An-Najah National University
Faculty of Graduate Studies

Modeling Pedestrian Behavior on Pedestrian Crosswalks

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3. Dr. Khaled Al-Sahili (Member)	…………………………

DEDICATION

To the owners of the glowing hearts and burning vigor…………….

To those who sacrificed their money, souls and blood for their faith.....

To those who faced the devil of evil and the devil of craving……….

To Al-Aqsa Intifada martyrs and all the martyrs of Palestine……….

To the spirit of the struggling martyr, my nephew, Rami Ganim………

To the stubborn heroes and political prisoners……………………….

To those who loved Palestine as a home land and Isalam as faith a way of life ………………………………………………………………..

To my tender mother, honored father and dear brothers and sisters.

To all of them,

I dedicate this work

ACKNOWLEDGMENT

Thank God for the blessing granted to us…………………...................

I feel oblige to extend my sincere thanks to my instructors in An-Najah National University, who were helpful and brace. They were really that burning candles to illuminate our path.

And special thanks to Dr. Osama Abaza who saved no effort in supporting me to complete this work in spite of the difficult circumstances.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

Modeling Pedestrian Behavior on Pedestrian Crosswalks

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Abstract

Ever since the revitalization of the central city area has become an urgent issue, especially for the countries where motorization accelerates the urban sprawl and the center of the city, there has been a tendency to emphasize the importance of studying the walking behavior and environment of pedestrians.

Insight into walking behavior is essential for theory and model development describing the behavior of pedestrians on pedestrian crosswalks. In turn, combined models (Birth-Death process) can be used to test and compare different infrastructure designs, both from the perspective of efficiency and safety. To calibrate these models, simple data is required such as pedestrian arrival rate and pedestrian departure rate.

This thesis deals with an approach to estimate the actual green time for pedestrian signal. The objective relates to the management of the pedestrians crosswalks to enhance utilization of traffic signals, which is considered one of the main issues facing transportation system especially inside the congested cities. A mathematical model was made to describe the behavior of pedestrians at and during the crossing of the roadway at signalized crosswalks. The queuing theory was utilized to model this process.

The proposed model was derived and developed for CBD areas based on actual field measurements of key parameters at crosswalks in the urban area of Nablus-Palestine. The model was tested and calibrated on other locations in the city and the CBD area of the city of Ramallah and showed that it can be applied with significant efficiency which eventually will be reflected in the design of pedestrian signal.

CHAPTER ONE

INTRODUCTION

Chapter One
Introduction

1.1 Background

Traffic research on roadways has traditionally focused around automobile traffic. Concerns for the safety and convenience of pedestrians have often come second to those of motorists. This is, in part, due to the relative difficulty of modeling pedestrian behavior. Much of this difficulty arises from the fact that pedestrian behavior tends to be highly complex and affected by a multitude of parameters.

However, close inspection of crowd behaviors reveals that the motion of individuals is often governed by a small, relatively simple set of behaviors. Having made this realization, the difficulty becomes organizing and keeping track of a large number of autonomous, interacting agents.

There have been many studies regarding the safety effects of managed crosswalks. Some studies contradict others regarding when a crossing location should be managed or unmanaged, making the decision process challenging. Some studies indicate that as traffic volume and speeds increase, such as on transportation system, pedestrian accidents may increase more at managed crosswalks than at unmanaged crosswalks.

Pedestrians are legitimate users of the transportation system and they should be able to use the transportation system safely and without unreasonable delay. Providing managed crosswalks is one of many ways to facilitate crossings.

The objective of this thesis related to the management of the pedestrians crosswalks to enhance utilization of traffic signals, which is considered one of the main issues facing transportation system especially inside the congested cities.

1.2 Pedestrian considerations

A wide range of pedestrians can be expected at sites, including the young, old, and disabled (for example, hearing, visual, and mobility). All of these pedestrians need a clearly delineated and usable travel path. It must be recognized that pedestrians are reluctant to retrace their steps to a prior intersection for a crossing. There are three considerations in planning for pedestrians in temporary traffic control zones:

A. Pedestrians should not be led into conflicts with work site vehicles, equipment, and operations.

B. Pedestrians should not be led into conflicts with vehicles moving through or around the site.

C. Pedestrians should be provided with a safe, convenient path that replicates as nearly as practical the most desirable characteristics of the existing sidewalk(s) or a footpath(s).

Consideration should be made to separate pedestrian movements from both site activity and motor vehicle traffic. Pedestrians should be appropriately directed with advance signing that encourages them to cross to the opposite side of the roadway.

In urban and suburban areas with high motor vehicle traffic volumes, these signs should be placed at intersections so that pedestrians are not confronted with mid-block work sites that will induce them to attempt skirting the site or making a mid-block crossing.

1.3 Objectives of the study

There are very limited number of studies that have been done with the specific objectives of modeling pedestrian behavior on pedestrian crosswalks.

The main objective of this thesis is related to the management of the pedestrians crosswalks to enhance utilization of traffic signals, which is considered one of the main issues facing transportation system especially inside the congested cities.

This thesis will attempt to develop a mathematical model which would describe the behavior of pedestrians at and during the crossing of the roadway at signalized crosswalks.

Since there are many pedestrians crossing the roadway randomly, it is highly important to organizing pedestrian's crosswalks with proper means and management. This will result in an increase in the factor of safety and encourages pedestrian to use crosswalks.

1.4 Study area

Palestine is a typical developing country located in a central location in the Middle East. Its significance is represented by its geographic location. Nablus is a major city located in the northern part of the West Bank. The location of the city is shown in Figure 1.1

This study focuses on Nablus City as the study area. The study locations are Alwatani intersection, Nablus municipality and Police Center.

A verification of results was tested on one crosswalk in Rammalah City.

Figure (1.1): Location of Nablus in the West Bank

The structure of the crosswalks in Nablus is affected by the nature of the city and congestion as we know. The location of Alwatani Intersection is very sensitive because it serves one of the important activity centers in the city, which are Alwatani Hospital in addition to being a sensitive bottle neck in the city.

It is of great importance to model the pedestrian behavior through several locations within the study area and the model will apply the concepts of modeling pedestrian behavior on pedestrian crosswalks.

1.5 Thesis outline

This thesis contains six chapters, which are summarized as follows:-

Chapter one presents the introduction, background, objectives, and study area.

Chapter two is the literature review.

Chapter three discusses the methodology.

Chapter four is data collection

Chapter five presents the model development and analysis

Chapter six provides conclusions and recommendations of this study.

CHAPTER TWO

LIBRARY SEARCH

Chapter Two
Library Search

2.1 Introduction

Development of any mathematical model now is related to the strength of the transportation sector. Although the level of technology in transportation varies and the needs and demands are expressed differently, the movement of people at crosswalk is essential for human activities and production.

Living in any urban or rural area without managing the crosswalks in those cities or villages is impossible. Use of any mathematical models to design the traffic signal is necessary to manage the crosswalk especially in the CBD area. Therefore, modeling of pedestrian behavior at pedestrian crosswalks has to be treated as an integral and basic component of any comprehensive development plan.

Modeling of pedestrian behavior at pedestrian crosswalks is one of the key elements in any development plan. There are no international standards to be adopted in any mathematical model. Historically, some of such projects are done differently in many countries, and each project is differing from the other according to many factors such as the behavior of the pedestrian, pedestrian volume crossing the road, traffic volume, location of the crosswalk, and public acceptance.

2.2 Crosswalk markings

In the literature review, crosswalk markings provide guidance for pedestrians who are crossing roadways by defining and delineating paths on approaches to and within signalized intersections, and on approaches to other intersections where traffic stops. Crosswalk markings also serve to alert road users of a pedestrian crossing point across roadways not controlled by traffic signals or STOP signs. At non-intersection locations, crosswalk markings legally establish the crosswalk.

Crosswalks should be marked at all intersections where there is substantial conflict between vehicular and pedestrian movements. Marked crosswalks also should be provided at other appropriate points of pedestrian concentration, such as at loading islands, mid-block pedestrian crossings, or where pedestrians could not otherwise recognize the proper place to cross.

For added visibility, the area of the crosswalk may be marked with white diagonal lines at a 45-degree angle to the line of the crosswalk or with white longitudinal lines parallel to traffic flow as shown in (Figure 2.1). When diagonal or longitudinal lines are used to mark a crosswalk, the transverse crosswalk lines may be omitted (MUTCD 2002).

According to the European code for crosswalks, which is more applicable to Palestine, crosswalks shall be solid white not less than 0.15 m (6 in) nor greater than 0.6 m (24 in) in width and not less than 1.8 m (71 in) nor greater than 3.0 m (120 in) in length (MUTCD 2002).

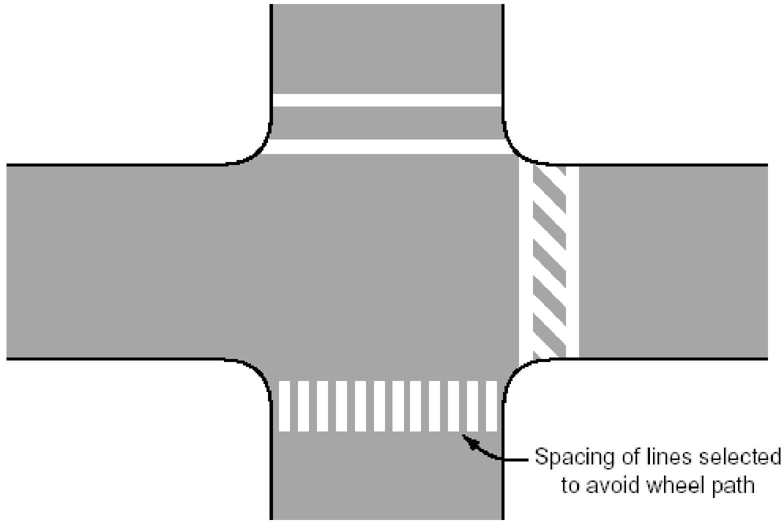


Figure (2.1): Typical types of crosswalk markings
Source: Manual on Uniform Traffic Control Devices (MUTCD), 2002.

2.3 Pedestrian intervals and signal phases

When pedestrian signal heads are used, a WALKING PERSON (symbolizing WALK) signal indication shall be displayed only when pedestrians are permitted to leave the curb or shoulder. A pedestrian clearance time shall begin immediately following the WALKING PERSON (symbolizing WALK) signal indication.

The first portion of the pedestrian clearance time shall consist of a pedestrian change interval during which a flashing UPRAISED HAND (symbolizing DONT WALK) signal indication shall be displayed. The remaining portions shall consist of the yellow change interval and any red clearance interval (prior to a conflicting green being displayed), during which a flashing or steady UPRAISED HAND (symbolizing DONT

WALK) signal indication shall be displayed (National Highway Traffic Safety Administration Traffic Safety Facts (2001).

At intersections equipped with pedestrian signal heads, the pedestrian signal indications shall be displayed except when the vehicular traffic control signal is being operated in the flashing mode. At those times, the pedestrian signal lenses shall not be illuminated (National Highway Traffic Safety Administration Traffic Safety Facts 2001).

Except as noted above, the walk interval should be at least 7 seconds in length so that pedestrians will have adequate opportunity to leave the curb or shoulder before the pedestrian clearance time begins. If it is desired to favor the length of an opposing signal phase and if pedestrian volumes and characteristics do not require a 7-second walk interval, walk intervals as short as 4 seconds may be used (Pedestrian Signalization Alternatives 1985).

The walk interval itself needs not equal or exceed the pedestrian clearance time calculated for the roadway width, because many pedestrians will complete their crossing during the pedestrian clearance time.

The pedestrian clearance time should be sufficient to allow a pedestrian crossing in the crosswalk who left the curb or shoulder during the WALKING PERSON (symbolizing WALK) signal indication to travel at a normal walking speed of 1.2 m (4 ft) per second, to at least the center of the farthest traveled lane or to a median of sufficient width for pedestrians to wait. Where pedestrians who walk slower than normal, or pedestrians who use wheelchairs, routinely use the crosswalk, a walking speed of less than 1.2 m (4 ft) per second should be considered in determining the pedestrian clearance time (MUTCD 2002).

2.4 Introduction to queuing theory

Queuing theory models are expressed in a standard notation and use a suite of parameters in the model formulae. A queuing model is defined in terms of the following primary characteristics. For use in calculations, these characteristics are expressed using the letters that is indicated in brackets following the name of the characteristic.

1. Request "Arrival Rate" (λ). Service requests arrive according to one of four patterns: steady, irregular, regular, or random.
2. Service "Distribution Rate" (μ). The mean number of requests that are processed within a time period.
3. "Utilization" (ρ). The intensity of the pedestrian, that is, the arrival rate divided by the service rate.
4. "Number of Servers" (c). The number of servers that can process the request. A server in this case may not be the physical server, but may be a critical subcomponent, depending on what is being modeled
5. Queue Discipline. How queued requests are processed, which affect the standard deviation calculation. Examples are: "first-in-first-out" (FIFO), "last-in-first-out" (LIFO), and priority ordered.

2.5 An M/G/∞ model

In this section, a model for an average crosswalk is presented where pedestrians often need to wait for the passing cars before they can cross the road. The system is treated as an M/G/∞ system and observes its behavior under steady state. Here M refers to the memoryless property of the system with regard to the pedestrian flow, that is, the arrival of pedestrians is a Poisson process.

The letter G refers to the general service time distribution, that is, any prior assumptions are not set on pedestrians' service time distribution.

The infinity sign ∞ means that there are an infinite number of servers to serve pedestrian requests to cross the roads. What this means is that all those who want to cross the road do not have to wait for other pedestrians in a queue. In other words, in M/G/∞ model, the pedestrian starts to be "served" by the server, namely the crosswalk, as soon as he/she arrives, and the service time is just the time that the pedestrian spends to wait for a proper chance to cross.

No distinguishing is set between "service time" and "waiting time". In reality the width of the crosswalk is not infinite but it is assumed that it is wide enough, the M/G/∞ model takes width of crosswalk equal to ∞.

A 60 cm diameter body circle was used to approximate the 50 cm by 60 cm body ellipse proposed by Tunner-Fairbank Highway Research Center, 1998. In addition, a "buffer zone", an area of open space around a pedestrian, of 0.75 m^2 will be applied to pedestrians while walking (Tunner-Fairbank Highway Research Center 1998). The other major parameters of the simulation will be considered from the literature, Road Engineering Journal, 1997, or collected in the field.

These parameters and the estimated values are summarized in (Table 2.1). The primary control over the simulation will be the cycle time of the crosswalk signal, but it may also have other parameters can be considered and how sensor-tripped signals impact the system.

Table (2.1): Some parameters of the simulation

Parameter	Value
Pedestrian diameter	$60cm$
Walking buffer	$0.75m^2$
Walking speed	$1.2m/s$
Response time	$3\sec$
Safe gap to cross	$\frac{1}{8}mi$
Street width, Sidewalk width, Width of crosswalk	variable
Cycle length	$\approx 60\sec$
Pedestrian arrival rate, Vehicle arrival rate	variable
Threshold	$0.75s^{-1}$

Source: Department of Computer Science Duke University 2001.

Average delay per person waiting at the traffic signal are monitored and attempt to find an optimal cycle time for the signal that will minimize the average delay per person. This should also reduce the average number of people waiting at the signal. However, undesirable queuing behavior and similar effects may not be adequately reflected by the average delay per person. Monitoring the average number of people waiting is needed for the calibration of the performance of M/G/∞.

2.6 An M/M/C model

2.6.1 Introduction

A steady-state M/M/C queuing system under batch service interruptions is introduced to model the traffic flow on a roadway link subject to incidents.

When a traffic incident happens, either all lanes or part of a lane is closed to the traffic. As such, these interruptions are modeled either as complete service disruptions where none of the servers work or partial fails where servers work at a reduced service rate.

