DOKUZ EYLÜL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

LIFE CYCLE ASSESSMENT APPLICATION FOR SUSTAINABLE TRANSPORTATION

by
İlke HEPDURGUN

July, 2019
İZMİR

LIFE CYCLE ASSESSMENT APPLICATION FOR SUSTAINABLE TRANSPORTATION

A Thesis Submitted to the
Graduate School of Natural and Applied Sciences of Dokuz Eylül University
In Partial Fulfillment of the Requirements for the Degree of Master of
Science in Environmental Engineering

by

İlke HEPDURGUN

July, 2019

İZMİR

M.Sc THESIS EXAMINATION RESULT FORM

We have read the thesis entitled **"LIFE CYCLE ASSESSMENT APPLICATION FOR SUSTAINABLE TRANSPORTATION"** completed by **İLKE HEPDURGUN** under supervision of **PROF. DR. NURDAN BÜYÜKKAMACI** and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

Prof.Dr. Nurdan BÜYÜKKAMACI

Supervisor

Prof.Dr. Serhan TANYEL

(Jury Member)

Dr. Öğr. Üyesi Hasan SARPTAŞ

(Jury Member)

Prof. Dr. Kadriye ERTEKİN

Director

Graduate School of Natural and Applied Sciences

ACKNOWLEDGEMENTS

I would first like to thank my thesis supervisor, Prof. Dr. Nurdan BÜYÜKKAMACI for her inspiring guidance and continuous encouragement throughout the course of the study. I am deeply grateful to Prof. Dr. Serhan TANYEL for his supervision, suggestions and sincere guidance.

I also thank the Scientific and Technical Research Council of Turkey (TUBITAK) - (Project No: 118Y315) for financial support.

I must express my very profound gratitude to my parents since they always provide and believe me throughout my years of study. Especially, I am indebted to my mother Dr. Bahriye HEPDURGUN, my aunt Dr. Betül PİŞKİN and my wonderful grandmother Ayşe PİŞKİN. This achievement would not have been possible without them.

I am also grateful to my deceased uncle Prof. Dr. Mustafa SABUNCU who help me choose the Dokuz Eylül University and had endless interest in my education life. Thankfulness to my cousins Prof. Dr. Metin SABUNCU and Assoc. Prof. Dr. Can Özgür ÇOLPAN for worthwhile suggestions.

I would also like to acknowledge Dr. Tuğçe ÖZDAMAR KUL and Asst. Prof. Dr. Yetkin DUMANOĞLU for their valuable help. Moreover, I owed to thanks my friends Pelin AKFESLİ, Gözde ÖZTÜRKOĞLU, Ezgi AKGÜL and Burcu YİĞİT for their continuous support to this thesis.

İlke HEPDURGUN

LIFE CYCLE ASSESSMENT APPLICATION FOR SUSTAINABLE TRANSPORTATION

ABSTRACT

In human life, transportation is one of the most important activities and needs. In terms of sustainable transportation, it is very important to select appropriate project for the least damage to the environment.

The road superstructure needs to be renewed over time due to wearing caused by high load, climatic conditions, and improper construction materials. One or more lane or the entire lanes are generally closed during road renovation works. As a result, traffic flow conditions change and normal function of the road is deteriorated due to closed lanes.

In this thesis, SIDRA Intersection analysis program and GaBi life cycle analysis software were used to determine the environmental effects caused by different lane changes during road renewal.

In the scope of the study, entrance intersection of Mavişehir in İzmir was chosen as an example and it was accepted that 100 meters superstructure would be undergoing renovation works. Firstly, SIDRA program was calibrated by making observations at the signalized intersection. SIDRA program was then used to calculate the relevant fuel consumption in scenarios based on lane changes due to traffic emissions resulting from traffic delays and road renewal activities. Finally, life cycle analysis studies have been conducted for each scenario to determine the environmental impacts by considering both the materials to be used for road renewal and traffic delays.

In life cycle impact analysis phase, eight different environmental impact categories were considered. The results obtained in the life cycle analysis were compared according to the scenarios produced for each impact category.

Keywords: Environmental effect, delay, signalized intersections, life cycle assessment, road structure renewal

SÜRDÜRÜLEBİLİR ULAŞIM İÇİN YAŞAM DÖNGÜSÜ ANALİZİ UYGULAMASI

ÖZ

İnsan hayatında, ulaşım en önemli faaliyetlerden ve ihtiyaçlardan birisidir. Bu yüzden çevreye en az zarar verecek projeyi seçmek sürdürülebilir ulaşım açısından çok önemlidir.

Yol üst yapısı maruz kaldığı yüklerin etkisi, iklim koşulları, yapımında doğru malzeme kullanılmaması gibi nedenlerle zamanla aşınmakta ve yenilenmesi gerekmektedir. Yol yenileme çalışmaları sırasında, yolun bir veya birkaç şeridinin veya tamamının trafiğe kapatılması gerekmektedir. Bu uygulamalar sonucunda kapatılan şeritler sebebiyle trafik akım koşulları değişmekte ve yolun normal işlevi bozulmaktadır.

Bu tez kapsamında, bir kavşak kolunda (yaklaşımında) yapılacak yol yenileme çalışmaları sırasında uygulanabilecek farklı şerit değişikliklerine bağlı olarak oluşacak çevresel etkilerin SIDRA kavşak analiz programı ve GaBi yaşam döngüsü analizi yazılımı ile belirlenmesi amaçlanmıştır.

Çalışma kapsamında, İzmir'deki Mavişehir giriş kavşağı örnek olarak seçilmiş ve bu kavşaktaki bir kolun 100 metrelik üst yapısında yenileme çalışmaları yapılacağı kabul edilmiştir. İlk aşamada, seçilen sinyalize (ışıklı) kavşaklarda gözlemler yapılmış ve SIDRA programı kalibre edilmiştir. İkinci aşamada, SIDRA programı kullanılarak yol yenileme çalışmaları nedeniyle uygulanabilecek şerit değişikliklerine göre oluşturulan senaryolarda meydana gelecek trafik gecikmeleri ve buna bağlı yakıt tüketimi ile trafik kaynaklı emisyon değerleri hesaplanmıştır. Çalışmanın son aşamasında ise, oluşturulan senaryolarda kullanılacak yol yenileme malzemelerine ve meydana gelecek gecikmelere bağlı çevresel etkilerin belirleneceği yaşam döngüsü analizi çalışmaları gerçekleştirilmiştir.

Yaşam Döngüsü Etki Analizi safhasında, sekiz farklı çevresel etki kategorilerisi dikkate alınmıştır. Yaşam döngüsü analizinde elde edilen sonuçlar, her bir etki kategorisi için üretilen senaryolara göre karşılaştırılmıştır.

Anahtar Kelimeler: Çevresel etki, gecikme, sinyalize kavşak, yaşam döngüsü analizi, yol kaplaması yenileme

CONTENTS

Page

M.Sc THESIS EXAMINATION RESULT FORM ii
ACKNOWLEDGEMENTS iii
ABSTRACT iv
ÖZ vi
LIST OF FIGURES xi
LIST OF TABLES xiii

CHAPTER ONE - INTRODUCTION 1

1.1 Introduction 1
1.2 Aim and Scope of the Thesis 2

CHAPTER TWO - GENERAL INFORMATION ABOUT THE DEFINITION AND TYPES OF INTERSECTION 3

2.1 Definition of Intersection 3
2.2 Basic Forms of Intersection 3
2.3 Specific Types of Intersections 4
2.4. Considerations for Intersections 6

CHAPTER THREE - ROAD CONSTRUCTION AND RENEWAL TECHNIQUES 7

3.1 Pavement Design Principles and Types 7
3.1.1 Flexible Pavement 7
3.1.2. Rigid Pavement 8
3.1.3 Semi Rigid Pavement 8
3.2 Deteriorations in the Road Pavement 8
3.2.1 Deterioration Criteria 9
3.2.1.1 Service Capability Index 9

3.2.1.2 Wheel Track Depth 9
3.2.1.3 Crack 10
3.2.1.4 Deflection 10
3.2.2 Deterioration Types in the Road Pavement 10
3.2.2.1 Wheel Track 12

CHAPTER FOUR - LIFE CYCLE ASSESSMENT APPROACH 14

4.1 Definition of Life Cycle Assessment (LCA) 14
4.1.1 Goal and Scope Definition in LCA 15
4.1.2 Inventory Analysis in LCA 16
4.1.3 Impact Assessment in LCA 16
4.1.4 Interpretation of LCA Results 17
4.2. Life Cycle Assessment Applications in Transportation Systems 18

CHAPTER FIVE - CASE STUDY: MAVİŞEHİR ENTRANCE INTERSECTION 23

5.1 Pilot Area 23
5.2 Data Collection 24

CHAPTER SIX- METHODOLOGIES FOR MODELING 26

6.1 Traffic Engineering Analyses and Modelling 26
6.1.1 General Introduction of SIDRA Intersection Software 26
6.1.2 Calibration and Validation of SIDRA Intersection Software 29
6.2 Environmental Impact Modeling 32
6.2.1 Inputs 33
6.2.2 Outputs 36
6.3 Created Scenarios 37

CHAPTER SEVEN- RESULTS AND DISCUSSION 40

7.1. Determination of the Emissions Related to Traffic Volume 40
7.1.1 Scenario 1 40
7.1.1.1 Case 1 41
7.1.1.2 Case 2 43
7.1.2 Scenario 2 46
7.1.2.1 Case 1 47
7.1.2.2 Case 2 48
7.1.3 Scenario 3 50
7.2 Evaluation of the Results on the Environmental Impact 52
7.2.1. Global Warming Potential (GWP).. 52
7.2.2. Acidification Potential (AP) 53
7.2.3. Eutrophication Potential (EP) 54
7.2.4. Photochemical Ozone Creation Potential (POCP) 55
7.2.5. Toxicity Potentials 56
7.2.5.1. Freshwater Aquatic Ecotoxicity Potential (FAETP).......................... 56
7.2.5.2. Marine Aquatic Ecotoxicity Potential (MAETP).............................. 57
7.2.5.3. Human Ecotoxicity Potential (HTP) 58
7.2.5.4. Terrestic Ecotoxicity Potential (TETP).. 59
7.2.6. Comparisons of all Impact Categories.. 60
7.3 Evaluation of the Results on the Transportation Capacity 62
7.3.1 Scenario 1- Case 1 and Case 2.. 62
7.3.2 Scenario 2- Case 1 64
7.3.3 Scenario 2- Case 2 66
7.3.4 Scenario 3 69
7.3.5 Comparisons of all Movement Parameters.. 70

CHAPTER EIGHT- CONCLUSIONS AND RECOMMENDATIONS............ 71

8.1. Conclusions 71
8.2. Recommendations 72

REFERENCES 73

LIST OF FIGURES

Page

Figure 2.1. Basic forms of intersection 4
Figure 2.2 An example of roundabout 5
Figure 2.3 An example of signalized intersection 5
Figure 3.1 Flexible pavement layers 8
Figure 3.2 Crack 10
Figure 3.3 Collapse 11
Figure 3.4 Blister 11
Figure 3.5 Wheel track 11
Figure 4.1 Life cycle assessment phases 14
Figure 5.1(a) General view of Mavişehir Entrance Intersection 23
Figure 5.1(b) General view of Mavişehir Entrance Intersection 23
Figure 5.2 Traffic observations between 08:00-09:00 at Mavişehir Intersection 24
Figure 5.3 Maneuver directions 24
Figure 6.1 Mavişehir Entrance Intersection modelling with SIDRA Intersection Software 27
Figure 6.2 Input node and some examples about input section sub-nodes 28
Figure 6.3 Output node and some examples about output section sub-nodes 29
Figure 6.4 Aliağa Tüpraş Intersection 30
Figure 6.5 Alsancak D.E.Ü. Rektörlük Intersection 30
Figure 6.6 Aliağa Entrance Intersection 31
Figure 6.7 Comparison of queue lengths calculated with SIDRA and observed queue lengths 32
Figure 6.8 Accepted system boundaries in LCA study 33
Figure 6.9 Entrance approach where maintenance work will be carried out 34
Figure 6.10 Layer dimensions of flexible pavement 34
Figure 6.11 Input and output values of the defined process 37
Figure 6.12 Process plan 37
Figure 6.13 Maintenance work continuing on the road and right lane was closed the traffic (Scenario 1) 38

Figure 6.14 Maintenance work continuing on the road and two lanes was closed the traffic (Scenario 2) 39
Figure 6.15 Maintenance work continuing on the road and all lanes was closed the traffic (Scenario 3) 39
Figure 7.1 Scenario 1- Case 1 41
Figure 7.2 Scenario 1 – Case 2........ 44
Figure 7.3 Scenario 2 – Case 1........ 47
Figure 7.4 Scenario 2 – Case 2........ 49
Figure 7.5 Scenario 3 51
Figure 7.6 Global warming potential 53
Figure 7.7 Acidification potential 54
Figure 7.8 Eutrophication potential........ 55
Figure 7.9 Photochemical ozone creation potential 56
Figure 7.10 Freshwater aquatic ecotoxicity potential 57
Figure 7.11 Marine aquatic ecotoxicity potential 58
Figure 7.12 Human ecotoxicity potential........ 59
Figure 7.13 Terrestic ecotoxicity potential 60

LIST OF TABLES

Page

Table 5.1 Observed traffic volumes (in pcu/h) at the intersection 25
Table 7.1 Generated scenarios 40
Table 7.2 Scenario-1 Case-1: emission outputs 42
Table 7.3 Scenario-1 Case-2: emission outputs 45
Table 7.4 Scenario-2 Case-1: emission outputs 47
Table 7.5 Scenario-2 Case-2: emission outputs 49
Table 7.6 Scenario-3: emission outputs 51
Table 7.7 Comparisons of all impact categories 61
Table 7.8 Scenario 1- Case 1 and Case 2 movement capacity parameters at the morning peak hours 62
Table 7.9 Scenario 1- Case 1 and Case 2 movement performance at the morning peak hours 63
Table 7.10 Scenario 1- Case 1 and Case 2 movement capacity parameters at the evening peak hours 63
Table 7.11 Scenario 1- Case 1 and Case 2 movement performance at the evening peak hours 64
Table 7.12 Scenario 2- Case 1 movement capacity parameters at the morning peak hours 65
Table 7.13 Scenario 2- Case 1 movement performance at the morning peak hours.. 65
Table 7.14 Scenario 2- Case 1 movement capacity parameters at the evening peak hours 66
Table 7.15 Scenario 2- Case 1 movement performance at the evening peak hours... 66
Table 7.16 Scenario 2- Case 2 movement capacity parameters at the morning peak hours 67
Table 7.17 Scenario 2- Case 2 movement performance at the morning peak hours.. 67
Table 7.18 Scenario 2- Case 2 movement capacity parameters at the evening peak hours 68
Table 7.19 Scenario 2- Case 2 movement performance at the evening peak hours... 68
Table 7.20 Scenario 3 movement capacity parameters at the morning peak hours ... 69
Table 7.21 Scenario 3 movement performance at the morning peak hours............... 69

Table 7.22 Scenario 3 movement capacity parameters at the evening peak hours 70
Table 7.23 Scenario 3 movement performance at the evening peak hours 70

CHAPTER ONE
INTRODUCTION

1.1 Introduction

The environment includes the places in which we live and the relations between living organisms and their environment. These relationships include the living environment, such as human, animal, plant, and inanimate environment in which their lives are formed. The inanimate environment component that people use the most is transportation and especially highways.

Transportation, which has a significant impact on people, is an indicator of a country's level of development. Road projects prepared in this direction are generally carried out in order to increase the economic and social welfare of those who use the highway or those who benefit from the service. Increasing the road capacity or improving the superstructure makes the transportation sustainable by reducing travel time and rising comfort. In addition to these positive results, road projects can adversely affect the living community (flora and fauna) and the drivers who use the road directly. These adverse effects: 1) excavation wastes generated during the maintenance of the superstructure, 2) increased noise and air pollution during transportation of new road construction materials, 3) encouraging people to get used to the new roads and thus increasing traffic accidents.

As highway projects are carried out in the natural and social environment, it requires a greater understanding than technical processes involving road construction. Environmental protection should be taken as the basis for the projects to be adopted by base on this understanding. In road studies, many factors such as emissions from possible traffic flow changes, materials to be used in the study and supply of these materials are important in determining environmental impacts. The Life Cycle Analysis (LCA) approach is used to systematically address these environmental impacts.

Life Cycle Analysis; is a scientific method used to systematically describe and evaluate the energy, material, etc. occurrences used during the life cycle of the environmental loads associated with a product or activity. This method is one of the emerging methods used for decision making since 1990 (Hendrickson, Lave & Matthews, 2006; Horne, Grant & Verghese, 2009; Özeler, Yetis & Demirer, 2006; Sonnemann, Castells & Schuhmacher, 2004).

1.2 Aim and Scope of the Thesis

In the scope of this thesis, determination of the environmental impacts due to the different lane usage, which can be applied during road reconstruction work at an intersection (approach) by using SIDRA Intersection analysis program and the GaBi life cycle analysis software, is aimed.

In the studies conducted in our country so far, there are a limited number of studies that reveal the environmental effects of highways with LCA. With this thesis, it is aimed to contribute to these studies by creating different scenarios. In line with this objective, the environmental impacts of the materials used during the superstructure maintenance work of an existing road and of the distorted or restricted traffic will be examined in detail.

CHAPTER TWO
GENERAL INFORMATION ABOUT THE DEFINITION AND TYPES OF INTERSECTION

2.1 Definition of Intersection

The areas where traffic flows from different directions have to use as common are called intersection (junction). Intersections can generally be grouped under two main groups. These are level crossings and intersections with different levels (interchanges) (Chlewick, 2003).

Intersection treatments may be described by:

- the number of legs and the angle of intersection
- the type of traffic control
- the way in which right-turning and left-turning movements are accommodated
- the presence and shape of traffic islands (Veith & Arndt, 2009).

2.2 Basic Forms of Intersection

The basic forms of intersections that exist on road networks are shown in Figure 2.1. The number of legs at an intersection, and the angle at which they meet, can vary. In addition, one or more of the legs may be curved.

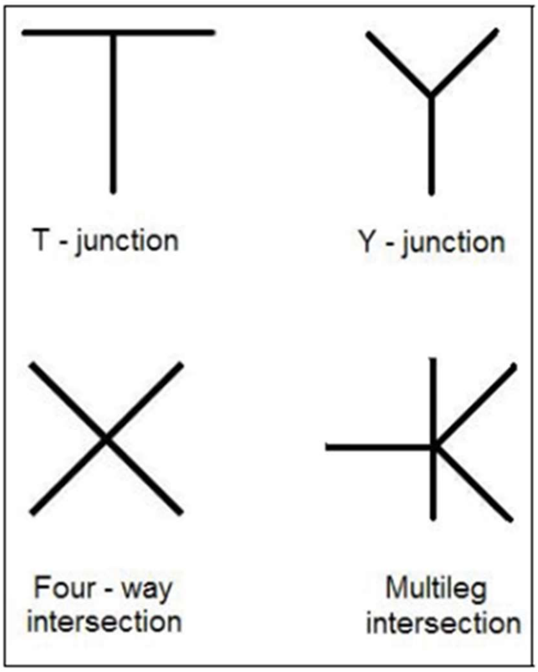

Figure 2.1 Basic forms of intersection (Austroads, 2009)

In selecting an appropriate form of intersection a designer should appreciate that:

- T-intersections are generally safe
- unsignalised Y-intersections are not a safe form because of the potential for high angle impacts and the provision of poor observation angles
- unsignalised crossroads generally are not safe in high-speed situations (> 80 km/h)
- signalised crossroads may not be safe in high-speed situations (> 80 km/h)
- unsignalised multi-leg intersections can lead to confusion with priority
- a Y-intersection or multi-leg intersection should generally not be adopted when setting out new road networks or new links in an existing network (Veith & Arndt, 2009).

