



Faculty of Engineering

***Evaluation and Improvement of Three-Leg Intersections:
A Case Study in Amman City***

Prepared by:

Ali Abdulkhaleq Hussein

Supervised by:

Prof. Dr. Basim K. Jrew

A Thesis

**Submitted to Faculty of Engineering as a Partial Fulfillment of the
Requirement for Master Degree in Engineering Project Management**

August 2020

COMMITTEE DECISION

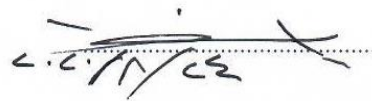
This Thesis (**Evaluation and Improvement of Three-Leg Intersections: A Case Study in Amman City**) was successfully defended and approved on 11/08/2020.

Examination Committee

Signature

Prof. Dr. Basim K. Jrew (Supervisor)

Isra University



Handwritten signature of Prof. Dr. Basim K. Jrew, dated 11/08/2020.

Dr. Moawiah A. Alnsour (Member)

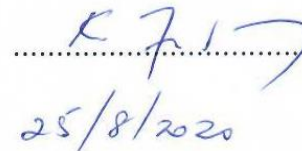
Isra University



Handwritten signature of Dr. Moawiah A. Alnsour, dated 27/08/2020.

Prof. Dr. Khair Said Jadaan (Member)

University of Jordan



Handwritten signature of Prof. Dr. Khair Said Jadaan, dated 25/8/2020.

AUTHORIZATION FORM

I am, Ali Abdulkhaleq Hussein, authorize Isra University to supply copies of my thesis to libraries or establishments or individuals upon request, in accordance with Isra University's regulations.

Signature:

A handwritten signature in blue ink, consisting of a large, stylized loop followed by a horizontal line and a vertical stroke.

Date: 28/08/2020

DEDICATION

This humble effort is dedicated to my esteemed parents for their love, care for me, and sacrifices for my education and preparing me for my future.

To my wife, who was a continuous source of support and encouragement during the challenges of this study.

To all my dear brothers and sisters.

To the soul of my dear uncle, who wished me success always and forever.

To everyone who wishes good to me.

ACKNOWLEDGEMENT

First and foremost, thanks and praises to THE ALMIGHTY GOD the most merciful, for providing me the blessings throughout my research work to complete this work successfully. Without his grace, this work could not become a reality.

I would like to express my heartiest and deep gratitude to my supervisor Prof. Dr. Basim K. Jrew, for his scientific guidance, endless support, and encouragement to me. He has taught me the methodology to carry out this study and to present the study works as clearly as possible.

I would like to extend my heartfelt thanks to Prof. Dr. Khair S. Jadaan / University of Jordan, Associate Prof. Dr. Majed Msallam / Al-Balqa Applied University, Eng. Luma Al-Akidy / Traffic Control Unit / Greater Amman Municipality, Eng. Alaa Atieh, Eng. Abdallah Abu Anz, and Eng. Ahmed Hirzallah for their cooperation and generous help.

Last but not least, a great thanks to everyone who helped me, even a little, in the task of completing this study.

TABLE OF CONTENTS

Committee Decision	i
Authorization Form.....	ii
Dedication	iii
Acknowledgement	iv
List of Figures.....	ix
List of Tables	xii
List of Abbreviations	xiv
Abstract.....	xv
1 Chapter One: Introduction	1
1.1 Background	1
1.1.1 Transportation System	2
1.1.2 Transportation System Modes	2
1.1.3 Transportation System Management (TSM)	3
1.1.4 Transportation Demand Management (TDM)	3
1.1.5 Traffic Management System (TMS)	4
1.1.6 Active Traffic Management (ATM)	5
1.2 Study Problem.....	5
1.3 Study Area.....	6
1.4 Study Objectives	8
1.5 Study Hypothesis	8
1.6 Study Structure.....	8
2 Chapter Two: Review of Literature.....	10
2.1 Introduction.....	10
2.2 Roadway System Elements.....	11
2.3 Classification of the Roadway System.....	13
2.3.1 Functional Classification	13
2.3.2 Operational Classification.....	13
2.3.2.1 Interrupted Flow Facilities	14
2.3.2.2 Interrupted Flow Parameters	14
2.3.2.2.1 Volume, Flow Rate, and Peak Hour Factor.....	15
2.4 Intersections	16

