 1	23 0
42	49 3	45 0	35 6	27 8	25 6	27 7
44	61 3	55 9	44 0	34 0	31 0	33 1
46	75 5	68 8	54 0	41 4	37 2	39 3
48	92 2	83 9	65 7	50 1	44 5	46 5
50	112	102	79	60	53	55

Table (C-2): Axle LEFs for Flexible Pavements, Tandem Axles, and p_t of 2.5.

Axle Load (kips)	Pavement Structural Number (SN)					
	1	2	3	4	5	6
2	0001	0001	0001	0000	0000	0000
4	0005	0005	0004	0003	0003	0002
6	002	002	002	001	001	001
8	004	006	005	004	003	003
10	008	013	011	009	007	006
12	015	024	023	018	014	013
14	026	041	042	033	027	024
16	044	065	070	057	047	043
18	070	097	109	092	077	070
20	107	141	162	141	121	110
22	160	198	229	207	180	166
24	231	273	315	292	260	242
26	327	370	420	401	364	342
28	451	493	548	534	495	470
30	611	648	703	695	658	633
32	813	843	889	887	857	834
34	1 06	1 08	1 11	1 11	1 09	1 08
36	1 38	1 38	1 38	1 38	1 38	1 38
38	1 75	1 73	1 69	1 68	1 70	1 73
40	2 21	2 16	2 06	2 03	2 08	2 14
42	2 76	2 67	2 49	2 43	2 51	2 61
44	3 41	3 27	2 99	2 88	3 00	3 16
46	4 18	3 98	3 58	3 40	3 55	3 79
48	5 08	4 80	4 25	3 98	4 17	4 49
50	6 12	5 76	5 03	4 64	4 86	5 28
52	7 33	6 87	5 93	5 38	5 63	6 17
54	8 72	8 14	6 95	6 22	6 47	/ 15
56	10 3	9 6	8 1	7 2	7 4	8 2
58	12 1	11 3	9 4	8 2	8 4	9 4

Table (C-2): Axle LEFs for Flexible Pavements, Tandem Axles, and p_t of 2.5.

(Continued)

60	14 2	13 1	10 9	9 4	9 6	10 7
62	16 5	15 3	12 6	10 7	10 8	12 1
64	19 1	17 6	14 5	12 2	12 2	13 7
66	22 1	20 3	16 6	13 8	13 7	15 4
68	25 3	23 3	18 9	15 6	15 4	17 2
70	29 0	26 6	21 5	17 6	17 2	19 2
72	33 0	30 3	24 4	19 8	19 2	21 3
74	37 5	34 4	27 6	22 2	21 3	23 6
76	42 5	38 9	31 1	24 8	23 7	26 1
78	48 0	43 9	35 0	27 8	26 2	28 8
80	54 0	49 4	39 2	30 9	29 0	31 7
82	60 6	55 4	43 9	34 4	32 0	34 8
84	67 8	61 9	49 0	38 2	35 3	38 1
86	75 7	69 1	54 5	42 3	38 8	41 7
88	84 3	76 9	60 6	46 8	42 6	45 6
90	93 7	85 4	67 1	51 7	46 8	49 7

Table (C-3): Axle LEFs for Flexible Pavements, Triple Axles and p_t of 2.5.

Axle Load (kips)	Pavement Structural Number (SN)					
	1	2	3	4	5	6
2	0000	0000	0000	0000	0000	0000
4	0002	0002	0002	0001	0001	0001
6	0006	0007	0005	0004	0003	0003
8	.001	002	001	001	001	001
10	.003	004	.003	002	002	002
12	005	007	006	004	003	003
14	008	012	010	008	006	006
16	012	019	.018	013	011	010
18	018	029	028	021	017	016
20	.027	.042	042	032	027	024
22	038	058	060	048	040	036
24	053	078	084	068	057	051
26	072	103	114	095	080	072
28	098	133	151	128	109	099
30	129	169	195	170	145	133
32	169	213	.247	220	191	175
34	219	266	308	281	246	228
36	279	329	379	352	313	292
38	352	403	461	436	393	368
40	439	491	554	533	487	459
42	543	594	661	644	597	567
44	666	714	781	769	723	692
46	811	854	918	911	868	838
48	979	1 015	1 072	1 069	1 033	1 005
50	1 17	1 20	1 24	1 25	1 22	1 20
52	1 40	1 41	1 44	1 44	1 43	1 41
54	1 66	1 66	1 66	1 66	1 66	1 66
56	1 95	1 93	1 90	1 90	1 91	1 93
58	2 29	2 25	2 17	2 16	2 20	2 24