2.3 Specific Types of Intersections

Issues associated with the basic forms of intersection may also be addressed by:

- addition of right-turn or left-turn auxiliary lanes
- channelisation, for example:
  - ✓ a traffic island in the minor road (e.g. splitter island)

- ✓ a right-turn lane and traffic island or a left-turn roadway and island
- ✓ a staggered T-intersection (right-left and left-right types)
- ✓ a seagull intersection
- ✓ a wide median treatment
- ✓ a roundabout (Figure 2.2)

- signalisation (Figure 2.3)

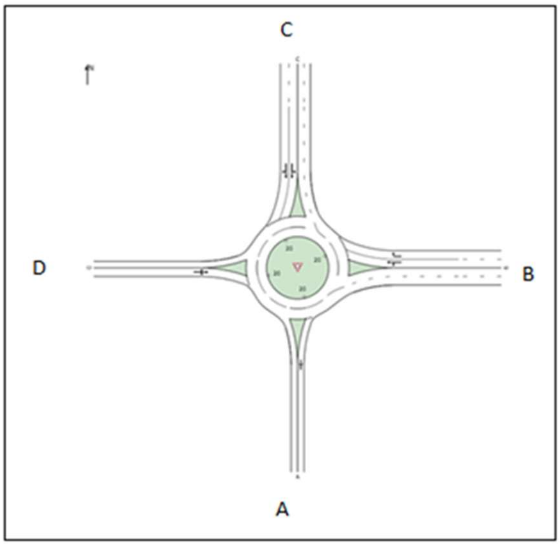

Figure 2.2 An example of roundabout

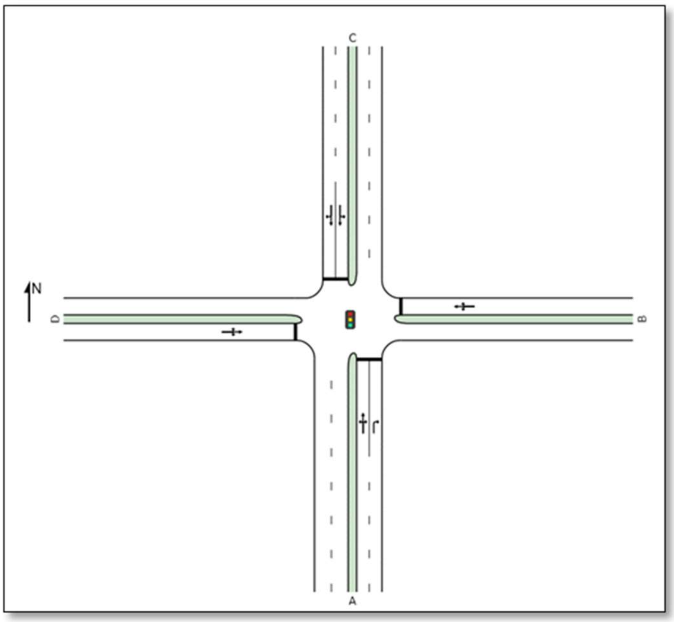

Figure 2.3 An example of signalized intersection

2.4 Considerations for Intersections

All types of intersections can be used in urban or rural environments with the exception that signalised intersections are generally not used on high-speed traffic routes. The design principles for intersections are the same irrespective of the type of intersection control. Generally, with the exception of roundabouts and wide median treatments all types of intersections can be signalised. The difference is in the detail with signalised layouts usually being provided in urban areas where:

- kerb and channel is provided rather than shoulders
- parking may have to be accommodated on the intersection approaches
- bus, transit and bicycle lanes and facilities may be required
- pedestrians have to be accommodated (Austroads, 2009).

CHAPTER THREE
ROAD CONSTRUCTION AND RENEWAL TECHNIQUES

3.1 Pavement Design Principles and Types

Road superstructure; is the road structure which is made to carry the traffic load and includes the surface, base and sub-base layers of the pavement. There are three types as flexible, rigid and semi rigid pavement (Association of Asphalt Contractors [ASMÜD], 2009).

3.1.1 Flexible Pavement

It is a superstructure form that provides tight contact with the leveling surface and distributes the loads to the floor. It is made of bituminous hot mix layers or bituminous surface coating depending on the traffic on subbase or base materials without binders. The superstructure type, in which all the layers on the base (including the subbase, base layers) are formed by asphalt mixtures in flexible pavements, is called perpetual pavement (ASMÜD, 2009). As the intersection approach, which is selected as part of the thesis, is known to have a flexible pavement, maintenance and repair works have been carried out with the choice of materials suitable for this type of superstructure. Figure 3.1 shows the flexible pavement layers (American Association of State Highway and Transportation [AASHTO], 1986).

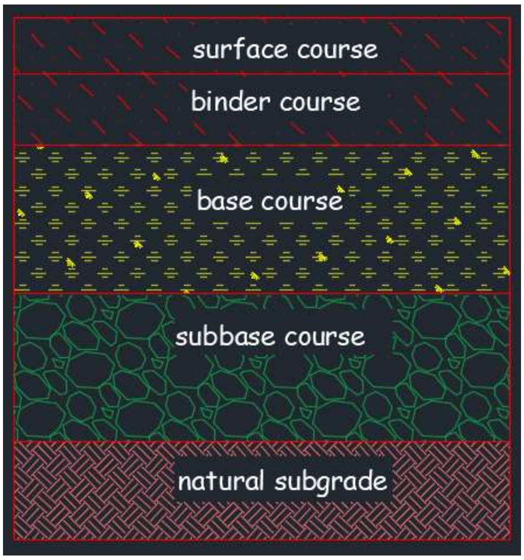

Figure 3.1 Flexible pavement layers

3.1.2 Rigid Pavement

It is a type of pavement that distributes loads through a single-layer plate made of portland cement with high bending strength. The concrete slab can be placed on a subbase or a cement-bonded sub-base or poor concrete, as well as directly on the base floor. The concrete slab can be constructed with continuous reinforcement or discrete reinforcement (ASMÜD, 2009).

3.1.3 Semi Rigid Pavement

It is a type of superstructure in which bituminous hot mix layers are formed on subbase and/or foundation with cement bonding (ASMÜD, 2009).

3.2 Deteriorations in the Road Pavement

Even a very well done road starts to deteriorate within a certain time due to environmental conditions. The only way to extend the service life of a road or to make the most of it in its economic life is to maintain the necessary level of continuous maintenance, and to increase the strength of the road superstructure by means of repair methods if necessary.

In Turkey; poor selection of design method and materials, rapid and uncontrolled increase in traffic, weight of climatic conditions, construction of infrastructure, which is not suitable for the project during road construction, are among the reasons for the deterioration of the main road.

Elimination of road deterioration depends on a thorough understanding of the reasons. Otherwise, the maintenance and repair services of a road whose cause is not understood or investigated is not going to be able to remedy any problems (Ilıcalı, Tayfur, Özen, Sönmez & Eren, 2001).

3.2.1 Deterioration Criteria

3.2.1.1 Service Capability Index

This method, developed by AASHTO 1986, has a serviceability of the road from 0 to 5 in order to measure the existing service capability of the road. 0 is indicate that road is very bad condition on the other hand 5 is signify that the road is very good condition.

A mathematical index has been developed according to the cross-section profile changes, cracking rate and patch amount of the road. Thus, the service capability index of that road was an indication of the extent to which the road required maintenance and repair.

3.2.1.2 Wheel Track Depth

If the wheel track depth exceeds a certain level, the road is considered to be damaged. Maintenance or repair decision is made according to the size of the wheel track depth. The general criterion is 1.0 - 2.5 cm (ASMÜD, 2009).

3.2.1.3 Crack

The cracking/unit area ratio gives the degree of cracking of that road and the necessary maintenance should be done if this value exceeds a certain value (ASMÜD, 2009).

3.2.1.4 Deflection

It is generally a criterion for increasing the strength of the superstructure and determining the thickness of the reinforcing layer.

3.2.2 Deterioration Types in the Road Pavement

Types of deterioration in the road superstructure; sitting, collapse, wheel tracking, undulation and blistering, cracks, separation, decomposition and disintegration, loss of slip resistance and leaching (Kumar, 2004; Orr, 2006). Some examples of these deterioration types are given in Figure 3.2 – 3.5.

Figure 3.2 Crack (Asphalt Institute, 2018)

Figure 3.3 Collapse (Asphalt Institute, 2018)

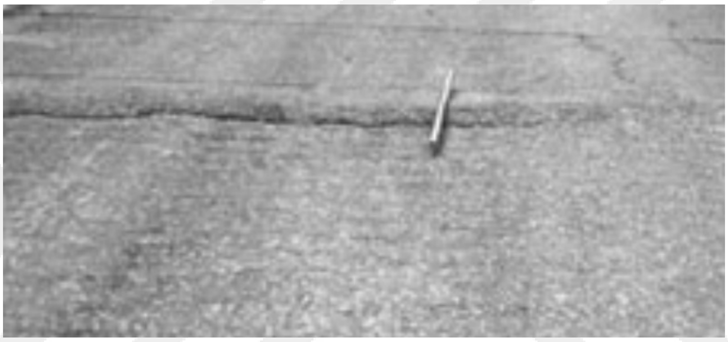

Figure 3.4 Blister (Asphalt Institute, 2018)

Figure 3.5 Wheel track (ASMÜD, 2009)

Within the scope of this thesis, it is foreseen that the road maintenance work will be taken to maintenance and repair due to the wheel trace and material and equipment selection has been made in accordance with this target. For this reason, the wheel track is discussed in detail in this section.

3.2.2.1 Wheel Track

Wheel tracks are formed by one or more layers at the bottom of the pavement, by means of consolidation or lateral movements caused by the traffic effect, or by displacements caused by the coating itself. The wheel track also consists of the accumulation of permanent deformations along the tracks through which traffic passes (ASMÜD, 2009).

Reasons for the formation of the wheel track:

1. Causes of asphalt layer:
   a. High percentage of bitumen
   b. Excess of filler
   c. Use of round materials in a mixture
   d. Inadequate compression of the mixture

2. Reasons for the sublayers:
   a. Insufficient thickness of sublayers
   b. Consolidation of natural ground
   c. Natural ground and lateral movements of the upper layers

3. Environmental reasons:
   a. Heavy repetitive load
   b. Hot weather conditions

Heavy vehicle traffic is the most important factor in the formation of traces and grooves. High axle load, high tire pressure, rapid repetition of the load and slow speed vehicles are adverse effects (ASMÜD, 2009).

Wheel tracks and grooves are repaired as follows:

1. The grooves formed are filled with hot asphalt mixture and graded. Then a thin reinforcing layer is constructed using a mix of plentmic asphalt.
2. Using a template or rope, the boundaries of the grooves are determined. The parts to be filled are marked with chalk.
3. Apply a thin cementing layer.
4. The gap-free asphalt concrete mixture is laid on the sections where grooves form. The thickness of the layer in which the striped material is formed must gradually decrease towards the edges and adhere to the old coating by diluting it at the boundaries of the groove.
5. It is compressed by rubber-wheeled roller.
6. A thin reinforcing layer is constructed from the hot asphalt mixture.

CHAPTER FOUR
LIFE CYCLE ASSESSMENT APPROACH

4.1 Definition of Life Cycle Assessment (LCA)

Life cycle assessment (LCA) includes all environmental aspects of an action; it is a system that evaluates the raw material from the nature until all the wastes are returned to the nature. LCA is a method to evaluate ecological effects related with an item over its life cycle; extraction of crude materials, produce, circulation, materials preparing, fabricating, transport, fix, upkeep, use, re-use and recyling. This assessment includes all the effects to air, water and soil during the production, use and final disposal of the raw material, including energy, as well as during the processing of the product (Itsubo, & Inaba, 2012).

Life Cycle Analysis (LCA) according to the Turkish Standard in TS-ISO 14040 / June 2007; is a set of procedures for collecting and reviewing information on the environmental impacts of a system of goods and services derived from a given material and energy system and the life cycle of this system and attributable directly to the system. According to the international standard ISO 14040, LCA consists of four main stages (Figure 4.1).

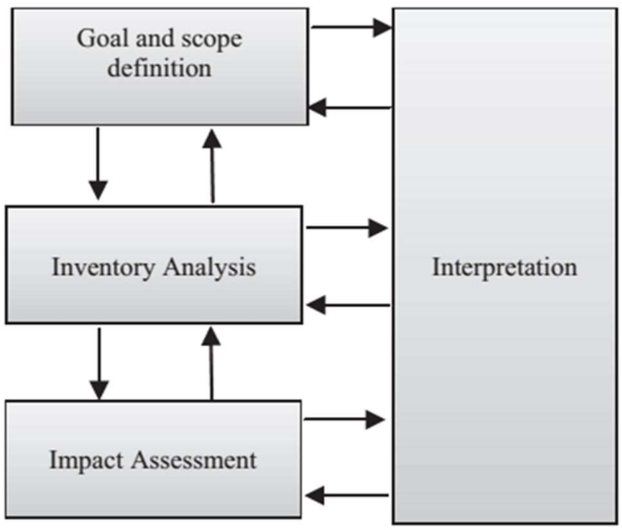

Figure 4.1 Life cycle assessment phases (ISO, 2006)

4.1.1 Goal and Scope Definition in LCA

Goal and scope determination is the first phase of life cycle analysis and it is considered as a critical part because it has a strong impact on the realization of other stages of LCA. At this stage, the objectives, boundary conditions, target audience, post-work expectations of LCA study should be clearly defined.

The goal definition is considered to be the most fundamental step of an LCA study, revealing the complexity and reporting requirements of the study. The goal can be redefined as a section of the review phase and as a result of the work (Bishop, 2000).

The goal and scope definition of an LCA study includes the components of the functional unit and system boundaries.

The functional unit is a part of the LCA that should be able to place a measure on two or more product comparisons, including the development of a product.

The system boundaries define the processes selected in the study (production, transport, waste management etc.) also define the inputs and outputs approaches in the LCA study. System boundaries are determined by four approaches:

- Obtain of raw material and energy
- Production (transport of materials to the factory, production at the factory, packaging, distribution of products)
- Use/reuse/maintenance repair
- Recycling/incineration/storage etc. waste management

When defining system boundaries, the process/product flow diagrams of the system must be established and system boundaries should be defined more clearly. Thus, by creating flow diagrams of the processes, the selected systems or processes can be treated as a closed box and the material and energy flow into the system or process can be determined (Bishop, 2000). LCA principles by ISO 14040 Standards and LCA conditions by ISO 14044 Standards are defined.

There are mainly four types of LCA approaches:

• Cradle-to-grave is the full Life Cycle Assessment from resource extraction ('cradle') to use phase and disposal phase ('grave').

• Cradle-to-gate is an assessment of a partial product life cycle from resource extraction (cradle) to the factory gate (i.e. before it is transported to the consumer)

• Cradle-to-cradle is a specific kind of cradle-to-grave assessment, where the end-of-life disposal step for the product is a recycling process. It is a method used to minimize the environmental impact of products by employing sustainable production, operation, and disposal practices and aims to incorporate social responsibility into product development.

• Gate-to-gate is a partial LCA looking at only one value-added process in the entire production chain.

4.1.2 Inventory Analysis in LCA

In order to create an inventory analysis, data must be collected. Inventory analysis is the part of the inputs (raw materials, water, energy, etc.) and outputs (emission, by-product, waste etc.) used during the life cycle of the product or activity (International Organization for Standardization [ISO 14044], 2006).

Special software designed for inventory analysis (GaBi, SimaPro, Umberto, etc.) can be used to process large amounts of data.

4.1.3 Impact Assessment in LCA

The impact assessment is a very important stage of life cycle analysis, based on the data obtained from the inventory analysis in accordance with the purpose and scope of the study, the classification of environmental impacts, the quantitative and qualitative evaluation and the characterization and normalization results of all the results obtained.

After the inventory analysis, environmental impact categories (climate change, acidification, eutrophication, carcinogenic effects etc.) are determined and discussed according to the purpose and scope definition of the product (Sonneman et al., 2004). In this section, it is determined that clearly what extent the product/service life cycle is causing the environmental effects.

4.1.4 Interpretation of LCA Results

The interpretation of the life cycle assessment is the process of qualifying, controlling, evaluating and presenting the information obtained from the results of the inventory analysis or impact assessment of a system and presenting it as specified in the goal and scope section.

Interpretation is performed between the other three stages of the life cycle. If those data from inventory analysis and impact assessment do not meet the objectives and scope definition, the system boundaries should be reviewed, developed by further data collection, followed by improved impact assessment. The requirements specified in this repetitive process, goal and scope stage must be repeated until the following conditions are met:

1. Determination of important environmental issues,
2. Evaluation of the method and results in terms of integrity, precision and consistency,
3. Control of compliance of the results with the requirements in the goal and scope definition,

If the above transactions are provided, a report should be written as a result, and if it is not provided, steps 1 and 2 should be repeated. This act should be repeated until the 3rd step is achieved (Özkan, 2008).

4.2 Life Cycle Assessment Applications in Transportation Systems

Galatioto, Huang, Parry, Bird & Bell, (2015) investigated the increases of traffic emissions due to delays in road maintenance. Modeling was done with SimaPro, a life cycle assessment software. Within the scope of the study, not only the emission values generated during the pavement maintenance but also the effects on the traffic caused by queuing and traffic routing were taken into consideration. In this respect, traffic modeling was conducted using AIMSUN simulation program. In order to determine the best time and day of the planned road maintenance work, statistical analyzes were used and the most appropriate periods between the daily peaks were determined and different scenarios were created. The scenarios were created by closing different lanes at different times and thus changing the signaling times. An alternative route has also been established in case the whole road is closed. As a result of the study, the scenario with the least impact on the environment and traffic is determined by considering all scenarios and possibilities.

Milachowski, Stengel & Gehlen, (2011) in a study, which they investigate, the environmental impact of highways has been determined. In this context, all of the inputs and outputs obtained from the production and use of the pavement of a highway section were taken into account. These inputs and outputs include the production of materials, supply of energy, production of required products, transportation services and the purchase and sale of self-sufficient products. Air, water and soil values were determined that been exposed emission. Then, the Dutch CML method was used for determine the effect categories of global warming potential (GWP), ozone depletion potential (ODP), photochemical ozone creation potential (POCP), acidification potential (AP) and eutrophication potential (EP). A database, which was developed in Switzerland, Ecoinvent was used; data not available in the database were modeled and analyzed according to the available data. The data were evaluated with SimaPro, a life cycle analysis software, and the possible reductions in environmental impacts were determined on the basis of different scenarios.

In another study, it is shown that the most important factors in assessing the acceptability of the transport system are not only direct fuel consumption and energy and material costs of the vehicles, but also energy and material costs used for infrastructure construction (Liu, Yang, Hao & Ulgiati, 2016).

Moretti, Mandrone, Andrea & Caro, (2018) evaluated the environmental and human health effects related to the construction processes of the embankment and trench sections of the road and analyzed the life cycle in order to consider them. Within the scope of the study, various scenarios have been formed by considering the raw material and fuel supply, the construction process of the road materials, the transportation of the materials to the site and the works to be done on-site. In the scenarios, the transport distances of the materials to the site and the types of vehicles used during transport were changed, and the construction activity results for the embankment and trench sections of the road were examined in detail in eight different impact categories. These categories are global warming potential (GWP), ozone depletion potential (ODP), photochemical ozone creation potential (POCP), acidification potential (AP), eutrophication potential (EP), abiotic depletion potential (ADP-E, ADP-F), and human toxicity potential (HTP). As a result of the study, all impact categories were of great importance in the first stage including the transportation of the product in the area, while EP, POCP and HTP were more important in the second stage which was construction time. They also emphasized that the construction of the embankment sections of the road has a higher environmental impact than the trench and that the results in the impact categories increase in ratio to the distance.

