

**An-Najah National University**  
**Faculty of Graduate Studies**

**Simulation in Queuing Models: Using Simulation at  
Beit-eba crossing check-point**

**By**  
**Fatima Yousef Abdalla Barham**

**Supervisors**  
**Dr. Mohammad Najeeb**  
**Dr. Luai Malhis**

**A Thesis submitted in Partial Fulfillment of the Requirements for the  
Degree of Masters of Computational Mathematics, Faculty of  
Graduate Studies at An-Najah National University, Nablus, Palestine.**  
**2008**



To my father  
My family  
Kana

## Simulation in Queuing Models: Using Simulation at Beit-eba crossing check-point

By:

**Fatima Yousef Abdalla Barham**

This thesis was successfully defended on 24.12.2008 and approved

By

Committee members:

Signatures

Dr. Mohammad Najeeb (Supervisors)

Dr. Luai Malhis (Co-Supervisors)

Dr. Rasheed Al-Jayose (External Examiner)

Dr. Ali Barakat (Internal Examiner)

To my fathers soul

My family

Rana

## **Acknowledgment**

I would like to express great thanks and sincere gratitude to my supervisors

Dr. Mohammad Najeeb

Dr. Luai Malhis

For their guidance, suggestions and assistance during preparing this thesis.

## الإقرار

أنا الموقع أدناه مقدم الرسالة التي تحمل العنوان:

### **Simulation in Queuing Models: Using Simulation at Beit-eba crossing check-point**

محاكاة أنظمة الطوابير: استخدام المحاكاة عند نقطة التفطيش بيت ايبا.

أقر بأن ما اشتملت عليه هذه الرسالة إنما هو نتاج جهدي الخاص، باستثناء ما تمت الإشارة إليه حيثما ورد، وان هذه الرسالة ككل، أو أي جزء منها لم يقدم من قبل لنيل أية درجة علمية أو بحث علمي أو بحثي لدى أية مؤسسة تعليمية أو بحثية أخرى.

### **Declaration**

The work provided in this thesis, unless otherwise referenced, is the researcher's own work, and has not been submitted elsewhere for any other degree or qualification.

**Student's name:**

اسم الطالب:

**Signature:**

التوقيع:

**Date:**

التاريخ:

## TABLE OF CONTENTS

Committee members .....	ii
Dedication .....	iii
Acknowledgment .....	iv
Declaration .....	v
Table of contents .....	vi
List of Tables.....	viii
Annexes.....	viii
List of Figures.....	ix
List of Abbreviations.....	xi
Abstract.....	xii
<b>Chapter One</b>	
1.1 Introduction.....	1
1.2 The pioneering period (1950–1960s).....	4
1.3 The period of innovation (1970s).....	4
1.4 The revolution (1980s).....	4
1.5 Evolution (1990s to the present).....	5
1.6 Computer simulation in science.....	5
1.7 Case Study.....	6
1.8 Metrological Data.....	6
1.9 Study Objectives.....	6
1.10 Significance of the Study.....	7
1.11 Motivation of the study .....	8
<b>Chapter Two</b>	
<b>Literature Review</b>	
2.1 Simulation in Queuing Theory .....	9
2.2 DES Model Development.....	12

2.3 Parameters of the Queue Model.....	13
2.4 Queue Configurations.....	14
2.5 Multiple line advantages.....	15
2.6 Single Line advantages.....	15
2.7 How is Simulation performed manually?.....	16
2.8 Techniques for the Steady State Simulation.....	17
<b>Chapter Three</b>	
<b>Methodology</b>	
3.1 Study area.....	20
3.2 Difficulties of the study.....	21
3.3 Data.....	21
3.4 SimQuick.....	22
3.5 Data Analysis.....	24
3.5.1 Analytical solution.....	24
3.5.2 Procedure of Simulation.....	26
<b>Chapter Four</b>	
<b>Other Models Configurations</b>	
4.1 Configurations for the cross checking-point.....	31
4.2 Model 1.....	32
4.3 Model 2.....	34
4.4 Model 3.....	35
4.5 Comparison between single-channel queue and multiple-channel queue	42
<b>Chapter Five</b>	
<b>Conclusions and Recommendations</b>	
5.1 Conclusions.....	49
5.2 Recommendation.....	50
<b>References.....</b>	<b>51</b>

<b>Annexes</b>	
Annex (A).....	55
Annex (B).....	56
Annex (C).....	57
Annex (D).....	58
Abstract Arabic.....	ب
<b>List of Tables</b>	
Table 3.5.1 Comparison between analytical solution and simulation	26
Table 4.4.a SimQuick results for model 1, model 2, and model 3: $\lambda$ and $\mu$ for the first server are 60% of the value of $\lambda$ and $\mu$ in model 1 And model 3.....	38
Table 4.4.b Results for Model1, Model 2, and Model 3 on Saturday morning: $\lambda$ and $\mu$ for the first server are 70% of the value of $\lambda$ and $\mu$ in model 1 and model 3.....	39
Table 4.4.c SimQuick results for model 1, model 2, and model 3: $\lambda$ and $\mu$ in the first server are 0% of the value of $\lambda$ and $\mu$ in model 1 and model 2. .....	39
Table 4.4.d SimQuick results for model 1, model 2, and model 3: $\lambda$ and $\mu$ in the first server are 100% of the value of $\lambda$ and $\mu$ in model 1 and model 3.....	40
Table 4.4.e SimQuick results for model 1, model 2, and model 3: $\lambda$ and $\mu$ in the first server are 20% of the value of $\lambda$ and $\mu$ in model 1 and model 3.....	40
Table 4.4.f SimQuick results for model 1, model 2, and model 3: $\lambda$ and $\mu$ for the first server are 40% of the value of $\lambda$ and $\mu$ in model 1 and model 3.....	41
Table 4.4.g SimQuick results for model 1, model 2, and model 3: $\lambda$ and $\mu$ for the first server are 80% of the value of $\lambda$ and $\mu$ in model 1 and model	



3.....	41
Table 4.5 Comparison between single-channel queue and multiple-channel queue.....	44
<b>List of Figures</b>	
Figure (1.1) Studying a system.....	3
Figure (2.3) Queuing system.....	13
Figure (2.4) Queue Configurations.....	15
Figure (2.8.1) Method of Batch means.....	17
Figure (2.8.2) The Independent Replication.....	18
Figure (2.8.3) Regenerative or( cycles Method).....	18
Figure (3.1.a) A model represents a cross-checking point at Beit-eba for people departing Nablus City.....	20
Figure (3.1.b) A model represents a cross-checking point at Beit-eba for people arriving to Nablus City.....	21
Figure (3.5.1) Solution using SimQuick.....	25
Figure (3.5.2.a) Men under forty departing Nablus on Saturday evening, the length of the queue vs time.....	28
Figure (3.5.2.b) Men under forty departing Nablus on Saturday evening, waiting time in the queue: ( $W_q$ ) vs time( $t$ ) .....	29
Figure(3.5.2.c) People arriving to Nablus on Sunday morning: the waiting time in the queue :( $W_q$ ) vs time( $t$ ).....	30
Figure (4.1.a) Model 1.....	31
Figure (4.1.b) Model 2.....	31
Figure (4.1.c) Model 3.....	32
Figure (4.2.a) The columns representation of departures for server1 in model 1, the service time can be approximated by the uniform distribution	33
Figure (4.2.b) The columns representation of departures for server2 (or server3)	

in model 1, the service time can be approximated by the uniform distribution	34
Figure (4.3) The columns representation of departures for server1, server2 and server3 in model 2, the service time can be approximated by the uniform distribution	35
Figure (4.4.a) The columns representation of departures on Saturday morning for people departing Nablus.....	36
Figure (4.4.b) The columns representation of departures on Monday morning for people departing Nablus.....	37
Figure (4.4.c) The columns representation of departures on Tuesday morning for people departing Nablus.....	37
Figure (4.5.a) Multiple-channel queues .....	42
Figure (4.5.b) Single-channel queue with two servers.....	43
Figure (4.5.c) The relation between $\lambda$ and ( $W_q$ & $L_q$ ) in multiple-channel queues(Model 1).....	45
Figure (4.5.d) The relation between $\lambda$ and ( $W_q$ & $W_q$ ) in single-channel queue.....	46
Figure (4.5.e) The relation between $\mu$ and ( $W_q$ & $L_q$ ) in multiple-channel queue while $\lambda$ is fixed to (10.125).....	47

**List of Abbreviations**

MS	Management Science
OR	Operation research
DES	Discrete-event simulation
$\lambda$	Arrival rate
$\mu$	Service rate
$W_q$	Average waiting time in the queue
$L_q$	Average length of the queue
M	Markovian (or poisson) arrivals or departures distribution (or equivalently exponential inter-arrival or service time distribution)
GD	General discipline (i.e., any type of discipline)

**Simulation in Queuing Models: Using Simulation at Beit-eba crossing  
check-point**

**By**

**Fatima Barham**

**Supervised by:**

**Dr. Mohammad Najeeb**

**Dr. Luai Malhis**

**Abstract**

This thesis consider some queuing models to determine the measures of performance of a model. The most important measures are the waiting time in the queue and the size of the queue. The queue we are studying is the Beit-eba crossing check-point for both people arriving and people departing from Nablus City.

A comparison is made in order to determine the best fit model among two assumed models and the one under study(real one)using a suitable tool of simulation "SimQuick" which performs process simulation within the Excel spreadsheet environment.

To prove that we got good results for our study. We started by an assumed queue model and solve it analytically by the known formulas of queuing theory.

Next, we use simulation by "SimQuick" to compare results, which showed a good agreement between analytical solution and simulation.

The study showed that the single-channel queue is more efficient than the multiple-channels queues.

## Chapter One

### Introduction

#### 1.1 Introduction

There are three basic methods can be used to get information of real system: Experiment, Analysis, and Simulation. One practical example to demonstrate the nature of these three methods is people waiting to cross a check-point. The question of interest is "what is the average time spent by a person in the queue". To get the answer we have three possibilities:

Experiment: take stop watches and measure the time every one spends in the queue. Count them, at the end sum all times and divide them by the number of people.

Analysis: A system of mathematical equations describing the (probabilistic) evolution of the system, which can be solved to yield explicit formulas for average congestion levels, probability that a server is idle, that a customer will have to wait more than a certain length of time, etc., expressed in terms of the parameters of the system[11].

Simulation: A computer "Game" which mimics the evolution of the real system, so that statistics can be gathered to estimate average congestion levels, etc., without the expense and inconvenience of experimenting with real systems [11].

Experiment is always the most accurate method as in the previous example of people waiting to cross the check-point we measure the time each one spends in the queue, sum them and divide by the number of persons. But

some experiments are costly and dangerous as in nuclear reactions; others are time consuming like weather forecasting.

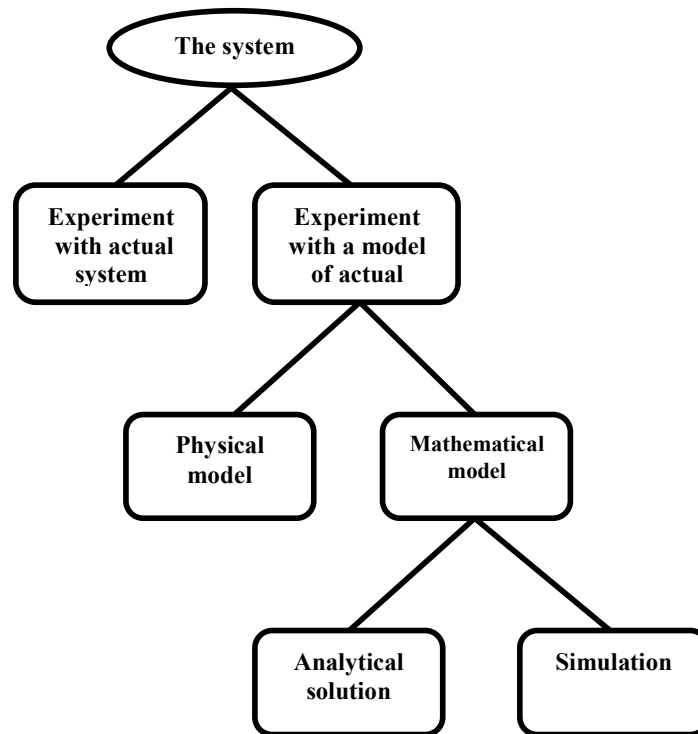
Analysis (mostly mathematical) is typically based on strong assumptions that are rarely true in practical life, in our example we can use queuing theory only if arrivals and departures follow poisson distribution. In this case we can only study steady-state behavior [15] and the number of performance measures that can be computed is small -for example the waiting time in the queue, the waiting time in the system, the average number of objects in the queue, and the average number of objects in the queue.

**Simulation is important because of several reasons:**

1. The number of performance measures that can be computed using simulation is much more than performance measures computed using the analytical solution –for example the final inventory in the queue, the maximum inventory in the queue, the minimum inventory in the queue...etc.
2. It may be the only way to provide solutions to problem under study.
3. It can represent a real-world as fewer assumptions are required compared to analytical solution which is based at strong assumptions.
4. We can easily change in configuration and provide means for direct and detailed observations within specific time limits.

5. It proved to be accurate to a high degree by comparing the results of analytical solution to simulation results.
6. Also less costly as in the flight simulators which uses video games to train pilots, and nuclear reactions.

**The following flow chart represents the steps used in studying a system:**



**Figure (1.1):** Steps for studying a system [7]

**In describing the history of simulation according to Robinson [12] in his paper, four distinct periods can be identified:**

## **1.2 The pioneering period (1950–1960s)**

According to Robinson in his paper [12] pioneers in the field of simulation laid the foundations for future developments. Advances were made in simulation methodology, for instance, Tocher published the three-phase simulation approach that is still used by a number of simulation packages today. The 1960s also saw the development of the first specialist simulation software, for example, GPSS, SIMSCRIP, and SIMULA[12].

## **1.3 The period of innovation (1970s)**

According to Robinson in his paper [12] computing technology continued to advance and with it simulation software continued to improve. Various new languages were developed, for instance, SLAM and GPSS-H. The late 1970s saw the introduction of the first microcomputers. Further to this, Hurrion published his PhD thesis describing the potential for visual interactive simulation [12].

## **1.4 The revolution (1980s)**

According to Robinson in his paper [12] up until the 1980s, the commercial application of simulation was limited by the need for expensive hardware and specialist computing skills.

By the end of the 1980s, powerful microcomputers were available in most organisations (and even in the home) and many commercial VIS packages were available such as WITNESS, HOCUS, GENETIK, SIMAN/CINEMA' and ProModel. Many organizations, particularly in the manufacturing sector, were using simulation as a decision-aiding tool[12].



### **1.5 Evolution (1990s to the present)**

In computing terms the decade that followed was typified by the ever-increasing power of the personal computer [12], the falling price of the PC, the use of Windows technology and, of course, the worldwide web

More powerful PCs enabled larger scale models to be developed and then to be run in a reasonable time-frame. The falling price of the PC made them ever more prevalent in both work and domestic life. Windows technology improved ease of use and created a common interface for computer users.

These changes owe much to the development of computing and then closely followed by development of simulation as hardware and software have improved. Simulation has moved little beyond the desks of researchers when used in the worldwide web and distributed computing.

### **1.6 Computer simulation in science**

Computer simulations are used in a wide variety of practical fields, such as [16]:

- Forecasting of equilibrium temperature of receiving waters.
- Computer simulation using molecular modeling for drug discovery.
- Computational fluid dynamics simulations are used to simulate the behavior of flowing air, water and other fluids.
- Analysis of air pollutant dispersion using atmospheric dispersion modeling.
- Design of complex systems such as aircraft and also logistics systems.
- Design of Noise barriers to effect roadway noise mitigation.
- Flight simulators to train pilots.
- Weather forecasting.

- Behavior of structures (such as buildings and industrial parts) under stress and other conditions.
- Design of industrial processes, such as chemical processing plants
- Strategic Management and Organizational Studies.
- Instruction Set Simulators for debugging and automatic error detection.
- Reservoir simulation for the petroleum engineering to model the subsurface reservoir.

Also simulation is used to study differential equations which cannot be solved analytically, theories which involve continuous systems such as phenomena in physical cosmology.

### **1.7 Case Study**

For our project we are going to study Beit-eba crossing check-point, for both people depart and people arrive to Nablus over two periods a day 7:30-9:30 in the morning and 1:45-3:45 in the evening, we chose those periods as they are the peak times. .

### **1.8 Metrological Data**

The collected data we got is summarized in three tables (annexes A, B and C).

### **1.9 Study Objectives**

Objectives of this study are to:

1. Study the performance measures of a queue at Beit-Eba crossing check-point. The most important measures are the waiting time in the queue ( $W_q$ ) and the size of the queue ( $L_q$ ).
2. Determine the best applicable model for people departing Nablus at Beit-eba crossing check-point.
3. Compare between single-channel queue and multiple-channel queues.

### **1.10 Significance of the Study**

Our study at Beit-eba crossing check-point is applicable in different real-life problems and different efficiency problems [4].

Examples of problems:

- People moving through a bank or post office
- Telephone calls moving through a call center
- Parts moving along an assembly line or through a batch process or a job shop
- Inventory moving through a retail store or warehouse
- Products moving by trucks, or ships through a supply chain
- A software development project

Examples of efficiency models:

- How many tellers are needed to keep waiting times at a bank reasonably short?
- What effect will a new answering system have on how long customers wait at a call center?

- What effect will a new just-in-time (JIT) inventory system have on the number of units produced per day on an assembly line?
- What is the best batch size to use in a factory?
- What is the best delivery policy for goods at a warehouse?
- How much inventory should be kept on the shelves in a grocery store?
- How many machines should each worker operate in a manufacturing cell?
- How should inventory be distributed along a supply chain?
- What is the expected duration of a software development project?

### **1.11 Motivation of the study**

We use simulation at the Beit-eba crossing check-point, to make sure that simulation is applicable at different waiting lines at different real-life problems, as waiting for service is part of our daily life

## Chapter two

### Literature Review

#### 2.1 Simulation in Queuing Theory

A stochastic dynamic model is a statistical term describing the state variables of the system with values determined by chance (stochastic) and evolve with time (dynamic), a stochastic dynamic model can be [7]:

- Discrete time model: state variables change at discrete points in time (queue length of a server) so it is called discrete-event simulation (DES).
- Continuous time model: state variables may change continuously, e.g., temperature in a class room.

Discrete-event simulation (DES) is one of the most popular modeling techniques. It has been developed significantly since the inception of computer simulation in the 1950s [13].