Analyze this system in steady state and present a scheme to obtain the generating function of stationary number of vehicles on a link. For those links with high C values, the closed-form solution of M/M/∞ queues under batch service interruptions can be used as an approximation. The results that show the validity of approximate model are presented.

2.6.2 Introduction of sensitivity analysis of M/M/C queuing system

The purpose of this discussion is to analyze the effects of changes in the system parameters, such as the service rate, the arrival rate and the number of servers on an M/M/C queuing system in which dynamic pricing is employed as the control policy.

The pricing control problem of a queuing system emerges from the question of whether or not to adjust the size of the queue by enforcing a toll or an entrance fee on arriving customers. The objective of the problem can be achieving either individual, in which each customer wants to maximize his own profit, or social optimality, in which maximizing the profit of whole system is the objective. The entrance fee can be either static, not depending on the state, or dynamic, depending on the state, in the pricing control problems.

An extensive sensitivity analysis for a dynamic pricing problem is performed by Gans and Savin (2004). They work on the dynamic pricing problem of a multi-server loss system. Besides the fact that their system is different from our system, we additionally analyze the effects of the number of servers on the queuing system and the optimal policy.

Naor (1969) is the first researcher who discusses the pricing problem by giving quantitative arguments based on an M/M/1/k queuing model. In this work, he shows the necessity of limiting the arrivals to a queuing system by a toll to achieve the social optimality. Knudsen (1972) extends Naor's study to a multiserver queuing system. In a recent research, Ziya et al. (2002) studied the effect of the customer willingness to pay, the system parameters (service and arrival rates), and the waiting room capacity on the optimal static pricing policies.

Low (1974) studied the optimal dynamic pricing policies of an M/M/c/k queuing system. As an important result, he states the monotonic of the optimal prices. In another study, Low (1974) extends his work for the system with unlimited waiting room capacity. Paschalidis and Tsitsiklis

(2000) work on the congestion dependent pricing by corresponding to the events.

In Summary, $M/G/\infty$, $M/M/C$ models may be applicable to Palestinian cities and city of Nablus in particular as a prototype. However, other models are not applicable or need further studying before they are recommended for CBD areas. The adoption and justification of mathematical model for pedestrian behavior is discussed in Chapter Five.

CHAPTER THREE
METHODOLOGY

Chapter Three
Methodology

3.1 Introduction

Studies that have dealt with the modeling pedestrian behavior on pedestrian crosswalks are extremely limited, if ever, in Palestine. Lack of proper transportation infrastructure facilities and services can be an obstacle to the development models of pedestrian sectors and may hinder the entire development efforts.

Based on the literature, better management of crosswalks not only increased number of crosswalks and reduced pedestrians' congestion and conflicting maneuvers, but also greatly increased safety.

The objective of this thesis relates to the management of the pedestrians crosswalks to enhance utilization of traffic signals, which is considered one of the main issues facing transportation system especially inside the congested cities, and to evaluate the compliance and effectiveness crosswalks in Nablus City. Nablus City was chosen in this study since there are several existing pedestrian crosswalks with reasonable operating conditions and the limitation of those facilities in the Palestinian territories.

The methodology adopted in this thesis is based on the following:

A- Data collection which includes :

- The status of the recent pedestrian's crosswalks.

- Pedestrian volume count on existing crosswalks.
- Survey to record pedestrian behavior.
- Crossing behavior.
- Previous studies of pedestrians crosswalks in Nablus city.
- Pedestrian compliance to existing crosswalks.
- Existing models and systems describing behavior on crosswalks.

B- Adopting An M/M/C Model depending on notation represented in Chapter 5 as a mathematical model considering the following:

- Defining variables which control pedestrians behavior during the maneuver of crossing the crosswalk and waiting to cross which include:
    1- The number of pedestrians crossing and waiting behavior during the peak hour which is symbolized with the symbol (N).
    2- The distance which the pedestrian crosses the road which is symbolized with the symbol (W).
    3- The average speed of the pedestrians which is symbolized with the symbol (V).
    4- The time required for the pedestrian to cross the road which is symbolized with the symbol (T).
    5- Traffic signal interval which is symbolized with the symbols (t_r, t_g, t_y).

6- The width and the length of existing crosswalks which are symbolized with the symbols (w, l)

7- Pedestrian signal intervals which are symbolized with the symbols (P_r, P_g).

- Calibrating the mathematical model with cases in other areas in the West Bank.

3.2 Literature review

A brief explanation of some of the models was described for pedestrian behavior on pedestrian crosswalks. Several studies list various items of models used in pedestrian behavior. The list of items includes:

- Variables which control pedestrians' behavior during the maneuver of crossing the crosswalk.
- Mathematical model which represents the pedestrian movement during crossing the road and sets the pedestrian design phase for pedestrian signal, which will meet the expected demand and maximize the utilization of traffic flow on the road.

3.3 Data collection

The required data for this project includes:

a) Data about pedestrian behavior on pedestrian crosswalks (the applicability of specific items for Palestinian cities will be examined).

b) Geometric conditions of the selected crosswalks, which show the location and dimensions of there crosswalks.

c) The status of the recent pedestrian's crosswalks.

d) Pedestrian volume count on existing crosswalks.

e) Survey to record pedestrian behavior.

f) Crossing behavior.

g) Existing models and systems describing behavior on crosswalks.

h) Review local regulations, if any, related to pedestrian behavior on pedestrian crosswalks.

The main sources of this data are:

1- Nablus Municipality, the geometry of the studied area and regulations.

2- Previous studies.

3- International sources.

4- Mathematics department at An-Najah National University

3.4 Calibrate the mathematical model

Techniques must be established to evaluate the applicability of this model. Available techniques will be reviewed and the most appropriate ones (that can solve the problems and can be implemented in a cost effective manner) will be identified. The application of the model will be conducted in Nablus City and another location in the West Bank.

A set of conclusions and recommendations will be developed based on the above analysis.

CHAPTER FOUR
DATA COLLECTION

Chapter Four
Data Collection

4.1 Introduction

For the development of the proposed model, measurements of certain pedestrian behavior and counts will be applied on three crosswalk locations in Nablus city. The first location is Alwatani Hospital crosswalk; this location has very heavy pedestrian crossing as its channels.

Most of the pedestrians coming from the northern mountainous area into the CBD area as well as those dropping from transit taxis and buses coming from eastern side of the city and commuters from outside the city. The data which collected was grouped into three classes.

The first group is geometric measurements which were used to locate the number of servers and time spend in the system ($1/\mu$) such as the width and the length of crosswalks and the width of the street implicitly included in ($1/\mu$).

The second group is pedestrian volume waiting and crossing the crosswalk in different locations at different times and days, which was used to calculate the arrival rate (λ) and service rate (μ) for pedestrians within 0.85m of the mid-width of crosswalk, since the buffer zone equals to $0.75m^2$, as presented in (Table 2.1).

The last group of data is pedestrian signal timing, green and red intervals, which was used along with pedestrian volume to calculate the arrival rate (λ) and service rate (μ) for the crosswalks.

4.2 Types of collection of data

The needed data to examine the mathematical model on these crosswalks are:

1. Geometric field measurements
2. Pedestrian volume count
3. Signal timing and plans

4.2.1 Geometric field measurements

All required dimensions are shown in (Figure 4.1, Figure 4.2 and Figure 4.3), and all significant measurements are presented in the upper portion of pedestrian volume sheets as shown in Appendix A**.**

However these measurements are not used directly in the model, such as width of the crosswalk must be converted to a number of servers by dividing it into 0.85 m sections which represents the length of walking buffer for pedestrian (Department of Computer Science Duke University, 2001).

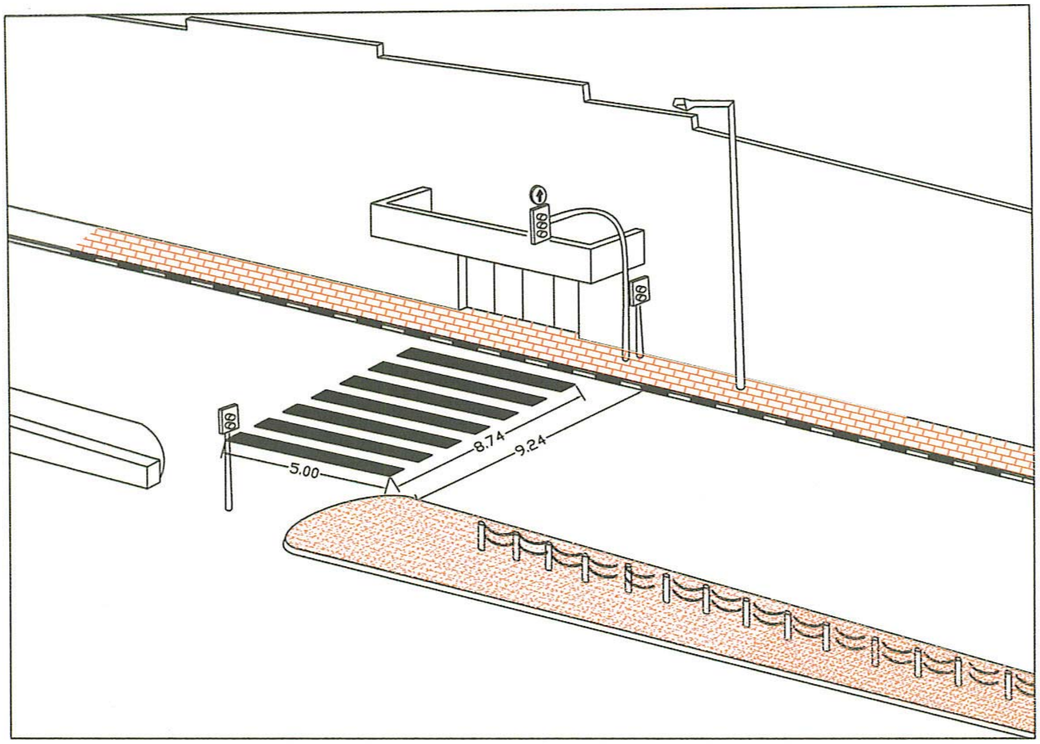


Figure (4.1): Alwatani crosswalk drawing

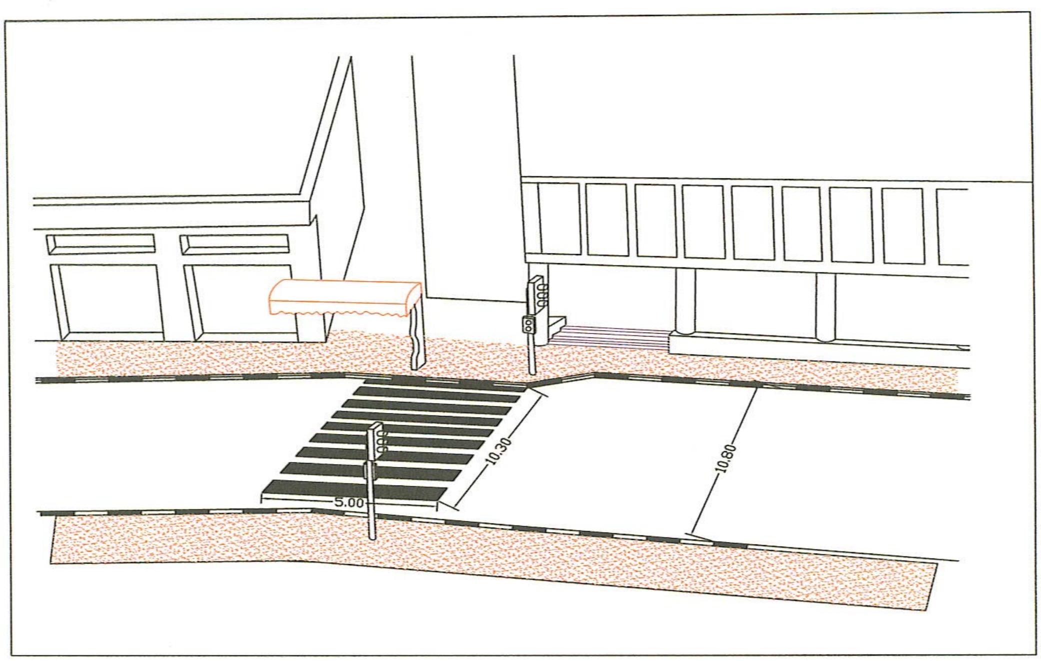


Figure (4.2): Municipality of Nablus crosswalk drawing

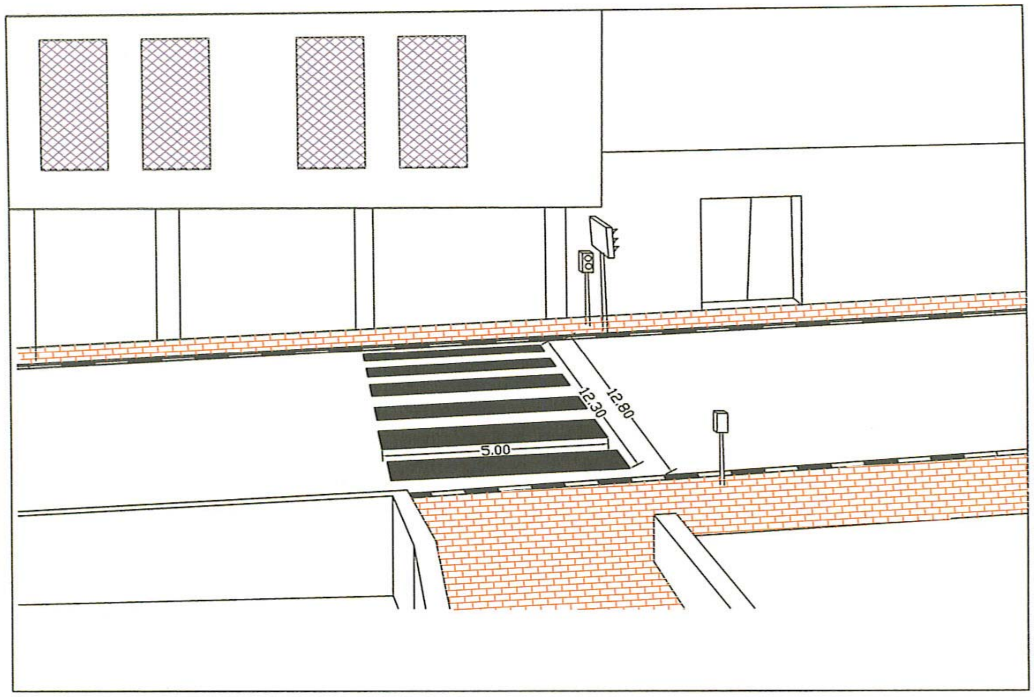


Figure (4.3): Police crosswalk drawing

4.2.2 Pedestrian volume count

(Figure 4.4 and Figure 4.5) show a typical output data and the variation of number of arrival and departure of pedestrians per time interval.

(Tables 4.1) and (4.2) give two typical outputs of the data collected. Appendix A gives details of the data collected for the different periods of the day and week. Appendix A shows the statistical analysis of the collected data and the average arrival rate and service rate for the collected data.