The effects of modern roundabouts and stop-controlled intersections on the environment were investigated using SIDRA Intersection software. In this study, the emission values of the vehicles (HC, CO, NOx and CO_2) are calculated in kg/h. At the end of the study, it was determined that the moden roundabouts produced less emission than the stop-controlled intersections. Thus, the operation of modern roundabouts has been shown to be more environmentally friendly (Mandevilli, Rys & Russell, 2008).

The majority of LCA studies on highways are about the environmental impact of road materials. Santero, Masanet & Horvath, 2011; Miliutenko, Björklund & Carlsson, 2013; Yu & Lu, (2012) made researches on the re-use of asphalt pavements. The majority of these studies are related to the process of use of asphalt pavements. However, the processes in the production and construction phases of asphalt are of great importance (Butt, Birgisson & Kringos, 2012; Vidal, Moliner, Martinez & Rubio, 2013). In our country, the research conducted by Polat & Bektaş (2015) on this subject is of great importance. In this study, they compared the environmental effects of different asphalt products with LCA. In the study, SimaPro software was used and the functional unit was considered as one ton of asphalt production. According to the results of the study, it was determined that the environmental impacts could be reduced by 10% when less bitumen is used in asphalt production and the carbon emission was 5% higher in the binding type asphalt production where the bitumen should remain hot.

Another application that demonstrates the importance of LCA in the construction and operation of highways is the PhD study conducted by Hameed (2013). In this study, it was emphasized that approximately 90% of the materials used in the construction and rehabilitation of the highway were destroyed in the landfill sites and the importance of the works for the recovery, reuse and recycling of these materials was revealed. Through integrated life cycle analysis, it has been proposed to develop programs for assessing the greater impact of transport investments and supporting sustainability.

In the studies described above, although it is of great importance in determining the environmental impacts of construction and maintenance works on highways, there is not indicate the environmental impact caused by traffic congestion during construction and/or maintenance works. The study by Ergun & Şahin (2006) showed that 11% of the traffic congestion in Istanbul was caused by road maintenance and repair work. This finding clearly demonstrates the importance of the inclusion of environmental pollutants as a result of delays caused by road maintenance studies in the LCA analysis.

Studies on road maintenance studies have mainly focused on the changes in road capacity resulting from road works (reductions) and modeling of the resulting traffic jams. A large part of these studies have aim attention at on ways in which vehicles such as highways or the ring road can travel at high speeds and have a high capacity (Kim, Lovell & Pracha, 2001; Sarasua, Davis, Clarke, Kottapally & Mulukutla, 2004; Bayraktar, 2006; Yeom, Heajbabaie, Schroeder, Vaughan, Xuan & Roulphail, 2015). In our country, Aydın (2013) explored the road maintenance works carried out in Fatih Sultan Mehmet Bridge in 2012. In this study, traffic flow parameters, peak hours, vehicle queues, vehicle classes, alternative routes, traffic incidents, toll charges, bottlenecks and the impact of box office assets on the traffic were analyzed.

Within the scope of these studies, it has been foreseen that a large number of parameters are effective in determining the capacity and performance changes resulting from the studies on ring road or highways. Thus, capacity and performance models that include these parameters have been tried to be developed for the areas where road works are performed (Al-Kaisy & Fred, 2002; Kim et al., 2001; Karim & Adeli, 2003; Adeli & Jiang, 2003). Some of these parameters can be listed like that; the duration and intensity of the work, the number of lanes that are open to traffic during the course of work and the direction of the traffic flow they serve, vehicle composition (characteristics of different types of vehicles in the traffic flow), location of the lanes, driver specifications, etc. Excessive parameters have led to intelligent transport systems using nonlinear advanced modeling techniques, such as artificial neural networks, to determine the delay in road traffic and the effect of queue length.

Although there are numerous studies examining the impacts of road maintenance and repair work on the highway, such as motorways or the ring road, on the traffic, the number of studies on road works in lighted (signalized) arteries is quite limited. The first known and important study in this subject is the research carried out by Joseph, Radwan & Rouphail (1988). In the study, road maintenance studies in an area between two light intersections were examined with a semi-simulation model called WZATA (Work Zone Analysis Tool for the Signalized Arterial), where they created their effects on capacit and performance. The majority of studies investigating the impact of road maintenance work in light arteries on traffic have been conducted in the United States. The Florida Department of Transportation identified an account process that calculates the capacity of a signalized artery that is road maintenance and repair depending on the duration of the traffic lights (FDOT, 2007). The Missouri Department of Transportation found that in the road maintenance and repair areas, the saturated current value of an illuminated strip fell from 1900 vehicles to 1000 vehicles/hour (MDOT, 2004). In South Carolina it was observed that this value was 800 vehicles/hour (Sarusua et al., 2004). Heaslip, Jain & Elefteriadou (2011) analyzed light artery capacity and performance from road maintenance and repair work with simulation programs based on different lane counts and different lane usage characteristics (such as right and / or left turn signs or not). As a result of the study, they found that the distance from the road work to the light is important.

When the studies are examined, it is accepted that the road works are generally made at a certain distance from the down-stream lights and the intersection is generally in service. However, this condition is not always valid. Especially in our country, during the road maintenance and repair works, one or more or all of the lanes at the signalized intersections are closed to traffic during the road works. In some cases, it is seen that some of the lanes in the opposite direction are allocated to traffic that uses the off-road route. Again, during road works, it was observed that the light times during the period of operation were not maintained even though the properties of the intersection changed. All these considerations suggest that the environmental impacts caused by road maintenance and repair works in our country may be higher than expected.

The literature research also reveals that the environmental effects caused by changes in traffic flow conditions not only in our country but also in other countries are not analyzed by LCA method.

CHAPTER FIVE
CASE STUDY: MAVİŞEHİR ENTRANCE INTERSECTION

5.1 Pilot Area

In this study, the intersection which is located at the entrance of Mavişehir distict is selected as pilot area (Figure 5.1(a)- 5.1(b)). This intersection is signal controlled "T" type intersection on the east side of Mavişehir, which is located where 2038th and 2040th streets intersect. Approaches 1 and 2 are located on the 2038th Street operated as a 2x3 lane devided road extending in northeast-southwest direction. There is a left turn lane designed on Approach 1. Approach 3 is located on the 2040th Street, which is operated as a 2x2 lane undivided road. 2-3 and 3-1 right turn movements are separated by an island.

Figure 5.1(a) General view of Mavisehir Entrance Intersection (Google Earth, 2018)

Figure 5.1(b) General view of Mavisehir Entrance Intersection (Google Earth, 2018)

5.2 Data Collection

The traffic counts of the intersection selected within the scope of the study were recorded with video for 24 hours. Permissions were obtained from the Izmir Metropolitan Municipality Transportation Department. Following the registration, the number of vehicles passing through the intersection for each hour interval was recorded. Considering the counting number of vehicles, the highest traffic volume was found between 08:00 and 09:00 in the morning (Figure 5.2). Maneuver directions are given in Figure 5.3.

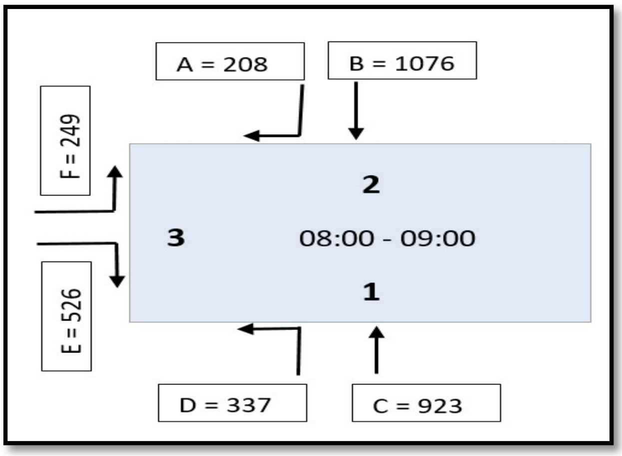

Figure 5.2 Traffic observations between 08:00-09:00 at Mavişehir intersection

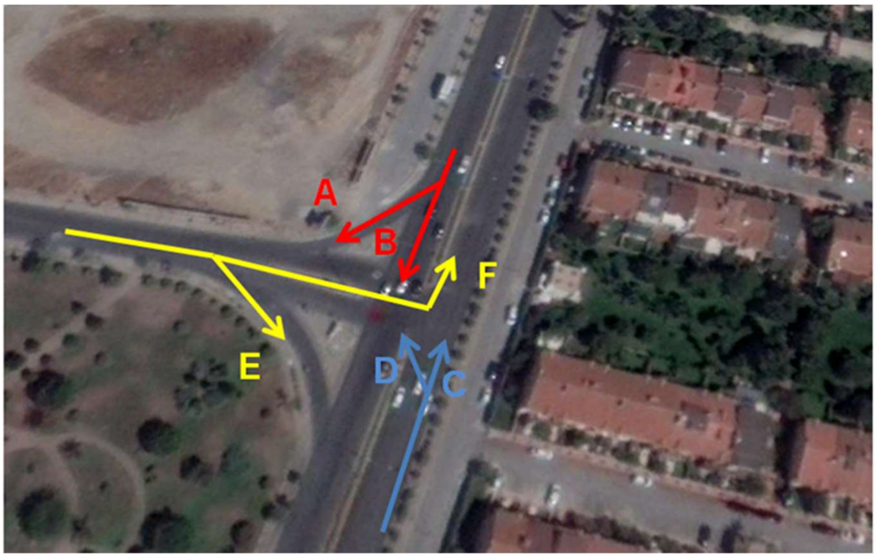

Figure 5.3 Maneuver directions (Google Earth, 2018)

The number of vehicles recorded for each hour interval is shown in the Table 5.1.

Table 5.1 Observed traffic volumes (in pcu/h) at the intersection

	Vehicle directions					
Time	**A**	**B**	**C**	**D**	**E**	**F**
00:00	18	94	81	30	46	22
01:00	11	57	49	18	28	13
02:00	6	30	26	10	15	7
03:00	4	21	18	6	10	5
04:00	4	20	17	6	10	5
05:00	7	34	29	11	17	8
06:00	24	123	106	39	60	29
07:00	122	630	540	197	308	146
08:00	208	1076	923	337	526	249
09:00	144	747	641	234	365	173
10:00	123	635	545	199	310	147
11:00	107	551	473	173	269	128
12:00	110	569	488	178	278	132
13:00	110	570	489	178	278	132
14:00	119	614	526	192	300	142
15:00	128	663	569	208	324	153
16:00	121	627	538	196	306	145
17:00	165	854	733	267	417	198
18:00	140	727	623	228	355	168
19:00	87	448	384	140	219	104
20:00	70	364	312	114	178	84
21:00	66	342	294	107	167	79
22:00	45	231	198	72	113	53
23:00	33	173	149	54	85	40

CHAPTER SIX
METHODOLOGIES FOR MODELING

6.1 Traffic Engineering Analyses and Modelling

In the study, traffic analyzes were performed by using SIDRA Intersection software. In the literature, it is seen that simulation programs are used predominantly in the calculation of capacity and performance of road maintenance and repair worksites. Simulation programs provide important information to engineers and researchers, but often require a large number of details and data. This situation increases the likelihood of users making errors during the modeling phase. On the other hand, analysis programs based on analytical and empirical calculation methods such as SIDRA Intersection software allow users to control the intersection model more precisely and to determine which variables can yield better results. For this reason, it was considered to be useful to use SIDRA Intersection software.

6.1.1 General Introduction of SIDRA Intersection Software

In SIDRA Intersection program, it is of great importance to correctly define the geometry of the intersection during the creation of the model. For this purpose, data entry in different submenus in SIDRA Intersection is required. Different vehicle types can be defined in SIDRA software. The approaches and lanes which are used by these vehicles can be entered as data when creating the model. In this way, it is possible to examine different vehicle compositions in terms of lanes as well as the movements of traffic flows in different lanes. In addition, the ideal flow rate and lane utilization rate for each lane can be defined. In Figure 6.1, the SIDRA Intersection model of Mavişehir Entrance Intersection is shown.

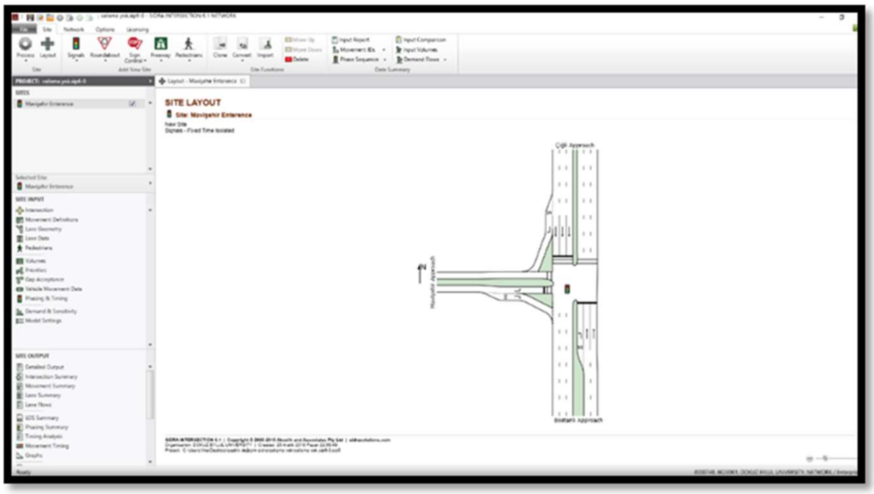

Figure 6.1 Mavişehir Entrance Intersection modelling with SIDRA Intersection software

The project framework on the left side of the user interface of the program includes a project network of sites. The main nodes in the project network are inputs and outputs. The software also has sub-nodes located under the main nodes. In the following figures, several instances of input (Figure 6.2) and output (Figure 6.3) nodes and sub-nodes have been given.

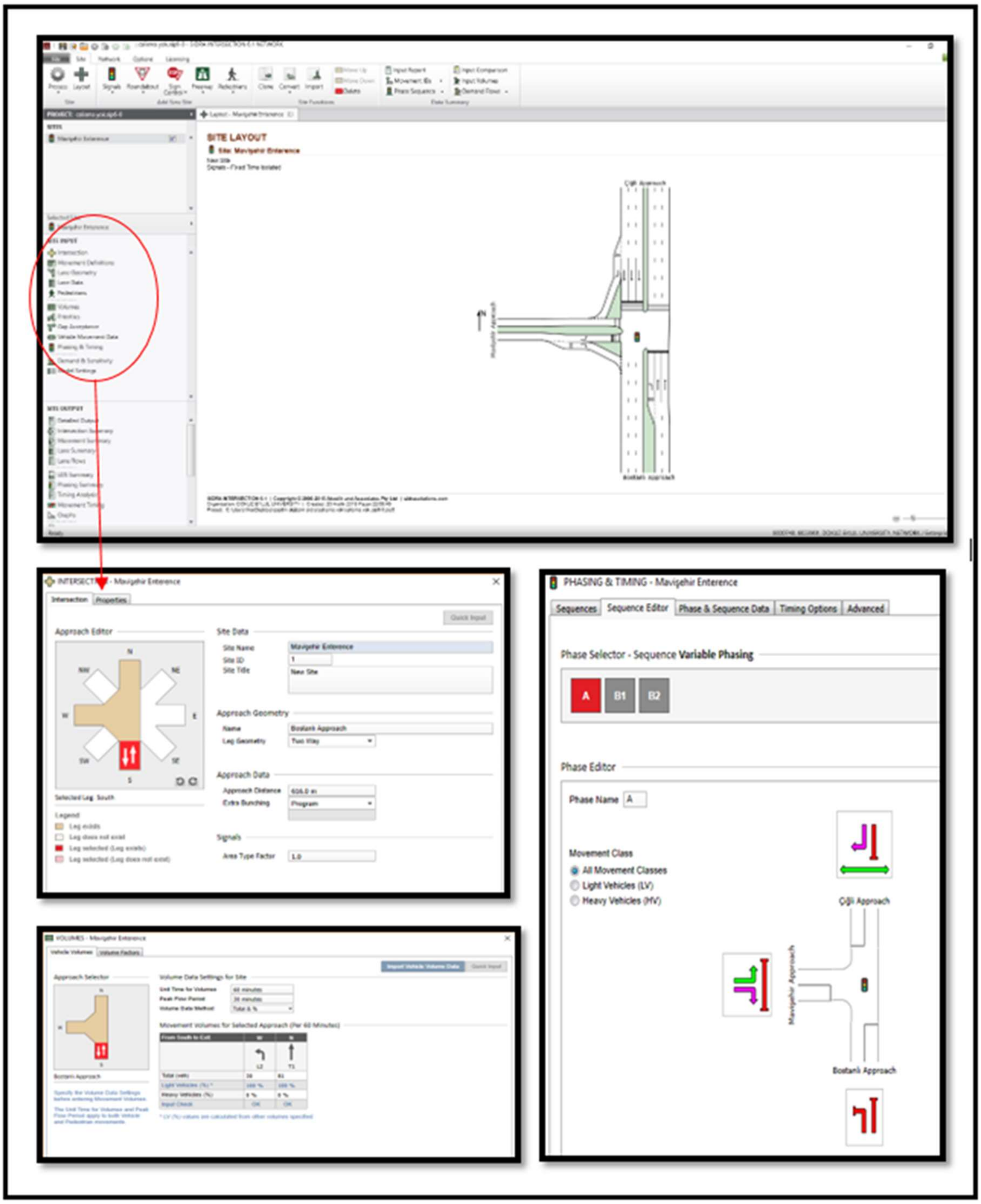

Figure 6.2 Input node and some examples about input section sub-nodes

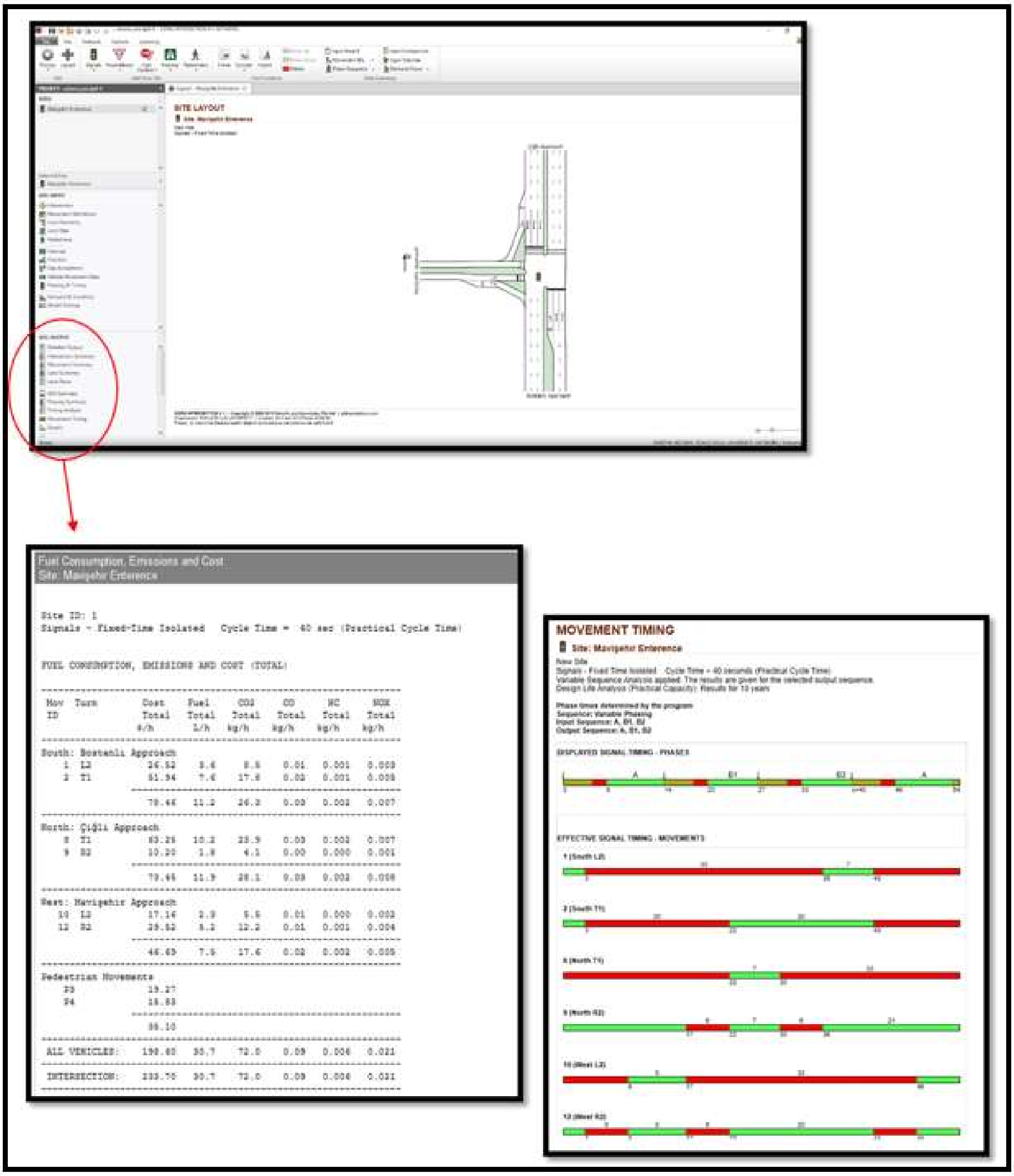

Figure 6.3 Output node and some examples about output section sub-nodes

6.1.2 Calibration and Validation of SIDRA Intersection Software

Different parameters can be used for the calibration of the SIDRA Intersection software. When creating a model in SIDRA, different vehicle types and lanes that are used according to the selected approach can be entered as data. In this way, it is possible to examine different vehicle compositions on a lane basis. In addition, the ideal saturation flow rate and lane utilization rate for each lane can be defined. Thus, it is possible to participate in the modeling of the data collected in the study, such as initial response time and signal discharge intervals of the drivers with their lane usage preferences. On the other hand, the program allows the identification of the characteristics of different types of vehicles.