A discrete event is something that occurs at an instant of time -for example, pushing an elevator button, starting of a motor, stopping of a motor, and turning on a light, arrival to a queue, departure from a queue are all discrete events because there is an instant of time at which each occurs. Activities such as moving a train from point A to point B are not discrete events because they have time duration.

Queuing theory has always been widely used in survey courses on management science (MS) and operations research (OR) [13]. Queuing theory is a powerful tool for computing certain steady-state queue performance measures (Markovian queues).

Queues can be solved by [13]: analytical queuing theory, dedicated simulation packages, and spreadsheet simulation.

Simulation using dedicated software packages is flexible, powerful and widely used for modeling queues, and it is often the best technology for computing quantitative results. Many simulation packages are available, such as SLAM, GPSS, Extend+, and Arena [13]. However, simulation packages hide the mechanics of queues, are expensive and time-consuming to learn, and are not widely used in survey courses on management science (MS) and operations research (OR).

Performing queuing simulations in spreadsheets offers six benefits: explicitness, immediacy, insight, flexibility, active modeling, and accessibility. These benefits apply not only to students, but also to instructors with expertise in queuing theory. Spreadsheet simulation is increasingly popular. Any spreadsheet model (including those built by people with no knowledge of management science) can be simulated using techniques that can be found in management science textbooks.

Evans and Olson (1998) [3] distinguish three classes of spreadsheet simulation models:

1. Activity-driven.
2. Event-driven.
3. Process-driven.

An activity-driven simulation [3] describes the activities that occur during fixed intervals of time (for example, an hour, day, or week), typically using one row of the spreadsheet for each time interval. The activity-driven approach (often used in textbook inventory models) seems to have first been used for queuing by Clauss (1996) for ship unloading. However, we think this approach oversimplifies most queuing systems.

An event-driven simulation [3] describes the changes in the system at the moment of each stochastic event, typically using one row of the spreadsheet for each event. This approach was apparently first used for queuing by Winston (1996) for a single-server queue. Evans and Olsen (1998) describe a similar model. The event-driven approach has technical advantages of efficiency and flexibility, but it is not good for teaching because it obscures the customer experience of queues, and it is less intuitive than the process-driven approach.

A process-driven simulation [3] models the logical sequence of events for each customer, typically using one row of the spreadsheet for each customer. This approach was apparently first used for queuing by Chase and Aquilano, who present a model of two serial single-server queues with zero queue size.

With process simulation, you begin by building a computer model of a real-world process. Your initial goal is to have the computer model behave in a way similar to real process, except much more quickly. One then try out various ideas for efficiency improvements on the computer model and use the best ideas for efficiency improvements on the computer model and use the best ideas on the real process. Thus a lot of time and money can be saved.

Simulation is particularly useful when there is uncertainty in a process (e.g. the arrival times of customers, the demand for a product, the supply of parts, the time it takes to perform the work, the quality of work).With uncertainty, it is often difficult to predict the effects of making changes to a process, especially if there are two or more sources of uncertainty that interact.

**Monte Carlo simulation** methods [17] are a class of computational algorithms that rely on repeated random sampling to compute deterministic or stochastic parameters and is often used when simulating physical and mathematical systems. Examples of Monte Carlo applications [15] include evaluation of multiple integrals and estimation of the constant  $\pi$ , and matrix inversion. Monte Carlo has similar procedures of the DES model development.

## 2.2 DES Model Development

DES Model Development which is typically an iterative process [1]:

- Determine the objectives.
- Build a conceptual model:
  - Very high level
  - How comprehensive should the model be?
  - What are the state variables, which are dynamic, and which are important?
- Convert into a specification model:
  - On paper
  - May involve equations, pseudo code, etc.
  - How will the model receive input?
- Convert into a computational model:
  - A computer program
  - General-purpose PL or simulation language?
- Verify: The process of comparing the model's output with the behavior of the phenomenon. In other words: comparing model execution to reality [14].



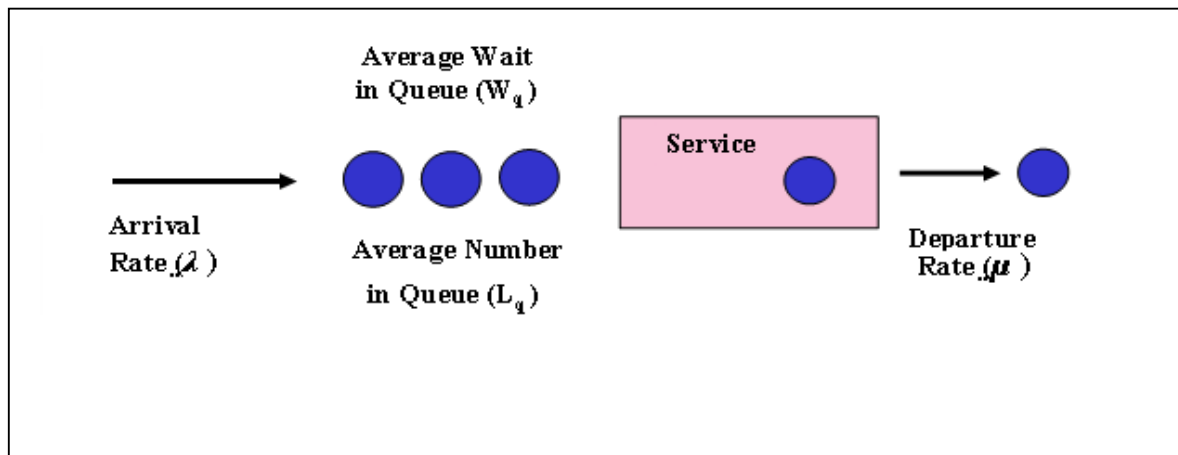
- **Validate:** The process of comparing the computer code with the model to ensure that the code is a correct implementation of the model [14].

### 2.3 Parameters of the Queue Model

The parameters of the queue are [9]:

1. Calling Population
2. Arrival Process
3. Service Process
4. Number of servers
5. Queue Discipline

### Queuing System



7

**Figure 2.3** Queuing systems [9]

A convenient notation for summarizing the characteristics of queuing situation in Queuing System Figure 2.3 is given by the following format [11]:

$(a/b/c): (d/e/f)$  where

a = Description of the arrivals distribution

b = Description of the departure (service time) distribution

c = Number of parallel servers

e = Maximum number (finite or infinite) allowed in the system (in the queue plus in the service)

f = Size of the calling source (finite or infinite)

If the standard notation for representing arrivals or departures distributions (symbols a and b) is M then

M = Markovian (or poisson) arrivals or departures distribution (or equivalently exponential inter-arrival or service time distribution)

There exist other notations.

The queue discipline notation (symbol d) include

FCFS = First come, first served

LCFS = Last come, first served

SIRO = Served in random order

GD = General discipline (i.e., any type of discipline)

## **2.4 Queue Configurations:**

The following are two queue configurations and the advantages of each of them [9]:

### **1. Single-Channel Queuing System (Single Queue)**

The single-channel queuing system can be seen in places such as banks and post offices, where one single queue will diverge into a few counters.

## 2. Multiple-Channels Queuing System (Multiple Queues)

The multiple-channels queuing system is commonly observed in fast food restaurants. It is a system whereby the customers line up in rows directly in front of each server.

The right of Figure (2.4) is a single channel-queue with four servers, while the left is multiple channel-queues.

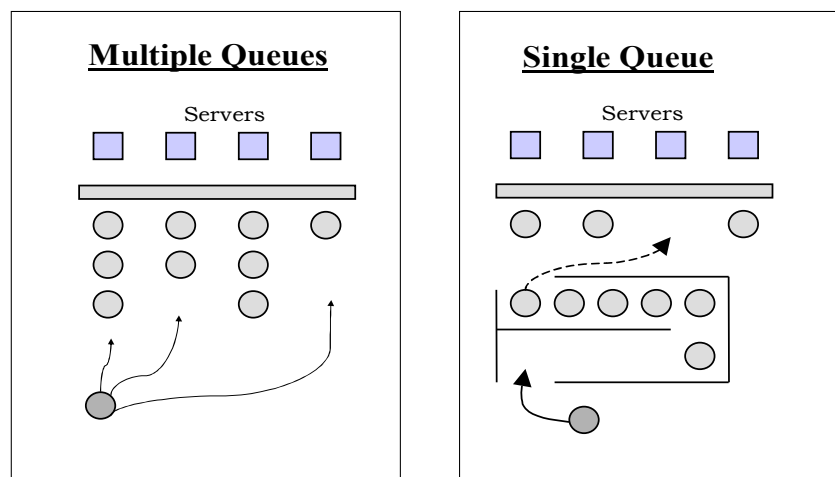


Figure (2.4) Queue Configurations [9]

### 2.5 Multiple line advantages

1. The service provided can be differentiated
2. Labor specialization possible
3. Customer has more flexibility
4. Balking behavior may be avoided

### 2.6 Single Line advantages

1. Guarantees fairness
2. No customer anxiety regarding choice of the queue
3. Avoids "cutting in" problems
4. The most efficient set up for minimizing time in queue
5. Jockeying (line switching) is avoided

## 2.7 How is Simulation performed manually? [14]

Simulations may be performed manually as indicated by the following example, most often the system model is written either as a computer program or as an input into simulator software.

Example: Building a simulation gas station with a single pump served by a single service man. Assume that arrival of cars as well their service times are random. At first identify the:

- States: number of cars waiting for service and number of cars served at any moment
- Events: arrival of cars, start of service, end of service
- Entities: these are the cars
- Queue: the queue of cars in front of the pump, waiting for service
- Random realizations: inter-arrival times, service times
- Distributions: we shall assume exponential distributions for both the inter-arrival time and service time.

Next, specify what to do at each event. The above example would look like this: At event of entity arrival: Create next arrival. If the server is free, send entity for start of service. Otherwise it joins the queue. At event of service start: Server becomes occupied. Schedule end of service for this entity. At event of service end: Server becomes free. If any entities waiting in queue: remove first entity from the queue; send it for start of service.

Some initiation is still required, for example, the creation of the first arrival. Lastly, the above is translated into code. This is easy with an appropriate library which has subroutines for creation, scheduling, proper timing of events, queue manipulations, random variate generation and statistics collection.

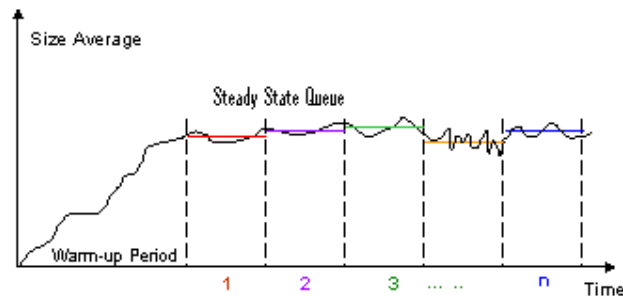
## 2.8 Techniques for the Steady State Simulation

Unlike in queuing theory where steady state results for some models are easily obtainable, the steady state simulation is not an easy task as obtaining steady state simulation output requires statistical assurance that the simulation model reached the steady state. The main difficulty is to obtain independent simulation runs with exclusion of the transient period.

The opposite is true for obtaining results for the transient period (i.e., the warm-up period).

**The methods commonly used for steady state simulation:**

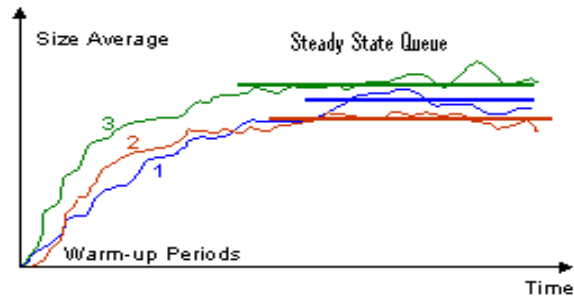
### 2.8.1 Method of Batch Means or (Subinterval method)



**Figure 2.8.1** Method of Batch Means [14]

Figure 2.8.1 illustrates the idea of subinterval method. The advantage of the subinterval method is that the effect of the transient conditions is mitigated. The disadvantage of the method is that successive subintervals or (batches) are necessarily correlated. The effect of correlation can be alleviated by increasing the time base of each batch [15].

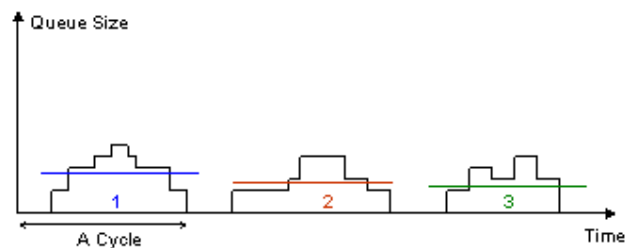
## 2.8.2 The Independent Replication.



**Figure 2.8.2** Method of Independent Replications [14]

Figure 2.8.2 illustrates the method of independent replications. The advantage of the method is that it yields observations that are truly independent. The disadvantage is that each observation may be biased by the initial effect of the transient conditions. This problem may be alleviated by making the run length sufficiently large [15].

## 2.8.3 Regenerative or( cycles) Method.



**Figure 2.8.3** Regenerative Method [14]

Figure (2.8.3) illustrates the regenerative method that may be regarded as an extended case of the subinterval method. This method reduces the effect of autocorrelation, it has the disadvantage of yielding a smaller number of batches for a given run length [15].

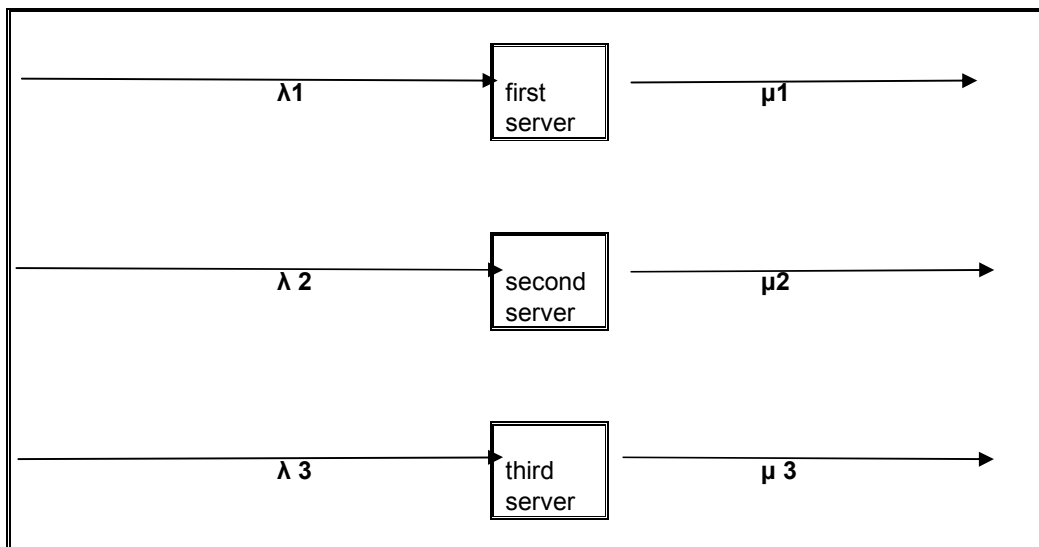
## Chapter Three

### Methodology

#### 3.1 Study area

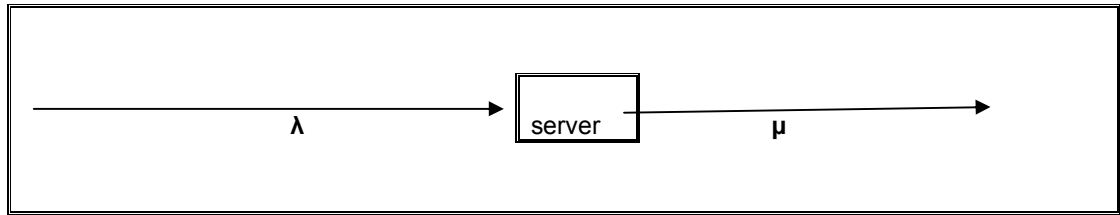
Data collection is done at Beit-eba crossing check-point for two time periods a day, (7:30-9:30) in the morning and (1:45-3:45) in the evening over two weeks which are the peak times of the day (see Annexes A, B, and C). Real data is needed to make sure that simulation is applicable to different real-life applications.

People arriving to Nablus City and people departing Nablus has to be checked. The crossing check- point offers one server for people arriving to Nablus and three servers for people departing Nablus , one of the servers is for women and men over forty (the first server) , the other two (the second and third server) are for men under forty as shown below:



**Figure (3.1.a)** a model represents the crossing check-point at Beit-eba for people departing Nablus City





**Figure (3.1.b)** A model represents the crossing check-point at Beit-eba for people arriving to Nablus City

The most suitable place for obtaining the data was where cars carried people on and down on both sides of the crossing check-point, thus we can count nearly every one. This process needed at least two persons one on each side.

Most days four persons counting two on each side including myself.

### 3.2 Difficulties of study

1. Collecting data was exhausting job. We had to pass through the crossing check-point about four times a day. Nevertheless we had to face the suspicious people all the time.
2. Looking for a suitable tool for simulation was time consuming. We tried dedicated software which needs elective courses in simulation then after searching we found SimQuick tool that works in excel spreadsheet.

### 3.3 Data

The data we got are summarized in three tables (Annexes A, B and C). The first two columns of each day describe the number of arrivals ( $\lambda$ ) to the check-point and departures ( $\mu$ ) from the check-point for people arriving to Nablus. The other two are for arrivals to the check-point and departures from the check-point for people departing Nablus City.

Time and date are indicated in each table.

### 3.4 SimQuick

The simulation tool we used is SimQuick [4] which is easy to learn and inexpensive. It is aimed primarily at business students and managers who want to understand process simulation and be able to analyze and improve real-world processes. SimQuick is flexible in its modeling capacity; that is, it is not a "hardwired" set of examples; it requires true modeling. In addition, SimQuick runs in the widely-known Microsoft Excel spreadsheet environment (it is an ordinary Excel 2000 file with some hidden macros). Hence, users of Excel are already familiar with much of the interface.

SimQuick allows the user to model simple processes as:

- Waiting lines (e.g., banks, fast-food restaurants, call centers).
- Inventory and supply chains (e.g., stores, warehouses, and simple combinations of these).
- Manufacturing (e.g., assembly lines, batch processes, simple job shops)

SimQuick has been used by a number of companies and by at least 40 colleges and universities, typically as a supplement to an Operations Management or Decision Science course.

There are three basic steps involved in using SimQuick :

1. Build a model of the process using building blocks of SimQuick.
2. Enter this model into SimQuick .
3. Test process improvement ideas on this computer model.

**Basic building blocks in SimQuick:**

1. **Objects:** represent things that move in a process as people, parts in a factory, paperwork, phone calls, e-mail messages, and so on.
2. **Elements:** Entrances, Buffers, Work Stations, Decision Points and Exits.
3. **Statistical distributions:** normal, exponential, uniform, constant and discrete.