Table (4.1): Sample of data collected at Alwatani crosswalk (Arrival)

PEDESTRIAN VOLUME SHEET					
LOCATION ID: Alwatani First Day /First Hour					
COUNTY: Nablus		**CITY: Nablus**		**TYPE OF CONTROL: Manual**	
STUDY DATE: 17/3/2007		**TIME: FROM 8:00 AM TO 9:00 AM**		**OBSERVER :B.C Group**	
CROSSWALK WIDTH: (5.00 m)			**CROSSWALK LENGTH: (8.74 m)**		
STREET WIDTH: (9.24m)			**RED INTERVAL LENGTH FOR(PEDESTRIAN) 75 Sec**		
GREEN INTERVAL LENGTH (FOR PEDESTRIAN):(30 Sec)			**GREEN INTERVAL LENGTH (FOR VEHICLES):(64 Sec)**		
RED INTERVAL LENGTH (FOR VEHICLES):(38 Sec)			**YELLOW INTERVAL LENGTH (FOR VEHICLES):(3 Sec)**		
PRI #	**No of Pedestrians**	**Arrival Rate (Peds/Hr)**	**PRI #**	**No of Pedestrians**	**Arrival Rate (Peds/Hr)**
1	8	384	19	10	480
2	5	240	20	11	528
3	2	96	21	30	1440
4	12	576	22	3	144
5	5	240	23	5	240
6	12	576	24	21	1008
7	6	288	25	9	432
8	7	336	26	13	624
9	5	240	27	25	1200
10	17	816	28	30	1440
11	4	192	29	35	1680
12	20	960	30	20	960
13	11	528	31	18	864
14	5	240	32	19	912
15	11	528	33	4	192
16	6	288	34	17	816
17	4	192	35	7	336
18	5	240			
Average Arrival Rate (Peds/Hr)		579			

PRI: Pedestrian Red Interval Number

Table (4.2): Sample of data collected at Alwatani crosswalk (Services)

PEDESTRIAN VOLUME SHEET					
LOCATION ID: Alwatani First Day /First Hour					
COUNTY: Nablus		**CITY: Nablus**		**TYPE OF CONTROL: Manual**	
STUDY DATE: 17/3/2007		**TIME: FROM 8:00 AM TO 9:00 AM**		**OBSERVER :B.C Group**	
CROSSWALK WIDTH: (5.00 m)			**CROSSWALK LENGTH: (8.74 m)**		
STREET WIDTH: (9.24M)			**GREEN INTERVAL LENGTH FOR(PEDESTRIAN) 30 Sec**		
RED INTERVAL LENGTH (FOR PEDESTRIAN):(75 Sec)			**GREEN INTERVAL LENGTH (FOR VEHICLES):(64 Sec)**		
RED INTERVAL LENGTH (FOR VEHICLES):(38 Sec)			**YELLOW INTERVAL LENGTH (FOR VEHICLES):(3 Sec)**		
PGI #	**No of Pedestrians**	**Arrival Rate (Peds/Hr)**	**PGI #**	**No of Pedestrians**	**Arrival Rate (Peds/Hr)**
1	1	120	19	2	240
2	2	240	20	3	360
3	2	240	21	1	120
4	2	240	22	2	240
5	4	480	23	3	360
6	2	240	24	1	120
7	2	240	25	2	240
8	1	120	26	2	240
9	3	360	27	3	360
10	3	360	28	5	600
11	2	240	29	6	720
12	2	240	30	6	720
13	1	120	31	5	600
14	3	360	32	4	480
15	3	360	33	1	120
16	2	240	34	4	480
17	2	240	35	2	240
18	3	360			
Average Service Rate (Peds/Hr)		315			

PGI: Pedestrian Green Interval Number

The second location that this thesis will analyze is Nablus Municipality crosswalk. This location is also sensitive because it is one of the important activity centers in the city, which is Nablus municipality, but the number of pedestrians at this location is less than that of Alwatani.

The third location that this thesis will discuss is Nablus Police Center crosswalk which has coordination with Nablus municipality crosswalk.

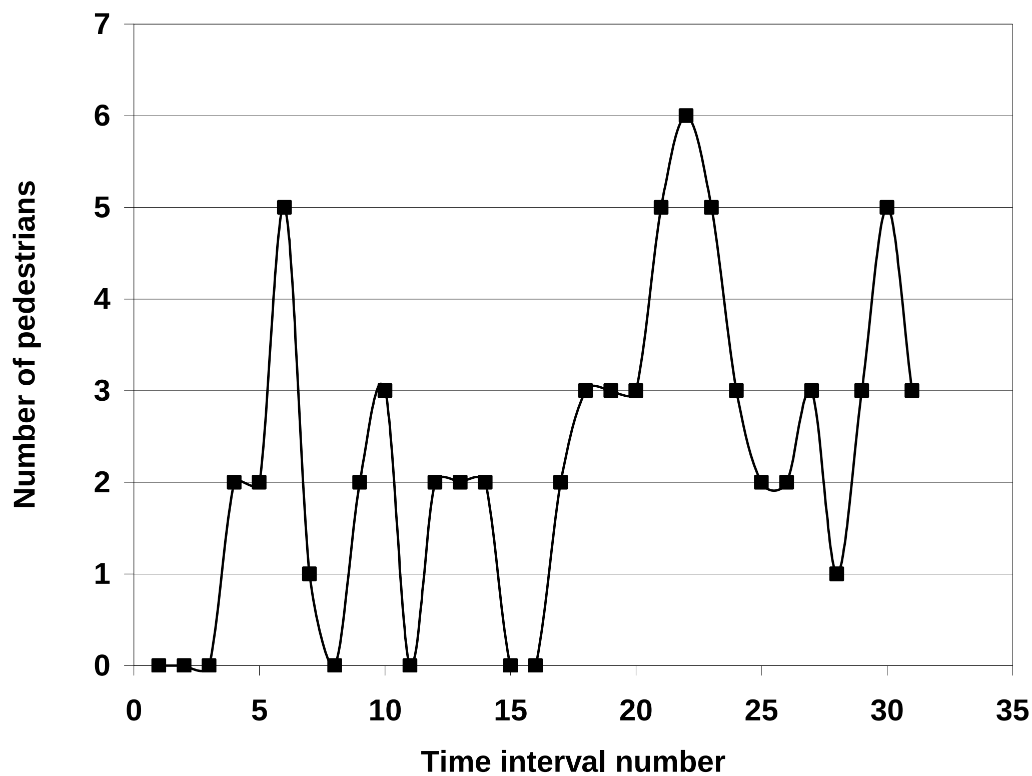


Figure (4.4): Pedestrian arrival distributions with respect to time intervals at Nablus Municipality crosswalk

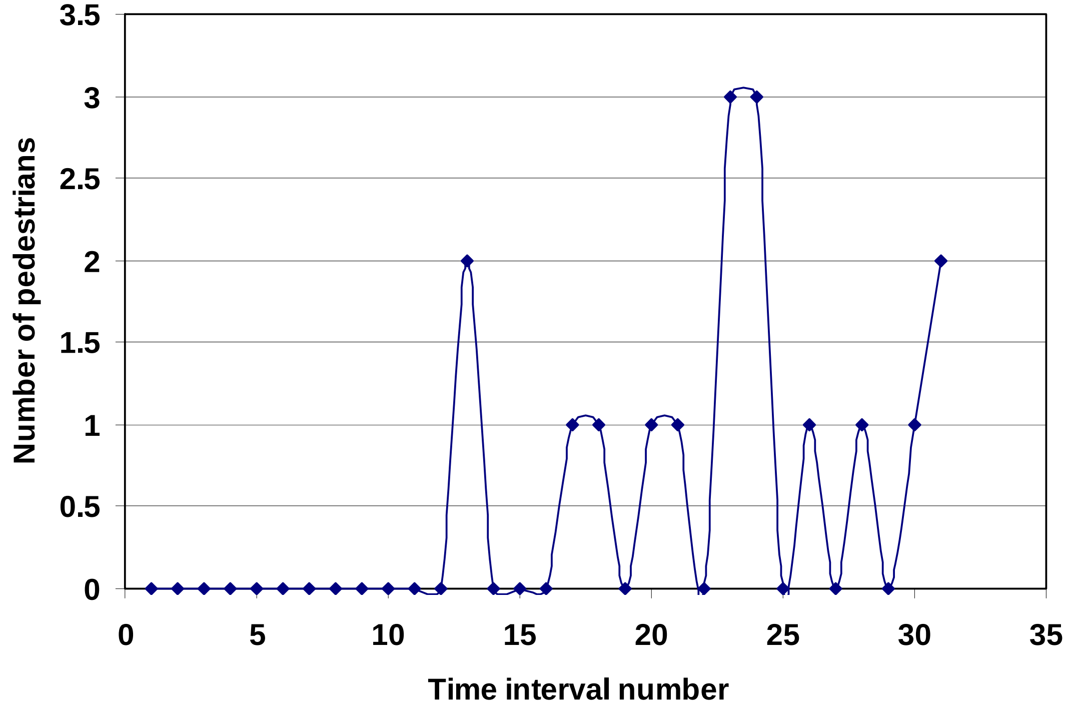


Figure (4.5): Pedestrian service distribution with respect to time intervals at Nablus Municipality crosswalk

The average arrival rate (λ), average service rate (μ) for the studied crosswalks, and the detailed pedestrian volume counts are shown in Appendix A**.** A summary sheet for the pedestrian volume counts is shown in Appendix A.

4.2.3 Signal timing and plans

There are several types of signal timing for pedestrian signals, including concurrent, exclusive, "leading pedestrian interval" (LPI), and all-red interval. In general, shorter cycle lengths and longer walk intervals provide better service to pedestrians and encourage better signal compliance. For optimal pedestrian service, fixed-time signal operation usually works best.

In this thesis, the final group of collected data is pedestrian signal timing, green interval and red interval, which were used with pedestrian volume to calculate the arrival rate (λ) and service rate (μ) of crosswalks, then to compare the pedestrian green time with the model output, which represents the total time spend in the system, (w_s).

4.3 Actual interval at the studied locations

The actual signal time in three locations are shown in (Table) 4.4. The difference between the three locations in pedestrian green interval (PGI) related to number of pedestrian entering the locations are presented .

Table (4.3): Traffic signal timing along the studied area

Crosswalk Name	VGP	VRP	VYP	PGP	PRP	CYCLE
Alwatani Hospital	64 Sec	38 Sec	3 Sec	30 Sec	75 Sec	105
Nablus Municipality	88 Sec	24 Sec	3 Sec	18 Sec	97 Sec	115
Nablus Police Center	82 Sec	30 Sec	3 Sec	21 Sec	94 Sec	115

VGP: Vehicles Green Interval (sec)
VRP: Vehicles Red Interval (sec)
VYP: Vehicles Yellow Interval (sec)
PGP: Pedestrians Green Interval (sec)
PRP: Pedestrians Red Green Interval (sec)

CHAPTER FIVE

MODEL DEVELOPMENT AND ANALYSIS

Chapter Five
Model Development and Analysis

5.1 Introduction

Model development and analysis measures will be applied on the three studied locations in Nablus City. This chapter represents the formulation of the model through the collected data variation, queuing theory notations, parameter of model formulae, frame work for $(M/M/C)$ model, and finally the discussion and analysis followed by the calibration of the model.

5.2 Data characteristics

The characteristics of collected data at the studied crosswalks shown in (Figures 5.1 through 5.5), which give an indications for the variation of collected data for different locations, days and periods.

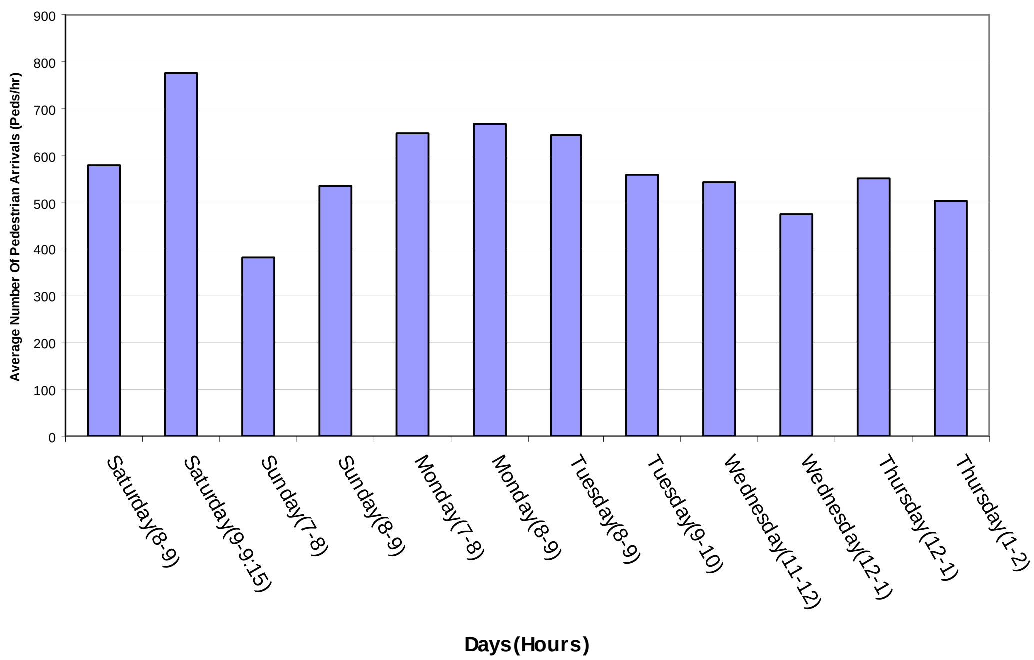


Figure (5.1): Pedestrian average arrival distribution with respect to time at Alwatani crosswalk

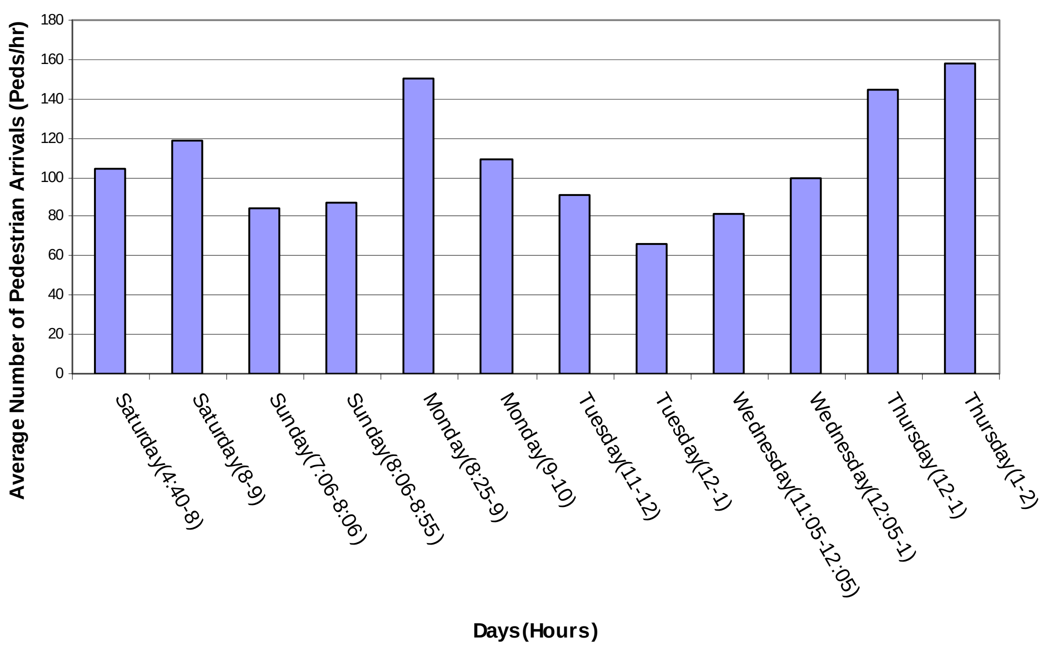


Figure (5.2): Pedestrian average arrival distribution with respect to time at Nablus Municipality crosswalk