For the calibration of the program, data obtained from three different intersection recordings made by Dokuz Eylül University Faculty of Engineering Civil Engineering Department Transportation Department were used. These intersections are listed below:

1. Aliağa TÜPRAŞ Intersection (Figure 6.4),
2. Alsancak D.E.Ü. Rektörlük Intersection (Figure 6.5),
3. Aliağa Entrance Intersection (Figure 6.6).

Figure 6.4 Aliağa TÜPRAŞ Intersection (Google Earth, 2018)

Figure 6.5 Alsancak D.E.Ü. Rektörlük Intersection (Google Earth, 2018)

Figure 6.6 Aliağa Entrance Intersection (Google Earth, 2018)

From these selected intersections, Aliağa Entrance Intersection is a signalized roundabout. From video camera shots made at these designated intersections, traffic volume and composition values and queue lengths were recorded. Using these values, intersections models had created and calibrated with in SIDRA Intersection software.

In SIDRA Intersection models, the queue length is selected as the calibration criterion. The ideal saturated current value at the intersections of TÜPRAŞ and D.E.Ü was 1720 vehicle/hour/lane value, which was proposed by Çalışkanelli & Tanyel (2018). However, for the Aliağa Entrance Intersection, 1640 vehicle/hour/lane value, which was proposed by again Çalışkanelli & Tanyel (2018), was used because this intersection is a signalized roundabout.

For the calibration process, 15-minute data groups were formed by using the observations made at each intersection. The validity of the model can be observed not only for intersection or approach but also for lanes with different uses. Observed and calculated queue length values are shown in Figure 6.7. When the figure is examined, it is seen that the program gives appropriate results.

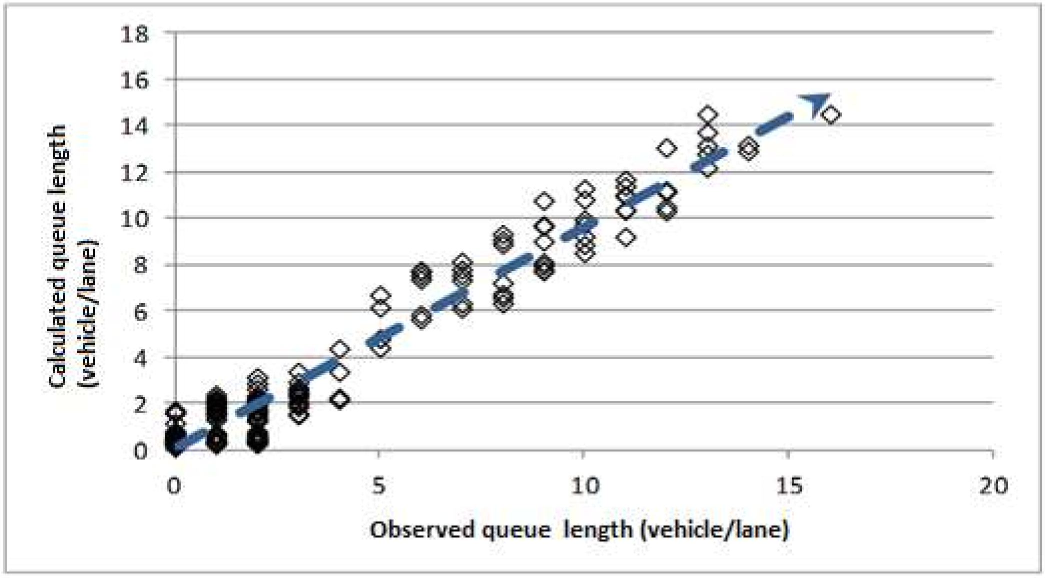

Figure 6.7 Comparison of queue lengths calculated with SIDRA and observed queue lengths

6.2 Environmental Impact Modeling

GaBi software was used to determine environmental impacts. GaBi is one of the commercial software that facilitates businesses to make Life Cycle Assessments (LCA) to protect their assets, and GaBi 6.1 software is used in this study (Thinkstep, Germany). With the Eco-invent database included in the program, the emission values obtained from the SIDRA Intersection software provided the necessary data for the operation of the software. In this selected program, the use of the software allows the design of the desired flow by working with the ideas we create, as it can intervene in every aspect of the design process. Within this thesis, system boundaries are modeled using gate to gate approach. System boundaries are designed to determine the effects of environmental impacts as a result of the supply of materials to the area where road maintenance will be carried out and road maintenance with different scenarios. The proposed system boundaries are given in Figure 6.8. In addition, the functional unit of the study was determined as lane/100 m road-vehicle.

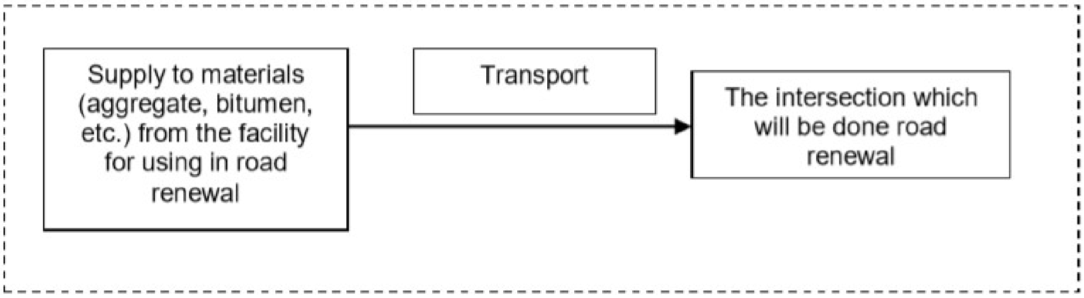

Figure 6.8 Accepted system boundaries in LCA study

The software is based on the principle of correctly identifying inputs and outputs of a process. In this context, the program provides mass balance in the process and provides the environmental effects of the designed process graphically. In the scope of this study, CML 2001 (Institute of Environmental Sciences, Leiden University) is used to produce results graphs. In the result graphs, eight environmental impact categories were considered. These are given below:

- global warming potential,
- acidification potential,
- eutrophication potential,
- photochemical ozone creation potential.
- fresh water aquatic ecotoxicity potential,
- marine aquatic ecotoxicity potential,
- human toxicity potential,
- terrestric ecotoxicity potential.

6.2.1 Inputs

Two types of inputs were considered: 1) the amount of the materials to be used during the road renewal work is formed by the transportation of the equipment used during the operation, and 2) the type of fuel used in the operation. It is proposed that the road belonging to the intersection has a flexible pavement and that it will go through a maintenance due to the wheel track deformation. In this context, the system boundaries were determined to be maintained in only 100 meters of the three lane road (Figure 6.9). Figure 6.10 shows the layer dimensions of the flexible pavement (AASHTO 1993 Flexible Pavement Structural Design). Maintenance will be made due to the wheel track deformation so that renewal of the road's surface and binder layers will be sufficient for the comfort of the road.

Figure 6.9 Entrance approach where maintenance work will be carried out (Google Earth, 2018)

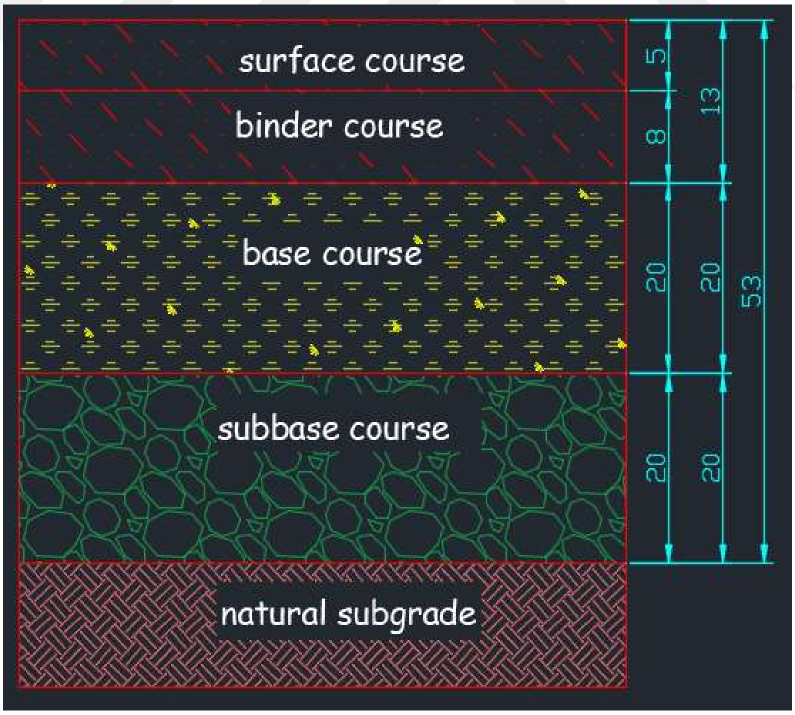

Figure 6.10 Layer dimensions of flexible pavement

The length of the road entering the maintenance work was considered 100 meters, the number of lanes 3 and the width of the lane is 3.3 meters. It was assumed that the rear dump truck, asphalt distributor, paver and static iron bandage roller will be used for maintenance work. Material quantities calculated in two layers.

The amount of material required for the binder layer was calculated as 100 m x 0.08 m x 3.30 m x 3 (length x layer thickness x lane width x lane number) = 79.2 m^3. Since the bonding between the two layers will be done, the amount of emulsion to be used was calculated as 100 m x 3.30 m x 3 (length x lane width x lane number) = 990 m^2. The use of 0.18 liters of emulsion per 1 m^2 of space will be sufficient. 0.18 m^3 is a negligible value due to the small area of the maintenance road. The amount of material required for the surface layer was calculated as 100 m x 0.05 m x 3.30 m x 3 (length x layer thickness x lane width x lane number) = 49.5 m^3.

The amount of fuel to be consumed is calculated by taking into account the type of vehicle to be used during transportation and the distance to be provided. In this direction, it was determined that materials could be brought from a facility at a distance of 25 km to the Mavişehir Entrance Intersection. The materials required for the binder layer and surface layer will be transported by truck. The total amount of material for both layers is about 130 m^3 (79.2+49.5). The truck used has a width of 2.4 meters and a volume of 18 m^3. It is known that a truck uses 25 liters of fuel at 100 km. It was assumed that the materials will be transported by 8 trucks one time, or 1 truck will be transported 8 times. In both cases, the amount of fuel to be consumed is 100 liters. According to the definition taken from the detail information of KGM/6405 pose, it is calculated by multiplying the volume of the mixture which is used by the principles of 1 m^2 asphalt concrete surface layer 5 cm thickness (type-1) with 2.4 ton/m^3. In this direction, 130 m^3 x 2.4 ton/m^3 = 312-ton material was laid during paving and compaction process in approximately one hour and it costs about 35 liters of fuel. The compaction process was carried out in 3 stages as the first roller, intermediate and final cylinder also 15 cm of overlapping length acceptance. According to the literature information, the first cylinder is 2-3.5 mph, the intermediate cylinder is 2.5-4 mph and the last cylinder is 3-5 mph (mph = 1.6 km/h). The asphalt roller width was chosen as

1.5 meters (Anonymous, 2000). As a result of the calculations and assumptions made, it was concluded that the first and last cylinder will be completed 9 times by passing once and the intermediate cylinder will be completed 45 times by passing five instance. 2 mph = 3.2 km/h speed for the first cylinder to complete the 100-meter path to complete in 18 minutes, for intermediate cylinders 2.5 mph = 4 km/h by selecting the speed in 68 minutes to complete and 3 mph = 4.8 km/h speed for the final cylinder by selecting the 12-minute compression is expected to be completed. Since the selected static iron bandaged roller consumes 15 liters of fuel per hour, it was estimated that it would consume 25 liters of fuel during the process. It was foreseen that the paver, asphalt distributor and truck used during the maintenance work would have approximately 30 liters of fuel consumption during fieldwork and on the way to the site. Considering all uses, 190 liters of fuel and 312 tons of bituminous materials were required to perform maintenance work.

6.2.2 Outputs

The outputs of the program are the emission values obtained from the SIDRA Intersection program. Figure 6.11 shows that the input and output data entered in the GaBi program. As for the process plan is given in Figure 6.12.

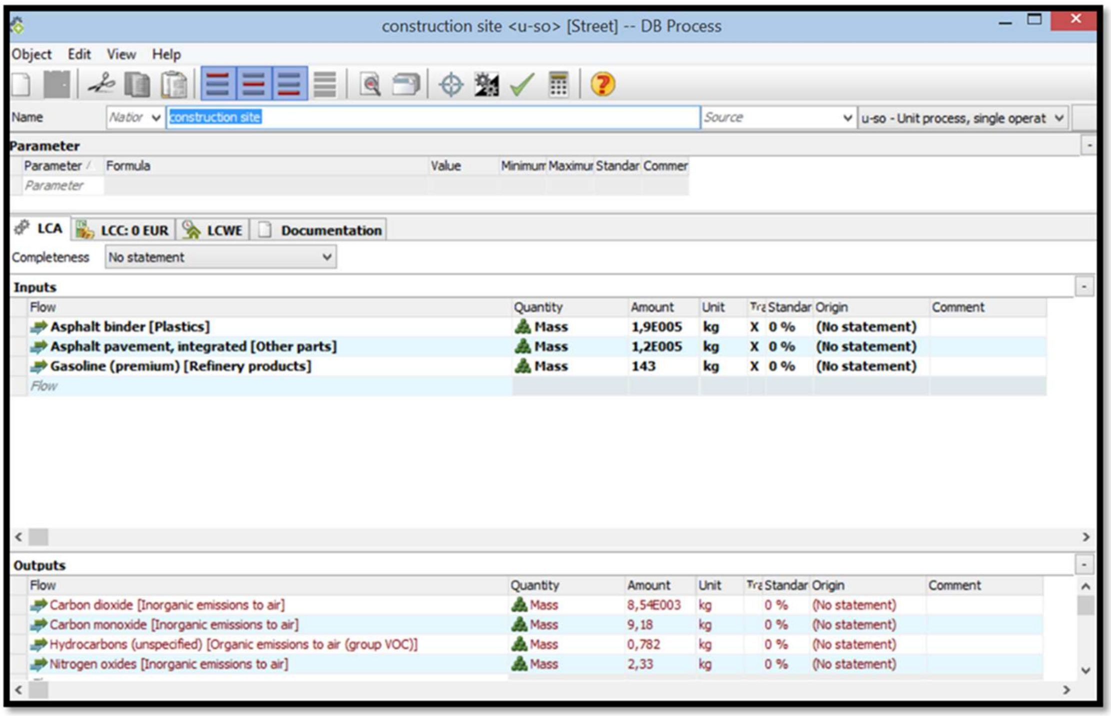

Figure 6.11 Input and output values of the defined process

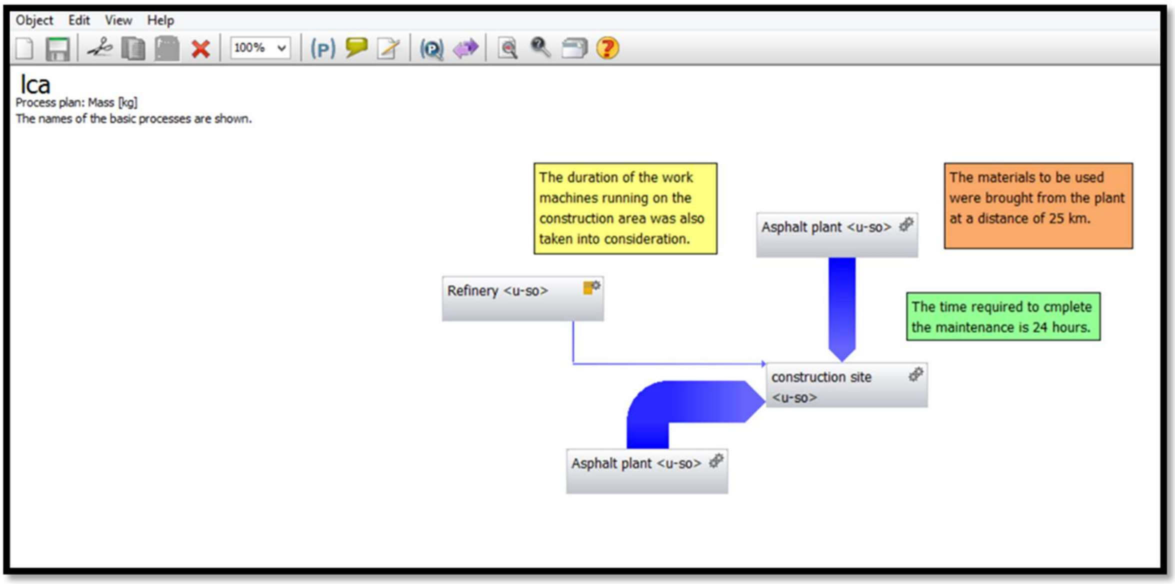

Figure 6.12 Process plan

6.3 Created Scenarios

In the study, three main scenarios were developed. As the first scenario, only the right lane of the road, where the work will be done, was closed and modeled in SIDRA

Intersection software (Figure 6.13). As the second scenario, the two lanes of the road will be closed and modeled in SIDRA Intersection software (Figure 6.14). In the third and last scenario, all the lanes of the road are closed and the other platform of the road is used by traffic flow for both directions (Figure 6.15).

In addition, in order to examine the environmental effects of these scenarios, sub-scenarios have been created and the data groups of GaBi software have been expanded. During the creation of these sub-scenarios, the renewal period of the road was determined as 24 hours. While the scenarios created, it was take into consideration that, the combinations of closure of the lanes and road renewal work periods. In the results section, the outputs of each scenario and sub-scenarios are given in detail.