**Entrances:** This is where objects enter a process. Entrances can represent a loading dock at a warehouse, a door at a store, and so on.

**Buffers:** This is where objects can be stored. Buffers can represent a location in a warehouse or a factory where inventory can be stored, a place where people can stand in line at a post office, a memory location in a computer for e-mail messages, and so on.

**Work Stations:** This is where work is performed on objects. Work stations can represent machines in a factory, cashiers in a store, operators at a call center, computers in a network, and so on.

### 3.5 Data Analysis

#### 3.5.1 Analytical solution

Example [1]:

A community is served by two cab companies. Each company owns two cabs, and the two companies are known to share the market equally. This is evident by the fact that calls arrive at each company's dispatching office at the rate of eight per hour. The average time per ride is 12 minutes. Calls arrive according to a Poisson distribution, and the ride time is exponential. The two companies recently were brought by an investor who is interested in consolidating them into a single dispatching office to provide faster service to customers.

The above two problems

1. (M/M/2) :( GD/ $\infty$ / $\infty$ ) with  $\lambda=8$  and  $\mu=5$
2. (M/M/4) :( GD/ $\infty$ / $\infty$ ) with  $\lambda=16$  and  $\mu=5$

The previous two problems are under steady-state conditions, arrivals and departures follow the poisson distribution, so the analytical solution is applicable using the known formulas in queuing theory.

Solving the first problem by simulation process using SimQuick can be done as follows:

<b>Simulation controls:</b>	
<b>Time units per simulation</b> →	7000
<b>Number of simulations</b> →	200

**Entrances:**

1	
---	--

<b>Name →</b>	door 1
Time between arrivals →	Exp(7.5)
Num. objects per arrival →	1
Output destination(s) ↓	
line	

**Work Stations:**

1			
<b>Name →</b>	teller1		
Working time →	Exp(12)		
Output destination(s) ↓	# of output objects ↓	Resource name(s) ↓	Resource # units needed ↓
served customers	1		

2			
<b>Name →</b>	teller2		
Working time →	Exp(12)		
Output destination(s) ↓	# of output objects ↓	Resource name(s) ↓	Resource # units needed ↓
served customers	1		

**Buffers:**

1		2	
<b>Name →</b>	line	<b>Name →</b>	served customers
Capacity →	Unlimited	Capacity →	Unlimited
Initial # objects →	0	Initial # objects →	0
Output destination(s) ↓	Output group size ↓	Output destination(s) ↓	Output group size ↓
teller1	1		
teller2	1		

**Figure (3.5.1)** Solution using SimQuick

Solving the two problems analytically (Taha [15] used TORA to get the following analytical results which depends on queuing theory formulas) and by simulation, yields the following results for  $L_q$  and  $W_q$ :

**Table( 3.5.1)**Comparison between analytical solution and simulation

Nbr		Analytically	Simulation
1	$L_q$	2.844	2.76
	$W_q$	21.36	20.67
2	$L_q$	2.386	2.33
	$W_q$	8.94	8.72

Table (3.5.1) shows a good agreement between analytical solution and simulation results.

This shows that simulation can accurately to some degree model queues in Beit-eba, since  $\lambda$  and  $\mu$  are not exactly poisson and exponential we can not use analytical solution here simulation is the choice.

### 3.5.2 Procedure of Simulation

Each table of the collected data(annexes A,B, and C) has four columns for each day ,the first two columns represent arriving people to Nablus through Biet-Eba , the other two for people departing out of Nablus through Biet-Eba .Where  $\lambda$  is the number of arrivals and  $\mu$  the number of departures.

People arriving to Nablus through the check-point pass through one server as in Figure (3.1.b).

People departing Nablus has three servers as in Figure (3.1.a). The values of  $\lambda$  and  $(\mu)$  in the table are divided on the three servers with ratio 6:2:2 except for 8-9/3/2008 it is 7:1.5:1.5 (this ratio can be changed).

According to this

$$\lambda_1 = .6 * \lambda, \lambda_2 = \lambda_3 = .2 * \lambda \text{ and } (\mu_1 = .6 * \mu, \mu_2 = \mu_3 = .2 * \mu).$$

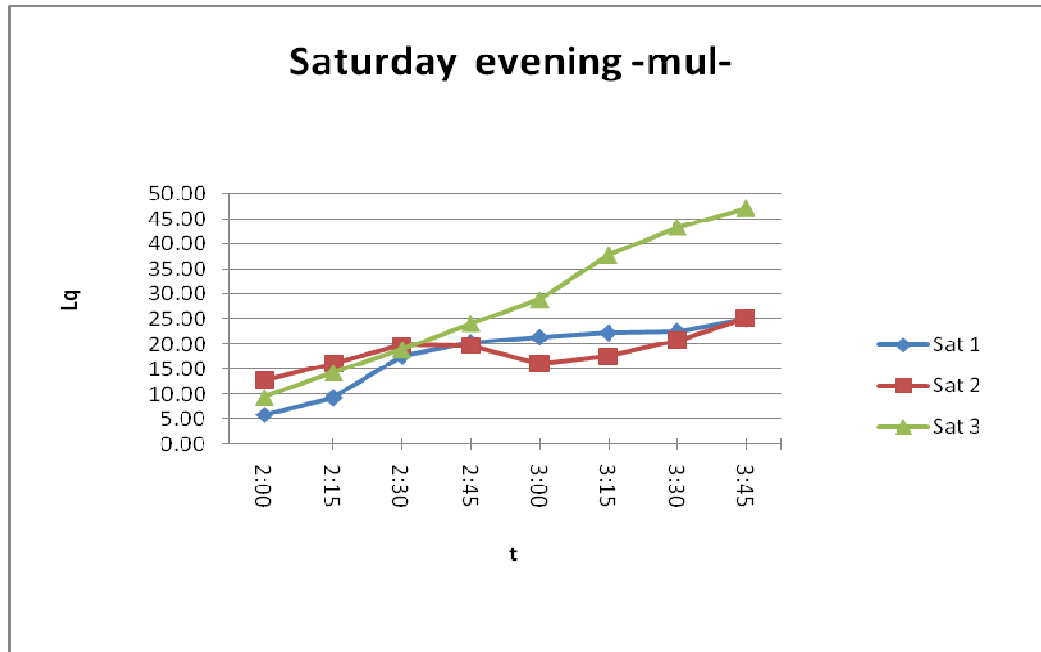
The data was collected over two time periods as discussed earlier, the first time period is 7:30-9:30 and the second is 1:45-3:45. The data of each time period was collected over eight intervals, each interval is of 15 minutes (at collecting data one can choose any other number of minutes for each interval).

For each time interval and each channel we build an  $(M/M/1) : (GD/\infty/\infty)$  model, because inter-arrival times and service times of people at services can often be closely approximated by exponential distribution which is a general principle [4].

The collected data represents a transient period, so we start simulation for the first interval then the next and so on until the eighth interval. Always use the final inventory of each time interval as an initial inventory for the next by converting the values of the final inventory (from the different simulation runs) to a discrete distribution.

In each interval we can obtain different performance measures, the most important are the waiting time in the queue ( $W_q$ ), and the length of the queue ( $L_q$ ).

The following two figures are the results for simulation carried out for the data collected of men under forty departing Nablus over the time period 1:45-3:45 on Saturday evening (sat3 16-2-2008, sat2 23-2-2008 and sat1 8-3-2008). At each time period we computed  $L_q$  and  $W_q$ .



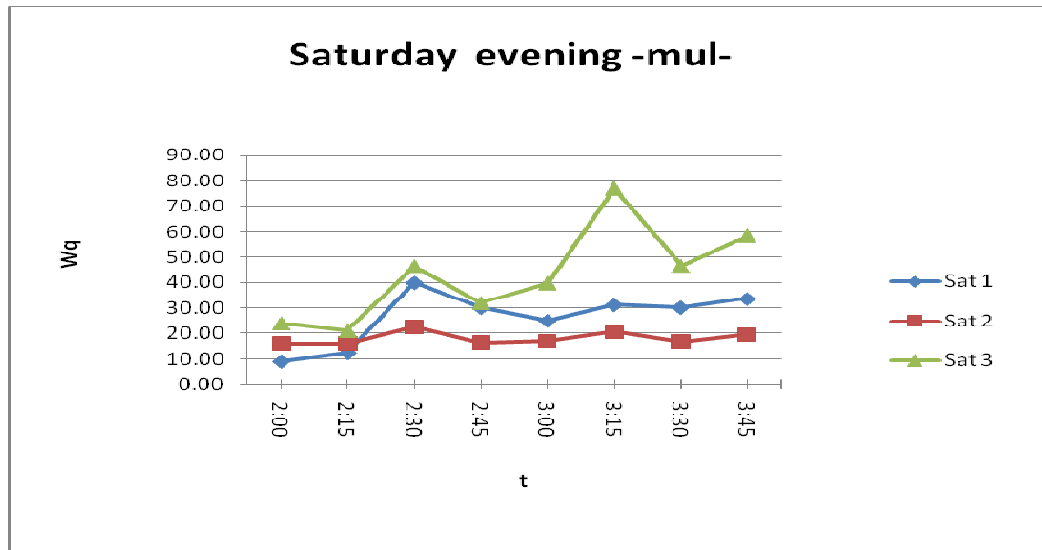
**Figure(3.5.2.a)** Men under forty departing Nablus on Saturday evening: the length of the queue( $L_q$ ) vs time( $t$ ).

In Figure (3.5.2.a) we see that at  $t=3:15$ ,  $L_q=22.22$  on Saturday1,  $L_q=17.55$  on Saturday2 and  $L_q=37.76$  on Saturday3.

Reasons for different values of  $L_q$  at the same time :

1. Economical reasons: data was collected during the second week of March, the third and the fourth week of February.
2. Reasons related to the server itself: the service time at the crossing check-point has a relation with the political situation and the mood of the server most times.

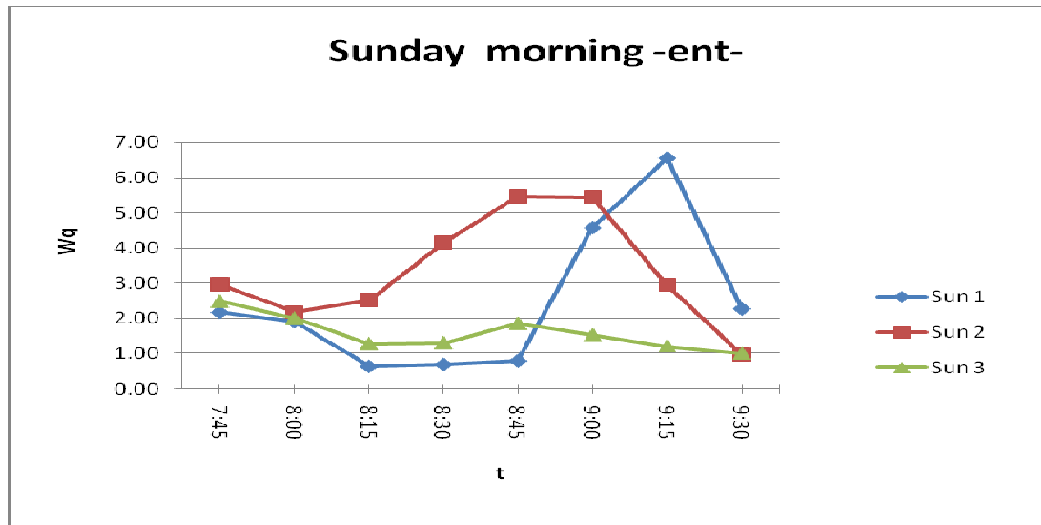




**Figure(3.5.2.b)** Men under forty departing Nablus on Saturday evening, waiting time in the queue vs time.

In Figure (3.5.2.b) above at  $t=3:15$ ,  $Wq=31.24$ minutes on Saturday1,  $Wq=20.58$ minutes on Saturday2 and  $Wq=76.88$  on Saturday3.

We see that at this time of Saturday3 people faced some delays as here  $\lambda$  from the table (see Annex C) is much more than  $\mu$ .



**Figure(3.5.2.c)** People arriving to Nablus on Sunday morning: the waiting time in the queue( $W_q$ ) vs time( $t$ ).

Figure(3.5.2.c) shows that at 9:15,  $W_q=6.56$  on Sunday1,  $W_q=2.95$  on Sunday2 and  $W_q=1.21$  on Sunday3.

The least mean waiting time is on Sunday3, that's because  $\lambda$  is much less than  $\mu$  in the table of collected data (see Annex C).

Simulation is carried out for all collected data, and the results are shown in figures in Annex D.

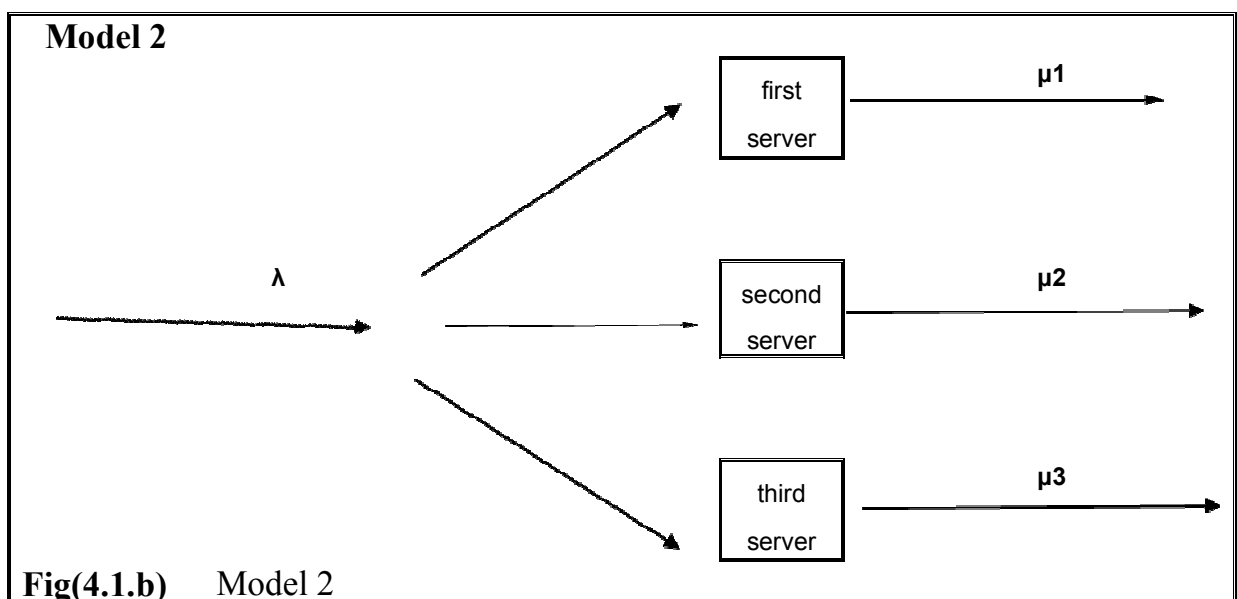
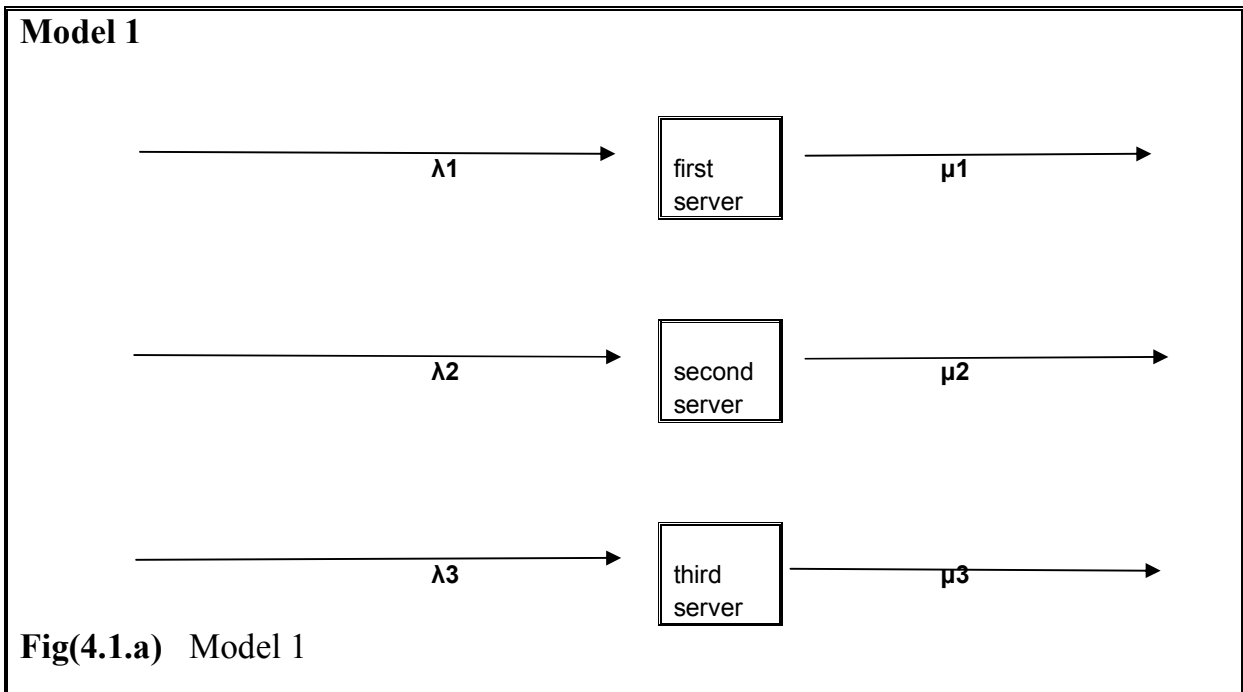
*Note: Most of the people arriving to Nablus through Beit-eba in the morning and people departing it in the evening are university students and employers.*

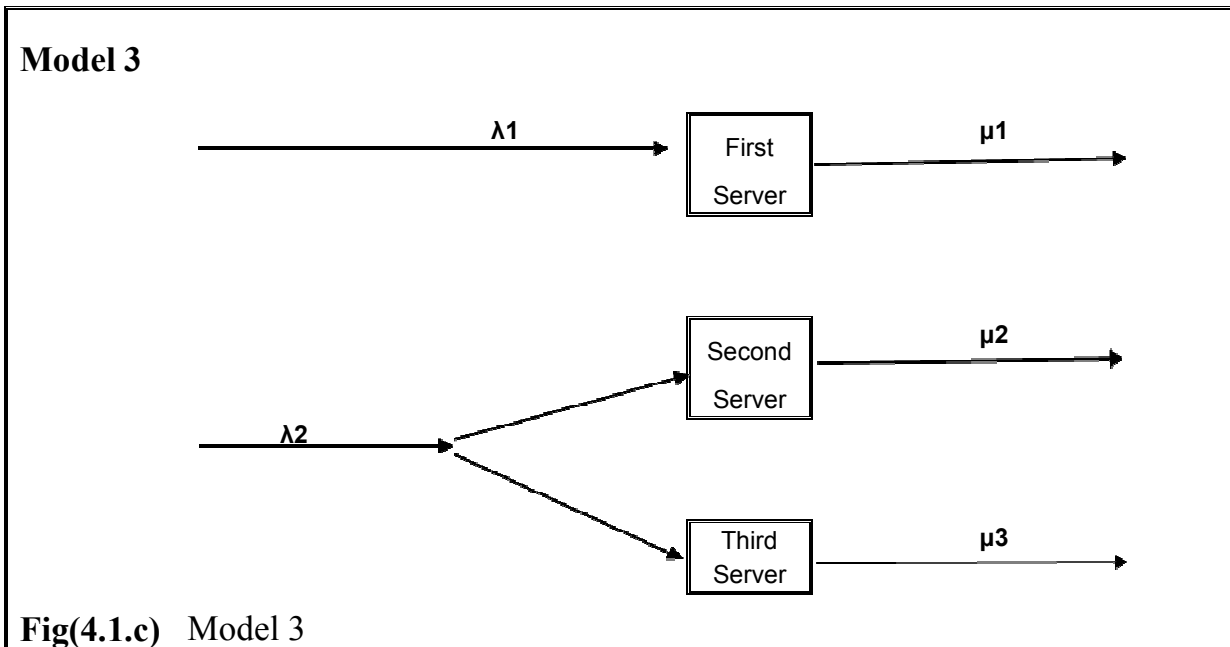
## Chapter Four

### Other Models Configurations

#### 4.1 Configurations for the crossing check-point

The crossing check-point may have one of those models





Model 1 resembles the actual crossing check-point at Beit-eba as discussed earlier.