2.4.1	Classification of At-Grade Intersections.....	16
2.4.1.1	Functional Classification	16
2.4.1.2	Geometrical Classification	17
2.4.2	Conflict Points at Intersections	17
2.4.3	Signalized Intersection.....	18
2.4.3.1	Measures of Effectiveness (MOEs) at Signalized Intersection	19
2.4.3.2	Headway and Saturation Flow at Signalized Intersection.....	22
2.4.3.3	Capacity at Signalized Intersection	25
2.4.3.4	Level of Service at Signalized Intersection	26
2.4.4	Un-signalized Intersection	28
2.4.4.1	Level of Service at Un-signalized Intersection	30
2.5	Justifying of Traffic Control Signals	31
2.6	Channelization of At-Grade Intersections.....	33
2.7	Computer Software	35
2.7.1	Highway Capacity Software (HCS-2010)	35
2.7.2	Synchro-10.....	35
2.7.3	PTV VISSIM-11	36
2.8	Previous Studies.....	36
3	Chapter Three: Methodology, Data Collection, and Evaluation.....	47
3.1	Study Methodology.....	47
3.2	Data Collection	50
3.3	Evaluation of the Existing Traffic and Geometric Conditions	63
3.3.1	First Intersection	63
3.3.2	Second Intersection.....	66
3.3.3	Third Intersection.....	67
3.3.4	Fourth Intersection	68
3.3.5	Fifth Intersection	69
3.3.6	Sixth Intersection	70
3.3.7	Seventh Intersection.....	71
3.3.8	Eighth Intersection	77
3.3.9	Ninth Intersection.....	79
3.3.10	Tenth Intersection	81
3.3.10.1	Manual Evaluation of the Tenth Intersection (Al-Baraka Mall Int.)..	83

4 Chapter Four: Improvements and Discussion of the Results	91
4.1 Introduction.....	91
4.2 Improvement of the Existing Traffic and Geometric Conditions	92
4.2.1 First Intersection	92
4.2.2 Second Intersection.....	96
4.2.3 Third Intersection.....	98
4.2.4 Fourth Intersection	99
4.2.5 Fifth Intersection	101
4.2.6 Sixth Intersection	102
4.2.7 Seventh Intersection.....	104
4.2.8 Eighth Intersection	105
4.2.9 Ninth Intersection.....	106
4.2.10 Tenth Intersection	107
4.3 Improvement for Short-Term Conditions, Year-2024	109
4.3.1 First Intersection	109
4.3.2 Second Intersection.....	111
4.3.3 Third Intersection.....	112
4.3.4 Fourth Intersection	115
4.3.5 Fifth Intersection.....	116
4.3.6 Sixth Intersection	117
4.3.7 Seventh Intersection.....	119
4.3.8 Eighth Intersection	120
4.3.9 Ninth Intersection.....	121
4.3.10 Tenth Intersection	121
4.4 Summary of Discussion of the Results	123
4.5 Management Process for the Improvements Summary	126
5 Chapter Five: Conclusions and Recommendations	134
5.1 Conclusions.....	134
5.2 Limitations of the Study.....	136
5.3 Recommendations.....	136
References	139
Appendices	143
Appendix-A: Aerial Photograph for the Selected Intersections	A

Appendix-B: Traffic Volume Data for the Selected Signalized Intersections.....	B
Appendix-C: Inputs and Outputs Reports Using HCS-2010 and HCS Warrants Software.....	C
Appendix-D: Inputs and Outputs Reports Using Synchro-10 and Traffic Signal Warrants-10 Software.....	D
Appendix-E: Inputs and Outputs Reports Using VISSIM-11 Software.....	E