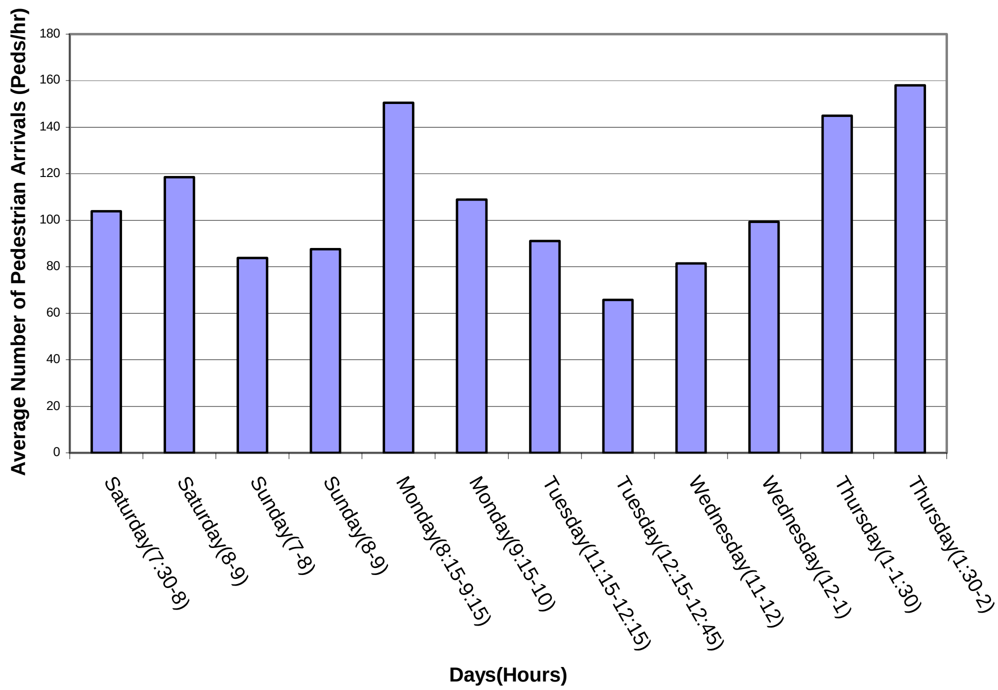


Figure (5.3): Pedestrian average arrival distribution with respect to time at Police Center crosswalk

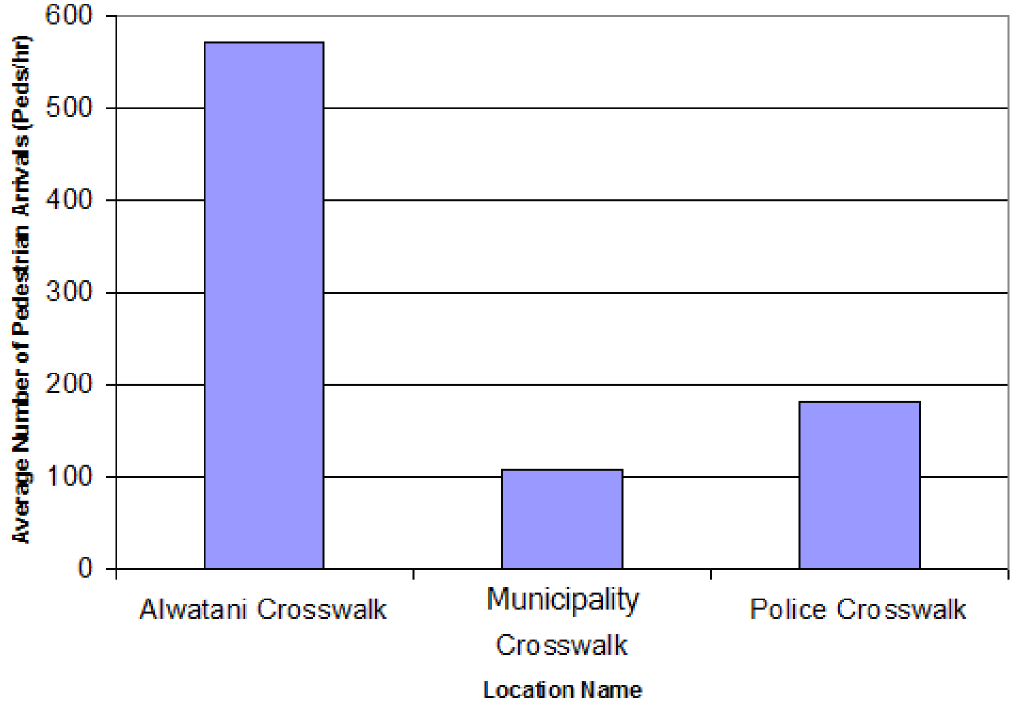


Figure (5.4): Pedestrian average arrival distribution at the three locations

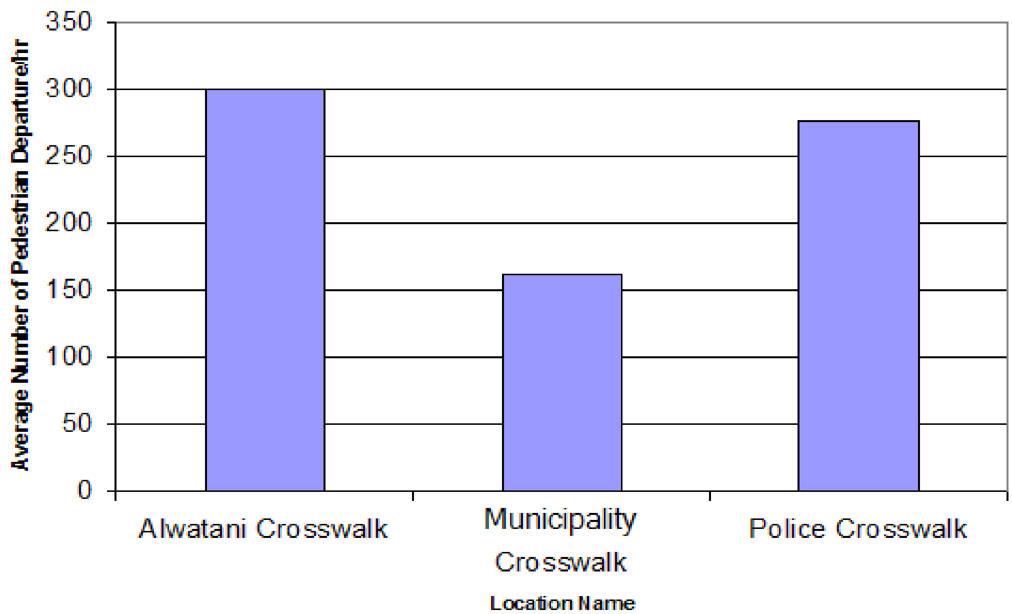


Figure (5.5): Pedestrian average service distribution at the three locations

5.3 Mathematical model notation

The basic queuing model is shown in (Figure 5.6). Queuing theory models are represented by a notation of the form A/S/C/K where:

- "A" is the probability distribution of the inter arrival times.
- "S" is the probability distribution of the service times.
- "C" is the number of servers.
- "K" is the maximum number of requests allowed to arrive.

The notation varies depending on the values of the parameters. "A" or "S" or both are replaced by the Poisson distribution notation, "M", when the probability distribution they follow is a Poisson distribution. Hence there are notations such as M/M/C/K, M/S/C/K, or A/M/C/K.

If there is no limit of the maximum number of requests allowed to arrive (i.e., if "K" is infinite), then "K" is commonly omitted from the notation. Hence there are notations such as A/S/C, M/M/1, or M/M/2.

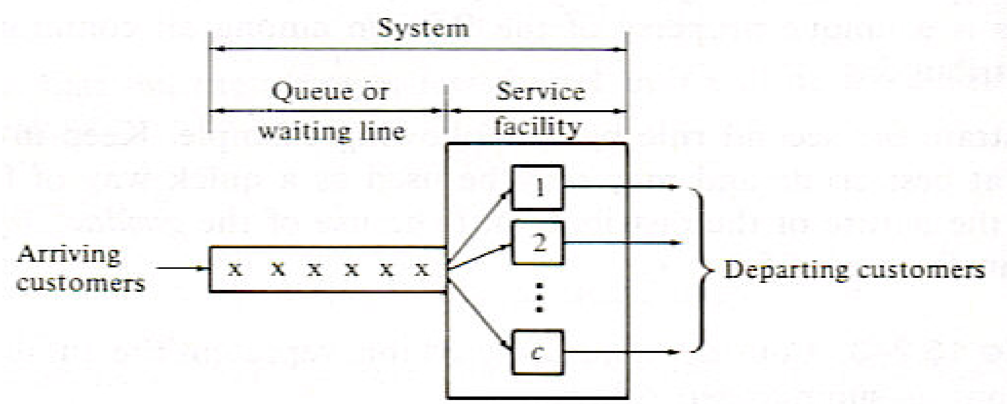


Figure (5.6): Basic queuing model
Source: Hamdy A. Taha, 1996.

5.4 Model adoption

Since pedestrian arrived at crosswalk and departure from it takes the form of a poison distribution, and based on notation mentioned above, the variables "A" and "S" become as "M" and the crosswalk is divided into more than one channel. This leads to use variable C to represent the number of channels.

For queuing discipline, this study assumed first-in-first-out (FIFO) queues in all cases. Which symbolized as "GD", then the type of pedestrians and number of pedestrians are not limited, this study assumed ∞ for the type and number of pedestrians.

5.5 Theoretical framework $(M / M / C)$, (GD, ∞, ∞)

This thesis gives a model for an optimal pedestrian green time at signalized intersections, The study treats this system as an $(M / M / C)$ system and observe its behavior under steady state. Here M refers to the pedestrian arrival and departure processes in the system with regard to the pedestrian flow, that is, the arrival and departure of pedestrians is a Poisson process. The letter C refers to the number of services in the system.

It is to be indicated that there should be a constrain on the maximum number of channels (C max) in the system. This constrains (C max) is subjected to the available geometry in the field, and is estimated as follows $\left|\frac{w}{0.85}\right|$ (where w equals to the existing crosswalk's length).

Then the word GD refers to services policy (First Come First Serve). The infinity sign ∞ means that the type and number of pedestrians are not limited.

5.6 Applicable behaviors

The arrival rates of pedestrians and vehicles are governed by a Poisson distribution. To control pedestrians behavior, $(M/M/C)$ and (GD,∞,∞) describes a methodology for creating simulations using "steering behaviors" that is well-suited to our objectives.

Some applicable behaviors include:

- Maintain a buffer zone while walking.
- Take the shortest path to a destination.
- Avoid collisions with obstacles and other pedestrians.
- Enter the crosswalk if the signal permits.

In $(M/M/C)$, (GD,∞,∞) implementation, this study focuses on the above four behaviors that are necessary for the implementation of the model.

It should be indicated that the model $(M/M/C)$ was applied for pedestrian traffic in one direction only. Pedestrians traffic in the opposite direction will be treated in the same way.

The following equations control the system (crosswalk) from arrival time to departure time.

Under steady state conditions and at any point, expected rate of flow in that point = expected rate of flow out from the same point. (Figure 5.7) shows the steady state case (Hamdy A. Taha, 1996).

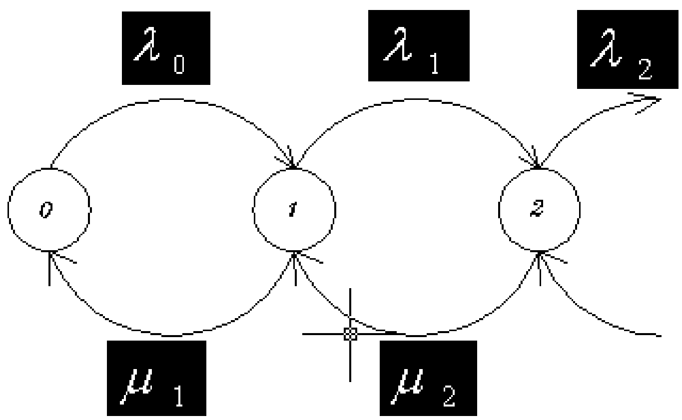


Figure (5.7): Steady state case

From (Figure 5.7) there are:

$$\lambda_0 \times p_0 = p_1 \times \mu_1 \Rightarrow$$

$$p_1 = \frac{\lambda_0}{\mu_1} p_0 \Rightarrow$$

$$p_2 = \frac{\lambda_0 \times \lambda_1}{\mu_1 \times \mu_2} p_0 \Rightarrow$$

$$p_n = \frac{\lambda_0 \times \lambda_1 \times \ldots\ldots\ldots\ldots\lambda_{n-1}}{\mu_1 \times \mu_2 \times \ldots\ldots\ldots\ldots\ldots\mu_n} p_0$$

$$\left[\sum_0^{\infty} p_n\right] = p_0 + p_1 + p_2 + \ldots\ldots\ldots\ldots p_n = 1 \Rightarrow$$

$$p_0 = 1 - p_1 + p_2 + \ldots\ldots\ldots\ldots p_n \Rightarrow$$

$$p_0 = \left[\sum_{0}^{c-1} \frac{\rho}{n!}^{n} + \frac{\rho^c}{c!} \times \sum_{c}^{\infty} \left(\frac{\rho}{c} \right)^{n-c} \right]^{-1} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5.1)$$

Since: $\sum_{c}^{\infty} \left(\frac{\rho}{c} \right)^{n-c} \Longleftrightarrow \sum_{n}^{\infty} \left(\frac{\rho}{c} \right)^{n} = \left(\frac{1}{1 - \frac{\rho}{c}} \right)$

P_0 Becomes as equation (5.2)

$$P_0 = \left[\sum_{n=0}^{c-1} \frac{\rho^n}{n!} + \frac{\rho^c}{c!} \times \left(\frac{1}{1 - \frac{\rho}{c}} \right) \right]^{-1} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5.2)$$

$$\rho = \left(\frac{\lambda}{\mu} \right) \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5.3)$$

$$L_q = \sum_{n=c}^{\infty} (n - c) \times p_n \Rightarrow$$

$$L_q = \left(\frac{\rho^{c+1}}{(c-1)! \times (c - \rho)^2} \right) \times p_0 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5.4)$$

From Little's formula given L_s, W_q and W_s

$$L_s = L_q + \rho \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5.5)$$

$$W_q = \frac{L_q}{\lambda} \qquad \text{.........(5.6)}$$

$$W_s = W_q + \frac{1}{\mu} \qquad \text{.........(5.7)}$$

At all time $\left(\frac{\rho}{c} < 1\right) \Leftrightarrow \left(\frac{\lambda}{\mu \times c} < 1\right)$

where:

P_n : Probability of having n Number of Customers in "the System"
L_s : Expected Number of Customers in "the System"
L_q : Expected Number of Customers in "the Queue"
W_s : Expected Waiting Time of a Customers in "the System"
W_q : Expected Waiting Time of a Customers in "the Queue"

5.7 Model's output

Since the average arrival rate "λ" and the average service rate "μ" for all locations has been calculated in Appendix A, it is very useful to use it directly in the above calculation to find "W_s" (Expected Waiting Time of a Customer in the System) which finally represents the pedestrian required green interval and to compare it with the actual signal interval.

An example for calculating (W_s) using a given "λ" and "μ":
Defining the known variables from Appendix A

"λ" = 287 P/Hr and "μ" =255 P/Hr.

Assuming number of servers = 2 servers which is equal to (2 ×0.85) = 1.70 meters from the crosswalk.

A- Calculating (ρ) from equation number 5.3

- $\rho = \left(\frac{\lambda}{\mu}\right)$

- $\rho = \left(\frac{287}{255}\right)$ =1.12549

B- Calculating (p_0) from equation number 5.2

- $P_0 = \left[\sum_{n=0}^{c-1} \frac{\rho^n}{n!} + \frac{\rho^c}{c!} \times \left(\frac{1}{1-\frac{\rho}{c}}\right)\right]^{-1}$

- $P_0 = \left[\sum_{n=0}^{2-1} \frac{1.12549^n}{n!} + \frac{1.12549^2}{2!} \times \left(\frac{1}{1-\frac{1.12549}{2}}\right)\right]^{-1}$

- $p_0 = 0.27980$

C- Calculating (L_q) from equation number 5.4

- $L_q = \left(\frac{\rho^{c+1}}{(c-1)!\times(c-\rho)^2}\right) \times p_0$

- $$L_q = \left(\frac{1.12549^3}{(2-1)! \times (2-1.12549)^2} \right) \times 0.27980$$

- $$L_q = 0.52161$$

D- Calculating (W_q) from equation number 5.6

- $$W_q = \frac{L_q}{\lambda}$$

- $$W_q = \frac{0.52161}{287}$$

- $$W_q = 0.00182$$

E- Calculating (Ws) from equation number 5.7

- $$W_s = W_q + \frac{1}{\mu}$$

- $$W_s = 0.00182 + \frac{1}{255}$$

- $$W_s = 0.00574 hr$$

- $$W_s = 0.00574 \times 3600 = 20.66 \sec$$

Since W_s (Expected Waiting Time of Customer in The System) represents the pedestrian green time which is equal to 20.66 Sec from above calculation, this means that at crosswalk with length of 1.70 m and pedestrian arrival rate "λ" equal to 287 P/Hr and pedestrian services rate "μ" equal to 255 P/Hr, $(M/M/C)$, (GD,∞,∞) model advanced the designer to use 21 sec of pedestrian green time at pedestrian signal.