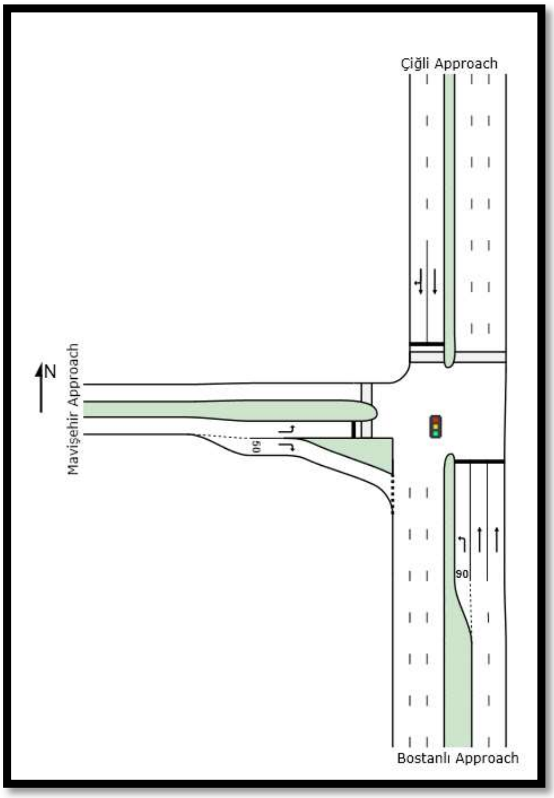

Figure 6.13 Maintenance work continuing on the road and right lane was closed the traffic (Scenario 1)

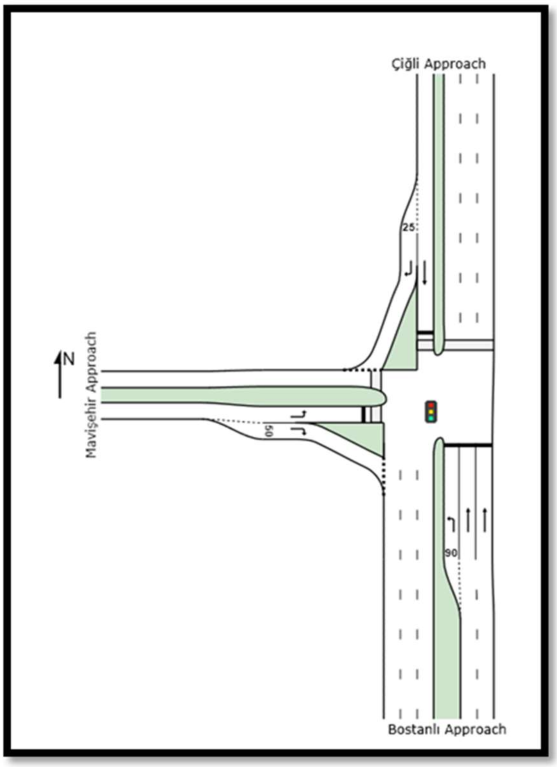

Figure 6.14 Maintenance work continuing on the road and two lanes was closed the traffic (Scenario 2)

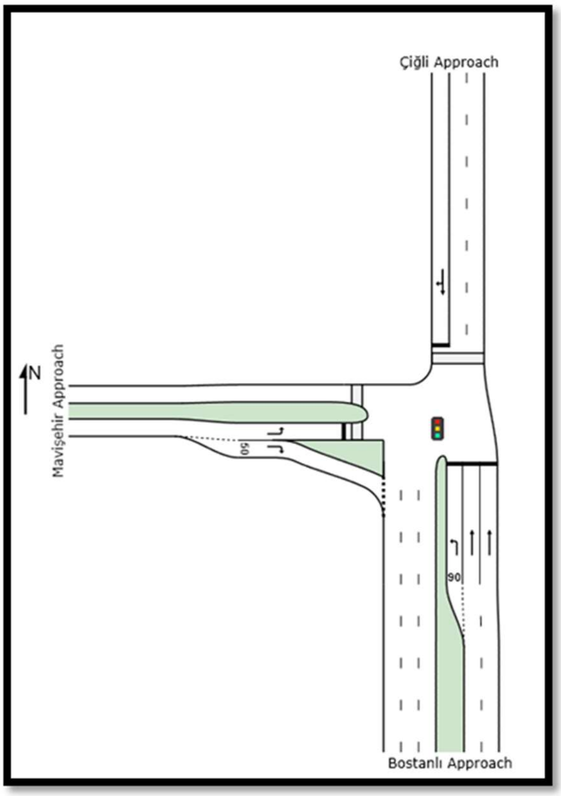

Figure 6.15 Maintenance work continuing on the road and all lanes was closed the traffic (Scenario 3)

CHAPTER SEVEN
RESULTS AND DISCUSSION

7.1 Determination of the Emissions Related to Traffic Volume

Considering the generated scenarios, the emission values were determined by using SIDRA Intersection software. Output of the SIDRA Intersection program was used as input of the GaBi program. The emission results are discussed based on each scenarios, which are given in Table 7.1.

Table 7.1 Generated scenarios

<table>
<tr><th colspan="2">Scenario-1</th><th colspan="2">Scenario-2</th><th>Scenario-3</th></tr>
<tr><td colspan="2">Maintenance period: 2 days
Operation time interval: 18:00 - 06:00</td><td colspan="2">Maintenance period: 1 day</td><td rowspan="3">- Maintenance period: 1 day
- the road completely closed to traffic</td></tr>
<tr><td>Case-1</td><td>Case-2</td><td>Case-1</td><td>Case-2</td></tr>
<tr><td>- first day two lanes are closed to traffic
- second day one lane is closed to traffic</td><td>- first day one lane is closed to traffic
- second day two lanes are closed to traffic</td><td>- Between 06:00 - 18:00 one lane is closed to traffic
- Between 18:00 - 06:00 two lanes are closed to traffic</td><td>- Between 06:00 -18:00 two lanes are closed to traffic
- Between 18:00 - 06:00 one lane is closed to traffic</td></tr>
</table>

7.1.1 Scenario 1

In this scenario, the runtime was set to two days, but the total run time is 24 hours. In this direction, it was foreseen that the road would be closed between 18:00 and 06:00 by considering the hours when low traffic demand is observed.

7.1.1.1 Case 1

As the sub-scenario of the first scenario, it was assumed that two lanes will be closed to traffic flow during the first day of the maintanence and other lane will be closed during the second day (Figure 7.1). The emission values taken as program outputs of this situation modeled in SIDRA Intersection program are given in Table 7.2.

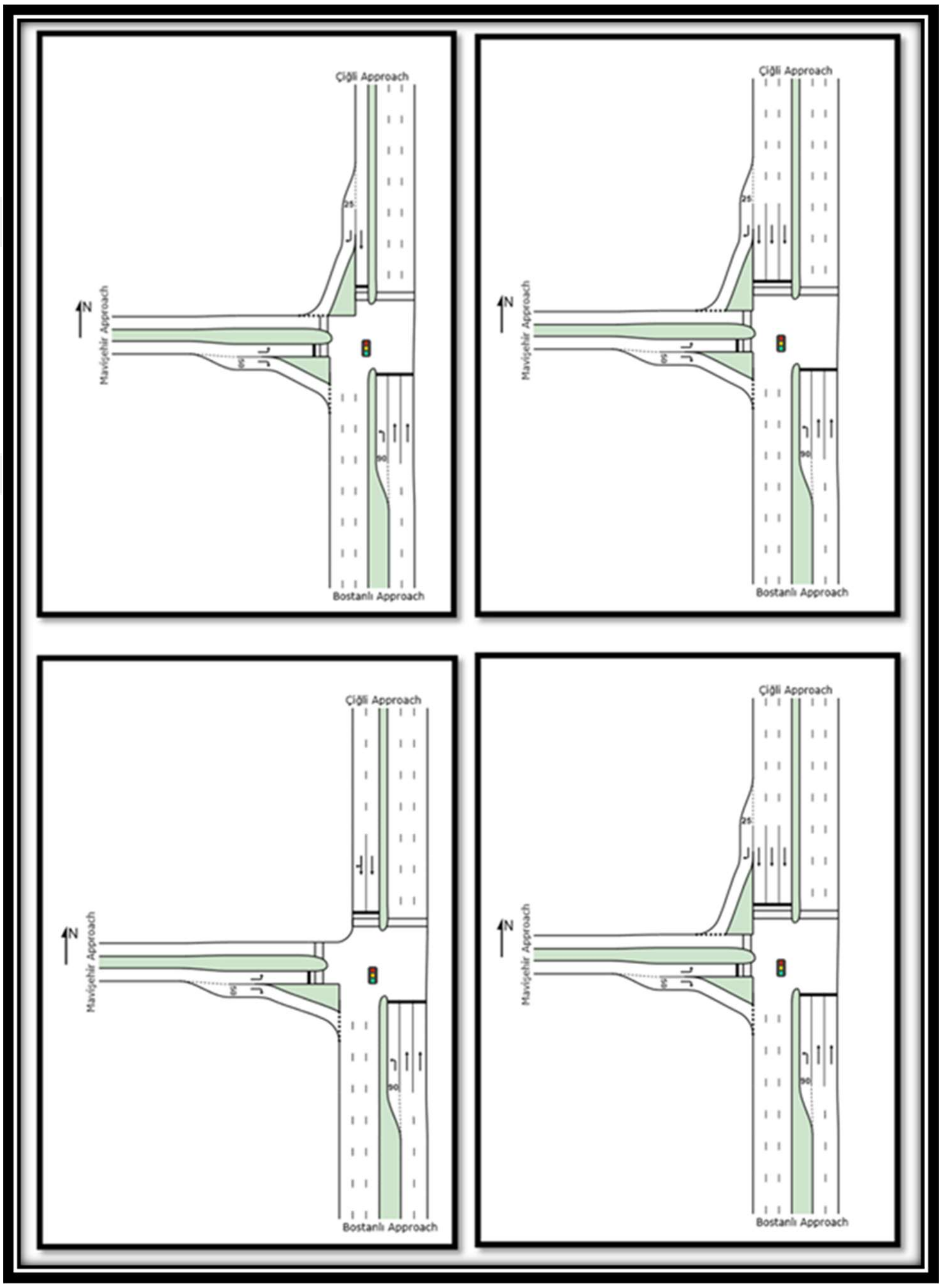

Figure 7.1 Scenario 1- Case 1

Table 7.2 Scenario-1 Case-1: emission outputs

Time	CO_2 (kg/h)	CO (kg/h)	HC (kg/h)	NO_x (kg/h)
00:00	71.3	0.08	0.006	0.020
01:00	42.9	0.05	0.003	0.012
02:00	22.8	0.03	0.002	0.007
03:00	15.5	0.02	0.001	0.005
04:00	15.0	0.02	0.000	0.004
05:00	25.8	0.03	0.003	0.008
06:00	94.4	0.11	0.008	0.028
07:00	496.9	0.59	0.042	0.147
08:00	836.7	0.96	0.074	0.242
09:00	601.1	0.71	0.052	0.179
10:00	501.3	0.59	0.043	0.148
11:00	437.5	0.51	0.037	0.130
12:00	452.5	0.54	0.039	0.135
13:00	453.0	0.54	0.039	0.135
14:00	492.0	0.58	0.042	0.147
15:00	525.2	0.62	0.045	0.156
16:00	504.2	0.59	0.044	0.151
17:00	696.1	0.80	0.061	0.205
18:00	546.1	0.60	0.049	0.154
19:00	356.3	0.42	0.031	0.103
20:00	283.4	0.33	0.024	0.082
21:00	264.3	0.31	0.023	0.077
22:00	178.1	0.21	0.015	0.052
23:00	132.2	0.16	0.011	0.039
00:00	71.8	0.08	0.006	0.020
01:00	43.2	0.05	0.003	0.012
02:00	23.1	0.03	0.002	0.007

Table 7.2 Scenario-1 Case-1: emission outputs (continuous)

Time	**CO_2** (kg/h)	**CO** (kg/h)	**HC** (kg/h)	**NO_x** (kg/h)
03:00	15.7	0.02	0.001	0.005
04:00	15.2	0.02	0.001	0.004
05:00	26.0	0.03	0.003	0.008
06:00	94.4	0.11	0.008	0.028
07:00	496.9	0.59	0.042	0.147
08:00	836.7	0.96	0.074	0.242
09:00	601.1	0.71	0.052	0.179
10:00	501.3	0.59	0.043	0.148
11:00	437.5	0.51	0.037	0.130
12:00	452.5	0.54	0.039	0.135
13:00	453.0	0.54	0.039	0.135
14:00	492.0	0.58	0.042	0.147
15:00	525.2	0.62	0.045	0.156
16:00	504.2	0.59	0.044	0.151
17:00	696.1	0.80	0.061	0.205
18:00	588.1	0.68	0.051	0.170
19:00	349.0	0.41	0.029	0.102
20:00	285.2	0.33	0.025	0.085
21:00	267.2	0.32	0.023	0.079
22:00	177.7	0.21	0.015	0.052
23:00	132.5	0.16	0.012	0.038
Total	16130.2	18.88	1.391	4.751

7.1.1.2 Case 2

As the sub-scenario of the first scenario, it was assumed that the first day will be closed one lane and the second day will be closed two lanes on the road (Figure 7.2). The emission values taken as program outputs of this situation modeled in SIDRA Intersection program are given in Table 7.3.

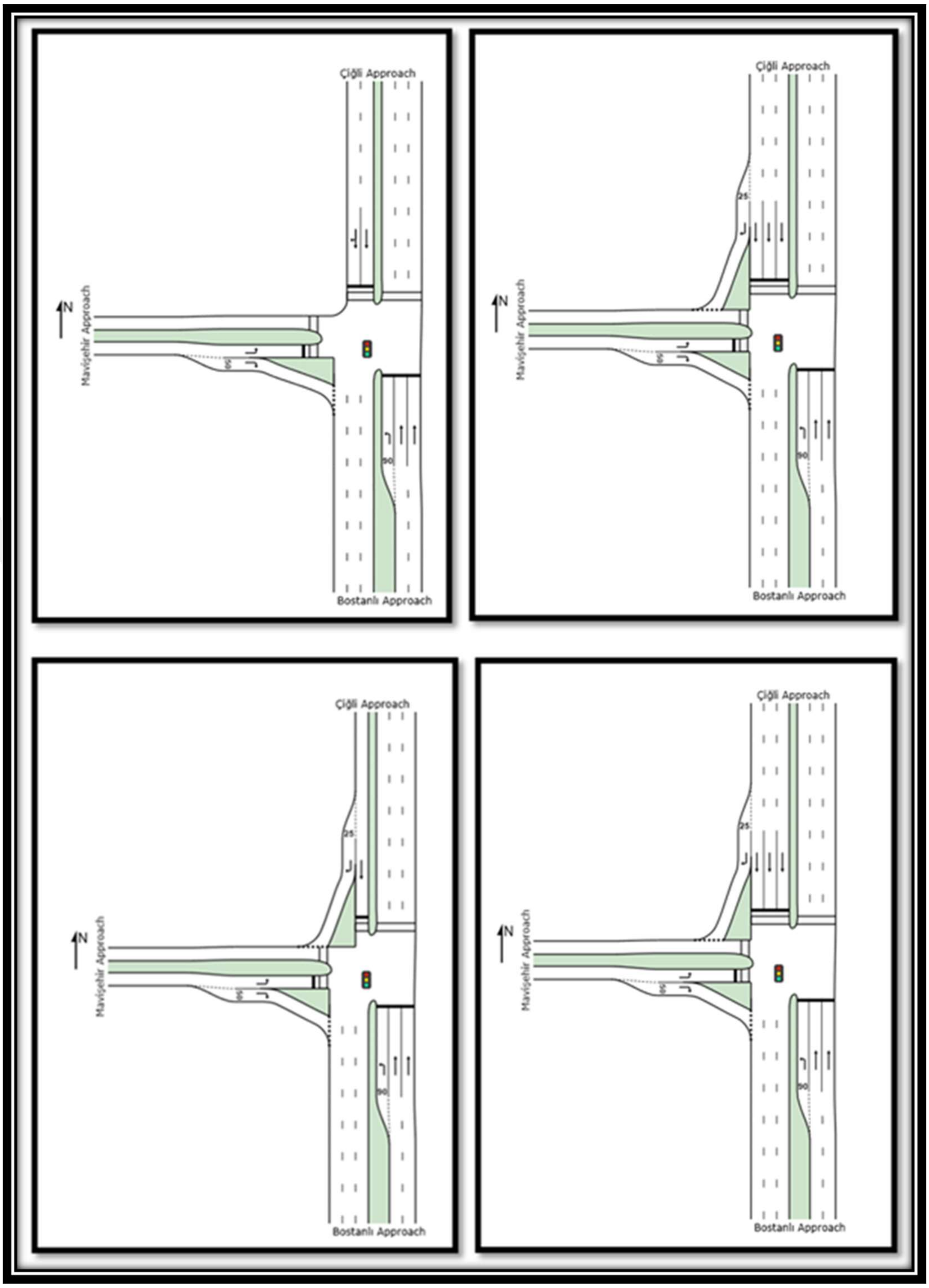

Figure 7.2 Scenario 1 – Case 2

Table 7.3 Scenario-1 Case-2: emission outputs

Time	CO_2 (kg/h)	CO (kg/h)	HC (kg/h)	NO_x (kg/h)
00:00	71.8	0.08	0.006	0.020
01:00	43.2	0.05	0.003	0.012
02:00	23.1	0.03	0.002	0.007
03:00	15.7	0.02	0.001	0.005
04:00	15.2	0.02	0.001	0.004
05:00	26.0	0.03	0.003	0.008
06:00	94.4	0.11	0.008	0.028
07:00	496.9	0.59	0.042	0.147
08:00	836.7	0.96	0.074	0.242
09:00	601.1	0.71	0.052	0.179
10:00	501.3	0.59	0.043	0.148
11:00	437.5	0.51	0.037	0.130
12:00	452.5	0.54	0.039	0.135
13:00	453.0	0.54	0.039	0.135
14:00	492.0	0.58	0.042	0.147
15:00	525.2	0.62	0.045	0.156
16:00	504.2	0.59	0.044	0.151
17:00	696.1	0.80	0.061	0.205
18:00	588.1	0.68	0.051	0.170
19:00	349.0	0.41	0.029	0.102
20:00	285.2	0.33	0.025	0.085
21:00	267.2	0.32	0.023	0.079
22:00	177.7	0.21	0.015	0.052
23:00	132.5	0.16	0.012	0.038
00:00	71.3	0.08	0.006	0.020
01:00	42.9	0.05	0.003	0.012
02:00	22.8	0.03	0.002	0.007
03:00	15.5	0.02	0.001	0.005

Table 7.3 Scenario-1 Case-2: emission outputs (continuous)

Time	CO_2 (kg/h)	CO (kg/h)	HC (kg/h)	NO_x (kg/h)
04:00	15.0	0.02	0.000	0.004
05:00	25.8	0.03	0.003	0.008
06:00	94.4	0.11	0.008	0.028
07:00	496.9	0.59	0.042	0.147
08:00	836.7	0.96	0.074	0.242
09:00	601.1	0.71	0.052	0.179
10:00	501.3	0.59	0.043	0.148
11:00	437.5	0.51	0.037	0.130
12:00	452.5	0.54	0.039	0.135
13:00	453.0	0.54	0.039	0.135
14:00	492.0	0.58	0.042	0.147
15:00	525.2	0.62	0.045	0.156
16:00	504.2	0.59	0.044	0.151
17:00	696.1	0.80	0.061	0.205
18:00	546.1	0.60	0.049	0.154
19:00	356.3	0.42	0.031	0.103
20:00	283.4	0.33	0.024	0.082
21:00	264.3	0.31	0.023	0.077
22:00	178.1	0.21	0.015	0.052
23:00	132.2	0.16	0.011	0.039
Total	16130.2	18.88	1.391	4.751

7.1.2 Scenario 2

In this scenario, the duration of work was determined as one day and it was assumed that the work would be completed in 24 hours.