LIST OF FIGURES

Figure 1.1: Transportation System Modes (Ram, 2017)	2
Figure 1.2: Project Management Triangle	4
Figure 1.3: Study Area (Source: Google Maps, 2020)	7
Figure 2.1: Elements of Roadway System (HCM, 2010).....	11
Figure 2.2: Other Elements of Roadway System (HCM, 2010).....	11
Figure 2.3: Conflict Points at Four-Leg Intersection (VDOT, 2019)	18
Figure 2.4: Conflict Points at Three-Leg Intersection (T-intersection) (VDOT, 2019)	18
Figure 2.5: Cycle Length and Delay Relationship (HCM,2016).....	21
Figure 2.6: Acceleration Headways at Signalized Intersection (HCM, 2016)	23
Figure 2.7: Concept of Saturation Flow and Lost Time (HCM, 2016)	23
Figure 2.8: (a)TWSC, (b)AWSC, and (c)Roundabout YIELD sign control (Elefteriadou, 2014)	29
Figure 2.9: Three-Leg Intersection with Stop Sign Control (Elefteriadou, 2014).....	29
Figure 2.10: Warrant 3, Peak Hour (MUTCD, 2009).....	32
Figure 2.11: Warrant 3, Peak Hour (70% Factor) (MUTCD, 2009)	33
Figure 2.12: Three-Leg intersection with Various Layouts (Garber and Hoel, 2015)	34
Figure 2.13: (a) Existing Layout, (b) Suggested Triangabout Layout (Chou and Nichols, 2014).....	42
Figure 3.1: Study Methodology Flow Chart.....	48
Figure 3.2: Ministry of Higher Education Intersection (Google Maps, 2020)	52
Figure 3.3: Flow Directions at Ministry of Higher Education Intersection (Source: GAM).....	52
Figure 3.4: Flow Directions at Um Al-Fadel Intersection (Source: GAM).....	54
Figure 3.5: Flow Directions at Wasfi Al-Tal Intersection (Source: GAM).....	55
Figure 3.6: Flow Directions at Abdallah Ghosheh Intersection (Source: GAM)	56
Figure 3.7: Flow Directions at Military Service Intersection (Source: GAM).....	57
Figure 3.8: Flow Directions at Al-Makhbaz Al-Aali Intersection (Source: GAM)	58
Figure 3.9: Layout of Khalil Al-Saket Un-signalized Intersection.....	59
Figure 3.10: Layout of Um Uthaynah Un-signalized Intersection	60

Figure 3.11: Layout of Princess Sumayyah Un-signalized Intersection.....	61
Figure 3.12: Layout of Al-Baraka Mall Un-signalized Intersection.....	62
Figure 3.13: Typical Inputs and Outputs of the 1 st Intersection Using HCS-2010.....	64
Figure 3.14: Typical Inputs and Outputs of the 1 st Intersection Using Synchro-10.....	65
Figure 3.15: Typical Report of Inputs and Outputs for the 7 th Intersection Using HCS-2010.....	73
Figure 3.16: Typical Report for Justification of Warrant 3, Peak Hour Volume at the 7 th Intersection Using HCS Warrant-2010.....	74
Figure 3.17: Typical Report of Inputs and Outputs for the 7 th Intersection Using Synchro-10.....	75
Figure 3.18: Typical Report for Justification of Warrant 3, Peak Hour Volume at the 7 th Intersection Using Synchro Traffic Signal Warrant-10.....	76
Figure 3.19: Traffic Signal Justification Curve at the 8 th Intersection Using Synchro warrant-10.....	78
Figure 3.20: Traffic Signal Justification Curve at the 9 th Intersection Using Synchro Warrant-10.....	80
Figure 3.21: Traffic Signal Justification Curve at the 10 th Intersection Using Synchro Warrant-10.....	82
Figure 3.22: Movements Pattern at TWSC Intersection (HCM, 2010).....	84
Figure 4.1: (a) Existing Layout, (b) Suggested CGT-Intersection Layout.....	93
Figure 4.2: Analysis and Simulation of the 1 st Intersection's Improvement Using VISSIM-11.....	95
Figure 4.3: (a) Suggested Layout, Year-2019, (b) Suggested Layout, Year-2024.....	110
Figure 4.4: Suggested Layout for the 3 rd Intersection (No Scale).....	113
Figure 4.5: Traffic Signal Justification for the 10 th Intersection in the Short-Term Period (Year, 2024) Using Synchro Warrant-10 Software.....	122
Figure 4.6: Comparison Bar Chart for the Delays at Signalized Intersections (1 st through 6 th) for the Existing and Short-Term Periods.....	128
Figure 4.7: Comparison Bar Chart for the Fuel Consumption at Signalized Intersections (1 st through 6 th) for the Existing and Short-Term Periods.....	129
Figure 4.8: Comparison Bar Chart of the Minor Approach Delay at Un-signalized Intersections (7 th through 10 th) for the Existing and Short-Term Periods.....	129
Figure 4.9: Management Flow Diagram for the Signalized Intersections (Evaluation and Improvements in the Existing-Term, Year-2019).....	130