All calculation for multiple numbers of servers is represented in Appendix C.

5.8 Using TORA software

Since manual calculation for $(M/M/C)$, and (GD,∞,∞) model is very difficult, it was very necessary to use available developed by Taha (1996) was used.

All procedures for using TORA software are shown in Appendix (D).

TORA has a total of 8 modules :

1. Linear programming
2. Transportation
3. Networks
4. Integer programming
5. Queuing
6. Histogramming / forecasting
7. Inventory

The most important model using in this study is queuing analysis, and the following forms show TORA output for all cases in studied area:

TORA Optimization System - Version 2.0, Oct 1996

Zahir W. Abu Sa'a

Date: Fri Apr 13 18:04:23 2007

QUEUEING OUTPUT

Problem title: For All Locations

Scenario 1 -- (M/M/2):(GD/*/*)

Lambda = 287.00000 Lambda eff = 287.00000

Mu = 255.00000 Rho = 1.12549

Ls = 1.64710 Lq = 0.52161

Ws = 0.00574 Wq = 0.00182

Values of p(n) for n=0 to 19, else p(n) < .00001

0 0.27980 1 0.31491 2 0.17721 3 0.09973 4 0.05612

5 0.03158 6 0.01777 7 0.01000 8 0.00563 9 0.00317

10 0.00178 11 0.00100 12 0.00056 13 0.00032 14 0.00018

15 0.00010 16 0.00006 17 0.00003 18 0.00002 19 0.00001

Cumulative values of p(n) for n=0 to 19

0 0.27980 1 0.59471 2 0.77193 3 0.87165 4 0.92777

5 0.95935 6 0.97713 7 0.98713 8 0.99276 9 0.99592

10 0.99771 11 0.99871 12 0.99927 13 0.99959 14 0.99977

15 0.99987 16 0.99993 17 0.99996 18 0.99998 19 0.99999

Scenario 2 -- (M/M/3):(GD/*/*)

Lambda = 287.00000 Lambda eff = 287.00000

Mu = 255.00000 Rho = 1.12549

Ls = 1.19823 Lq = 0.07274

Ws = 0.00418 Wq = 0.00025

Values of p(n) for n=0 to 12, else p(n) < .00001

0 0.31856 1 0.35853 2 0.20176 3 0.07569 4 0.02840

5 0.01065 6 0.00400 7 0.00150 8 0.00056 9 0.00021

10 0.00008 11 0.00003 12 0.00001

Cumulative values of p(n) for n=0 to 12

0 0.31856 1 0.67709 2 0.87886 3 0.95455 4 0.98295

5 0.99360 6 0.99760 7 0.99910 8 0.99966 9 0.99987

10 0.99995 11 0.99998 12 0.99999

Scenario 3 -- (M/M/4):(GD/*/*)

Lambda = 287.00000 Lambda eff = 287.00000

Mu = 255.00000 Rho = 1.12549

Ls = 1.13728 Lq = 0.01179

Ws = 0.00396 Wq = 0.00004

Values of p(n) for n=0 to 10, else p(n) < .00001

0 0.32368   1 0.36429   2 0.20500   3 0.07691   4 0.02164

5 0.00609   6 0.00171   7 0.00048   8 0.00014   9 0.00004 10 0.00001

Cumulative values of p(n) for n=0 to 10

0 0.32368   1 0.68797   2 0.89298   3 0.96989   4 0.99153

5 0.99762   6 0.99933   7 0.99981   8 0.99995   9 0.99999

10 1.00000

Scenario 4 -- (M/M/5):(GD/*/*)

Lambda =   287.00000   Lambda eff =   287.00000

Mu =   255.00000   Rho =   1.12549

Ls =   1.12732   Lq =   0.00183

Ws =   0.00393   Wq =   0.00001

Values of p(n) for n=0 to 9, else p(n) < .00001

0 0.32439   1 0.36509   2 0.20545   3 0.07708   4 0.02169

5 0.00488   6 0.00110   7 0.00025   8 0.00006   9 0.00001

Cumulative values of p(n) for n=0 to 9

0 0.32439   1 0.68948   2 0.89493   3 0.97201   4 0.99370

5 0.99858   6 0.99968   7 0.99993   8 0.99998   9 1.00000

Scenario 5 -- (M/M/6):(GD/*/*)

Lambda = 287.00000 Lambda eff = 287.00000

Mu = 255.00000 Rho = 1.12549

Ls = 1.12575 Lq = 0.00026

Ws = 0.00392 Wq = 0.00000

Values of p(n) for n=0 to 8, else p(n) < .00001

0 0.32448 1 0.36520 2 0.20551 3 0.07710 4 0.02169

5 0.00488 6 0.00092 7 0.00017 8 0.00003

Cumulative values of p(n) for n=0 to 8

0 0.32448 1 0.68968 2 0.89519 3 0.97229 4 0.99399

5 0.99887 6 0.99979 7 0.99996 8 0.99999

Since the users need more useful data to use in designing green interval for pedestrian signal, TORA can give summary tables including all measures used to design green phase of pedestrian signals. (Table 5.1) through 5.3 show TORA output summary for all locations in the studied area.

Table (5.1): Comparative measures for Alwatani crosswalk

Nbr	c	Lambda	Mu	l'da_eff	Ls	Ws	Lq	Wq
1	2	571	299	571	21.637	0.038	19.727	0.035
2	3	571	299	571	2.615	0.005	0.706	0.001
3	4	571	299	571	2.049	0.004	0.139	0.000
4	5	571	299	571	1.941	0.003	0.031	0.000
5	6	571	299	571	1.917	0.003	0.007	0.000

where:
Nbr : Scenario Number (No)
C : Number of Servers (No)
Lambda : "Arrival Rate" (λ) (Peds/hr)
Mu : "Arrival Rate" (μ) (Peds/hr)
l'da_eff : Effective "Arrival Rate" (λ_{eff}) (Peds/hr)

L_s : **Expected Number of Customers in "the System" (No)**

L_q : **Expected Number of Customers in "the Queue" (No)**

W_s : **Expected Waiting Time of Customers in "the System" (Hr)**

W_q : **Expected Waiting Time of Customer in "The Queue" (Hr)**

Table (5.2): Comparative measures for Nablus Municipality crosswalk

Nbr	c	Lambda	Mu	l'da_eff	Ls	Ws	Lq	Wq
1	1	108	161	108	2.038	0.019	1.364	0.013
2	2	108	161	108	0.756	0.007	0.085	0.001
3	3	108	161	108	0.680	0.006	0.010	0.000
4	4	108	161	108	0.672	0.006	0.001	0.000

Table (5.3): Comparative measures for Nablus Police Center crosswalk

Nbr	c	Lambda	Mu	l'da_eff	Ls	Ws	Lq	Wq
1	1	181	275	181	1.926	0.011	1.267	0.007
2	2	181	275	181	0.738	0.004	0.080	0.000
3	3	181	275	181	0.667	0.004	0.009	0.000

From (Table 5.1) and for W_s column (expected waiting time of customer in the system), which represents the required pedestrian green time in relation to the number of servers (C), it is found that the expected waiting time of a customer in the system decreases as the number of servers (C) increases until reaches the optimal value which is equal to 0.003 hr 5 servers. However, based on the available geometry in the field, the maximum number of servers are limited to 3. As shown in (Table 5.1), the W_s corresponding to 3 channels in 0.005 hrs. therefore the required pedestrian green time for Alwatani crosswalk equals to 0.005 X 3600 = 18 sec and the width of crosswalk equal to 3 multiplied by 0.85 or 2.5 m.

(Figure 5.8) shows the relationship between the number of servers and required pedestrian green time.

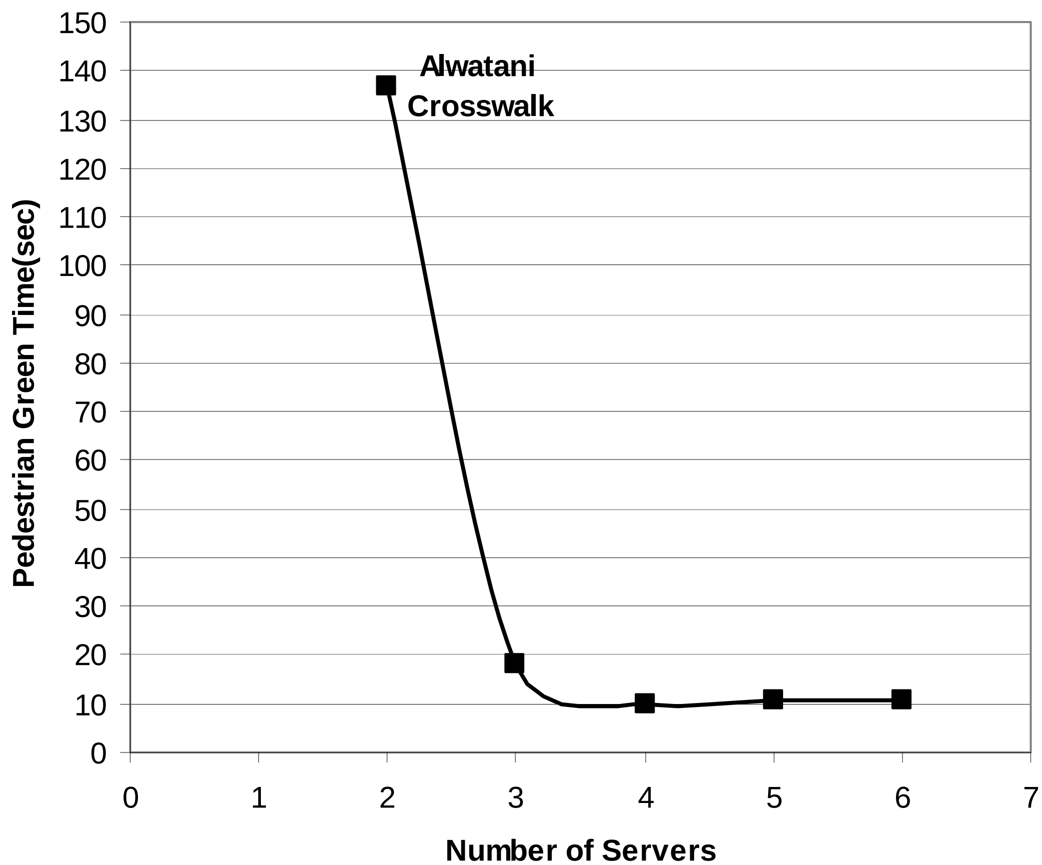


Figure (5.8): Relationship between the number of servers and required pedestrian green time at Alwatani crosswalk

From (Figure 5.8) the designer can use the optimal value or any pedestrian green time relative to number of servers. By this method, the $(M/M/C)$, (GD,∞,∞) will be more flexible to designer for designing pedestrian green interval.

(Tables 5.2) and 5.3, and (Figure 5.9) show the relationship between the last two locations in the studied area.

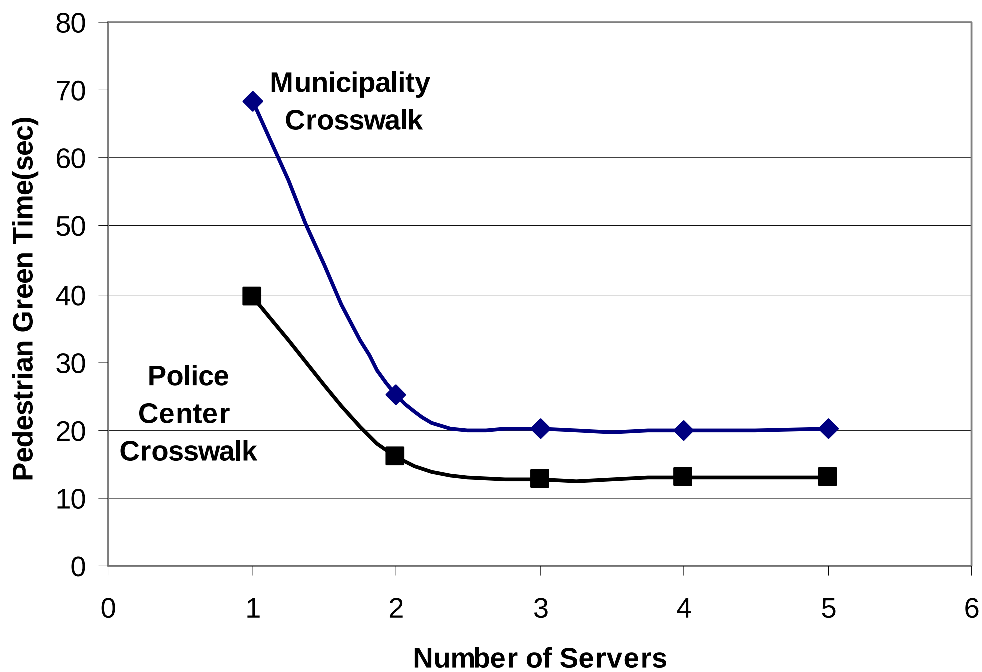


Figure (5.9): Variation between Municipality crosswalk and Police Center crosswalk with relative of pedestrian green time and number of servers

From (Figure 5.9), the upper curve represents the relationship between pedestrian green time and number of servers at municipality crosswalk and the lower curve represents the relationship between pedestrian green time and number of servers at police center crosswalk. The variation of upper and lower curves depend on the value of (ρ), where municipality crosswalk has greater value.

But for Alwatani crosswalk, it not possible to compare the two locations represented in (Figure 5.9) because at Alwatani crosswalk the "Arrival Rate" (λ) is greater than the "Services Rate" (μ) and number of servers equal one which make it inapplicable.

5.9 Variation of model output and actual pedestrian green time

(Table 5.4) shows the variation of actual pedestrian green time at studied location and required pedestrian green time based on $(M/M/C)$, (GD,∞,∞).

Table (5.4): The variation of actual green time and model output

Time / Crosswalk Name	AGT	MOP	CW
Alwatani Hospital	30 Sec	18 Sec	2.50m
Nablus Municipality	18 Sec	22 Sec	2.5m
Nablus Police Center	21 Sec	15 Sec	1.70m

AGT : Actual Green Time

MOP : Model Output

CW : Crosswalk Width (based on $(M/M/C)$, (GD,∞,∞)

Form (Table 5.4), it is found that Alwatani crosswalk actual green time is greater than model output which means that there is no need for 30 sec of green time for pedestrian; only 18 sec. Since Alwatani crosswalk are considered a sensitive location in Nablus city, Nablus Police assigns a policeman for scheduling pedestrian movement at this crosswalk from 7 Am to 8 Am. It was observed that the policeman overrides the traffic signal and gives priority for pedestrians to cross, while stopping vehicles during vehicular green interval.

For Nablus Police Center crosswalk and Nablus Municipality crosswalk, these two locations have coordination. The pedestrian flow from Police crosswalk moving towards the Municipality crosswalk, the design engineer used a very limited green time to satisfy coordination requirements. For that, model output at Nablus Municipality crosswalk is larger than the actual pedestrian green value.