7.1.2.1 Case 1

As the sub-scenario of the second scenario, it was anticipated that two lanes will be closed between the hours of 18:00-06:00 and one lane will be closed between the hours of 06:00-18:00 (Figure 7.3). The emission values taken as program outputs of this situation modeled in SIDRA Intersection program are given in Table 7.4.

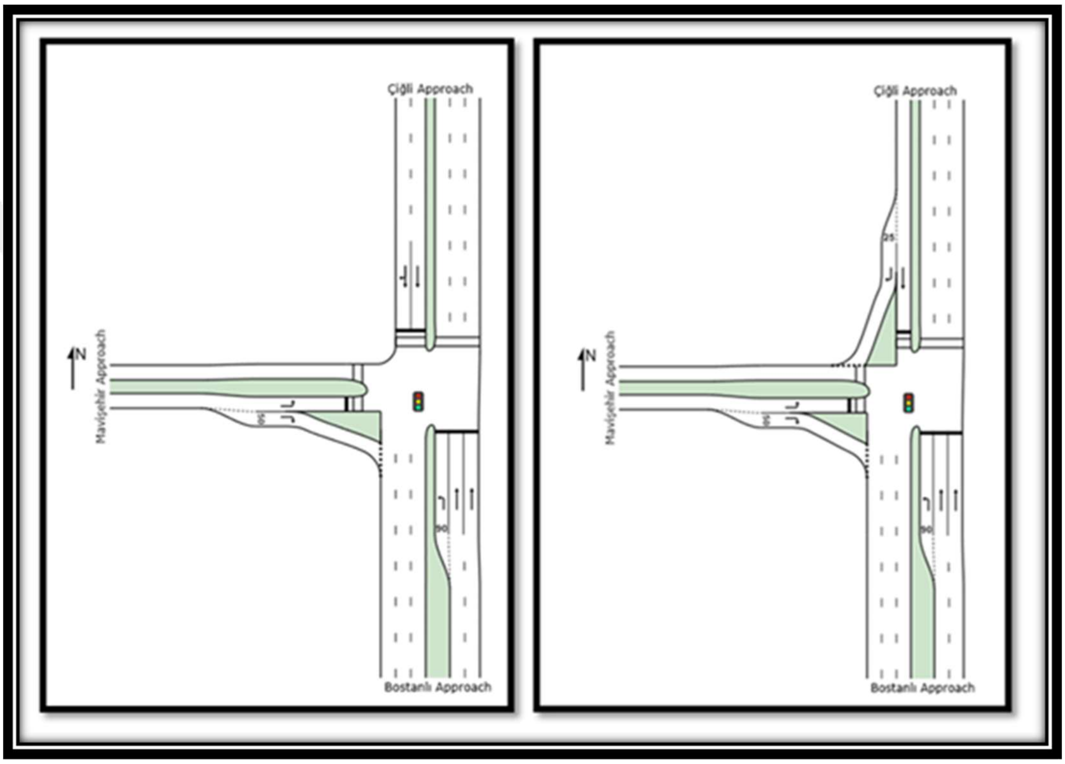

Figure 7.3 Scenario 2 – Case 1

Table 7.4 Scenario-2 Case-1: emission outputs

Time	CO_2 (kg/h)	CO (kg/h)	HC (kg/h)	NO_X (kg/h)
00:00	71.3	0.08	0.006	0.020
01:00	42.9	0.05	0.003	0.012
02:00	22.8	0.03	0.002	0.007
03:00	15.5	0.02	0.001	0.005
04:00	15.0	0.02	0.000	0.004
05:00	25.8	0.03	0.003	0.008

Table 7.4 Scenario-2 Case-1: emission outputs (continuous)

Time	CO_2 (kg/h)	CO (kg/h)	HC (kg/h)	NO_x (kg/h)
06:00	94.2	0.11	0.008	0.027
07:00	507.0	0.59	0.044	0.149
08:00	797.2	0.88	0.072	0.225
09:00	609.7	0.70	0.053	0.176
10:00	512.1	0.60	0.045	0.150
11:00	440.0	0.51	0.038	0.129
12:00	456.6	0.53	0.040	0.135
13:00	457.2	0.53	0.040	0.135
14:00	491.0	0.58	0.043	0.143
15:00	541.0	0.63	0.047	0.159
16:00	503.6	0.58	0.044	0.147
17:00	672.1	0.77	0.059	0.192
18:00	546.1	0.60	0.049	0.154
19:00	356.3	0.42	0.031	0.103
20:00	283.4	0.33	0.024	0.082
21:00	264.3	0.31	0.023	0.077
22:00	178.1	0.21	0.015	0.052
23:00	132.2	0.16	0.011	0.039
Total	8035.4	9.27	0.701	2.330

7.1.2.2 Case 2

As the sub-scenario of the second scenario, it was anticipated that one lane will be closed between the hours of 18: 00-6:00 and two lanes will be closed between the hours of 06:00-18:00 (Figure 7.4). The emission values taken as program outputs of this situation modeled in SIDRA Intersection program are given in Table 7.5.

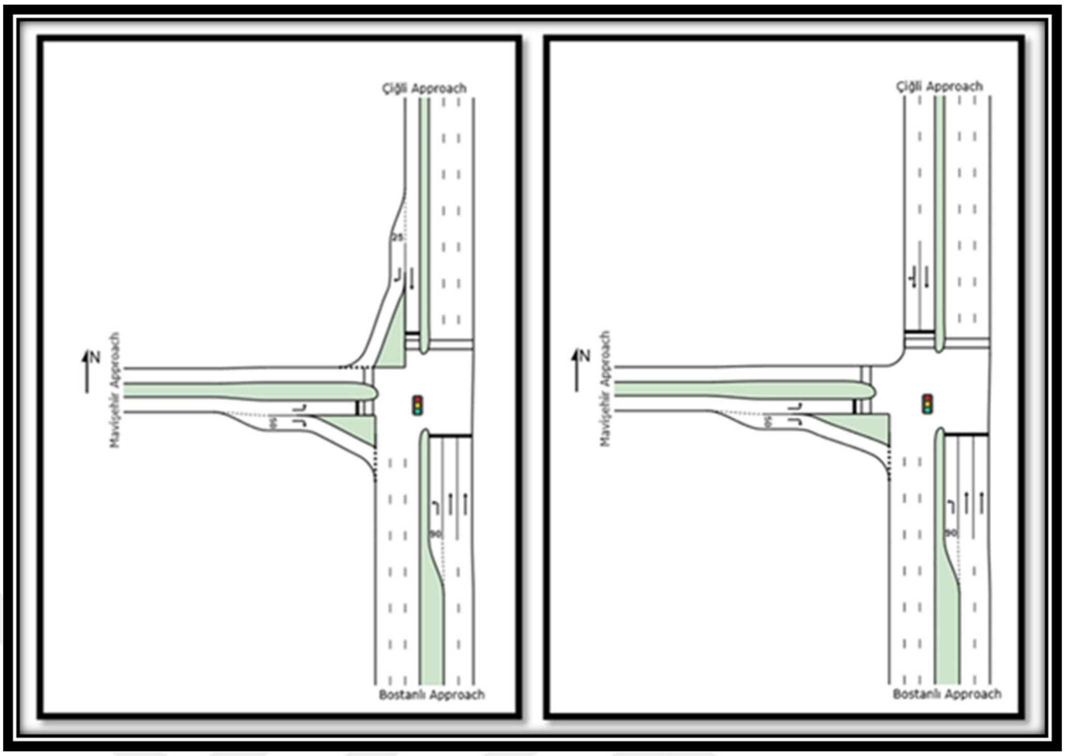

Figure 7.4 Scenario 2 – Case 2

Table 7.5 Scenario-2 Case-2: emission outputs

Time	CO_2 (kg/h)	CO (kg/h)	HC (kg/h)	NO_X (kg/h)
00:00	71.8	0.08	0.006	0.020
01:00	43.2	0.05	0.003	0.012
02:00	23.1	0.03	0.002	0.007
03:00	15.7	0.02	0.001	0.005
04:00	15.2	0.02	0.001	0.004
05:00	26.0	0.03	0.003	0.008
06:00	93.7	0.11	0.008	0.027
07:00	427.3	0.50	0.036	0.121
08:00	1599.8	1.35	0.169	0.372
09:00	584.1	0.63	0.054	0.164
10:00	432.4	0.50	0.038	0.122
11:00	418.3	0.48	0.036	0.118

Table 7.5 Scenario-2 Case-2: emission outputs (continuous)

Time	**CO_2** (kg/h)	**CO** (kg/h)	**HC** (kg/h)	**NO_X** (kg/h)
12:00	407.1	0.48	0.036	0.116
13:00	407.8	0.48	0.036	0.116
14:00	423.3	0.50	0.036	0.121
15:00	448.2	0.52	0.040	0.127
16:00	424.1	0.50	0.036	0.121
17:00	823.4	0.81	0.080	0.220
18:00	588.1	0.68	0.051	0.170
19:00	349.0	0.41	0.029	0.102
20:00	285.2	0.33	0.025	0.085
21:00	267.2	0.32	0.023	0.079
22:00	177.7	0.21	0.015	0.052
23:00	132.5	0.16	0.012	0.038
Total	8484.2	9.20	0.776	2.327

7.1.3 Scenario 3

In the last scenario, it was accepted that the road will be closed completely and the renewal work will be finished in 24 hours (Figure 7.5). During the study period, no alternative route was determined and one lane of the other platform was allocated to the vehicles towards the intersection. The emission values taken as program outputs of this situation modeled in SIDRA Intersection program are given in Table 7.6.

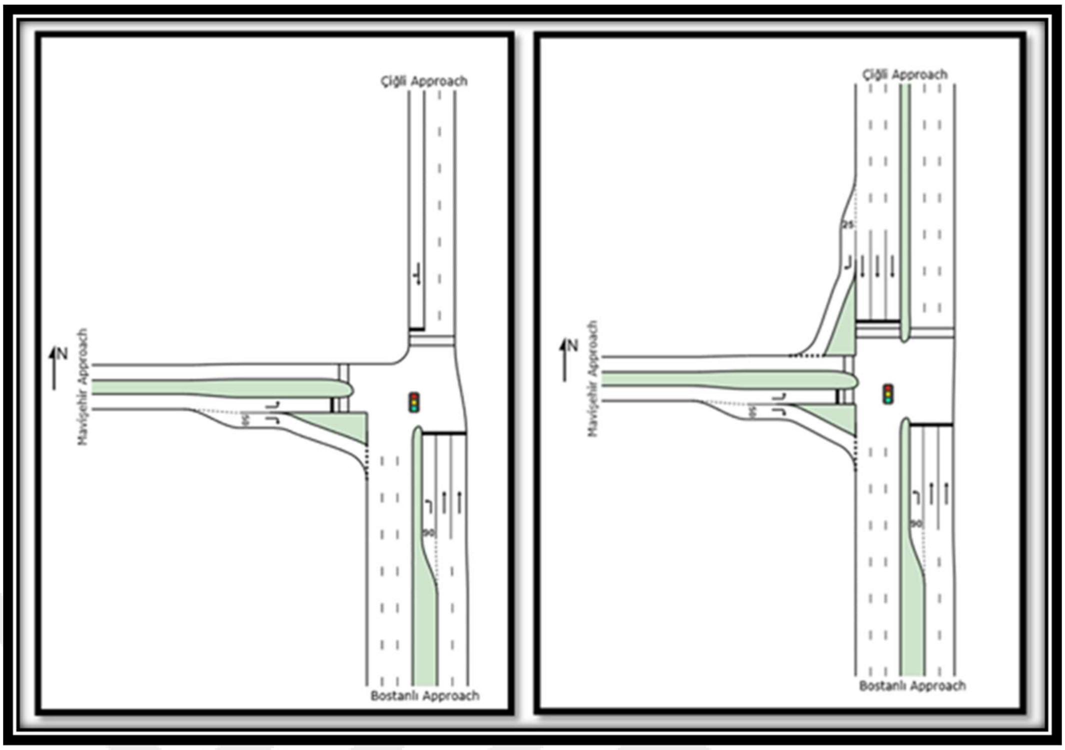

Figure 7.5 Scenario 3

Table 7.6 Scenario-3: emission outputs

Time	CO_2 (kg/h)	CO (kg/h)	HC (kg/h)	NO_x (kg/h)
00:00	71.7	0.08	0.006	0.020
01:00	43.0	0.05	0.003	0.012
02:00	22.9	0.03	0.002	0.007
03:00	15.5	0.02	0.001	0.005
04:00	15.1	0.02	0.001	0.004
05:00	25.9	0.03	0.003	0.008
06:00	94.3	0.11	0.008	0.027
07:00	433.5	0.50	0.038	0.122
08:00	1541.5	1.28	0.161	0.359
09:00	579.9	0.63	0.053	0.161
10:00	439.0	0.51	0.038	0.124
11:00	442.2	0.51	0.039	0.126

Table 7.6 Scenario-3: emission outputs (continuous)

Time	CO_2 (kg/h)	CO (kg/h)	HC (kg/h)	NO_X (kg/h)
12:00	439.7	0.51	0.038	0.125
13:00	440.7	0.51	0.038	0.126
14:00	442.1	0.52	0.039	0.126
15:00	455.6	0.52	0.040	0.129
16:00	443.1	0.52	0.039	0.126
17:00	829.8	0.80	0.080	0.216
18:00	543.8	0.59	0.049	0.151
19:00	353.9	0.42	0.031	0.103
20:00	284.0	0.33	0.024	0.083
21:00	264.5	0.31	0.023	0.077
22:00	181.4	0.22	0.016	0.053
23:00	133.4	0.16	0.012	0.039
Total	8536.5	9.18	0.782	2.329

7.2 Evaluation of the Results on the Environmental Impact

The GaBi program was run by considering the scenarios produced. The program gives graphs the environmental impacts of each scenario. CML 2001 (Institute of Environmental Sciences, Leiden University) was used to create graphs generated by the impact assessment method.

7.2.1 Global Warming Potential (GWP)

The amount of CO_2 is increasing rapidly according to the scientific observations. Especially considering the amount of accumulation in the atmosphere and life expectancy, CO_2 emerges among the greenhouse gases. For this reason, global warming potential is expressed in CO_2. Global warming potential (GWP) also shows the effects of greenhouse gases on global warming for different periods, such as 20 years, 100 years, and 500 years, and it is generally calculated for 100 years. In this study, calculations were made for 100 years.

GWP of all scenarios are given in Figure 7.6. It was determined that the longer working time increased the amount of greenhouse gas. As shown in Figure 7.6, two times more GWP values, which are 15030 kg CO_2-Eq, were achieved in Scenario 1 - Case 1 and Case 2, which have working time of 2 days, comparing to other options. When the options with 1-day working time are compared, it is seen that the best result is in Scenario 2 - Case 1 with 7610 kg CO_2-Eq. Almost the same global warming potential was determined for Scenario 2 - Case 2 (8089 kg CO_2-Eq) and Scenario 3 (8040 kg CO_2-Eq).

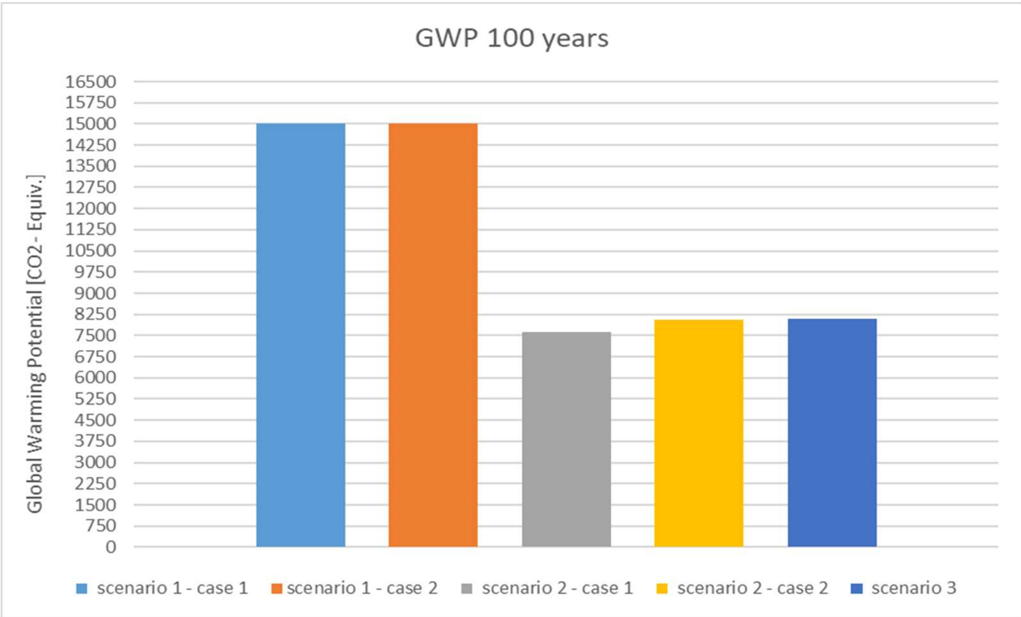

Figure 7.6 Global warming potential

7.2.2 Acidification Potential (AP)

Acidification Potential (AP) occurs a result of acids that are spread to the atmosphere and then accumulate in surface soils and waters. AP is defined as acid rain/forest decline.

AP results were obtained in a similar trend with GWP. As shown in Figure 7.7, higher AP values were determined in options with higher working time. 2.25 kg SO_2-Eq of AP, which is almost twice higher than other scenarios, were found in Scenario

1 - Case 1 and Case 2. Case 1 and Case 2 of Scenario 2 have the same acidification potential with Scenario 3 (1.1 kg SO_2-Eq). In accordance with the findings, scenarios with working day of 1-day were better than the scenarios with working day of 2-day, in terms of acidification potential.

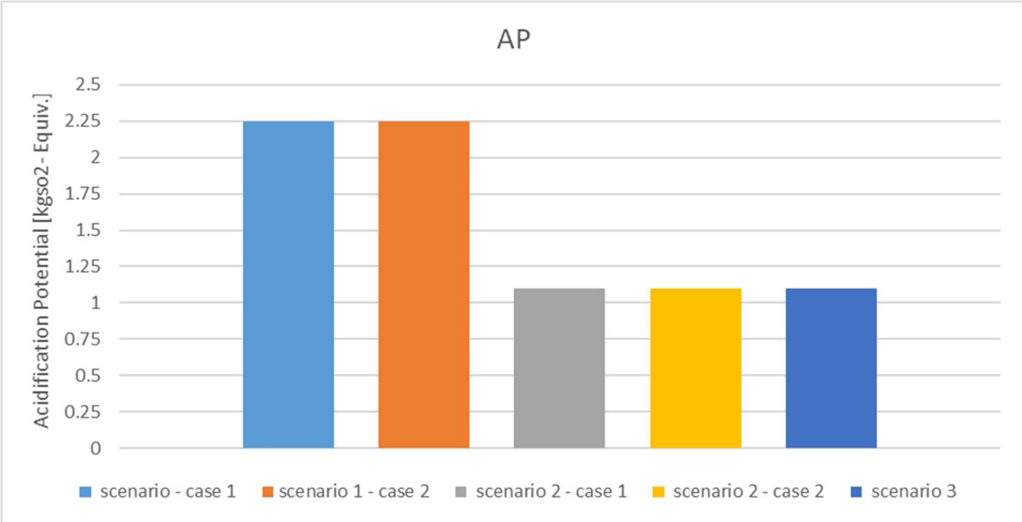

Figure 7.7 Acidification potential

7.2.3 Eutrophication Potential (EP)

Eutrophication Potential (EP) is the increase and enrichment of nutrients (nitrogen and phosphorus) in an ecosystem or in certain parts of the ecosystem. Thus, the increase of in-water plants, mainly algae, and hence the production of organic matter, is increased. EP is defined as over-fertilization of the soil or water and it is expressed in kg as the phosphate ion equivalent.