Figure 4.10: Management Flow Diagram for the Signalized Intersections Improvements in the Existing-Term (2019) and Short-Term (2024)	131
Figure 4.11: Management Flow Diagram for the Unsignalized Intersections (Evaluation and Improvements in the Existing-Term, Year-2019)	132
Figure 4.12: Management Flow Diagram for the Unsignalized Intersections Improvements in the Existing-Term (2019) and Short-Term (2024)	133

LIST OF TABLES

Table 2.1: Level of Service and Corresponding Delays for Signalized Intersection (HCM,2010).....	27
Table 2.2: Level of Service and Corresponding Delays for Unsignalized Intersection (HCM,2010)	30
Table 3.1: Locations, and Control Types of the Selected Intersections.....	49
Table 3.2: Traffic Flow Data in the 1 st Intersection at Each Approach	53
Table 3.3: Evaluation of the 1 st Intersection Using HCS-2010 and Synchro-10.....	63
Table 3.4: Evaluation of the 2 nd Intersection Using HCS-2010 and Synchro-10	66
Table 3.5: Evaluation of the 3 rd Intersection Using HCS-2010 and Synchro-10.....	67
Table 3.6: Evaluation of the 4 th Intersection Using HCS-2010 and Synchro-10.....	68
Table 3.7: Evaluation of the 5 th Intersection Using HCS-2010 and Synchro-10.....	69
Table 3.8: Evaluation of the 6 th Intersection Using HCS-2010 and Synchro-10.....	70
Table 3.9: Traffic Volume Data in the 7 th Intersection at Each Approach	71
Table 3.10: Evaluation of the 7 th Intersection Using HCS-2010 and Synchro-10.....	72
Table 3.11: Traffic Volume Data in the 8 th Intersection at Each Approach	77
Table 3.12: Evaluation of the 8 th Intersection Using HCS-2010 and Synchro-10.....	78
Table 3.13: Traffic Volume Data in the 9 th Intersection at Each Approach	79
Table 3.14: Evaluation of the 9 th Intersection Using HCS-2010 and Synchro-10.....	80
Table 3.15: Traffic Volume Data in the 10 th Intersection at Each Approach	81
Table 3.16: Evaluation of the 10 th Intersection Using HCS-2010 and Synchro-10.....	82
Table 3.17: Calculation of the Flow Rates in the 10 th Intersection.....	83
Table 3.18: Evaluation Results Using HCS-2010, Synchro-10, and Manual Calculation	90
Table 4.1: Improvement of the 1 st Intersection, Year 2019) Using Synchro-10 and HCS-2010.....	92
Table 4.2: Maximum Approaches Delay Calculation According to VISSIM-11 Outputs	94
Table 4.3: Improvement of the 1 st Intersection Using Synchro-10 and VISSIM-11	94
Table 4.4: Results Comparison Between the Existing Evaluation and the Improvement at the 1 st Intersection.....	96

Table 4.5: Improvement of the 2 nd Intersection (Year, 2019) Using HCS-2010 and Synchro-10	97
Table 4.6: Improvement of the 3 rd Intersection (Year, 2019) Using HCS-2010 and Synchro-10	99
Table 4.7: Improvement of the 4 th Intersection (Year, 2019) Using HCS-2010 and Synchro-10	100
Table 4.8: Improvement of the 5 th Intersection (Year, 2019) Using HCS-2010 and Synchro-10	102
Table 4.9: Improvement of the 6 th Intersection (Year, 2019) Using HCS-2010 and Synchro-10	103
Table 4.10: Designation of the Traffic Signal Cycle Time for the 7 th Intersection at the Existing-Term Period Using Synchro-10 Software	105
Table 4.11: Comparison of HCS-2010, Synchro-10, VISSIM-11, and Manual Calculation Results for the 10 th Intersection Analysis	108
Table 4.12: Predicted Traffic Volumes for the Short-Term Period at the 1 st Intersection	109
Table 4.13: Improvements Comparison at the 1 st Intersection in the Existing and Short-Term Periods Using Synchro-10 and VISSIM-11	111
Table 4.14: Improvements Comparison at the 2 nd Intersection in the Existing and Short-Term Periods Using HCS-2010 and Synchro-10	112
Table 4.15: Improvement of the 3 rd Intersection at the Short-Term Period Using HCS-2010 and Synchro-10	114
Table 4.16: Improvements Comparison at the 4 th Intersection in the Existing and Short-Term Periods Using HCS-2010 and Synchro-10	116
Table 4.17: Improvements Comparison at the 5 th Intersection in the Existing and Short-Term Periods Using HCS-2010 and Synchro-10	117
Table 4.18: Improvements Comparison at the 6 th Intersection in the Existing and Short-Term Periods Using HCS-2010 and Synchro-10	118
Table 4.19: Designation of the Traffic Signal Cycle Time for the 7 th Intersection in the Short-Term Period Using Synchro-10 Software	119
Table 4.20: The Predicted Short-Term Traffic Volumes at the 10 th Intersection (Year, 2024)	122