We will look at two assumed models to determine which is the best model to follow among the three models.

The best model is the one with the least average waiting time, of course.

To check for that, we take the data of people departing Nablus on Sunday morning (24/2/2008) from the table (Annex B).

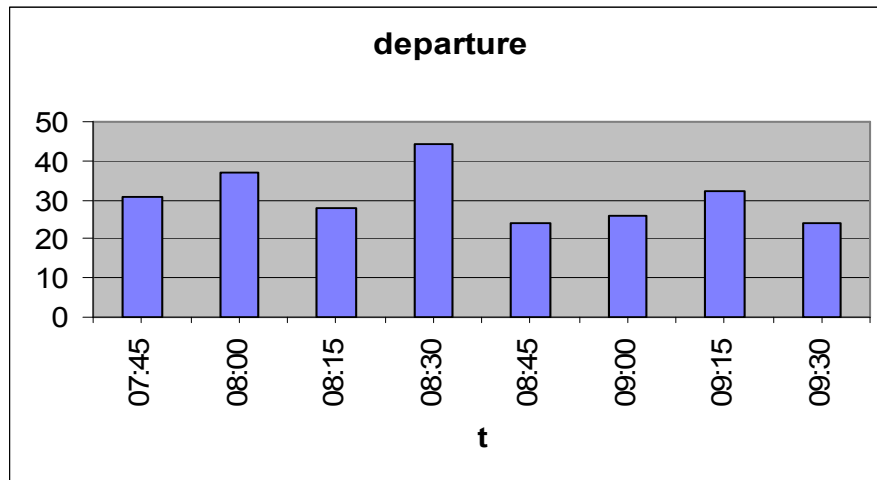
#### 4.2 Model 1

Assume that  $\lambda$  and  $\mu$  from the table are divided on the three servers with ratio 6:2:2, that is 60% of  $\lambda$  for the first server which is a reasonable percent for women and men over forty.

To determine the average waiting time in the queue for the first server ( $W_{q1}$ ):

1. Multiply  $\lambda$  in each interval by 0.6.

2. Multiply  $\mu$  in each interval by 0.60 and represent the resulting values by columns, we will have Figure (4.2.a).



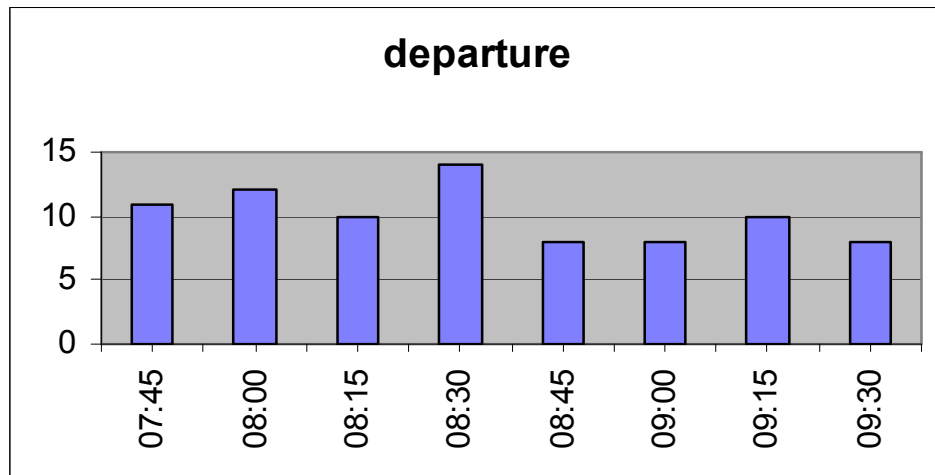
**Figure (4.2.a)** The columns representation of departures for server1 in model 1, the service time can be approximated by the uniform distribution :  $\mu$  vs t.

3. The service time can be approximated by the uniform distribution according to Figure (4.2.a).
4. Input this model into SimQuick, the resulting average waiting time from this model is  $Wq1$ .

To determine the average waiting time in the queue for the second or the third server( $Wq2$ ):

1. Multiply  $\lambda$  by 0.20 in each interval.
2. Multiply  $\mu$  by 0.20 in each interval. Represent the resulting values by columns, we will have Figure (4.2.b).
3. The service time can be approximated by the uniform distribution according to Figure (4.2.b).

4. Input this model into SimQuick .The resulting average waiting time is  $Wq2$ .



**Figure (4.2.b)** The columns representation of departures for server 2 and server 3) in model 1, the service time can be approximated by the uniform distribution :  $\mu$  vs  $t$ .

Hence, the average waiting time ( $Wq$ ) for Model 1 is computed from the equation:

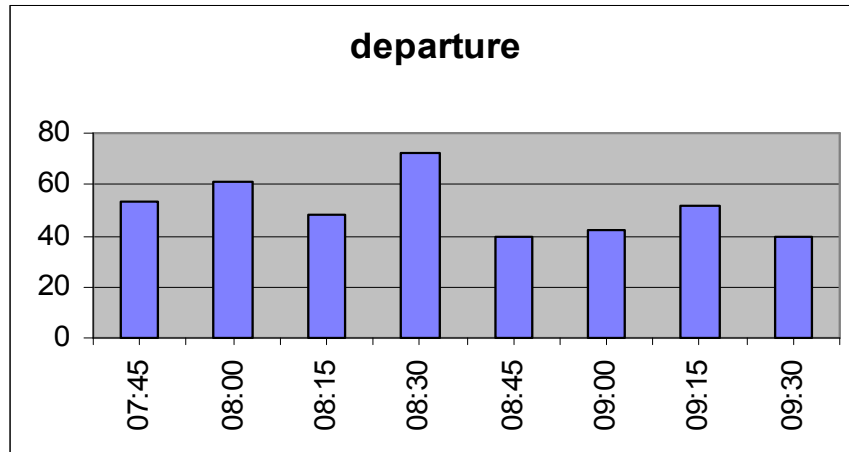
$$Wq = 60\% * Wq1 + 40\% * Wq2$$

### 4.3 Model 2

To determine the average waiting time( $Wq$ ) in the queue for Model 2:

1. We feed the values of  $\lambda$  from the table in model 2 directly, as it is a single-channel queue of three servers.
2. We divide the value of  $\mu$  by three in each interval. Represent the resulting values by columns, we will have Figure (4.3).

Note: Here in Model 2 Figure (4.1.b), we took  $\mu_1 = \mu_2 = \mu_3 = \mu/3$ . We can change this ratio.



**Figure (4.3)** The columns representation of departures for server1, server2 and server3 in model 2, the service time can be approximated by the uniform distribution:  $\mu$  vs  $t$ .

3. The service time can be approximated by the uniform distribution according to Figure (4.3).
4. Input this model into SimQuick, the resulting value of the waiting time is  $W_q$  for model 2.

#### 4.4 Model 3

Assume for Model 3 in Figure (4.1.c) that:

$$\mu_1 = 60\% * \mu, \mu_2 = \mu_3 = 20\% * \mu$$

$$\lambda_1 = 60\% * \lambda, \lambda_2 = 40\% * \lambda$$

Hence, the average waiting time for server 1 is  $Wq1$  we determined earlier in model 1.

To determine  $Wq2$  for the single channel-queue of two servers (the second server and the third):

1. Multiply  $\lambda$  in the table by 0.40 in each interval.
2. Multiply  $\mu$  by 0.2 in each interval. Represent the resulting values by columns, we will have Figure (4.2.b) again.
3. The service time can be approximated by the uniform distribution according to Figure (4.2.b).
4. Input this model into SimQuick, the resulting value of  $Wq$  is  $Wq2$ .

Hence, the average waiting time ( $Wq$ ) for Model 3 is computed from the equation:

$$Wq = 60\% * Wq1 + 40\% * Wq2$$

Repeat the previous steps for people departing Nablus on the morning of Saturday (23-2-2008). Figure (4.4.a) next shows that the service time can be approximated by the uniform distribution.

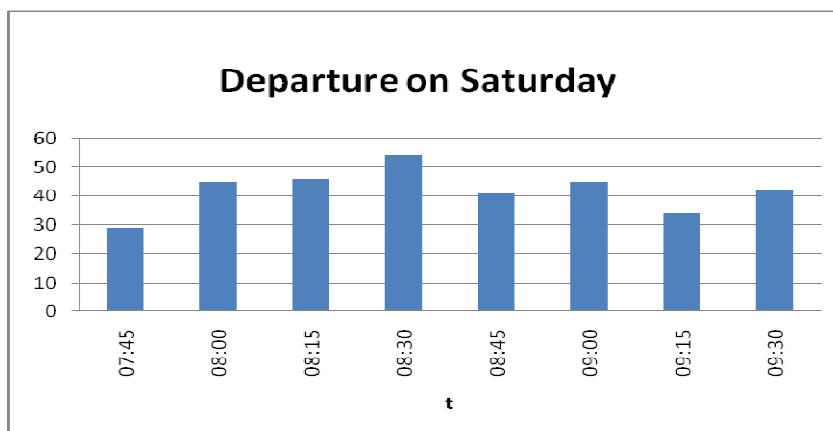


Figure (4.4.a) the columns representation of the departue on Saturday morning for people departing Nablus:  $\mu$  vs t.



Repeat again the previous steps for people departing Nablus on the morning of Monday and Tuesday (25, 26-2-2008).

In Figure (4.4.b), the service time can be approximated by the uniform distribution.

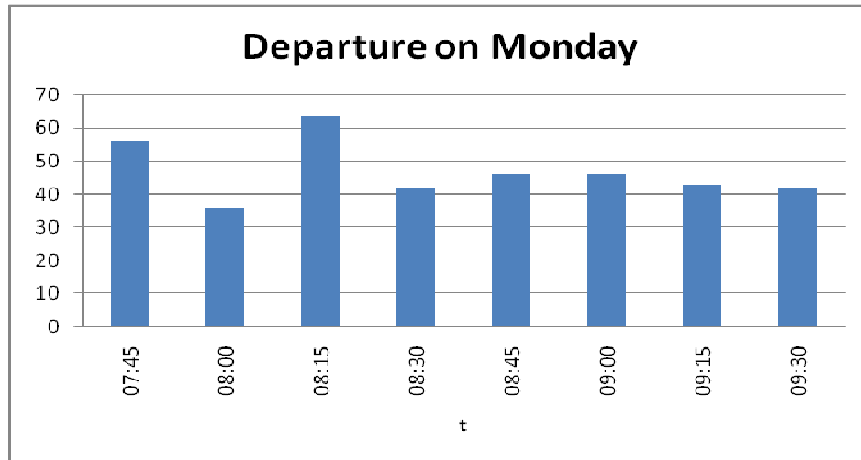


Figure (4.4.b) the columns representation of the departue on Monday morning for people departing Nablus:  $\mu$  vs  $t$ .

In Figure (4.4.c), the service time can be approximated by the uniform distribution.

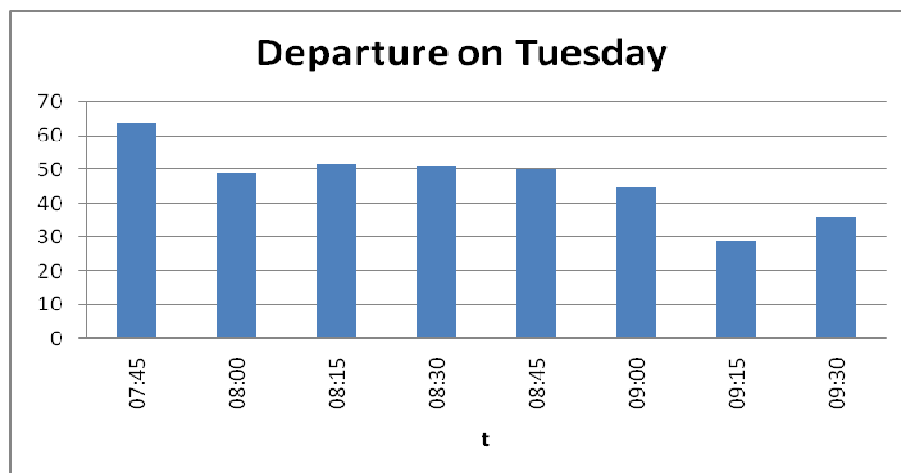


Figure (4.4.c) the columns representation of the departue on Tuesday morning for people departing Nablus:  $\mu$  vs  $t$ .

We can summarize our results in table (4.4), mathematically it is clear that model 2 gives the least waiting time in the queue as on Saturday  $W_q=16.058$  in Model 1,  $W_q=12.3$  in Model 2, and  $W_q=13.142$  minutes in Model 3, hence the best model that should be applied is model 2.

**Table (4.4.a)** SimQuick results for model 1, model 2, and model 3:  $\lambda$  and  $\mu$  for the first server are 60% of the value of  $\lambda$  and  $\mu$  in model 1 and model 3.

<b>Wq at</b>	<b>Model 1</b>	<b>Model 2</b>	<b>Model 3</b>
<b>Saturday</b>	16.058	12.3	13.142
<b>Sunday</b>	19.796	16.99	17.344
<b>Monday</b>	18.66	13.48	15.364
<b>Tuesday</b>	33.28	25.45	29.904

#### **The ratio 70% of $\lambda$ and $\mu$**

Repeat the previous steps again using the data for people departing Nablus on the morning of Saturday (8-3-2008) in the table (Annex A).

In Model 1:

Assume that  $\lambda$  and  $\mu$  from the table are divided on the three servers with ratio 7:1.5:1.5. In Model 3 let:

$$\mu_1=70\% * \mu, \mu_2= \mu_3=15\% * \mu$$

$$\lambda_1= 70\% * \lambda, \lambda_2= 30\% * \lambda$$

By the departures representation, the service time can be approximated by the uniform distribution.

Use SimQuick, the computed the average waiting time ( $W_q$ ) in Model 1 is (21.15),  $W_q$  in Model 3 is (17.946), and in Model 2 is the least and equals (8.92).

These results can be summarized in the next Table 4.4.b

**Table (4.4.b)** Results for Model1, Model 2, and Model 3 on Saturday morning:  $\lambda$  and  $\mu$  for the first server are 70% of the value of  $\lambda$  and  $\mu$  in model 1 and model 3.

	<b>Model 1</b>	<b>Model 2</b>	<b>Model 3</b>
<b>Wq</b>	21.15	8.92	17.946

**The ratio 0% of  $\lambda$  and  $\mu$**

Repeat the previous steps again using the same data, with  $\lambda$  and  $\mu$  in the first server are 0% of the value of  $\lambda$  and  $\mu$  in model 1 and model 3, the results are summarized in Table 4.4.c

**Table (4.4.c)** SimQuick results for model 1, model 2, and model 3:  $\lambda$  and  $\mu$  for the first server are 0% of the value of  $\lambda$  and  $\mu$  in model 1 and model 3.

<b>Wq at</b>	<b>Model 1</b>	<b>Model 2</b>	<b>Model 3</b>
<b>Saturday</b>	13.16	12.3	12.53
<b>Sunday</b>	18.43	16.99	16.34
<b>Monday</b>	15.44	13.48	13.78
<b>Tuesday</b>	30.2	25.45	24.39

Table (4.4.c) above shows that model 2 and model 3 are better than model 1, for example on Sunday Wq in model 1 is (18.43) which is larger than (16.99) in model 1 and (16.34) in model 3, but no conclusion can be made about the best model among the three models.

### The ratio 100% of $\lambda$ and $\mu$

Repeat the previous steps again using the same data, with  $\lambda$  and  $\mu$  in the first server are 100% of the value of  $\lambda$  and  $\mu$  in model 1 and model 3, the results are summarized in Table 4.4.d.

**Table (4.4.d)** SimQuick results for model 1, model 2, and model 3:  $\lambda$  and  $\mu$  for the first server are 100% of the value of  $\lambda$  and  $\mu$  in model 1 and model 3.

Wq at	Model 1	Model 2	Model 3
Saturday	12.5	12.3	12.5
Sunday	15.41	16.99	15.41
Monday	12.78	13.48	12.78
Tuesday	23.98	25.45	23.98

In Table (4.4.d), no conclusion can be made about the best model among the three models.

### The ratio 20% of $\lambda$ and $\mu$

Repeat the previous steps again using the same data, with  $\lambda$  and  $\mu$  in the first server are 20% of the value of  $\lambda$  and  $\mu$  in model 1 and model 3, the results indicate that model 2 is the best model for this ratio as shown in Table 4.4.e.