The results obtained for EP are given in Figure 7.8. Higher working time for road renewal adversely effects the EP. Two times more EP values, which are 0.585 kg PO_4-Eq, were determined for the Scenario 1 - Case 1 and Case 2, comparing to other scenarios, which have working time of 1-day. The same EP was achieved for Scenario 2 and Scenario 3 (0.287 kg PO_4-Eq).

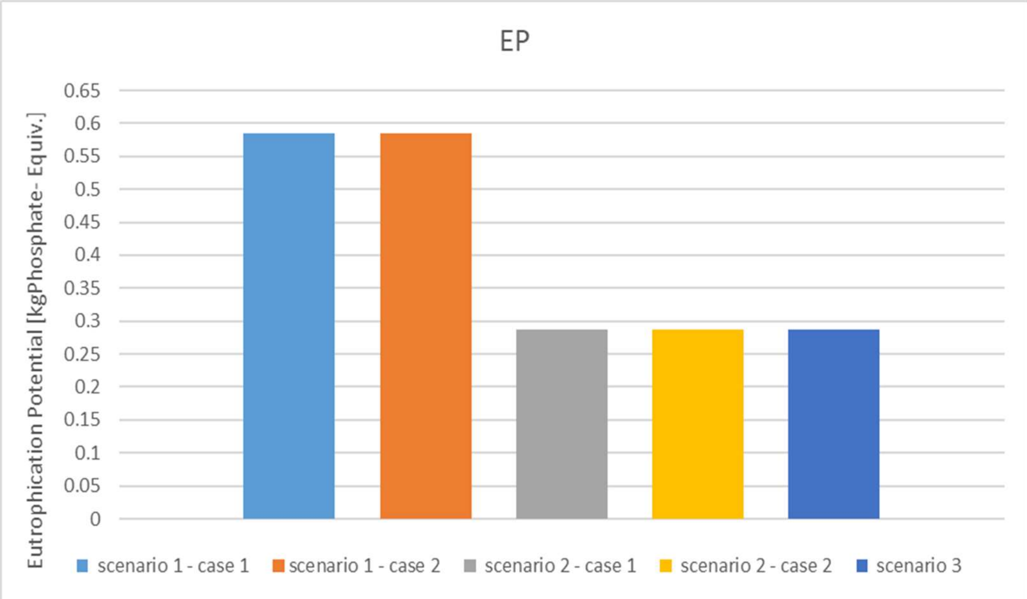

Figure 7.8 Eutrophication potential

7.2.4 Photochemical Ozone Creation Potential (POCP)

It is also known as Summer Smog and it is defined as ozone formation in the lower atmosphere. Although ozone is critical for protection against ultraviolet light (UV) in high atmosphere, low-level ozone, product damage causes various effects, such as increased asthma and other respiratory complaints. Ozone is formed by the reactions of nitrogen oxides (NO_x) and volatile organic compounds (VOC) in the atmosphere. The photochemical ozone generation potential is expressed in kg ethylene (C_2H_4) equivalents.

Results obtained for POCP are given in Figure 7.9. The highest POCP was determined as 0.758 kg C_2H_4-Eq in higher working time (Scenario 1). Almost twice lower values were found in other scenarios. Photochemical ozone creation potential of 0.374 kg C_2H_4-Eq, 0.380 kg C_2H_4 –Eq, and 0.381 kg C_2H_4- Eq were determined for Scenario 2 - Case 1, Scenario 2 - Case 2, and Scenario 3, respectively.

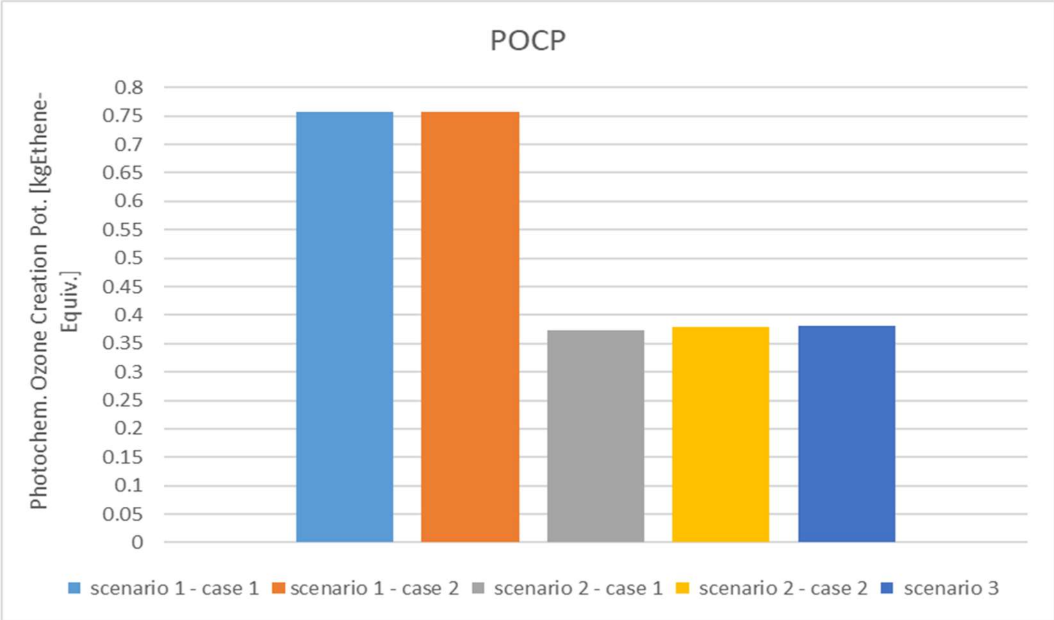

Figure 7.9 Photochemical ozone creation potential

7.2.5 Toxicity Potentials

The capacity of a substance to damage a living organism is called toxicity. There are several toxicity categories, such as freshwater aquatic, marine aquatic, human, and terrestic ecotoxicity potentials. The results of each toxicity potential considered in the scope of this thesis are given below separately.

7.2.5.1 Freshwater Aquatic Ecotoxicity Potential (FAETP)

Freshwater is an essential in the worldwide biological system. Freshwater is one of a kind ecological living spaces and furthermore basic for human life. Freshwater contamination represents a hazard to the earth; however, it can affect human wellbeing also. Thusly, it is essential to keep up anthropogenic contamination beneath an edge that would describe a hazard.

The results obtained for FAETP are given in Figure 7.10. Almost twice-higher FAETP (0.0196 kg DCB-Eq) was calculated for both cases in Scenario 1 comparing to other scenarios (0.0110 kg DCB-Eq). Hence, it was found that higher working period increases the FAETP.

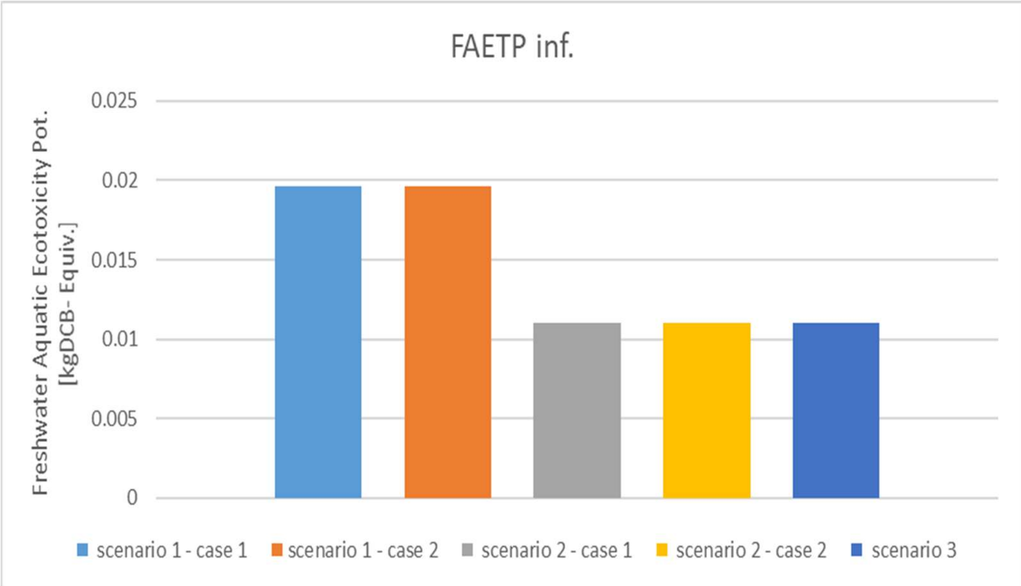

Figure 7.10 Freshwater aquatic ecotoxicity potential

7.2.5.2 Marine Aquatic Ecotoxicity Potential (MAETP)

This potential is an increased level of toxic heavy metals in aquatic environment. Toxic heavy metals damage marine organisms. In addition, some emission concentration, such as heavy metal in the air, sulfuric acid and so on, increases as a result of evaporation. Results obtained for MAETP are given in Figure 7.11.

The highest MAETP was determined in the Case 1 and Case 2 of the Scenario 1 as 0.194 kg DCB-Eq (dichlorobenzene). In other scenarios, very similar results were achieved. 0.098 kg DCB-Eq, 0.108 kg DCB-Eq, and 0.109 kg DCB-Eq of MAETP was found for Scenario 2 - Case 1, Scenario 2 - Case 2, and Scenario 3, respectively.

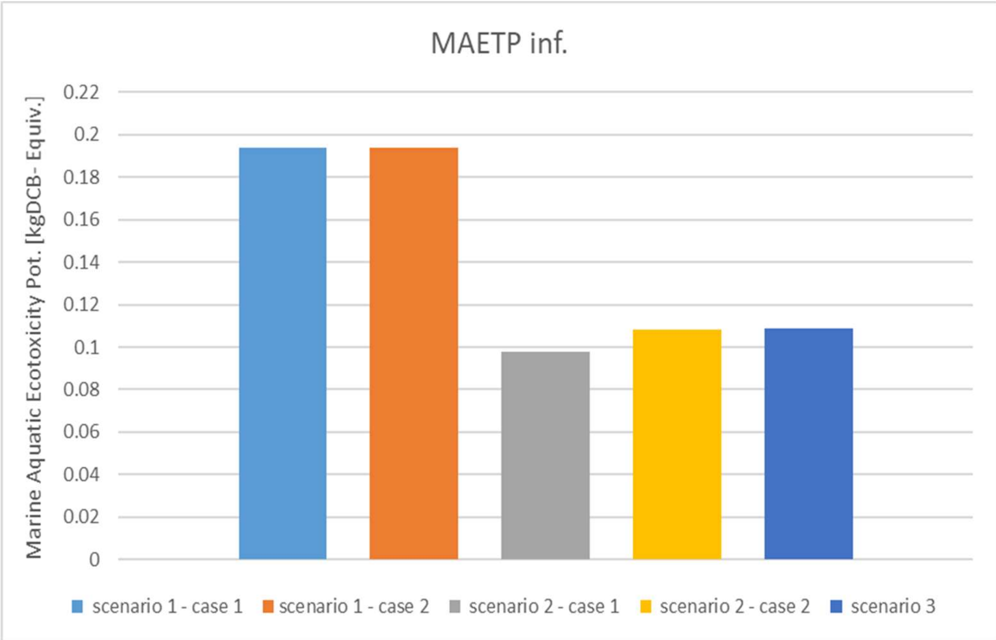

Figure 7.11 Marine aquatic ecotoxicity potential

7.2.5.3 Human Ecotoxicity Potential (HTP)

The release of certain substances (such as heavy metals) may have adversely effects on human health. Human Toxicity Potential (HTP) is used to express the potential hazards of these harmful chemicals released to the environment.

Results for HTP are given in Figure 7.12. As shown in Figure 7.12, HTP value in Scenario 1- Case 1 and Case 2 were found to be 5.42 kg DCB-Eq (dichlorobenzene) and this value is twice higher than HTP values of other scenarios. Case 1 and Case 2 of Scenario 2 gave the same results with Scenario 3 (2.66 kg DCB-Eq).

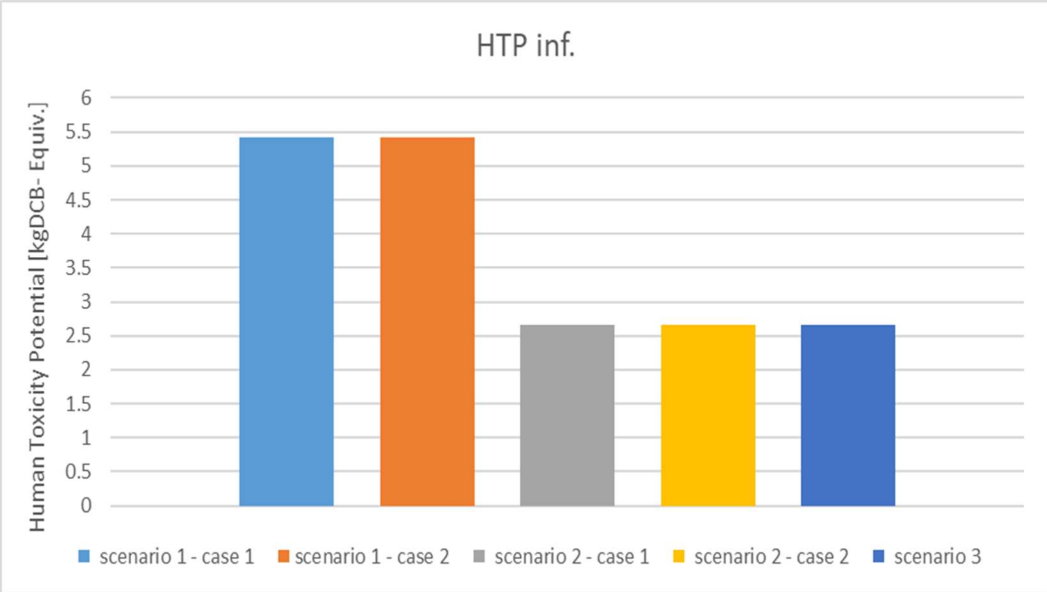

Figure 7.12 Human ecotoxicity potential

7.2.5.4 Terrestic Ecotoxicity Potential (TETP)

All pollutants that disrupt the natural structure of the soil and cause the not expect productivity to be attained from the soil form the terrestic ecotoxicity. It is expressed as kg BCB-Eq (benzocyclobutene). Results obtained for TETP are given in Figure 7.13.

As shown in Figure 7.13, higher working time has negative impacts on TETP values. The highest TETP was determined in Scenario 1 - Case 1 and Case 2 (0.111 kg BCB-Eq). Scenario 2 - Case 1 gave the best results with 0.056 kg BCB-Eq of TETP. Scenario 2 - Case 2 and Scenario 3 have the same TETP (0.062 kg BCB-Eq).

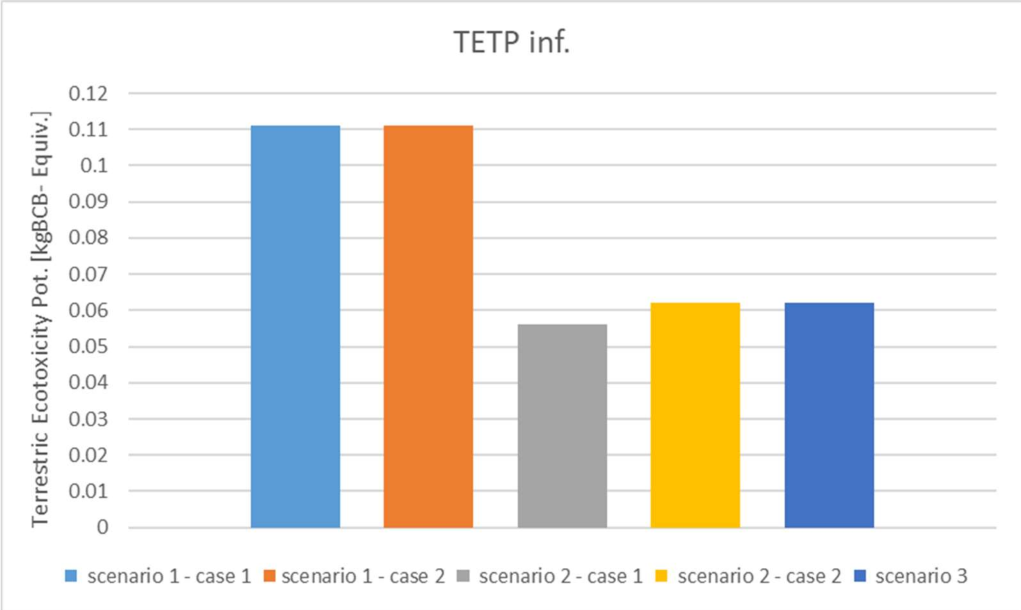

Figure 7.13 Terrestic ecotoxicity potential

7.2.6 Comparisons of all Impact Categories

When the categories of impacts of all scenarios are examined, Case 1 and Case 2 of Scenario 1 gave the worst results. The results of the other two main scenarios (Scenario 2 and Scenario 3) are similar, but the best results were obtained in Scenario 2- Case 1. The values of all impacts of all generated scenarios are given in Table 7.7

Table 7.7 Comparisons of all impact categories

Environmental Impact Categories	**Unit**	**Scenario 1 Case 1**	**Scenario 1 Case 2**	**Scenario 2 Case 1**	**Scenario 2 Case 2**	**Scenario 3**
Global Warming Potential	kg CO_2-Eq.	15030	15030	**7610**	8040	8089
Acidification Potential	kg SO_2-Eq.	2.2500	2.2500	**1.100**	1.100	1.100
Eutrophication Potential	kg PO_4-Eq.	0.5850	0.5850	**0.287**	0.287	0.287
Photochemical Ozone Creation Potential	kg C_2H_4-Eq.	0.7580	0.7580	**0.374**	0.380	0.381
Freshwater Aquatic Ecotoxicity Potential	kg DCB-Eq.	0.0196	0.0196	**0.011**	0.011	0.011
Marine Aquatic Ecotoxicity Potential	kg DCB-Eq.	0.1940	0.1940	**0.098**	0.108	0.109
Human Ecotoxicity Potential	kg DCB-Eq.	5.4200	5.4200	**2.660**	2.660	2.660
Terrestic Ecotoxicity Potential	kg BCB-Eq.	0.1110	0.1110	**0.056**	0.062	0.062

7.3 Evaluation of the Results on the Transportation Capacity

Traffic peak hours in the selected pilot area were observed between 08:00 and 09:00 in the morning and it was observed between 17: 00-18: 00 in the evening. In this respect, some parameters affecting the intersection capacity were interpreted in the time intervals where the number of vehicles was highest for each scenario. The selected parameters are tabulated in this section.

7.3.1 Scenario 1- Case 1 and Case 2

In two sub-scenarios of Scenario 1, three lanes of the road to be serviced are available for drivers at the peak hours. In other words, in terms of traffic, this scenario is give that the lowest delay in the intersection. During peak times, parameters related to maneuverability of vehicles, intersection delay data and speed and delay values during maneuver were taken from SIDRA Intersection program. The results of the program are given in Table 7.8-7.11 considering morning and evening peak hours.