Based on relative difference in statistical analysis and referring to (Table 5.4). (Table 5.5) shows the difference between actual green time and the model output.

Table (5.5): Difference between actual green time and the model output

Time / Crosswalk Name	AGT	MOP	RD
Alwatani Hospital	30 Sec	18 Sec	0.40
Nablus Municipality	18 Sec	22 Sec	0.18
Nablus Police Center	21 Sec	15 Sec	0.29

AGT : Actual Green Time

MOP : Model Output

RD : Relative Deference (absolute value)

Form (Table 5.5), it is found that there is a relatively high percentage deference in all locations in studied area which makes it more efficient to use the model output in all locations to reduce delay.

5.10 Model calibration relative to other locations

Calibration of the developed model is conducted in other urban locations in the West Bank. For example, one location in Nablus city at Alfatimia intersection, the other locations is in Ramallah city at the Islamic Arab Bank intersection to record the arrival rate and departure rate of the pedestrian to be tested as model's input, and to draw an output parameter representing the green phase for pedestrian. (Tables 5.6 and 5.7) show the data collected at Alfatimia crosswalk.

Table (5.6): Data collected at Alfatimia crosswalk (Arrival)

PEDESTRIAN VOLUME SHEET					
LOCATION ID: Alfatimia Crosswalk					
COUNTY:Nablus		CITY: Nablus		TYPE OF CONTROL: Manual	
STUDY DATE: 10/4/2007		TIME: FROM 10:00AM TO 11:30AM		OBSERVER :B.C Group	
CROSSWALK LENGTH (8.5)m					
GREEN INTERVAL LENGTH (FOR PEDESTRIAN):(11 Sec)			RED INTERVAL LENGTH FOR(PEDESTRIAN): 94 Sec		
RED INTERVAL LENGTH (FOR VEHICLES):(40 Sec)			GREEN INTERVAL LENGTH (FOR VEHICLES):(61 Sec)		
PRI #	No of Pedestrians	Arrival Rate (Peds/hr)	YELLOW INTERVAL LENGTH (FOR VEHICLES):(4 Sec)		
1	3	115	PRI #	No of Pedestrians	Arrival Rate (Peds/hr)
2	6	230	24	3	115
3	3	115	25	1	38
4	1	38	26	1	38
5	1	38	27	2	77
6	2	77	28	3	115
7	1	38	29	1	38
8	2	77	30	1	38
9	3	115	31	2	77
10	1	38	32	1	38
11	1	38	33	2	77
12	1	38	34	1	38
13	2	77	35	2	77
14	3	115	36	1	38
15	2	77	37	1	38
16	3	115	38	2	77
17	2	77	39	0	0
18	2	77	40	1	38
19	1	38	41	3	115
20	1	38	42	1	38
21	1	38	43	0	0
22	2	77	44	2	77
23	2	77	45	1	38
Average Arrival Rate (Peds/hr) =		66			

PRP: Pedestrian Red Interval Number

Table (5.7): Data collected at Alfatimia crosswalk (Services)

<table>
<tr><td colspan="6">PEDESTRIAN VOLUME SHEET</td></tr>
<tr><td colspan="6">LOCATION ID: Alfatimia Crosswalk</td></tr>
<tr><td colspan="2">COUNTY:Nablus</td><td colspan="2">CITY: Nablus</td><td colspan="2">TYPE OF CONTROL: Manual</td></tr>
<tr><td colspan="2">STUDY DATE: 10/4/2007</td><td colspan="2">TIME: FROM10:00 AM TO 11:30 AM</td><td colspan="2">OBSERVER :B.C Group</td></tr>
<tr><td colspan="4">CROSSWALK LENGTH (8.5)m</td><td colspan="2"></td></tr>
<tr><td colspan="3">RED INTERVAL LENGTH (FOR PEDESTRIAN):(94 Sec)</td><td colspan="3">GREEN INTERVAL LENGTH FOR(PEDESTRIAN): 11 Sec</td></tr>
<tr><td colspan="3">RED INTERVAL LENGTH (FOR VEHICLES):(40 Sec)</td><td colspan="3">GREEN INTERVAL LENGTH (FOR VEHICLES):(61 Sec)</td></tr>
<tr><td>PGI #</td><td>No of Pedestrians</td><td>Service Rate/Hr</td><td colspan="3">YELLOW INTERVAL LENGTH (FOR VEHICLES):(4 Sec)</td></tr>
<tr><td>1</td><td>0</td><td>0</td><td>PGI #</td><td>No of Pedestrians</td><td>Service Rate/Hr</td></tr>
<tr><td>2</td><td>4</td><td>1309</td><td>24</td><td>1</td><td>327</td></tr>
<tr><td>3</td><td>1</td><td>327</td><td>25</td><td>1</td><td>327</td></tr>
<tr><td>4</td><td>0</td><td>0</td><td>26</td><td>1</td><td>327</td></tr>
<tr><td>5</td><td>1</td><td>327</td><td>27</td><td>0</td><td>0</td></tr>
<tr><td>6</td><td>1</td><td>327</td><td>28</td><td>2</td><td>655</td></tr>
<tr><td>7</td><td>0</td><td>0</td><td>29</td><td>0</td><td>0</td></tr>
<tr><td>8</td><td>1</td><td>327</td><td>30</td><td>1</td><td>327</td></tr>
<tr><td>9</td><td>1</td><td>327</td><td>31</td><td>0</td><td>0</td></tr>
<tr><td>10</td><td>1</td><td>327</td><td>32</td><td>1</td><td>327</td></tr>
<tr><td>11</td><td>1</td><td>327</td><td>33</td><td>1</td><td>327</td></tr>
<tr><td>12</td><td>0</td><td>0</td><td>34</td><td>1</td><td>327</td></tr>
<tr><td>13</td><td>2</td><td>655</td><td>35</td><td>1</td><td>327</td></tr>
<tr><td>14</td><td>2</td><td>655</td><td>36</td><td>1</td><td>327</td></tr>
<tr><td>15</td><td>1</td><td>327</td><td>37</td><td>0</td><td>0</td></tr>
<tr><td>16</td><td>0</td><td>0</td><td>38</td><td>1</td><td>327</td></tr>
<tr><td>17</td><td>1</td><td>327</td><td>39</td><td>1</td><td>327</td></tr>
<tr><td>18</td><td>0</td><td>0</td><td>40</td><td>2</td><td>655</td></tr>
<tr><td>19</td><td>1</td><td>327</td><td>41</td><td>1</td><td>327</td></tr>
<tr><td>20</td><td>1</td><td>327</td><td>42</td><td>1</td><td>327</td></tr>
<tr><td>21</td><td>0</td><td>0</td><td>43</td><td>0</td><td>0</td></tr>
<tr><td>22</td><td>1</td><td>327</td><td>44</td><td>2</td><td>655</td></tr>
<tr><td>23</td><td>1</td><td>327</td><td>45</td><td>1</td><td>327</td></tr>
<tr><td colspan="2">Average Services Rate (Peds/hr) =</td><td>298</td><td></td><td></td><td></td></tr>
</table>

PGI: Pedestrian Green Interval Number

From (Tables 5.6 and 5.7), the average arrival rate "λ" equals to 66 ped/hr and the average service rate "μ" equals to 298 ped/hr. Applying these variables using TORA program, gives the output shown in (Table 5.7).

Table (5.8): Comparative measures for Alfatimia crosswalk

Nbr	c	Lambda	Mu	l'da_eff	Ls	Ws	Lq	Wq
1	1	66	298	66	0.284	0.004	0.063	0.001
2	2	66	298	66	0.224	0.003	0.063	0.000
3	3	66	298	66	0.222	0.003	0.000	0.000

From (Table 5.8) and for W_s column (expected waiting time of customer in the system), which represents the required pedestrian green time and compare it with the number of servers (C), it is found that the expected waiting time of customer in the system decreases if the number of servers (C) increases until reach the optimal value which is equal to 0.003 hr at number of servers equal to 2. This means that the required pedestrian green time for Alfatimia crosswalk equal to 0.003 multiplied by 3600 or 11 sec and the width of crosswalk equal to 2 multiplied by 0.85 or 1.70 m. (Figure 5.10) shows the relationship between the number of servers and required pedestrian green time.

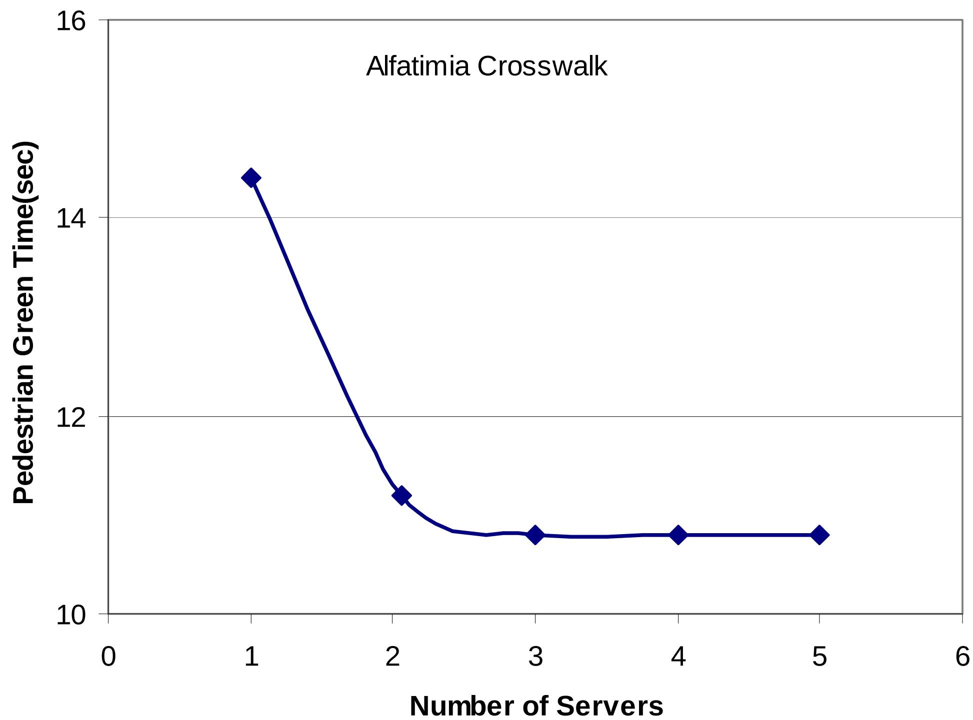


Figure (5.10): Relationship between the number of servers and required pedestrian green time at Alfatimia crosswalk

Comparing model output with the actual pedestrian green time, (Table 5.9) shows the difference between the actual green time and model output.

Table (5.9): The variation of actual green time and model output at Alfatimia crosswalk

Time / Crosswalk Name	AGT	MOP	CW
Alfatimia	11 Sec	11 Sec	1.70m

AGT : Actual Green Time

MOP : Model Output

CW : Crosswalk Width Based on $(M / M / C), (GD, \infty, \infty)$ **Model**

Form (Table 5.9), it is found that at Alfatimia crosswalk, the actual green time is equal to the model output which means that the designing of pedestrian green time at Alfatimia crosswalk is accurate based on $(M / M / C), (GD, \infty, \infty)$ model.

The other location where the model calibrated on is in Ramallah city at the Islamic Arab Bank intersection. (Tables 5.10 and 5.11) show the data collected at Islamic Arab Bank crosswalk.

Table (5.10): Data collected at Islamic Arab Bank crosswalk (Arrival)

PEDESTRIAN VOLUME SHEET					
LOCATION ID: Islamic Arab Bank					
COUNTY: Ramallah		CITY: Ramallah		TYPE OF CONTROL: Manual	
STUDY DATE: 21/4/2007		TIME: FROM 10:00AM TO 11:25AM		OBSERVER :B.C Group	
CROSSWALK LENGTH (16.8)m					
GREEN INTERVAL LENGTH (FOR PEDESTRIAN):(16 Sec)			RED INTERVAL LENGTH FOR(PEDESTRIAN): 84 sec		
RED INTERVAL LENGTH (FOR VEHICLES):(82 Sec)			GREEN INTERVAL LENGTH (FOR VEHICLES):(15 Sec)		
PRI #	No of Pedestrians	Arrival Rate (Peds/hr)	YELLOW INTERVAL LENGTH (FOR VEHICLES):(3 Sec)		
1	3	129	PRI #	No of Pedestrians	Arrival Rate (Peds/hr)
2	6	257	24	1	43
3	3	129	25	4	171
4	2	86	26	3	129
5	3	129	27	2	86
6	2	86	28	3	129
7	1	43	29	2	86
8	2	86	30	1	43
9	3	129	31	2	86
10	0	0	32	5	214
11	3	129	33	4	171
12	5	214	34	6	257
13	2	86	35	3	129
14	3	129	36	2	86
15	2	86	37	0	0
16	3	129	38	2	86
17	2	86	39	1	43
18	2	86	40	2	86
19	0	0	41	1	43
20	2	86	42	2	86
21	5	214	43	3	129
22	2	86	44	0	0
23	2	86	45	2	86
Average Arrival Rate (Peds/hr) =		104			

PRI: Pedestrian Red Interval Number

Table (5.11): Data collected at Islamic Arab Bank crosswalk (Services)

PEDESTRIAN VOLUME SHEET					
LOCATION ID: Islamic Arab Bank					
COUNTY: Ramallah		CITY: Ramallah		TYPE OF CONTROL: Manual	
STUDY DATE: 21/4/2007		TIME: FROM 10:00AM TO 11:25AM		OBSERVER :B.C Group	
CROSSWALK LENGTH (16.8)m					
RED INTERVAL LENGTH (FOR PEDESTRIAN):(84 Sec)			GREEN INTERVAL LENGTH FOR(PEDESTRIAN): 16 Sec		
RED INTERVAL LENGTH (FOR VEHICLES):(82 Sec)			GREEN INTERVAL LENGTH (FOR VEHICLES):(15 Sec)		
PGI #	No of Pedestrians	Service Rate (Peds/hr)	YELLOW INTERVAL LENGTH (FOR VEHICLES):(3 Sec)		
1	1	225	PGI #	No of Pedestrians	Service Rate/ (Peds/hr)
2	2	450	24	2	450
3	1	225	25	2	450
4	1	225	26	0	0
5	0	0	27	1	225
6	2	450	28	2	450
7	1	225	29	0	0
8	1	225	30	2	450
9	0	0	31	0	0
10	0	0	32	0	0
11	1	225	33	1	225
12	1	225	34	0	0
13	0	0	35	2	450
14	2	450	36	1	225
15	1	225	37	0	0
16	0	0	38	0	0
17	1	225	39	2	450
18	2	450	40	1	225
19	0	0	41	2	450
20	1	225	42	1	225
21	0	0	43	2	450
22	0	0	44	1	225
23	1	225	45	1	225
Average Arrival Rate (Peds/hr) =		210			

PGI: Pedestrian Green Interval Number

From (Tables 5.10 and 5.11), the average arrival rate "λ" equal to 104 ped/hr and the average services rate "μ" equal to 210 ped/hr. Applying these variables to the model developed (TORA program) the output is as shown in (Table 5.12).

Table (5.12): Comparative measures for Islamic Arab Bank crosswalk

Nbr	c	Lambda	Mu	l'da_eff	Ls	Ws	Lq	Wq
1	1	104	210	210	0.981	0.009	0.486	0.005
2	2	104	210	210	0.528	0.005	0.032	0.000
3	3	104	210	210	0.498	0.005	0.003	0.000

From (Table 5.12) and for W_s column (expected waiting time of customer in the system), which represents the required pedestrian green time and compare it with number of servers (C), it is found that the expected waiting time of customer in the system decreases if the number of servers (C) increases until reach the optimal value of 0.005 hr at number of servers equal to 2 . This means that the required pedestrian green time for Islamic Arab Bank crosswalk equal to 0.005 multiplied by 3600 or 18 sec and the width of crosswalk equal to 2 multiplied by 0.85 or 1.70 m. (Figure 5.11) shows the relationship between the number of servers and required pedestrian green time.