**Table( 4.4.e)** SimQuick results for model 1, model 2, and model 3:  $\lambda$  and  $\mu$  for the first server are 20% of the value of  $\lambda$  and  $\mu$  in model 1 and model 3

Wq at	Model 1	Model 2	Model 3
Saturday	13.99	12.3	13.166
Sunday	19.838	16.99	17.302
Monday	24.892	13.48	17.676
Tuesday	30.952	25.45	27.24

### The ratio 40% of $\lambda$ and $\mu$

Repeat the previous steps again using the same data, with  $\lambda$  and  $\mu$  in the first server are 40% of the value of  $\lambda$  and  $\mu$  in model 1 and model 3, the results indicate that Model 2 is the best model for this ratio as shown in Table 4.4.f.

**Table (4.4.f)** SimQuick results for model 1, model 2, and model 3:  $\lambda$  and  $\mu$  for the first server are 40% of the value of  $\lambda$  and  $\mu$  in model 1 and model 3

Wq at	Model 1	Model 2	Model 3
Saturday	17.612	12.3	16.034
Sunday	22.85	16.99	20.792
Monday	23.388	13.48	19.956
Tuesday	38.164	25.45	34.648

### The ratio 80% of $\lambda$ and $\mu$

Repeat the previous steps again using the same data, with  $\lambda$  and  $\mu$  in the first server are 80% of the value of  $\lambda$  and  $\mu$  in model 1 and model 3, the results indicate that Model 2 is the best model for this ratio as shown in Table 4.4.g.

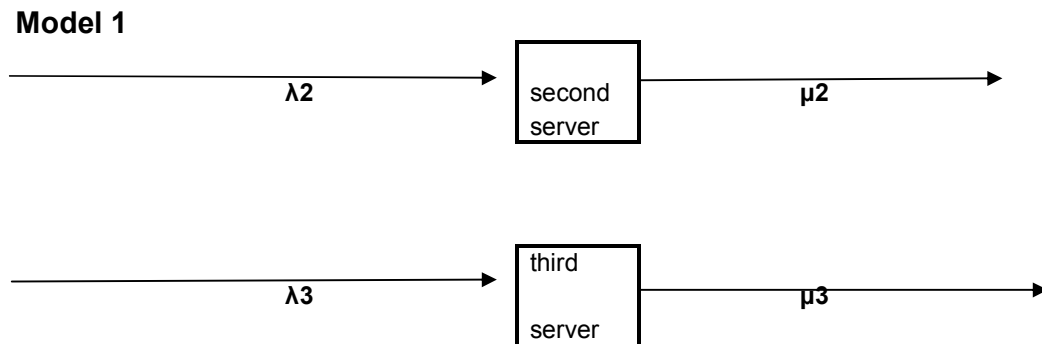
**Table (4.4.g)** SimQuick results for model 1, model 2, and model 3:  $\lambda$  and  $\mu$  for the first server are 80% of the value of  $\lambda$  and  $\mu$  in model 1 and model 3

Wq at	Model 1	Model 2	Model 3
Saturday	19.498	12.3	16.022
Sunday	23.072	16.99	20.848
Monday	25.504	13.48	22.102
Tuesday	35.89	25.45	32.472

### 4.5 Comparison between single-channel queue and multiple-channels queues

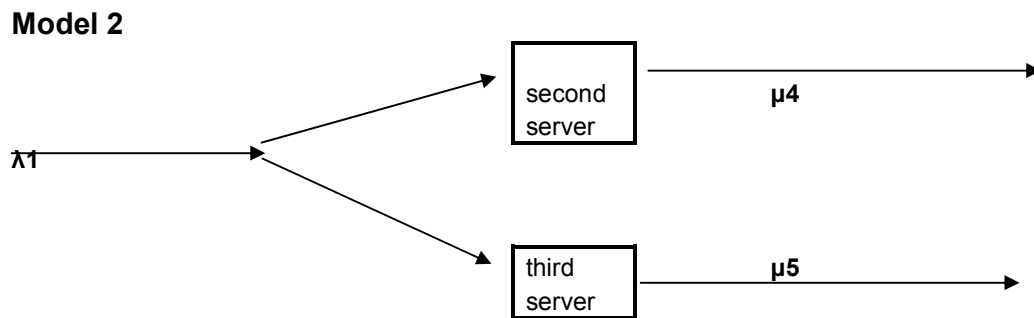
If we took again men under forty departing Nablus on Sunday (24/2/2008) morning ,and assuming that men under forty form 40% of the average of  $\lambda$  column and 40% of the average of  $\mu$  column , the resulting values are  $\lambda_1=20.5$  and  $\mu_1=20.25$  . Build a model assuming exponential inter-arrival (and service) time with 720 time units per simulation and number of simulations to be 100.

In Figure (4.5.a) model 1 resembles the actual check-point for men under forty departing Nablus which is multiple channel-queues, so assume  $\lambda_2 = \lambda_3 = \lambda_1 / 2 = 10.25$  and  $\mu_2 = \mu_3 = \mu_1 / 2 = 10.125$ .



**Figure (4.5.a)** Multiple-channel queues

Figure (4.5.b) shows an assumed model for the check-point of men under forty departing Nablus which is a single channel-queue, let  $\mu_4 = \mu_5 = \mu_1 / 2 = 10.125$ .



**Figure (4.5.b)** Single-channel queue with two servers

Input these two models into SimQuick, assume the inter-arrival time and the service time are exponential as we have a general principle: the inter-arrival times and the service times at services can often be closely approximated by the exponential distribution [David Hartvigsen]. Take the time units per simulation 720 as we have two hours, and the number of simulations to be 100.

The result of simulation for the average waiting time ( $Wq1$ ) for model 1 (the multiple-channel queues) is (36.06) minutes. While for model 2 (the single channel-queue)  $Wq2=(25.16)$ .

Repeat these calculations for different values of  $\lambda$  while keeping  $\mu$  fixed to (10.125) under the same previous assumptions, the results can be summarized in table (4.5).

**Table (4.5)** Comparison between single-channel queue and multiple-channel queues

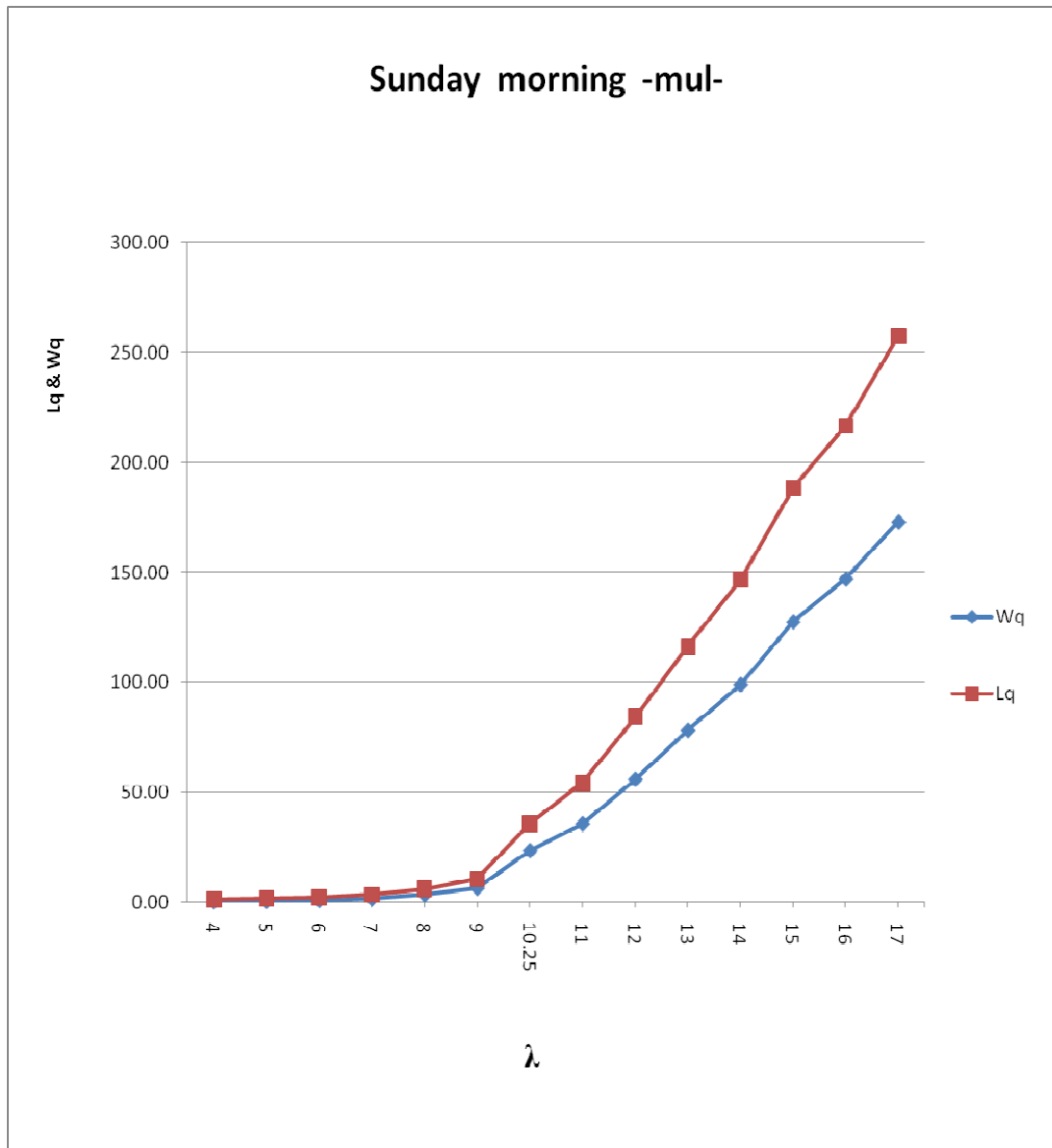
$\lambda 1$	8	10	12	14	16	18	20.5	22	24	26	30	32
Wq1 for the multiple channel-queues Model 1	1.48	2.01	2.47	3.63	6.39	10.85	36.06	54.57	84.72	116.42	188.69	226.97
Wq2 for the single channel-queue Model 2	0.82	1.02	1.36	2.01	3.20	6.50	25.16	45.75	76.66	112.21	184.31	223.05

The computed results in table (4.5) show that the waiting time (Wq1) in Model 1 is greater than the waiting time (Wq2) in Model 2, for example at  $\lambda 1=18$ ,  $Wq1=10.85$  and  $Wq2=6.50$ , that is the single-channel queue is more efficient than the multiple-channel queues.

We can use the results of table 4.5 to represent the relation between Wq and Lq versus  $\lambda$  for both model 1 and model 2 while keeping  $\mu$  is fixed and equals (10.125) as discussed earlier.

These results are next shown in Figure (4.5.c) and Figure (4.5.d).



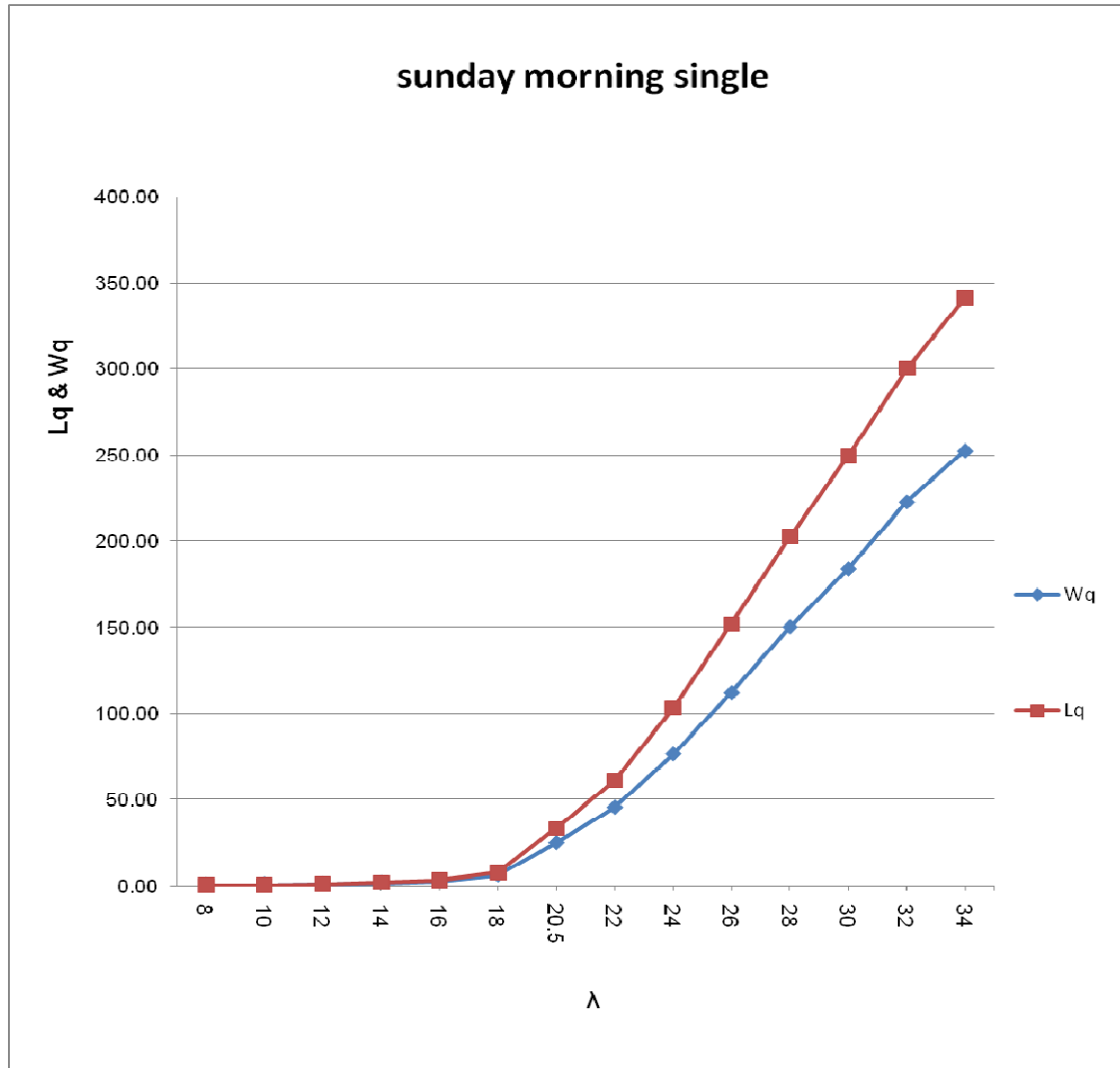


**Figure (4.5.c)** The relation between  $\lambda$  and ( $W_q$  &  $L_q$ ) in multiple-channel queues (Model 1).

In Figure (4.5.c) above, when  $\lambda$  increases ( $\mu$  is fixed=10.125) then  $W_q$  and  $L_q$  will increase.

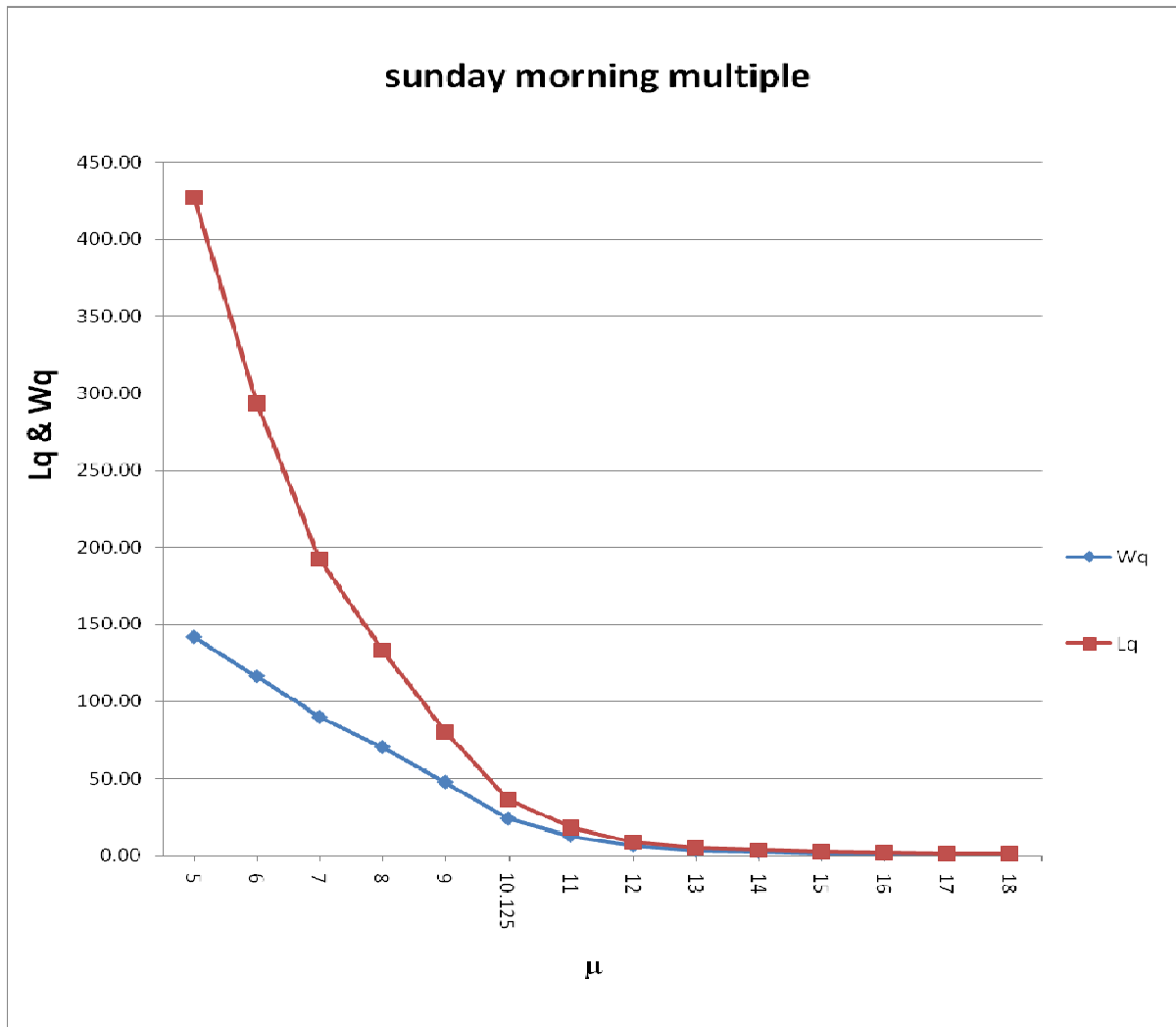
When  $\lambda$  is less than  $\mu$  ( $\lambda = 4, \dots, 10.25 < \mu = 10.125$ ), a slight increase in the value of  $W_q$  and  $L_q$  can be seen.