Table (C-3): Axle LEFs for Flexible Pavements, Triple Axles and p_t of 2.5.

(Continued)

60	2 67	2 60	2 48	2 44	2 51	2 58
62	3 09	3 00	2 82	2 76	2 85	2 95
64	3 57	3 44	3 19	3 10	3 22	3 36
66	4 11	3 94	3 61	3 47	3 62	3 81
68	4 71	4 49	4 06	3 88	4 05	4 30
70	5 38	5 11	4 57	4 32	4 52	4 84
72	6 12	5 79	5 13	4 80	5 03	5 41
74	6 93	6 54	5.74	5 32	5 57	6 04
76	7 84	7 37	6 41	5 88	6 15	6 71
78	8 83	8 28	7 14	6 49	6 78	7 43
80	9 92	9 28	7 95	7 15	7 45	8 21
82	11 1	10 4	8 8	7 9	8 2	9 0
84	12 4	11 6	9 8	8 6	8 9	9 9
86	13 8	12 9	10 8	9.5	9 8	10 9
88	15 4	14 3	11 9	10 4	10 6	11 9
90	17 1	15 8	13,2	11 3	11 6	12 9

Structural Layer Coefficient Charts

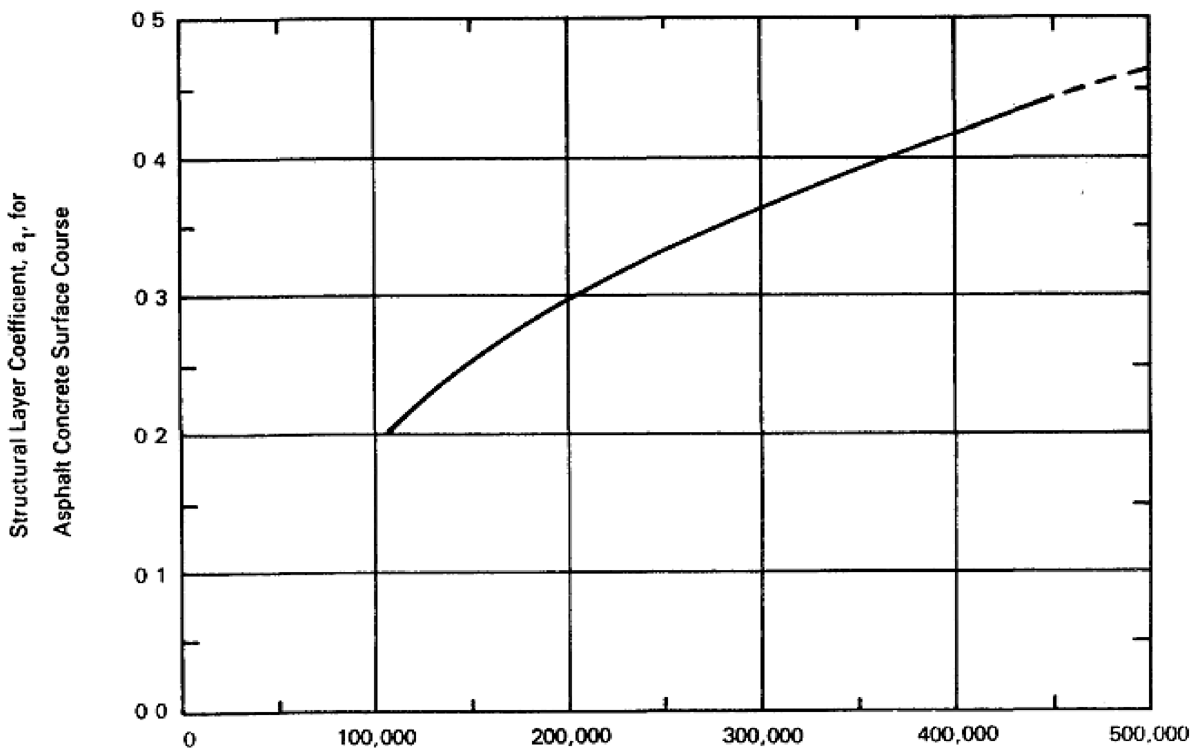


Figure (C-1): Chart for Estimating Structural Layer Coefficient of Asphalt Concrete Surfacing. **[AASHTO, 1993]**.

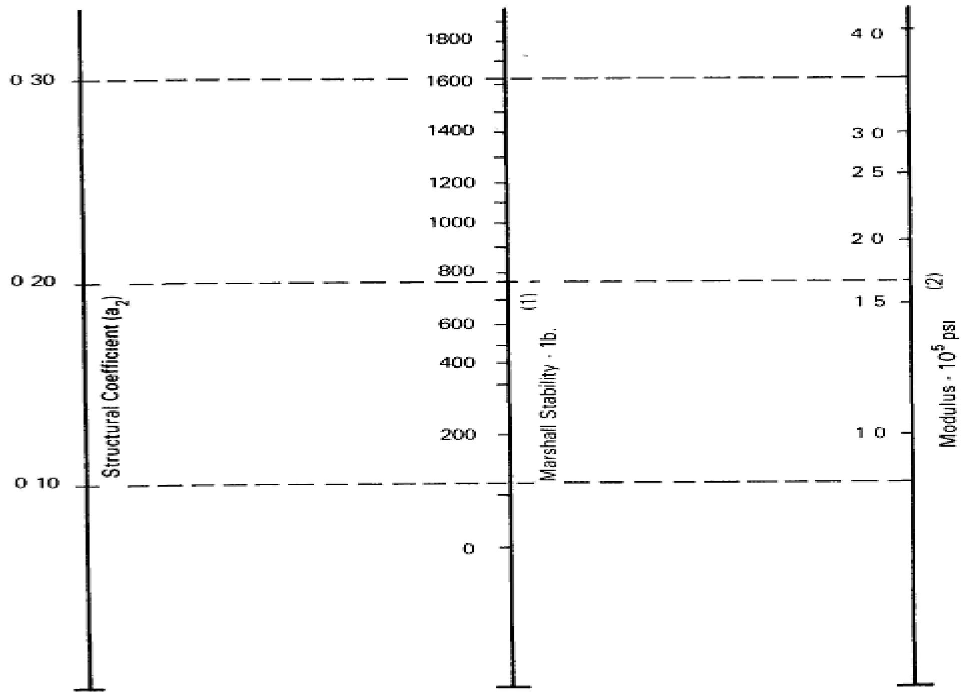


Figure (C-2): Variation in (a_2) for Bituminous-Treated Bases with Strength Parameters. **[AASHTO, 1993]**.