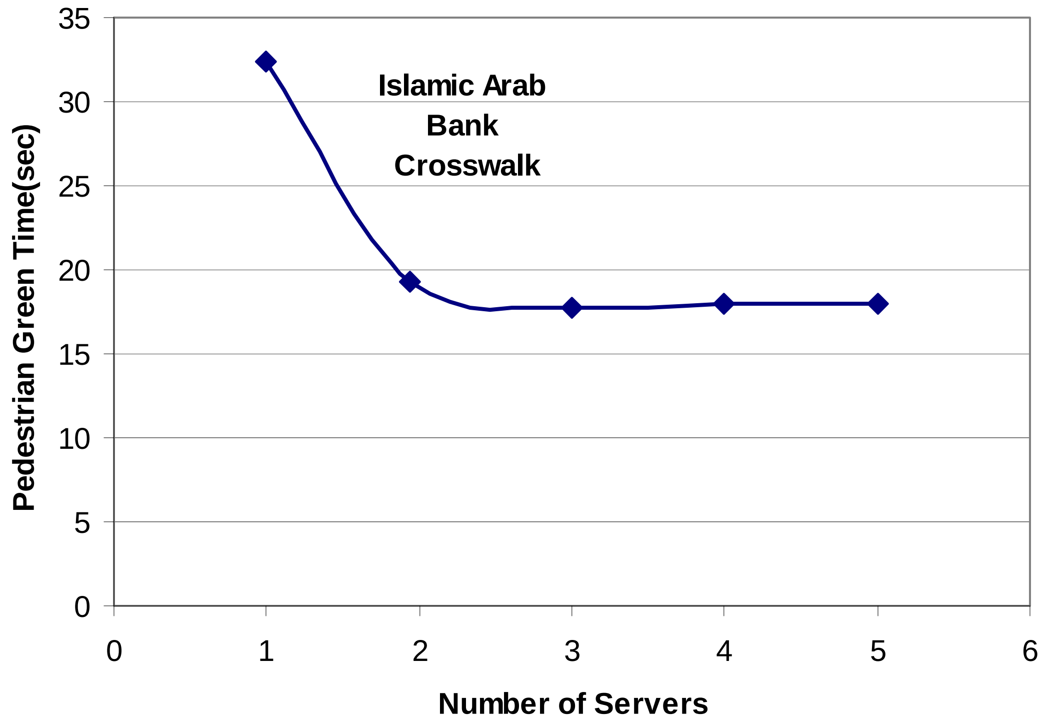


Figure (5.11): Relationship between the number of servers and required pedestrian green time at Islamic Arab Bank

Comparing model output with the actual pedestrian green time, (Table 5.13) shows the difference between the actual green time and model output.

Table (5.13): The variation of actual green time and model output at Islamic Arab Bank

Time / Crosswalk Name	AGT	MOP	CW
Islamic Arab Bank	16 Sec	18 Sec	1.70m

AGT : Actual Green Time

MOP : Model Output

CW : Crosswalk Width Based on $(M/M/C), (GD,\infty,\infty)$ **Model**

Form (Table 5.13), it is found that at Islamic Arab Bank crosswalk, the actual green time is less than model output which means that the designing of pedestrian green time at Islamic Arab Bank crosswalk must be increased by 2 sec based on $(M/M/C), (GD,\infty,\infty)$ model.

CHAPTER SIX
CONCLUSIONS AND RECOMMENDATIONS

Chapter Six
Conclusions and Recommendations

6.1 Introduction

Modeling pedestrian behavior is designed and built with the intention of providing better service than is available in the CBD area. One of the important considerations in CBD area is the behavior of pedestrian, especially at crosswalk; pedestrian becomes under tension to pass the road safely. Modeling pedestrian behavior is usually not too difficult to obtain in a rural area where development is light. However, this becomes challenging in urban areas where the area is built-up and space is limited.

6.2 Conclusions and recommendations

Based on the analysis presented in the thesis and the model developed, several conclusions were reached as follows:

- The model developed is based on queuing theory, "first-in-first-out" FIFO queues in all cases.
- It is concluded that the model adopted based on the Poisson distribution notation of the form A/S/C/K where:
    - "A" is the probability distribution of the inter arrival times.
    - "S" is the probability distribution of the service times.
    - "C" is the number of servers.
    - "K" is the maximum number of requests allowed to arrive.

- The model can be used to design pedestrian signal (green time) since (W_s) "time spent in the system" is the main element of model output. However pedestrian signal design procedure considers a minimum crossing time and a departure walk time.
- The model considered the crosswalk width as part of the design output.
- The model can be applicable in other locations in the studied area and CBD urban areas in general.
- The model is considered comparable to other methods of designing pedestrian signals.

This study showed the importance of modeling pedestrian behavior. As a result of this study, the following recommendations were depicted:

- Develop an extension of the model to include a full scale intersection signal design by modeling behavior of all road users.
- Develop a more user friendly software to be more useful in layout.
- Analysis of the potential applicability of a model in non-CBD areas.
- The possibility of the inclusion of handicapped pedestrian in the model.

- Develop the model to consider the width of crosswalk as a direct input.

- Develop a coordination of crosswalk system in CBD area from the same methodology considered in this thesis.

References

AASHTO (2001). ***A Policy on Geometric Design of Highways and Streets,*** American Association of State Highway and Transportation Officials (AASHTO).

Ancker, C., and Gafarian, A. (1968). "Queuing with Impatient Customers Who Leave at Random." ***Journal of Industry Engineering,*** XIII, 8490.

Anderson, T.W. (2000). ***The Statistical Analysis Data, Second Edition,*** Stanford University.

Boyce, P., and John Van, J. (2002). "Evaluating In-Pavement, Flashing Warning Lights." ***Lighting Research Center Rensselaer Polytechnic Institute,*** <http://www.Sideris@ucla.edu > (Sep.5, 2006).

Charles, V. (2004). "Safety Effects of Marked vs Unmarked Crosswalks at Uncontrolled Locations." ***University of North Carolina's Highway Safety Research Center,*** <http://www.tsc.berkeley.edu> (Sep.5, 2006).

Conte, S. and de Boor, C. (1980). ***Elementary Numerical Analysis,*** 3rd ed., McGraw-Hill.

Daamen, W. and Hoogendoorn, S.P. (2003). ***Experimental Research on Pedestrian Walking Behavior,*** 82nd Annual Meeting at the Transportation Research Board.

Department of Transportation. (2001). ***National Highway Traffic Safety Administration Traffic Safety Facts,*** Pedestrians (DOT HS 809 478).

Foley, D. (1998). "Capacity Analysis of Pedestrian and Bicycle Facilities." ***Technical report, Turner-Fairbank Highway Research Center,***
< http://www.tfhrc.gov/safety/pedbike/98-107/sect2.htm > (Jan.2.2006)

Godfrey, D., and Mazzella T. (1999). **"Kirkland's Experience with In Pavement Flashing Lights at Crosswalks"** <http:/www.ci.kirkland.wa.us/depart/pw/transportation/flscrswk.htm> (March.1, 2007).

Taha, Hamdy A. (1996), ***Operations Research An Introduction. Fourth Edition,*** Department of Industrial Engineering, University of Arkabsas, Fayetteville.

Hoogendoorn, S.P., and Bovy, P.H.L. (2002). ***Normative Pedestrian Behavior Theory And Modeling, Proceedings Of The 15th International Symposium On Transportation And Traffic Theory,*** Adelaide, P. 219-245.

Institute of Transportation Engineers (ITE) (1992). ***Traffic Engineering Handbook,*** ITE Washington D.C.

Reid, Jonathan D. (2000). ***Standard for Crosswalk,*** Institute of Transportation Engineers, ITE Journal, Washington D.C.

Katz, O. (2000). "An Evaluation Study and Policy Recommendations". ***City of Fountain Valley Illuminated Crosswalks,*** < http://www.katzokitsu.com/peds.htm > (May.27,2006).

Nablus Municipality (2005). ***Interviews with Staff of the Department of Planning and Studies,*** Nablus, Palestine.

Newell, G. F. (1965). ***Approximation Methods for Queues with Application to the Fixed-Cycle Traffic Light.***

Purdue, P. (1973). ***The M/M/1 queue in a Markovian Environment,*** Operations Research.

Reynolds, C. (1999). "Steering Behaviors for Autonomous Characters." ***Game Developers Conference,*** < http://www.red3d.com> (Jan.1,2006)

Shawky, A., (2000). ***The Machine Interference Model: M/M/C/K/N with Balking, Reneging and Spares.*** Opsearch, 37, 25–35.

TRB (1998). ***Highway Capacity Manual, Special Report 209,*** Third Edition, Transportation Research Board, National Research Council, Washington, D.C.

U.S. Department of Transportation (2002). ***Manual on Uniform Traffic Control Devices for Streets and Highways,*** *MUTCD*, Washington D.C.

Virkler, M., and Geethakrishnan, S. (1995). ***High-Volume Pedestrian Crosswalk Time Requirements*****,** Transportation Research Record 1495, TRB, National Research Council, Washington, D.C., pp. 41– 48.

Zegeer, C., Opiela, K., and Cynecki, M. (1985). ***Pedestrian Signalization Alternatives (Final Report),*** Federal Highway Administration, Washington, DC.

APPENDICES

APPENDIX (A)

- ✓ **(Data collection at the studied area)**
- ✓ **(Statistical analysis of the collected data)**
- ✓ **(Average arrival rate and service rate)**

- ✓ **(Data collection at the studied area)**

Excel Sheet

✓ (Statistical analysis of the collected data)

Excel Sheet

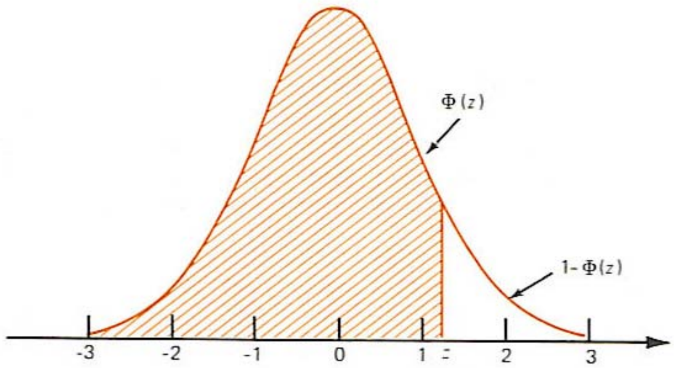
✓ (Average arrival rate and service rate)

Excel Sheet

APPENDIX (B)

(Student's t-Distributions)

(Standard Normal Distributions)



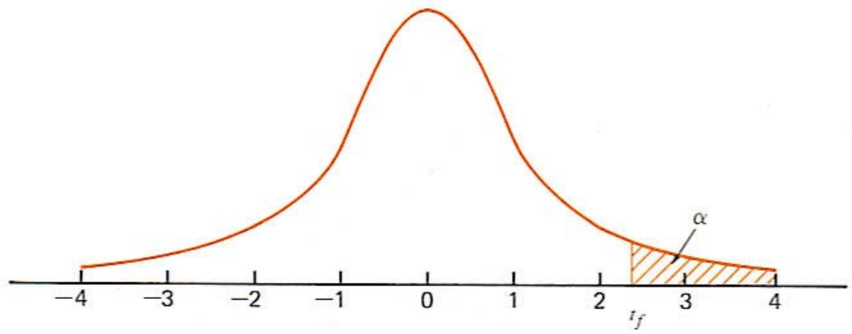
INTEGER AND FIRST DECIMAL OF z	SECOND DECIMAL OF z									
	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
0.0	.5000	.5040	.5080	.5120	.5160	.5199	.5239	.5279	.5319	.5359
0.1	.5398	.5438	.5478	.5517	.5557	.5596	.5636	.5675	.5714	.5753
0.2	.5793	.5832	.5871	.5910	.5948	.5987	.6026	.6064	.6103	.6141
0.3	.6179	.6217	.6255	.6293	.6331	.6368	.6406	.6443	.6480	.6517
0.4	.6554	.6591	.6628	.6664	.6700	.6736	.6772	.6808	.6844	.6879
0.5	.6915	.6950	.6985	.7019	.7054	.7088	.7123	.7157	.7190	.7224
0.6	.7257	.7291	.7324	.7357	.7389	.7422	.7454	.7486	.7517	.7549
0.7	.7580	.7611	.7642	.7673	.7704	.7734	.7764	.7794	.7823	.7852
0.8	.7881	.7910	.7939	.7967	.7995	.8023	.8051	.8078	.8106	.8133
0.9	.8159	.8186	.8212	.8238	.8264	.8289	.8315	.8340	.8365	.8389
1.0	.8413	.8438	.8461	.8485	.8508	.8531	.8554	.8577	.8599	.8621
1.1	.8643	.8665	.8686	.8708	.8729	.8749	.8770	.8790	.8810	.8830
1.2	.8849	.8869	.8888	.8907	.8925	.8944	.8962	.8980	.8997	.9015
1.3	.9032	.9049	.9066	.9082	.9099	.9115	.9131	.9147	.9162	.9177
1.4	.9192	.9207	.9222	.9236	.9251	.9265	.9279	.9292	.9306	.9319

$\Phi(z)$ for $z = 0.02$ is found in the row labelled 0.0 and the column labelled .02. Thus, for $z = 0.02$, $\Phi(z) = \Phi(0.02) = .5080$. $\Phi(z) = 1 - \Phi(-z)$; thus for $z = -0.02$, $\Phi(-0.02) = 1 - \Phi(0.02) = 1 - .5080 = .4920$.

Source: The Statistical Analysis of Data, Second Edition T.W.Anderson/S.L.Sclove

Integer and First Decimal of z	Second Decimal of z									
	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
1.5	.9332	.9345	.9357	.9370	.9382	.9394	.9406	.9418	.9429	.9441
1.6	.9452	.9463	.9474	.9484	.9495	.9505	.9515	.9525	.9535	.9545
1.7	.9554	.9564	.9573	.9582	.9591	.9599	.9608	.9616	.9625	.9633
1.8	.9641	.9649	.9656	.9664	.9671	.9678	.9686	.9693	.9699	.9706
1.9	.9713	.9719	.9726	.9732	.9738	.9744	.9750	.9756	.9761	.9767
2.0	.9772	.9778	.9783	.9788	.9793	.9798	.9803	.9808	.9812	.9817
2.1	.9821	.9826	.9830	.9834	.9838	.9842	.9846	.9850	.9854	.9857
2.2	.9861	.9864	.9868	.9871	.9875	.9878	.9881	.9884	.9887	.9890
2.3	.9893	.9896	.9898	.9901	.9904	.9906	.9909	.9911	.9913	.9916
2.4	.9918	.9920	.9922	.9925	.9927	.9929	.9931	.9932	.9934	.9936
2.5	.9938	.9940	.9941	.9943	.9945	.9946	.9948	.9949	.9951	.9952
2.6	.9953	.9955	.9956	.9957	.9959	.9960	.9961	.9962	.9963	.9964
2.7	.9965	.9966	.9967	.9968	.9969	.9970	.9971	.9972	.9973	.9974
2.8	.9974	.9975	.9976	.9977	.9977	.9978	.9979	.9979	.9980	.9981
2.9	.9981	.9982	.9982	.9983	.9984	.9984	.9985	.9985	.9986	.9986
3.0	.9987	.9987	.9987	.9988	.9988	.9989	.9989	.9989	.9990	.9990

Source: The Statistical Analysis of Data, Second Edition T.W.Anderson/S.L.Sclove



f	Significance Level for One-Tailed Test α .10	.05	.025	.01	.005
1	3.078	6.314	12.706	31.821	63.657
2	1.886	2.920	4.303	6.964	9.925
3	1.638	2.353	3.182	4.541	5.841
4	1.533	2.132	2.776	3.747	4.604
5	1.476	2.015	2.571	3.365	4.032
6	1.440	1.943	2.447	3.143	3.707
7	1.415	1.895	2.365	2.998	3.499
8	1.397	1.860	2.306	2.896	3.355
9	1.383	1.833	2.262	2.821	3.250
10	1.372	1.812	2.228	2.764	3.169
11	1.363	1.796	2.201	2.718	3.106
12	1.356	1.782	2.179	2.681	3.054
13	1.350	1.771	2.160	2.650	3.012
14	1.345	1.761	2.145	2.624	2.977
15	1.341	1.753	2.132	2.602	2.947
16	1.337	1.746	2.120	2.584	2.921
17	1.333	1.740	2.110	2.567	2.898
18	1.330	1.734	2.101	2.552	2.878
19	1.328	1.729	2.093	2.540	2.861
20	1.325	1.725	2.086	2.528	2.845
21	1.323	1.721	2.080	2.518	2.831
22	1.321	1.717	2.074	2.508	2.819
23	1.320	1.714	2.069	2.500	2.807

Source: The Statistical Analysis of Data, Second Edition T.W.Anderson/S.L.Sclove

f	Significance Level for One-Tailed Test α .10	.05	.025	.01	.005
24	1.318	1.711	2.064	2.492	2.797
25	1.316	1.708	2.060	2.485	2.788
26	1.315	1.706	2.056	2.479	2.779
27	1.314	1.703	2.052	2.473	2.771
28	1.312	1.701	2.048	2.467	2.763
29	1.311	1.699	2.045	2.462	2.756
30	1.310	1.697	2.042	2.457	2.750
40	1.303	1.684	2.021	2.423	2.704
60	1.296	1.671	2.000	2.390	2.660
120	1.289	1.658	1.980	2.358	2.617
∞	1.282	1.645	1.960	2.326	2.576

For a one-tailed test α is the significance level of the test against the alternative that the mean is positive. For a two-tailed test refer to the column headed by 1/2 of the desired significance level; for example, if the significance level is 5% use the percentage point in the column headed .025.