When  $\lambda$  is greater than  $\mu$  ( $\lambda = 11, \dots, 17 > \mu = 10.125$ ), a great increase in the value of  $W_q$  and  $L_q$  can be seen. This discussion also applies to the single channel-queue figure (4.5.d).



**Figure (4.5.d)** The relation between  $\lambda$  and ( $W_q$  &  $L_q$ ) in single-channel

In Figure (4.5.a) of model 1, change the value of  $\mu$  while keeping  $\lambda$  fixed to (10.25), and under the same assumptions we used earlier we represent the relation between  $W_q$  and  $L_q$  versus  $\mu$  in Figure (4.5.e).



**Figure (4.5.e)** The relation between  $\mu$  and ( $W_q$  &  $L_q$ ) in multiple-channel queues while  $\lambda$  is fixed to (10.25).

In Figure (4.5.e), when  $\mu$  increases ( $\lambda$  is fixed) then  $W_q$  and  $L_q$  will decrease.

When  $\mu$  is less than  $\lambda$  ( $\lambda = 10.25 > \mu = 5, \dots, 10.125$ ), a great decrease in the value of  $W_q$  and  $L_q$  can be seen.

When  $\mu$  is greater than  $\lambda$  ( $\lambda = 10.25 < \mu = 11, \dots, 18$ ), a slight decrease in the value of  $W_q$  and  $L_q$  can be seen.

## Chapter Five

### Conclusions and Recommendations

#### 5.1 Conclusions

Process simulation in spreadsheet is an easy task and has many benefits, so SimQuick is used in this thesis which is a computer package for process simulation that is easy to learn and inexpensive.

Results in table (3.5.1) show a good agreement between queuing theory (analytical solution) and simulation by SimQuick, so SimQuick can be applied for our study and for many real- world applications of queuing systems .

The crossing check-point at Beit-eba may have any form of the models 1, 2 or 3 indicated earlier in Figures (4.1.a), (4.1.b) and (4.1.c). The best model among the three is the one with the least average waiting time, where Model 1 resembles the actual crossing check-point, Model 2 and Model 3 are two alternative assumed models.

Using SimQuick, we found that the best model among the three models is Model 2 using the ratios 20%, 40%, 60%,70% and 80% of  $\lambda$  and  $\mu$  from the table(Annex A), see Table 4.4.a, Table 4.4.b, Table 4.4.e, Table 4.4.f, and Table 4.4.g . In case of 0% and 100% ratios no conclusion can be made, see Table 4.4.c and Table 4.4.d. These ratios are not realistic and do not compromise our conclusion. Hence, Model 2 is the model that should be applied in reality.

Both of multiple-channel queues and single-channel queue have advantages and disadvantages. But the computed results in Table 4.5 show that the

single-channel queue is more efficient than the multiple-channel queue using the collected data at Beit-eba crossing check-point, that is the average waiting time for the single channel-queue is less than the average waiting time for the multiple channel-queues.

We verified that changing  $\lambda$  increasingly and fixing  $\mu$  to 10.125 will increase the waiting time in the queue and the length of the queue as shown in Figures (4.5.c) and (4.5.d).

And verified that changing  $\mu$  increasingly and fixing  $\lambda$  to 10.25 will decrease the waiting time in the queue and the length of the queue as shown in Figure (4.5.e).

## 5.2 Recommendations

Results of our study lead to many recommendations:

- The single-channel queue should be used instead of the multiple-channels queue.
- The simulation of queuing system should be applied to other real-world applications that has waiting lines as: People moving through a bank or post office, telephone calls moving through a call center, parts moving along an assembly line or through a batch process or a job shop ...etc.
- The study can be carried to another crossing check-point around Nablus City, Howara.

**References:**

**1. Discrete-Event Simulation: A First Course**, Steve Park, Larry Leemis, College of William and Mary.

World Web Page:

<http://www.google.com/search?hl=ar&q=discrete+event+simulation&lr>

Accessed date: 18/9/2007

**2. DISCRETE–EVENT SIMULATION OF QUEUING SYSTEMS**, Zhang Laifu Joel, Ng Wen Wei Jonathan Louis and Tay Seng Chuan, Anglo-Chinese School (Independent), 121 Dover Road, Singapore.

World Web Page:

<http://www.physics.nus.edu.sg/~phytaysc/articles/queue.pdf>. Accessed date: 4/8/2007

**3. Graphical Spreadsheet Simulation of Queues**, Armann Ingolfsson, School of Business, University of Alberta, Edmonton T6G2R6, Canada.

World Web Page:

<http://archive.itejournal.informs.org/Vol2No2/IngolfssonGrossman/index.php> . Accessed date: 2/10/2007

**4. Hartvigsen David, SIMQUICK: Process Simulation with Excel.** Second edition. Mendoza College of Business Administration, University of Notre Dame, New Jersey.

**5. Hospital Management Knowledge using Discrete Event Simulation**, Bain Christopher A., Raikundalia Getish K., Mehta Snehal,. World Web Page: <http://eprints.vu.edu.au/621/1/CRPITV68Bain.pdf>.

Accessed date: 13/4/2008

**6. M/M/1 Queuing System, World Web Page:**

[http://www.eventhelix.com/RealtimeMantra/CongestionControl/m\\_m\\_queueue.htm](http://www.eventhelix.com/RealtimeMantra/CongestionControl/m_m_queueue.htm). Accessed date:23/10/2008

**7. Modeling and Simulation, Rassul Ayani , professor,**

Royal Institute of Tecknology,Stockholm,Sweden.

**8. OR-Notes ,Beasley J E., World Web Page:**

<http://people.brunel.ac.uk/~mastjjb/jeb/or/contents.htm>.

Accessed date: 3/7/2007

**9. Part II: Queuing & Simulation, Lawrence Stephen, Professor, Leeds school of Business, University of Colorado-Boulder.**

**10. Process Simulation in Excel for a Quantitative Management**

**Course** Raymond R. Hill, Department of Operational Sciences, Air Force Institute of Technology Wright-Patterson. World Web Page:

<http://archive.itejournal.informs.org/Vol2No3/Hill/Hill.pdf>

Accessed date: 28/11/2007

**11. Queuing Networks, Lecture Notes. Muhammad El-Taha, Department of Mathematics and Statistics, University of Southern Main, Portland.**

[http://www.usm.maine.edu/~eltaha/root\\_queue\\_07.pdf](http://www.usm.maine.edu/~eltaha/root_queue_07.pdf).

Accessed date: 7/4/2008

**12. Robinson, S, Discrete-event simulation: from the pioneers to the present, what next?, Journal of the Operational Research Society, Volume 56, Number 6, June 2005, pp. 619-629(11).**



**13. SPREADSHEET MODELING AND SIMULATION. IMPROVES**

**UNDERSTANDING OF QUEUES**, Thomas A., Grossman Jr., Faculty of Management, University of Calgary, Canada. World Web Page: <http://www.acs.ucalgary.ca/~grossman/ubiq.htm>. Accessed date: 3/9/2007

**14. Systems Simulation: The Shortest Route to Applications**, Professor

Hussein Arsham . World Web Page:

<http://ubmail.ubat.edu/~harsham/simulation/sim.htm>.

Accessed date: 2/5/2007

**15. Taha Hamdy A, (2003), Operations research: An Introduction,**

Programming (Mathimatics), An-Najah National University, Nablus, Palestine.

**16. Wikipedia, The Free Encyclopedia, World Web Page:**

[http://en.wikipedia.org/wiki/computer\\_simulation](http://en.wikipedia.org/wiki/computer_simulation).

Accessed date:14/5/2007

**17. Wikipedia, The Free Encyclopedia, World Web Page:**

[http://en.wikipedia.org/wiki/Monte Carlo method](http://en.wikipedia.org/wiki/Monte_Carlo_method). (3/1/2009)

**Annexes**

## Annex A :

الخميس 13/3/2008			الأربعاء 12/3/2008			الثلاثاء 11/3/2008			الاثنين 10/3/2008			الأحد 9/3/2008			السبت 8/3/2008						
μ	λ	λ	μ	λ	λ	μ	λ	λ	μ	λ	λ	μ	λ	λ	μ	λ	λ				
46	41	300	220	57	54	311	299	269	56	61	230	224	39	43	307	349	70	52	41	108	7:30-7:45
49	52	155	153	35	42	195	177	186	36	38	111	96	54	35	307	244	43	55	96	65	7:45-8:00
41	34	173	183	40	45	158	190	182	64	68	123	160	40	59	326	303	47	50	98	116	8:00-8:15
28	36	160	164	31	39	218	183	192	42	57	106	94	45	61	214	186	41	49	136	127	8:15-8:30
53	56	202	214	23	71	193	145	139	46	56	98	105	59	28	242	243	43	56	147	128	8:30-8:45
53	48	150	173	40	59	141	128	140	46	59	149	113	26	45	223	317	51	45	103	118	8:45-9:00
31	39	172	103	36	33	105	81	146	43	46	142	107	57	39	226	187	47	35	131	106	9:00-9:15
41	32	144	109	59	55	100	86	163	42	46	101	98	50	47	271	170	61	50	145	135	9:15-9:30
71	168	30	59	94	113	26	25	43	121	120	28	35	119	198	19	23	73	61	37	42	1:45-2:00
163	277	41	38	115	116	22	40	195	106	107	27	26	102	146	34	19	81	90	63	61	2:00-2:15
199	207	31	25	104	124	43	52	25	68	136	36	47	149	101	31	46	47	56	55	43	2:15-2:30
198	139	39	42	99	111	20	15	36	109	145	40	37	193	198	48	24	75	72	42	59	2:30-2:45
179	186	37	33	127	122	24	25	45	140	207	52	41	206	228	23	25	88	74	36	37	2:45-3:00
164	291	66	76	115	103	31	34	34	148	148	30	25	184	136	36	13	70	61	30	41	3:00-3:15
214	269	41	39	122	184	39	30	43	134	136	38	41	200	104	14	32	76	50	37	55	3:15-3:30
257	147	41	59	136	141	39	41	41	98	101	28	34	148	159	32	47	71	72	71	32	3:30-3:45

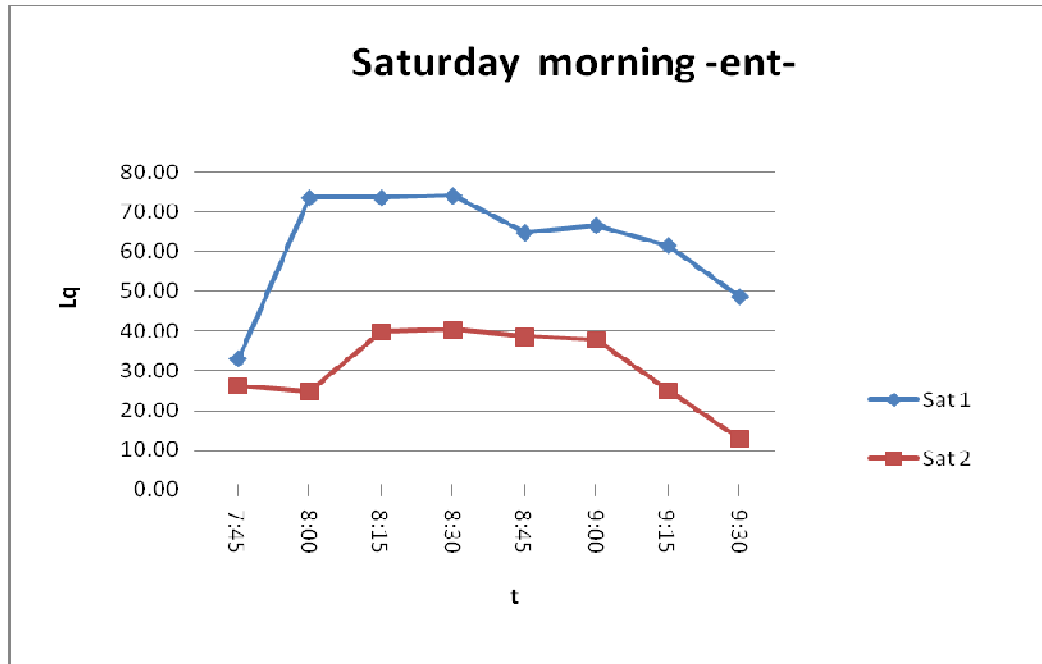
## Annex B:

الخميس 28/2/2008				الأربعاء 27/2/2008				الثلاثاء 26/2/2008				الاثنين 25/2/2008				الأحد 24/2/2008				السبت 23/2/2008				
μ	λ	μ	λ	μ	λ	μ	λ	μ	λ	μ	λ	μ	λ	μ	λ	μ	λ	μ	λ	μ	λ	μ	λ	
54	50	241	219	64	52	229	198	41	38	173	177	36	62	246	271	53	59	241	250	29	48	36	19	7:30-7:45
34	39	160	130	48	40	233	201	35	43	139	115	25	27	236	175	61	70	239	198	45	18	52	64	7:45-8:00
32	27	105	141	24	47	141	131	29	34	139	160	43	18	135	131	48	52	192	214	46	28	69	81	8:00-8:15
36	40	268	251	27	32	111	125	43	45	121	170	44	39	130	126	72	83	198	208	54	47	77	68	8:15-8:30
46	51	154	114	41	39	120	113	25	38	189	148	30	22	131	145	40	27	206	234	41	43	78	85	8:30-8:45
32	36	127	111	32	37	143	197	32	36	101	85	53	28	185	189	42	51	193	163	45	51	75	67	8:45-9:00
28	22	117	93	27	47	138	113	46	50	150	111	32	45	128	120	52	23	198	148	34	35	86	59	9:00-9:15
29	33	87	80	39	27	128	78	30	32	135	100	48	29	125	67	40	43	168	124	42	29	79	67	9:15-9:30
91	181	36	27					44	95	29	39	81	101	32	24	67	102	26	32	60	89	63	52	1:45-2:00
189	206	56	34					73	181	12	16	72	93	19	19	107	88	31	29	80	83	23	33	2:00-2:15
147	205	29	41					120	131	18	21	69	106	33	39	104	134	42	43	66	97	45	46	2:15-2:30
172	142	53	51					115	105	25	12	39	88	17	28	78	42	35	29	93	62	40	59	2:30-2:45
132	190	61	65					89	130	39	41	8	109	41	36	105	115	35	41	76	86	36	27	2:45-3:00
210	254	62	42					98	184	29	26	93	102	28	27	155	120	49	32	65	71	55	57	3:00-3:15
220	215	35	46					100	111	10	22	126	85	38	41	118	132	38	41	96	108	42	46	3:15-3:30
254	131	62	44					70	119	22	17	132	78	40	32	96	136	29	30	98	87	39	51	3:30-3:45

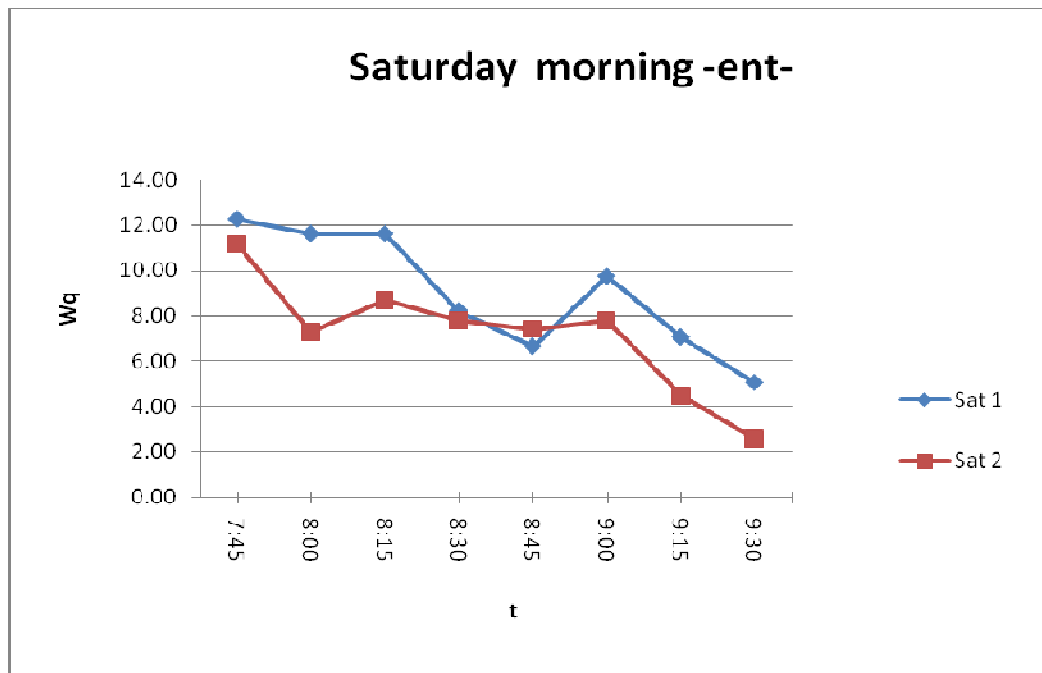
closed



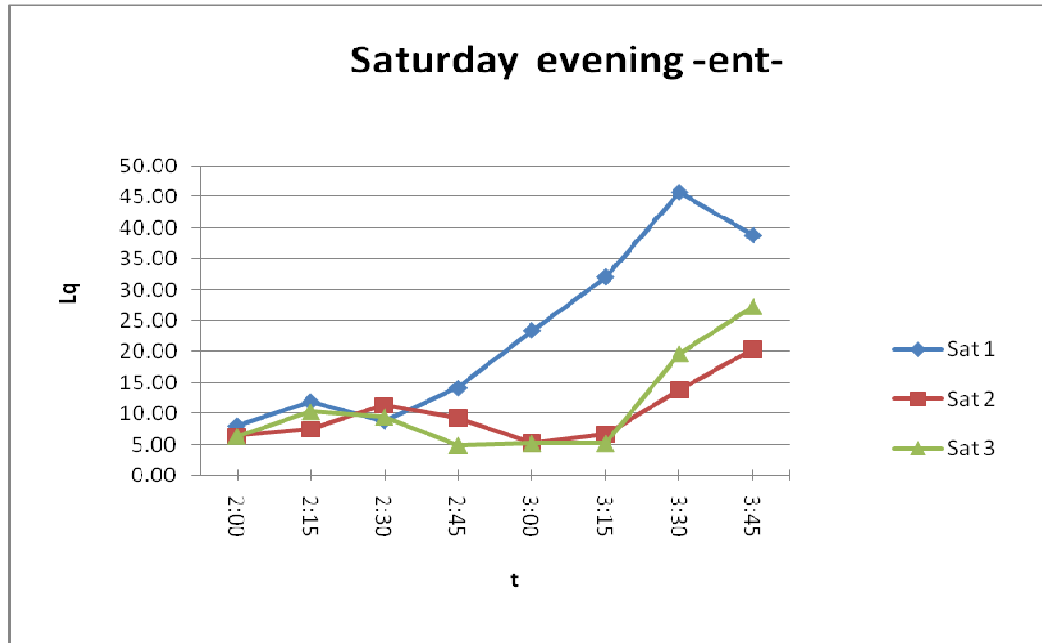
### Annex D: Simulation results for the whole collected data