Table 7.8 Scenario 1- Case 1 and Case 2 movement capacity parameters at the morning peak hours

08:00-09:00	**MOVEMENT CAPACITY PARAMETERS**		
	Average Flow (veh/h)	Total Capacity (veh/h)	Degree of Saturation
South:Bostanlı Approach L2	397	448	0.887
T1	1088	2255	0.483
North: Çiğli Approach T1	1269	1446	0.877
R2	245	1022	0.240
West: Mavişehir Approach L2	294	346	0.849
R2	620	847	0.732

Table 7.9 Scenario 1- Case 1 and Case 2 movement performance at the morning peak hours

08:00-09:00	**MOVEMENT PERFORMANCE**	
Intersection Average Delay (sec)	Average Delay (sec)	Average Speed (km/h)
28.4		
South: Bostanlı Approach L2	52.5	33.5
T1	8.3	52.9
North: Çiğli Approach T1	42.9	35.5
R2	11.1	49.4
West: Mavişehir Approach L2	51.2	30.9
R2	14.8	48.8

Table 7.10 Scenario 1- Case 1 and Case 2 movement capacity parameters at the evening peak hours

17:00-18:00	**MOVEMENT CAPACITY PARAMETERS**		
	Average Flow (veh/h)	Total Capacity (veh/h)	Degree of Saturation
South: Bostanlı Approach L2	337	403	0.837
T1	926	2064	0.449
North: Çiğli Approach T1	1079	1217	0.887
R2	208	995	0.210
West: Mavişehir Approach L2	250	328	0.763
R2	527	952	0.553

Table 7.11 Scenario 1- Case 1 and Case 2 movement performance at the evening peak hours

17:00-18:00	**MOVEMENT PERFORMANCE**	
Intersection Average Delay (sec)	Average Delay (sec)	Average Speed (km/h)
21.8		
South: Bostanlı Approach L2	36	38.7
T1	7.1	53.8
North: Çiğli Approach T1	35	38.4
R2	9.1	50.9
West: Mavişehir Approach L2	34.2	36.7
R2	10.6	51.2

7.3.2 Scenario 2- Case 1

According to Case 1 of Scenario 2, at the peak hours of the intersection road maintenance work, the single lane of the road was closed to traffic. The maneuvering capacities of vehicles belonging to these time zones, intersection delay data and speed and delay values during maneuver are taken from SIDRA Intersection program (Table 7.12-7.15). Considering all the scenarios created, it is seen that this scenario gives the closest results to the intersection delay in the current situation.

Table 7.12 Scenario 2- Case 1 movement capacity parameters at the morning peak hours

08:00-09:00	**MOVEMENT CAPACITY PARAMETERS**		
	Average Flow (veh/h)	Total Capacity (veh/h)	Degree of Saturation
South: Bostanlı Approach L2	355	358	0.990
T1	972	2408	0.403
North: Çiğli Approach T1	1133	1217	0.963
R2	219	227	0.963
West: Mavişehir Approach L2	262	273	0.960
R2	554	705	0.786

Table 7.13 Scenario 2- Case 1 movement performance at the morning peak hours

08:00-09:00	**MOVEMENT PERFORMANCE**	
Intersection Average Delay (sec)	Average Delay (sec)	Average Speed (km/h)
43.9		
South: Bostanlı Approach L2	85.9	26.3
T1	6.0	54.7
North: Çiğli Approach T1	61.2	30.1
R2	67.0	27.6
West: Mavişehir Approach L2	73.8	25.3
R2	24.5	43.8

Table 7.14 Scenario 2- Case 1 movement capacity parameters at the evening peak hours

17:00-18:00	**MOVEMENT CAPACITY PARAMETERS**		
	Average Flow (veh/h)	Total Capacity (veh/h)	Degree of Saturation
South: Bostanlı Approach L2	320	358	0.894
T1	880	2408	0.365
North: Çiğli Approach T1	1025	1176	0.872
R2	198	227	0.872
West: Mavişehir Approach L2	238	273	0.870
R2	500	734	0.682

Table 7.15 Scenario 2- Case 1 movement performance at the evening peak hours

17:00-18:00	**MOVEMENT PERFORMANCE**	
Intersection Average Delay (sec)	Average Delay (sec)	Average Speed (km/h)
28.7		
South: Bostanlı Approach L2	56.4	32.5
T1	5.8	54.9
North: Çiğli Approach T1	36.5	37.6
R2	42.1	34.8
West: Mavişehir Approach L2	55.7	29.4
R2	17.5	47.2

7.3.3 Scenario 2- Case 2

According to Case 2 of Scenario 2, two lanes of the road were closed to traffic during peak hours in the section where road maintenance will be carried out. The maneuvering capacities of vehicles belonging to these time zones, intersection delay data and speed and delay values during maneuver are taken from SIDRA Intersection program (Table 7.16-7.19). Considering other scenarios created; it is observed that the intersection delay values of this scenario give the worst results in the morning peak hours. However, it was found that the results were better than the Scenario 3 where the road was completely closed during the peak hours of the evening.

Table 7.16 Scenario 2- Case 2 movement capacity parameters at the morning peak hours

08:00-09:00	**MOVEMENT CAPACITY PARAMETERS**		
	Average Flow (veh/h)	Total Capacity (veh/h)	Degree of Saturation
South: Bostanlı Approach L2	355	251	1.414
T1	972	2523	0.385
North: Çiğli Approach T1	1133	755	1.500
R2	219	1165	0.188
West: Mavişehir Approach L2	262	218	1.200
R2	554	377	1.469

Table 7.17 Scenario 2- Case 2 movement performance at the morning peak hours

08:00-09:00	**MOVEMENT PERFORMANCE**	
Intersection Average Delay (sec)	Average Delay (sec)	Average Speed (km/h)
302.1		
South: Bostanlı Approach L2	434.8	8.1
T1	4.7	55.8
North: Çiğli Approach T1	504.8	6.6
R2	8.7	51.2
West: Mavişehir Approach L2	245.2	11
R2	467.2	7.6

Table 7.18 Scenario 2- Case 2 movement capacity parameters at the evening peak hours

17:00-18:00	**MOVEMENT CAPACITY PARAMETERS**		
	Average Flow (veh/h)	Total Capacity (veh/h)	Degree of Saturation
South: Bostanlı Approach L2	281	251	1.120
T1	772	2523	0.306
North: Çiğli Approach T1	899	755	1.191
R2	174	1165	0.149
West: Mavişehir Approach L2	208	218	0.954
R2	439	416	1.056

Table 7.19 Scenario 2- Case 2 movement performance at the evening peak hours

17:00-18:00	**MOVEMENT PERFORMANCE**	
Intersection Average Delay (sec)	Average Delay (sec)	Average Speed (km/h)
117.8		
South: Bostanlı Approach L2	177.7	16.5
T1	4.4	56.1
North: Çiğli Approach T1	229.6	12.8
R2	8.6	51.2
West: Mavişehir Approach L2	72.4	25.6
R2	114.4	22.3

7.3.4 Scenario 3

According to Scenario 3, because of the road maintenance work is road completely closed to traffic. During the whole day, a single lane from the other platform was left open for traffic to the intersection. This scenario is which the most adverse conditions occur, considering the intersection delay data and other parameters. The data obtained from the SIDRA Intersection program of Scenario 3 are given in Table 7.20-7.23.

Table 7.20 Scenario 3 movement capacity parameters at the morning peak hours

08:00-09:00	**MOVEMENT CAPACITY PARAMETERS**		
	Average Flow (veh/h)	Total Capacity (veh/h)	Degree of Saturation
South: Bostanlı Approach L2	355	251	1.414
T1	972	2599	0.374
North: Çiğli Approach T1	1133	763	1.485
R2	219	147	1.485
West: Mavişehir Approach L2	262	182	1.440
R2	554	567	0.976

Table 7.21 Scenario 3 movement performance at the morning peak hours

08:00-09:00	**MOVEMENT PERFORMANCE**	
Intersection Average Delay (sec)	Average Delay (sec)	Average Speed (km/h)
279.2		
South: Bostanlı Approach L2	434.8	8.1
T1	4.0	56.4
North: Çiğli Approach T1	485.2	6.8
R2	490.8	6.1
West: Mavişehir Approach L2	458.3	6.4
R2	72.3	29.0

Table 7.22 Scenario 3 movement capacity parameters at the evening peak hours

17:00-18:00	**MOVEMENT CAPACITY PARAMETERS**		
	Average Flow (veh/h)	Total Capacity (veh/h)	Degree of Saturation
South: Bostanlı Approach L2	281	251	1.120
T1	772	2599	0.297
North: Çiğli Approach T1	899	763	1.179
R2	174	147	1.179
West: Mavişehir Approach L2	208	182	1.145
R2	439	578	0.76

Table 7.23 Scenario 3 movement performance at the evening peak hours

17:00-18:00	**MOVEMENT PERFORMANCE**	
Intersection Average Delay (sec)	Average Delay (sec)	Average Speed (km/h)
120.8		
South: Bostanlı Approach L2	177.7	16.5
T1	3.7	56.7
North: Çiğli Approach T1	212.7	13.6
R2	218.2	12.3
West: Mavişehir Approach L2	198	13.0
R2	27.0	42.6

7.3.5 Comparisons of all Movement Parameters

At the determining the impact of road maintenance on the traffic at the selected intersection, Scenario 1 (Case 1- Case 2) obtained the best result. The effect of the study on traffic was interpreted by taking into consideration the morning and evening peak hours. In this scenario, the road closed between 18:00 - 06:00 and the road maintenance work had been done out of the peak hours. When each parameter given in the above tables is examined, it is seen that the best result in terms of traffic is given by Scenario 1.

CHAPTER EIGHT
CONCLUSIONS AND RECOMMENDATIONS

8.1 Conclusions

All scenarios generated within the scope of the study were evaluated under two main headings. The first one is to examine the environmental impact of road maintenance work, which is the main purpose of the thesis, through the life cycle analysis approach. For this purpose, Mavişehir Entrance Intersection was chosen as a pilot region and it was assumed that 100 - meter section of the road in this region will be renewed due to the wheel track maintenance. Five different scenarios considering lane changes were generated for road maintenance. Environmental impacts of the scenarios were modeled by using GaBi software. Life cycle analysis evaluations were carried out based on the required material and equipment information for road renewal works, and emission values obtained from the SIDRA Intersection program and flexible pavement design principles. As a results of the study, Case 1 of Scenario 2, in which the road works will be done continuously within 24 hours, gave the best results comparing to other scenarios. In this scenario, because of the single lane of the road will be closed at the peak hours of traffic (08:00 - 09:00 and 17:00 - 18:00), the emissions from the vehicles are lower.

The second aim of the thesis is to evaluate the traffic delays impact of road maintenance in the selected intersection with SIDRA Intersection software. Within the scope of this assessment, Scenario 1 (Case 1- Case 2) gave the best result among the generated scenarios. Although it gives best results in terms of movement performance, it gave the worst environmental results. This negative effect is due to the fact that road maintenance is continued for two days in Scenario 1. Although the work will continue for two days, the total maintenance work period will be 24 hours. Since the impact of the study on traffic is interpreted by taking into consideration the morning and evening peak hours, the road will be closed between 18:00 and 06:00 hours. Therefore, road maintenance work has not affected the vehicles using the intersection.

If a general evaluation is to be made in terms of both the environment and traffic, it will be more accurate to choose Case 1 of the Scenario 2. This scenario, which gives the best results in terms of environmental impact, gave the almost similar results with to Scenario 1, which gives the best result in terms of traffic. For example, when the intersection delay data were compared, it was seen that Scenario 1 gave a value of 28.4 seconds in the morning peak hours and 21.8 seconds in the evening peak hours whereas Case 1 of the Scenario 2 gave that values 43.9 seconds and 28.7 seconds in the peak hours.

As a result, when all the conditions and variables are taken into consideration, Case 1 of Scenario 2 is chosen as the most suitable scenario in the road maintenance of the chosen Mavişehir Entrance Intersection.

8.2 Recommendations

This study can be extended by the creation of different scenarios. By selecting different hours, lane closure combinations can be increased or the duration of work can be changed. In addition, creating different routes that are not made within the scope of this thesis can be examined in more detail instead of just taking the lane from the other platform when the road was completely closed during the maintanence work. Since road maintenance work is carried out on the intersection arm, how other intersections caused by the work can be affected by this situation may also have a different result. Therefore, it would be beneficial to create a network with other intersections where the selected intersection is connected. In line with all these suggestions, the study can be evaluated more broadly.

REFERENCES

AASHTO Guide for Design of Pavement Structures (1986). *American Association of State Highway and Transportation Officials.* Washington, D.C. 20001, 11-26.

Adeli, H., & Jiang, X. (2003). Neural-fuzzy logic model for freeway work zone capacity estimation. *Journal of Transportation Engineering, 129*(5), 484-493.

Al-Kaisy, A., & Fred, H. (2002). Guidelines for estimating freeway capacity at long-term reconstruction zones. *Present at 81st Annual Meeting of the Transportation Research Board*, Washington, D.C.

Anonymous, (2000). *Hot-Mix Asphalt Paving Handbook*. (Türkiye Asfalt Müteahhitleri Derneği). Washinghton DC. ISBN 0-309-07157-7.

ASMÜD, (2009). *Asfalt ile ilgili terimler ve tanımları*. Retrieved March 25, 2019, from http://www.asmud.org.tr/asfalt.php?sayfa=27G.

Asphalt Institute Foundation Magazine, (2019). Retrieved May 31, 2019, from https://www.movea.com.tr/asfalt-bozulmalari-neden-olusur/.

Austroads, (2009). Guide to Road Design Part 4: Intersections and Crossings – General, *Austroads Publication No. AGRD04/09*, 7-10.

Aydın, Ö.F. (2013). *Evaluation of work zone management strategies: The FSM Bridge case study*. Yüksek Lisans Tezi, Boğaziçi Üniversitesi, İstanbul.

Bayraktar, M.E. (2006). *A decision model to determine the optimal time-cost trade off in highway work zone projects*. PhD Thesis, Purdue Üniversitesi, West Lafayette, Indiana, A.B.D.

Bishop, L.P. (2000). *Pollution prevention* (1st ed.) A.B.D.: Waveland Press.

Butt, A.A., Birgisson, B., & Kringos, N. (2012). Optimizing the highway lifetime by improving the self healing capacity of asphalt. *Procedia - Social and Behavioral Sciences, 48*, 2190-2200.

Chlewick, G. (2003). New interchange and intersection designs: the synchronized split-phasing intersection and the diverging diamond interchange. *2nd Urban Street Symposium Anaheim*, California July 28-30.

Çalışkanelli, S.P., & Tanyel, S. (2018). Sinyalize kavşaklarda doygun akım değerinin irdelenmesi. *İMO Teknik Dergi, 29* (1)*,* 8225-8248.

Ergün, G., & Şahin, N. (2006). *Development of traffic congestion management strategies: strategic plan studies*, İstanbul.

FDOT (Florida Department of Transportation) (2007). FDOT *Plans Preparation Manual, Section 10.12.7*, 1.

Galatioto, F., Huang, Y., Parry, T., Bird, R., & Bell, M. (2015). Traffic modelling in system boundry expansion of road pavement life cycle assessment. *Transportation Research Part D 36*, 65-75.

Hameed, F. (2013). *Integrated life cycle analysis approach (ILCA2) for transportation project and program development*. PhD Thesis, Virginia Polytechnic Institute and State University, A.B.D.

Heaslip K., Jain, M., & Elefteriadou, L. (2011). Estimation of arterial work zone capacity using simulation. *Transportation Letters, 3*(2), 123-134.

Hendrickson, C.T., Lave, L.B., & Matthews H.S. (2006). *Environmental life cycle assessment of goods and services: an input-output approaches*. Washington: RFF Press.

Horne, R.E., Grant, T., & Verghese, K.L. (2009). *Life cycle assessment: principles, practice and prospects*. Australia: Csiro Publishing.

Ilıcalı, M., Tayfur, S., Özen, H., Sönmez, İ., & Eren, K. (2001). Asfalt ve Uygulamaları, İstanbul Asfalt Fabrikaları Sanayi ve Ticaret A.Ş., *İsfalt,* (1). 181-204. İstanbul.

ISO (2006), *Environmental Management - Life Cycle Assessment - Requirement and Guidelines*. International Organization for Standardization. ISO 14044:2006(E). Geneva, Switzerland.

Itsubo, N., & Inaba, A. (2012). Life-cycle impact assessment method based on endpoint modelling, Chapter 2- Characterization and damage evaluation 82 Methods. *JLCA News English Edition - Life-Cycle Assessment Society of Japan, 15*.

Joseph, C.T., Radwan, E., & Rouphail, N.M. (1988). Work zone analysis model for the signalized arterial, Transportation Research Record, 1194. *Transportation Research Board* Washington, D.C.

Karim, A., & Adeli, H. (2003). Radial basis function neural network for work zone capacity and queue estimation. *Journal of Transportation Engineering, 129*(5), 494-503.

KGM/6405 pozu detay bilgileri. (n.d.). Retrieved March 25, 2019, from https://www.birimfiyat.net/kgm-6405-5-cm-sikismis-kalinlikta-1-m2-asfalt betonu asinma-tabakasi-yapilmasi-kirilmis-ve-elenmis-ocak-tasi-ile-tip-1.

Kim, T., Lovell, D., & Pracha, J. (2001). A new methodology to estimate capacity for work zones. *Proceedings of the Transportation Research Board 80th Annual Meeting*, Washington, DC, 01-0566.

Kumar, P. (2004). Case studies on failure of bituminous pavements. *First International Conference on Pavement Preservation ,52*, 1-5.

Liu, G., Yang, Z., Hao, Y., & Ulgiati, S. (2016). Assessment of urban transportation metabolism from life cycle perspective: A multi-method study. *Energy Procedia, 88*, 243 – 249.

Mandevilli, S., Rys, M.J., & Russell, E.R. (2008). Environmental impact of modern roundabouts. *International Journal of Industrial Ergonomics, 38*, 135-142.

MDOT (Missouri Department of Transportation) (2004). *Work Zone Guidelines*. Jefferson City, MO.

Milachowski, C., Stengel, T., & Gehlen, C. (2011). *Life Cycle Assessment for Road Construction and Use*, EuPAVE European Concrete Paving Association. Münih.

Miliutenko, S., Björklund, A., & Carlsson, A. (2013). Opportunities for environmentally improved asphalt recycling: the example of Sweden. *Journal of Cleaner Production, 43*, 156-165.

Moretti, L., Mandrone, V., Andrea, A.D., & Caro, S. (2018). Evaluation of the environmental and human health impact of road construction activities. *Journal of Cleaner Production, 172*, 1004-1013.

Orr, D.P. (2006). Pavement Maintenance Engineer. *Cornell Local Roads Program*. 17-40.

Özkan, A. (2008), *Kentsel katı atık yönetim sistemlerinin oluşturulmasında farklı karar verme tekniklerinin kullanımı*. Doktora Tezi, Anadolu Üniversitesi, Eskişehir.

Özeler D., Yetis Ü., & Demirer G.N. (2006). Life cycle assesment of municipal solid waste management methods: Ankara case study. *Environment International, 32*, 405 – 411.

Polat, M.Ö., & Bektaş, N. (2015). Life cycle assessment of asphalt pavement product. *Sustainable Environment Research, 25*(5), 275-281.

Santero, N.J., Masanet, E., & Horvath, A. (2011). Life-cycle assessment of pavements. Part I: Critical review. *Resources, Conservation and Recycling, 55*, 9–10., 801-809.

Sarasua, W. A., Davis, W. J., Clarke, D.B., Kottapally, J., & Mulukutla, P. (2004). Evaluation of interstate highway capacity for short-term work zone lane closures. *Transportation Research Record: Journal of the Transportation Board*, *No. 1877, Transportation Research Board of the National Academies*, Washington, D.C., 85–94.

Sonnemann, G., Castells, F., & Schuhmacher, M. (2004). *Integrated life-cycle and risk assessment for industrial processes*. Florida: CRC Press LLC.

Veith, G., & Arndt, O. (2009). *Guide to Road Design Part 4: Intersections and Crossings – General.* Austroads Publication No. AGRD04/09, 7-10. Australia.

Vidal, R., Moliner, E., Martínez, G., & Rubio, M.C. (2013). Life cycle assessment of hot mix asphalt and zeolite-based warm mix asphalt with reclaimed asphalt pavement. *Resources, Conservation and Recycling, 74*, 101-114.

Yeom, C., Hajbabaie, A., Schroeder, B., Vaughan, C., Xuan, X., & Rouphail, N. (2015). Innovative work zone capacity models from nationwide field and archival sources. *Paper presented at the 94th TRB Annual Meeting*, Washington D.C.

Yu, B., & Lu, Q. (2012). Life cycle assessment of pavement: Methodology and case study. *Transportation Research Part D: Transport and Environment, 17*(5), 380-388.