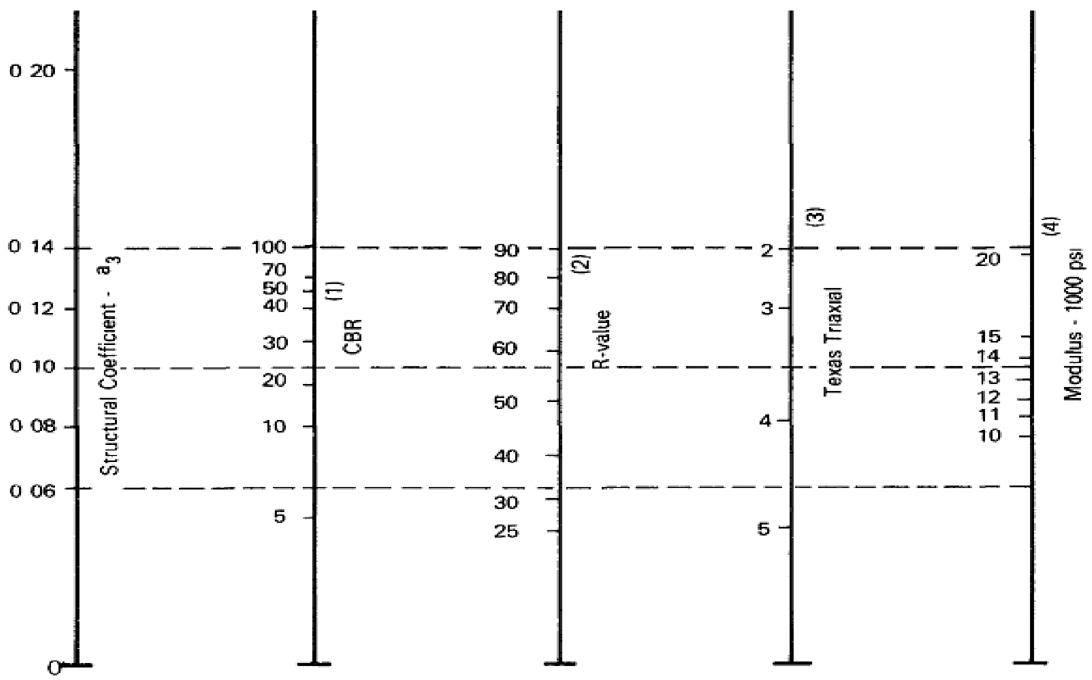


Figure (C-3): Variation in (a_3) for Granular Subbase Strength Parameters. **[AASHTO, 1993]**.

المستخلص

يتأثر التبليط الاسفلتي بالعديد من العوامل المرورية التي تؤثر على أدائه و ديمومة خدماته ، وعادة ما يتم تصميم التبليط الاسفلتي بناءًا على حدود معينة للأحمال المحورية ، و قد حددت وزارة الاعمار و الاسكان/ دائرة الطرق و الجسور سنة (٢٠٠٩) الحدود المسموح بها لكل نوع من أنواع محاور المركبات ، ولكن العديد من المركبات الثقيلة تخالف المواصفة المقررة بحملها أوزانًا إضافية مما يؤدي الى ظهور عيوب التبليط اضافة لعدم وجود خطط لكيفية ادارة الصيانة مما يجعل الطريق يتدهور بسرعة بمرور الوقت وبالتالي يقلل من عمره التصميمي.

تهدف الدراسة إلى التحقق من العوامل المرورية المؤثرة على عيوب التبليط في المقاطع المختارة ، وتعمل على تقييم تأثير الأحمال المحورية على الطبقات الإسفلتية ، وكذلك اقتراح تصميم يتناسب مع الأحمال المحورية المؤثرة على الطريق باستخدام مفهوم الحمل المحوري المكافئ (ESAL) وفقًا لطريقة الرابطة الأمريكية للطرق السريعة ومسؤولي النقل (AASHTO 1993) لتصميم سمك الطبقات المطلوبة للطريق. أُجريت الدراسة في مدينة الحلة على مقطعين (مقطع طريق الحلة – نجف ، مقطع شارع٨٠) وذلك لوجود العديد من حالات الفشل في المقاطع المذكورة أعلاه ، و بُنيت على أساس دراسة استطلاعية تضمنت مناطق الفشل و نوع المرور المستخدم للطريق وكذلك المؤثرات على الطريق ، اضافةً الى مسح هندسي و دراسة مرورية تضمنت دراسة حالة المرور حيث قامت الدراسة بإحصاء و تصنيف الحجوم المرورية على أساس ساعتي الذروة المرورية الصباحية و المسائية. و قد تم استخدام برنامج (Highway Capacity Software HCS 2010) لتحليل مستوى الخدمة الحالية للمقاطع المختارة . تم اجراء فحص بصري على تشوهات التبليط تضمن نوع ، مستوى الخطورة ، و كمية الفشل في العينات المفحوصة للطرق المحددة ، و تم تقييم البيانات المُجمعة لكل مقطع باستخدام برنامج (Micro PAVER 5.2.3) للتنبؤ بمؤشر حالة الطريق (PCI).