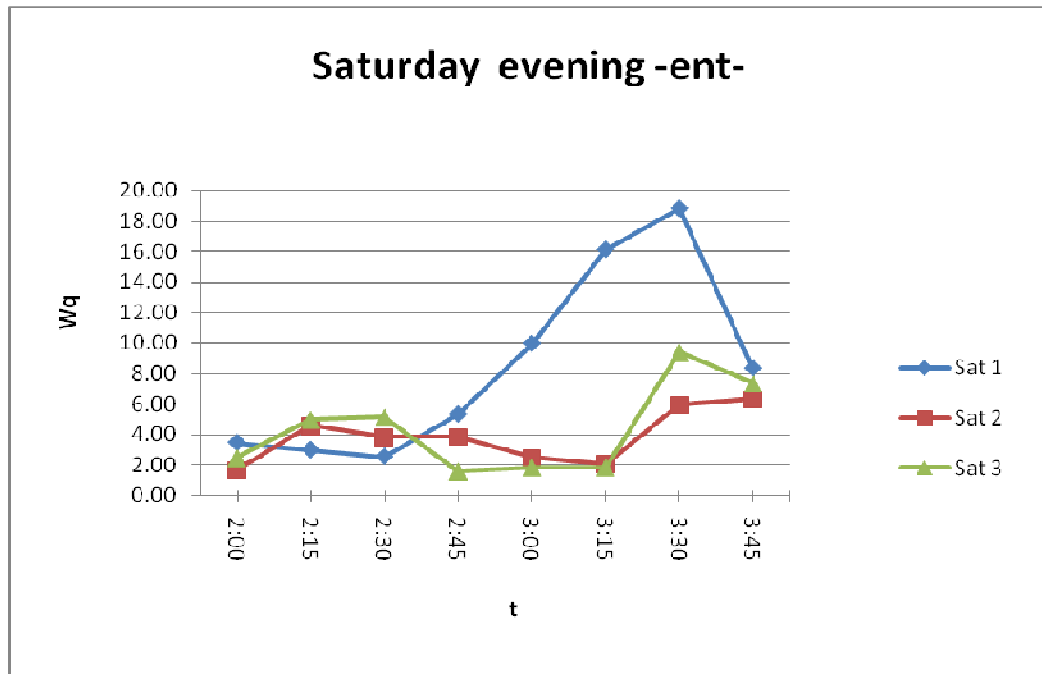
People arriving to Nablus on Saturday morning, length of the queue vs t



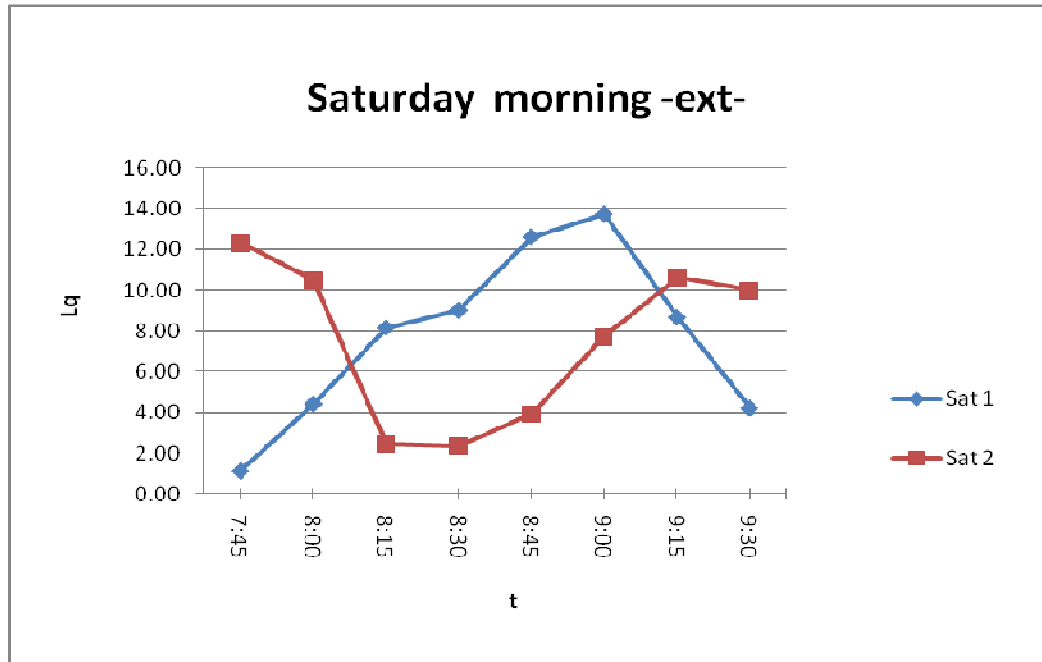
People arriving to Nablus on Saturday morning, waiting time in the queue vs t.



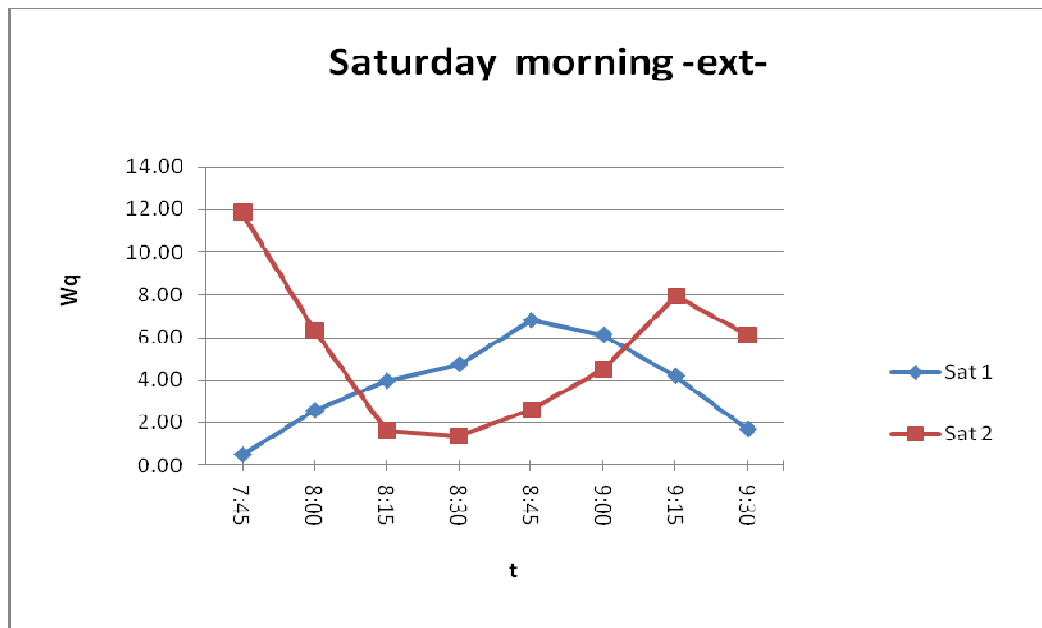
People arriving to Nablus on Saturday evening, the length of the queue vs t.



People arriving to Nablus on Saturday evening, waiting time in the queue vs t.

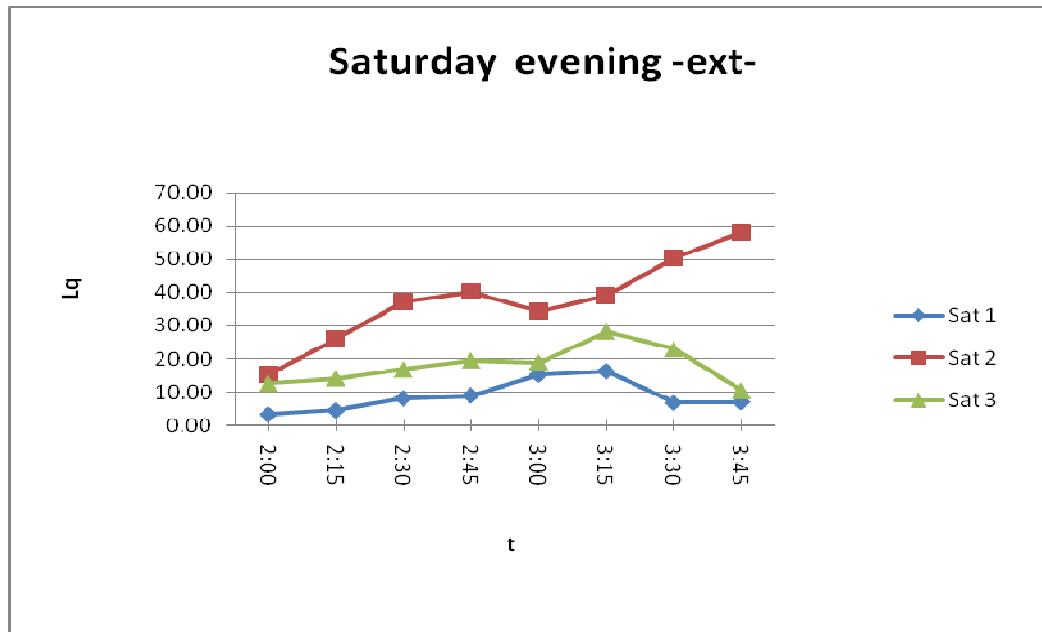


Women and men over forty departing Nablus on Saturday morning, length of the queue vs t.

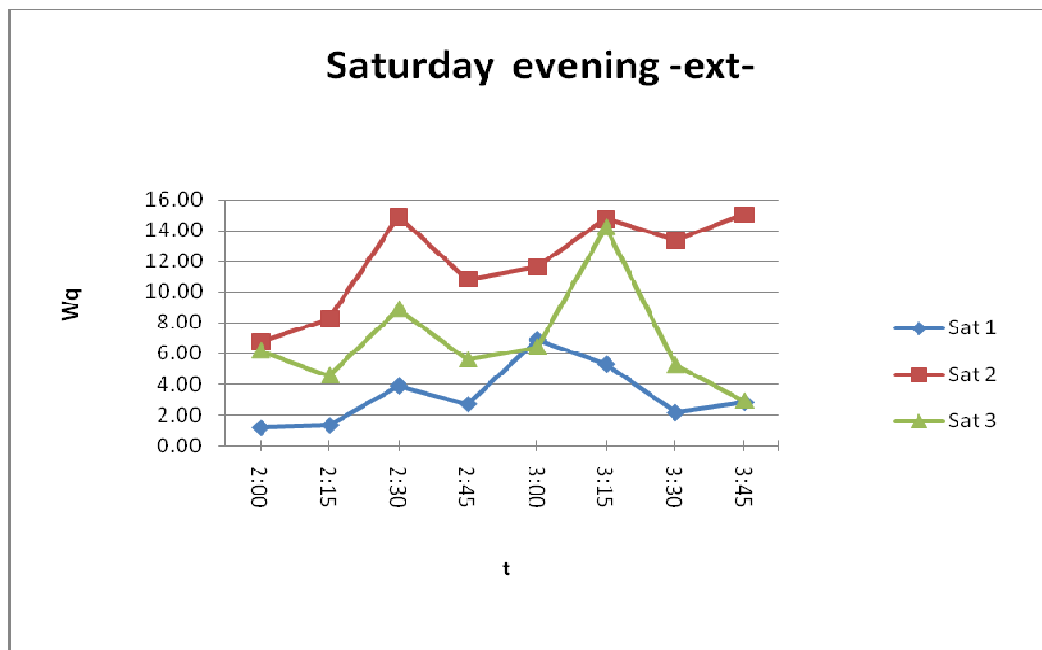


Women and men over forty departing Nablus on Saturday morning, waiting time in the queue vs t.

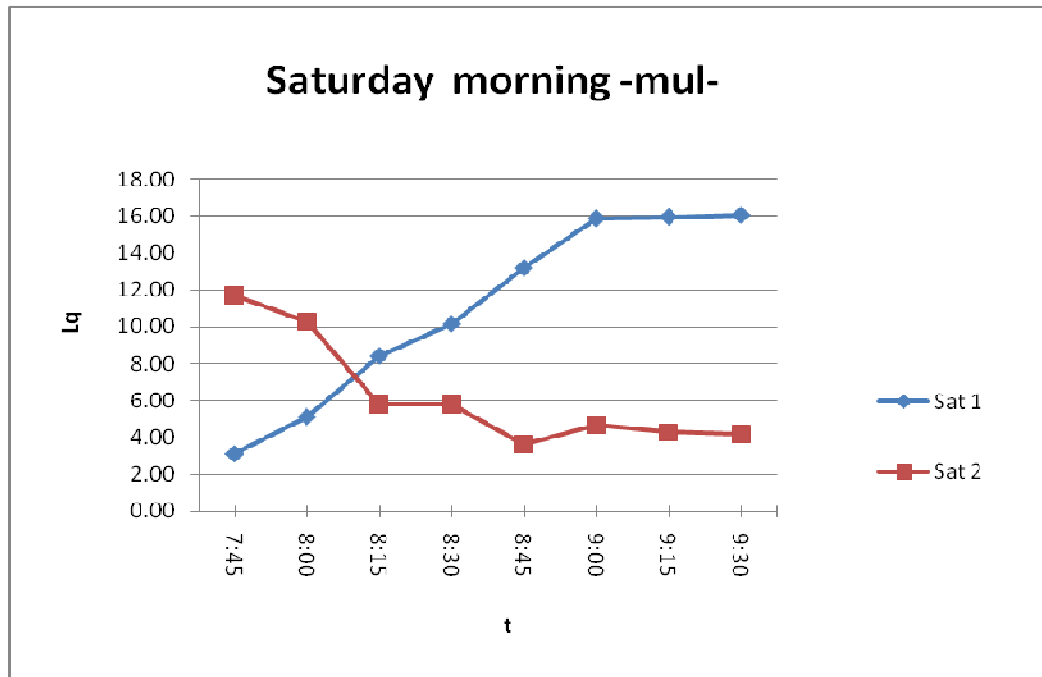




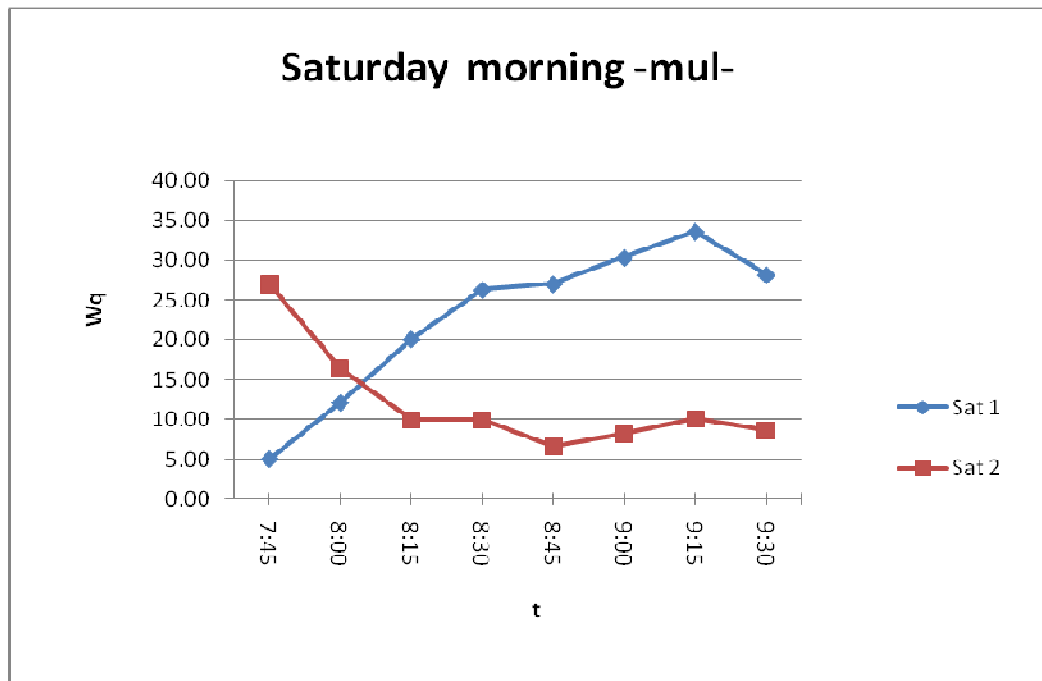
Women and men over forty departing Nablus on Saturday evening, the length of the queue vs t.



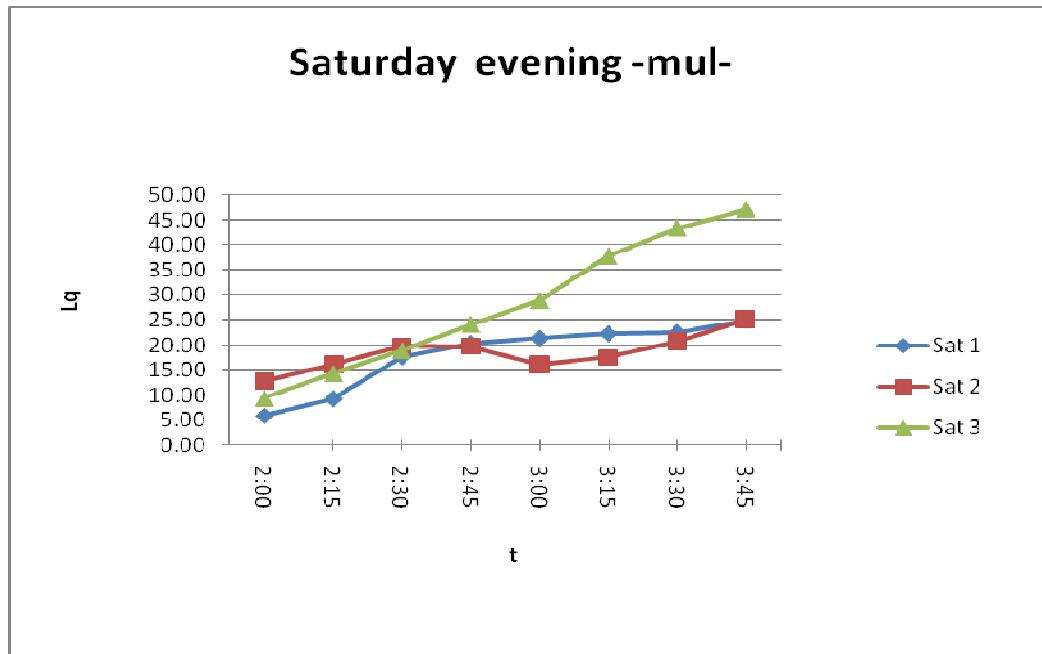
Women and men over forty departing Nablus on Saturday evening, waiting time in the queue vs t.