Source: The Statistical Analysis of Data, Second Edition T.W.Anderson/S.L.Sclove

APPENDIX (C)

(TORA Output)

Programs Sheet

APPENDIX (D)

(TORA Procedures)

TORA INSTALLATION AND EXECUTION

The TORA software is written for the IBM/PC/XT/AT and true compatible. It requires 512K RAM and MS-DOS 3.2 or higher. The software uses the notation and procedures developed in :TAHA, H., OPERATIONS RESEARCH: AN INTRODUCTION, 6/e, Prentice Hall, 1979

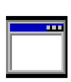
TORA can be executed from the floppy drive (a: or b:) or from the hard disk (c:). A hard disk is recommended.

INSTALLATION ON HARD DISK

Make a separate directory named TORA (or any other name of your choice) and copy all the contents of this diskette into the created directory.

STEP-BY-STEP HARD DISK INSTALLATION:

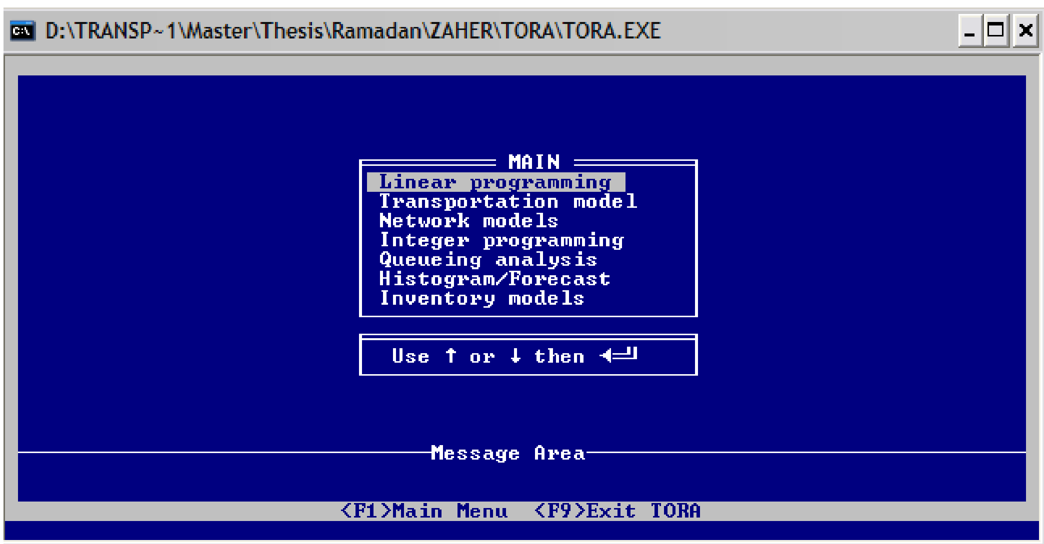
1. Turn on the computer.
2. Copy the software folder to your computer
3. The installation is now complete.
4. Open the TORA folder and double click on this icon



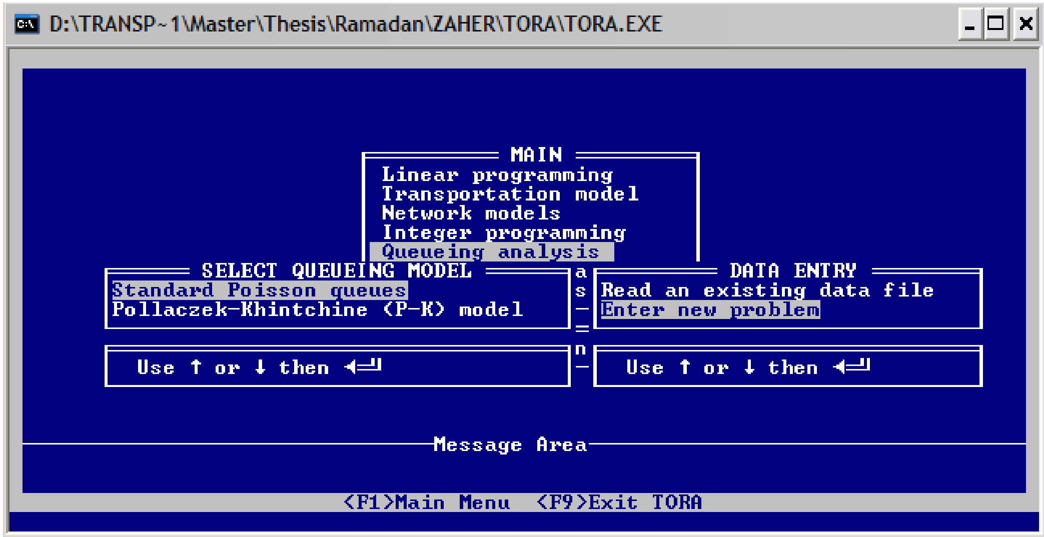
Tora.exe

5. TORA is running now and the following windows appear

6. Press enter to next stage and the following windows appear

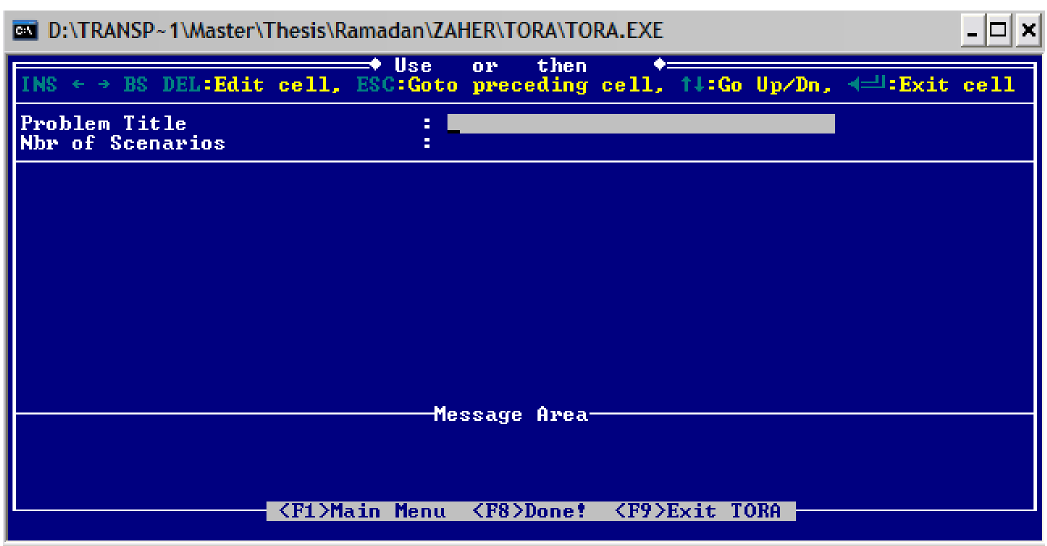


7. From the windows shown in step 6 you can and using down arrow choose queuing analysis then press enter by this way the following window appears

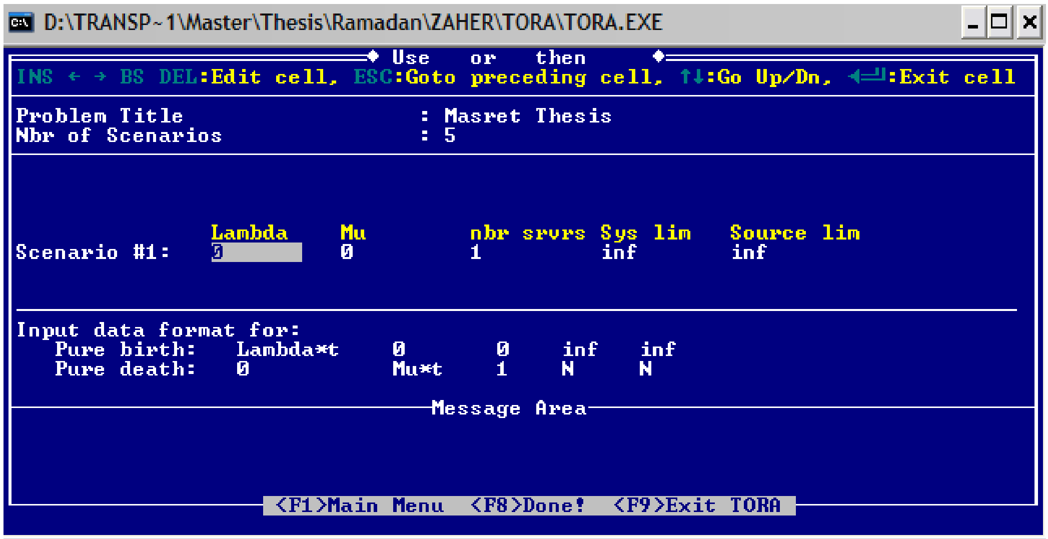


8. choose enter new problem then follow the instruction appear in the screen as follows;

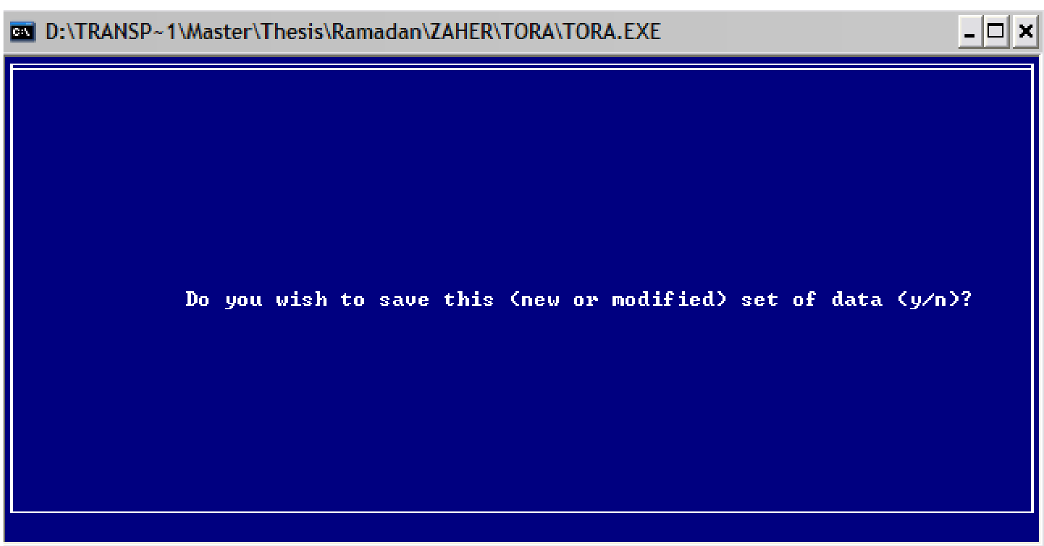
   - enter problem title and number of scenarios as shown in the following window then press enter



   - After filling problem title and number of scenarios the following window appears



- Fill all required variables such as Lamda and Mu, you can discursiveness between the variables by clicking Enter key.
- When finishing all required variable press F8 then the following window appears



- From the above step you can choose Yes or No by writing Y or N from the key board, choosing Y recommended. Then the following widow appears

- You can see you output or print it in to file or to the printer directly by clicking Enter on any choose
- If you choose print output in to file, TORA directly saved you output file in the same folder mentioned in step 2.

جامعة النجاح الوطنية
كلية الدراسات العليا

نمذجة سلوك المشاة على الممرات الخاصة بعبورهم الشارع

إعداد
زاهر وصفي توفيق أبوصاع

إشراف
د. أسامه أباظه

قدمت هذه الأطروحة استكمالا لمتطلبات درجة الماجستير في هندسة الطــرق والمواصـــلات بكلية الدراسات العليا في جامعة النجاح الوطنية في نابلس، فلسطين
2007

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د. أسامه أباظه

الملخص

منذ القدم كان ومازال الاهتمام بمركز المدينة وتطوير البنية التحتية فيها يعتبر من القضايا الهامة والملحة التي شغلت العالم وخصوصا للبلدان التي تشهد ثورة حضرية وازدحاما سكانيا. وظهر هنالك اهتمام يميل إلى دِراسَة سلوكِ المشاة والبيئةِ المحيطة بهم.

إذا أمعنا النظر في سلوك المشي فإننا نلمس الدور الهام الذي يلعبه في النماذج والتطبيقات التي تصف سلوك المشاة في الأماكن المخصصة لعبورهم الشارع، وبمقارنة نماذجَ (الوفيات والولادةِ) يمكن اختبار كلا منها مِنْ منظورِ الكفاءةِ والأمانِ.

لإجراء معايرة لهذه النماذجِ، فإننا سنكون بحاجة إلى توفير بعض البيانات البسيطة، مثل معدل وصول المشاة إلى ممر المشاة ومعدل مغادرتهم عن ممر المشاة.

هذه الأطروحة تعالج طريقة لتصميم الزمن الأخضر في الإشارة الضوئية الخاصة بالمشاة وتتمثل أهدافها بإدارةِ ألاماكن المخصصة لعبور المشاة وتحسين فعالية إشارات المرور التي تُعتَبرُ إحدى القضايا الرئيسية الهامة التي تواجه أي نظام للنقل وخاصة في المدن المزدحمة بحركة المرور وحركة المشاة.

تم تبني نموذج رياضي يَصِفُ نمذجة سلوك المشاة على الممرات الخاصة بعبورهم الشارع، واستخدمت نظرية الطوابير لتطبيق هذا النموذج. أشتق النموذج وطُوّرَ في مناطق مركز المدينة مستندة على مقاييسِ حقلية في المنطقة الحضريةِ لمدينة نابلس في فلسطين.

النموذج أختبر على مواقعِ أخرى في مدينة نابلس وفي ْ مدينةِ رام الله أيضا، وأظهرت النتائج بأنّ النموذج يُمْكِنُ أَنْ يطبّقَ ويحقق الكفاءة العالية في تصميمِ الإشارةِ الضوئية الخاصة بالمشاة.