استنتجت الدراسة بأن السمك المقترح للطبقات الاسفلتية و طبقات الحصى الخابط لمقطع طريق (الحلة – نجف) هو (٣٣، ٣٤) سم على التوالي، حيث تنفذ بموجب المواصفات الفنية للهيئة العامة للطرق و الجسور (SCRB) و حسب الخطوات التالية :

- فَرش الطبقة الاسفلتية بسمك ٦ سم.
- الطبقة الرابطة بسمك ٧ سم و تُرش مادة التاك كوت قبل الفَرش.

- طبقة الاساس بسمك كلي ٢٠ سم و تفرش بهيئة طبقتين، ١٠ سم لكل طبقة و تُرش مادة البرايم كوت قبل الفَرش.
- طبقة الحصى الخابط بسمك ٣٤ سم و تنفذ بهيئة طبقتين.

بينما لمقطع شارع ٨٠ هو (٣٣، ٣٢) سم على التوالي ، يتم تنفيذ الطبقات بموجب المواصفات الفنية للهيئة العامة للطرق والجسور (SCRB) و حسب الخطوات التالية:

- فَرش الطبقة الاسفلتية بسمك ٦ سم.
- الطبقة الرابطة بسمك ٧ سم و تُرش مادة التاك كوت قبل الفَرش.
- طبقة الاساس بسمك كلي ٢٠ سم و تفرش بهيئة طبقتين، ١٠ سم لكل طبقة و تُرش مادة البرايم كوت قبل الفَرش.
- طبقة الحصى الخابط بسمك ٣٢ سم و تنفذ بهيئة طبقتين.

و أشارت نتائج PCI لمقطع طريق الحلة – نجف بأن ٥٠٪ من مساحة الرصف بحالة جيدة ، ٢٥٪ بحالة مقبولة ، ١٤٪ بحالة جيدة جدا ، و ١١٪ بحالة ضعيفة ، بينما أشارت النتائج لمقطع شارع ٨٠ بأن ٤٦٪ من مساحة الرصف بحالة جيدة ، ٢٧٪ بحالة مقبولة ، و ٢٧٪ بحالة ضعيفة.

كما أوصت الدراسة باعتماد الاحمال المحورية القانونية ونتائج التحليل الهندسي المبني على الأحمال المحورية المستخدمة للطريق و هذا يعتبر من أهم متطلبات التصميم ، و ضرورة انشاء محطات الوزن عند مداخل المدن للسيطرة على الأحمال المحورية وكذلك تقييم حالة الطريق ووضع المعايير لاعتماد أنواع الصيانة من قبل الإدارات المتخصصة في أوقات محددة مع التوثيق.

جمهورية العراق

وزارة التعليم العالي و البحث العلمي

جامعة بابل / كلية الهندسة

قسم الهندسة المدنية

تأثير الأحمال المرورية على تشوهات الطرق المرنة في مدينة الحلة

رسالة

مقدمة الى كلية الهندسة في جامعة بابل و هي جزء من متطلبات نيل درجة الماجستير في الهندسة المدنية / المواصلات

من قبل

سالي موفق طالب عبد الكريم

(بكالوريوس هندسة مدنية/ ٢٠١٨)

بأشراف

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هجري ١٤٤٣ ميلادي ٢٠٢٢