LIST OF ABBREVIATIONS

- ATM	Active Traffic Management
- AWSC	All-Way Stop Control
- BRT	Bus Rapid Transit
- EB	Eastbound
- GAM	Greater Amman Municipality
- HCM	Highway Capacity Manual
- HCS	Highway Capacity Software
- LOS	Level of Service
- MOEs	Measures of Effectiveness
- MUTCD	Manual on Uniform Traffic Control Devices
- NB	Northbound
- PHF	Peak Hour Factor
- PHV	Peak Hour Volume
- SB	Southbound
- TDM	Transportation Demand Management
- TSM	Transportation System Management
- TWSC	Two-Way Stop Control
- V/C	Volume to Capacity ratio (Degree of Saturation)
- VMS	Variable Message Sign
- WB	Westbound

Evaluation and Improvement of Three-Leg Intersections: A Case Study in Amman City

Prepared by: Ali Abdulkhaleq Hussein

Supervised by : Prof. Dr. Basim K. Jrew

ABSTRACT

The rise in car ownership in the last decades in Jordan caused high traffic demand in most of the urban roadway network in Amman City, especially in the peak periods. The growth in traffic demand results in congestion on the urban network, high delay, low Level of Service (LOS), and more fuel consumption and air pollution. Intersections are considered as the most critical elements in the urban roadway network, therefore, the evaluation of intersections within the network helps the decision-makers to improve the traffic operation performance, in short, medium, and long-term periods of time. Based on these facts, this study involves evaluating and improving six 3-leg signalized intersections and four 3-leg unsignalized intersections at different locations in Amman City using HCS-2010 and Synchro-10 computer software and validated by VISSIM-11 simulation tool and manual calculation. The evaluation and improvement for each intersection are conducted for the existing and short-term traffic conditions (Year 2019 and Year 2024, respectively). The results of the evaluation revealed that all intersections operate at LOS-E or breakdown condition (LOS-F) during peak hour period. Many low-cost solutions such as prohibiting on-street parking, prohibiting U-turn, adding additional lanes for minor-street and major-street, redirection of flow, and optimization of the cycle length were suggested on the existing and short term period assuming growth rate of 5.5% combined with strict law enforcement. The output results of the used software showed significant improvements such as a reduction in delay, number of stopped vehicles, and fuel consumption. The operational performance was also improved to LOS-C or LOS-D at all six selected signalized intersections.

For unsignalized intersections, the evaluation process showed that the current left-turn from the minor-street faces high delay and operates with LOS-F. To prioritize traffic movements at these four intersections, the installation of traffic signals was suggested and justified according to warrant 3; Peak Hour Volume only. The results

showed that three intersections are warranted for signalization under the existing conditions while the fourth is warranted for signalization only in the short-term period. Also, the optimum cycle time was selected for each intersection with two operation modes for left-turn from the major street; Protected and Protected-Permitted. Accordingly, the LOS of the minor approach improved to LOS-C or D as well as the LOS of the entire intersection to LOS-C or D.

Finally, flow management diagrams with bar charts were prepared for decision-makers to show and summarize the improvements results in the existing and short-term condition based on the output resulted from HCS-2010 and Synchro-10 software and validated by VISSIM-11 simulation tool.

Further medium- and long-term improvements of the urban road network in Amman require costly infrastructures such as overpass interchanges or underpass tunnels. Therefore, it is recommended to apply transportation demand strategies to reduce travel demand besides applying useful sustainable transportation that is based on the five pillars; public transportation, electrical vehicles or hybrid, carpooling, bicycle, and walking.

Keywords: Three-Leg intersection, Signalized Intersection, Unsignalized Intersection, Synchro Software, VISSIM Software, Traffic Signal Warrants, Project Management, Transportation System Management (TSM).