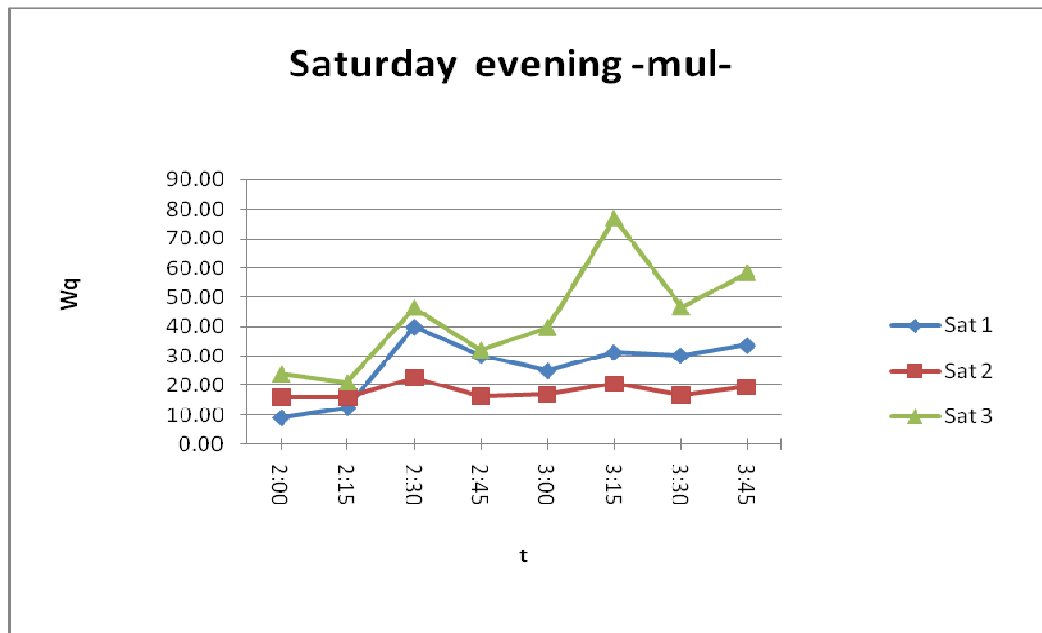
Men under forty departing Nablus on Saturday morning, the length of the queue vs t.



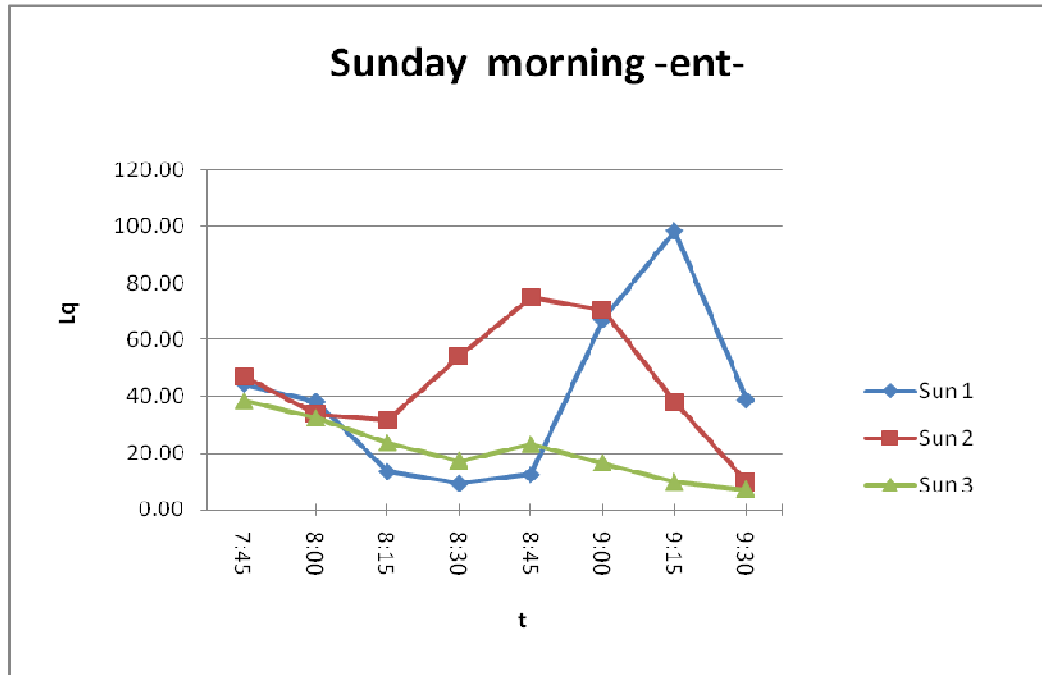
Men under forty departing Nablus on Saturday morning, waiting time in the queue vs t.



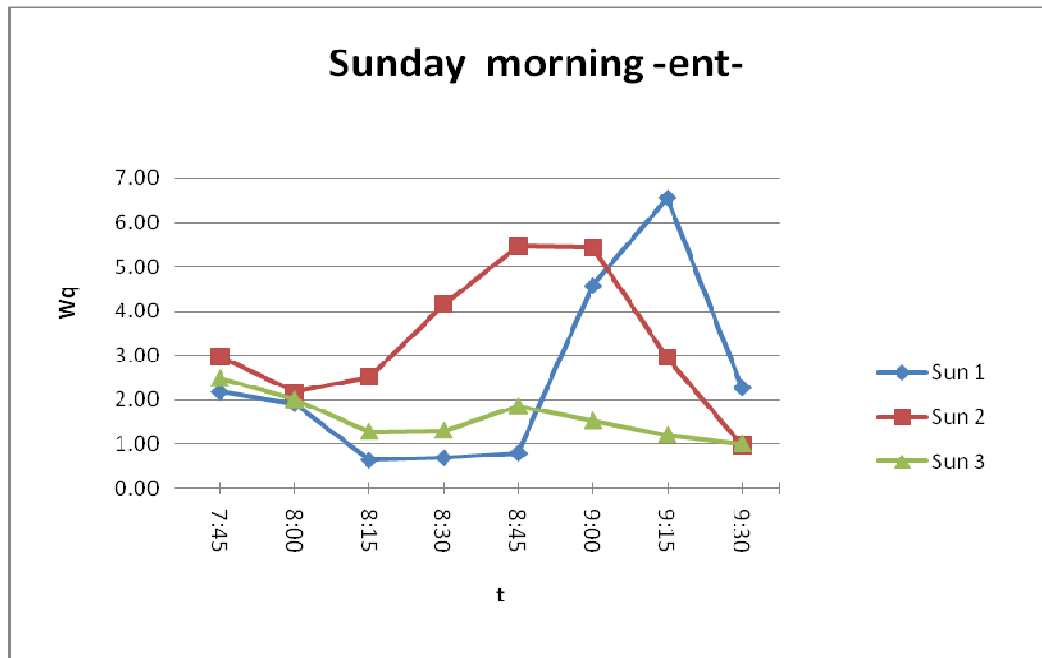
Men under forty departing Nablus on Saturday evening, the length of the queue vs t.



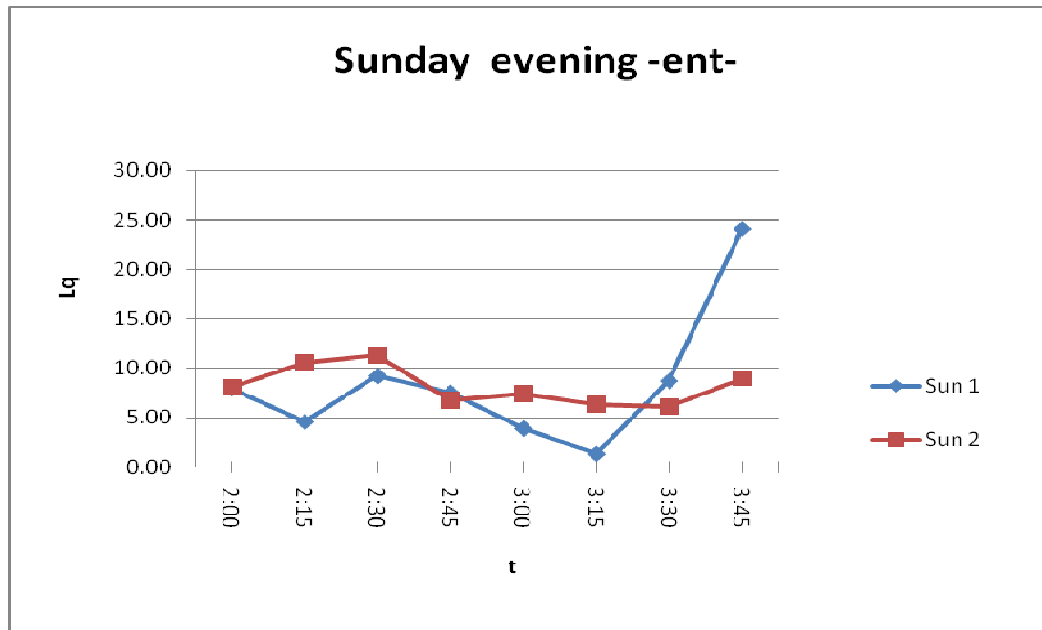
Men under forty departing Nablus on Saturday evening, waiting time in the queue vs t.



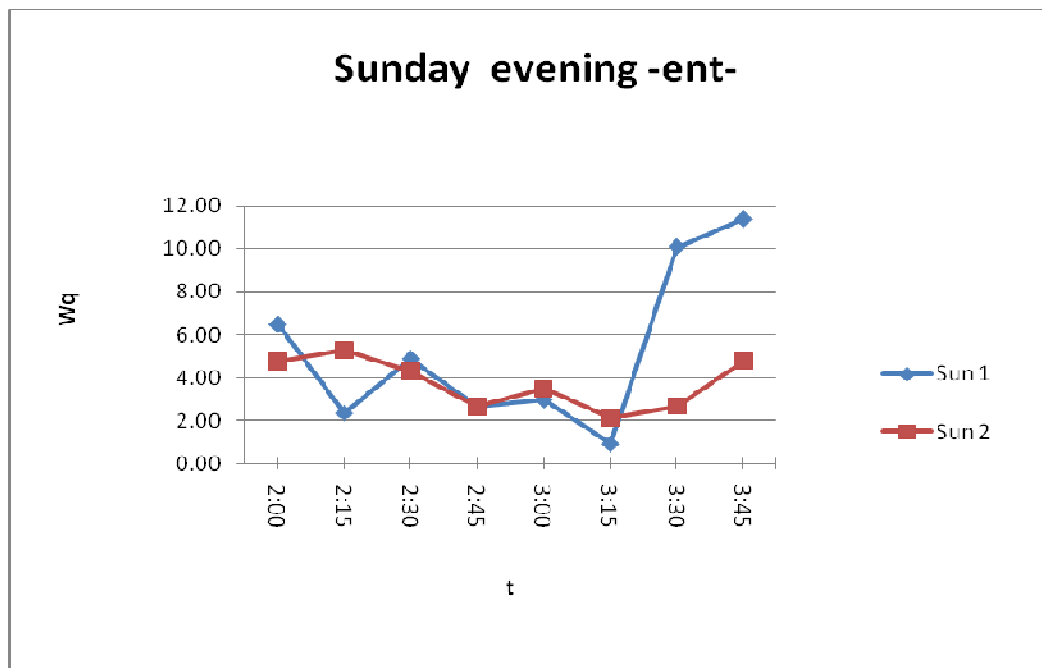
People arriving to Nablus on Sunday morning, the length of the queue vs t.



People arriving to Nablus on Sunday morning, the waiting time in the queue vs t.



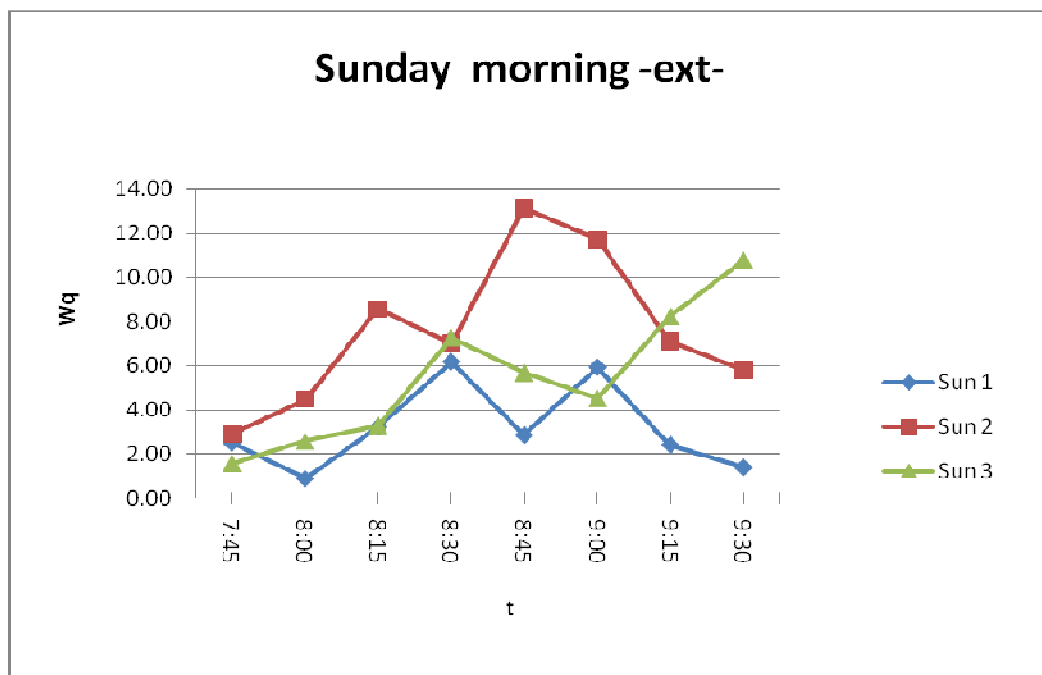
People arriving to Nablus on Sunday evening, the length of the queue vs t.



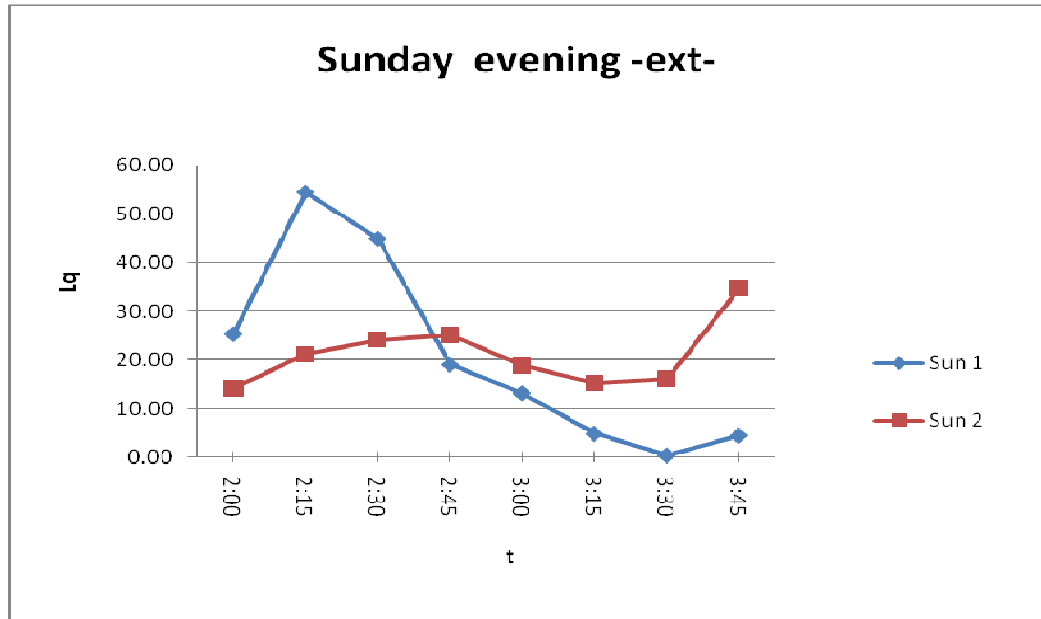
People arriving to Nablus on Sunday evening, waiting time in the queue vs t.



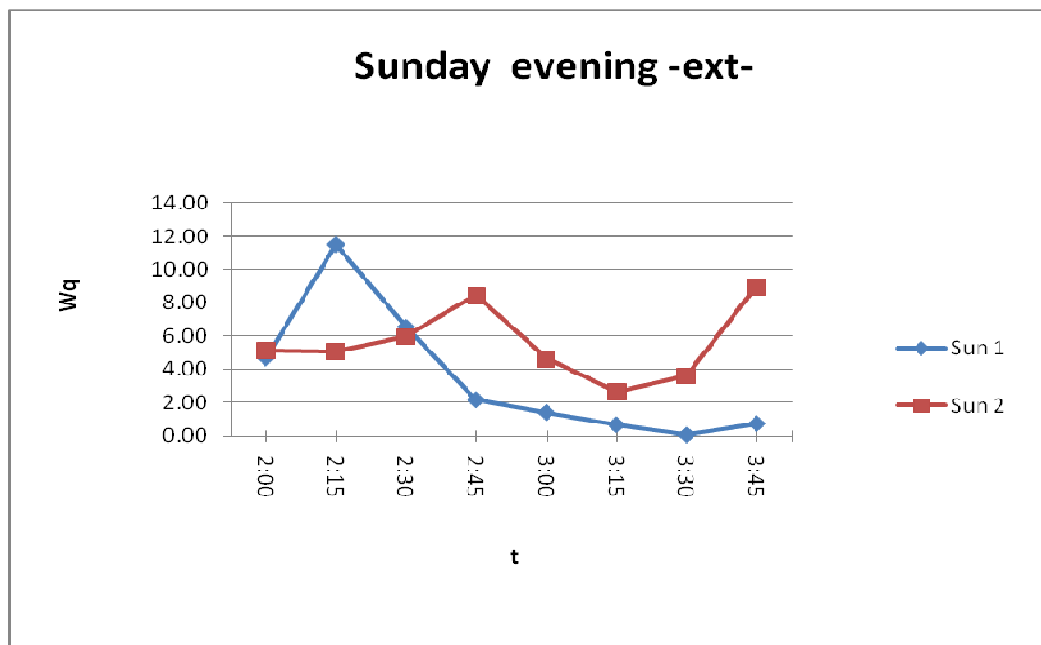
Women and men over forty departing Nablus on Sunday morning, the length of the queue vs t.



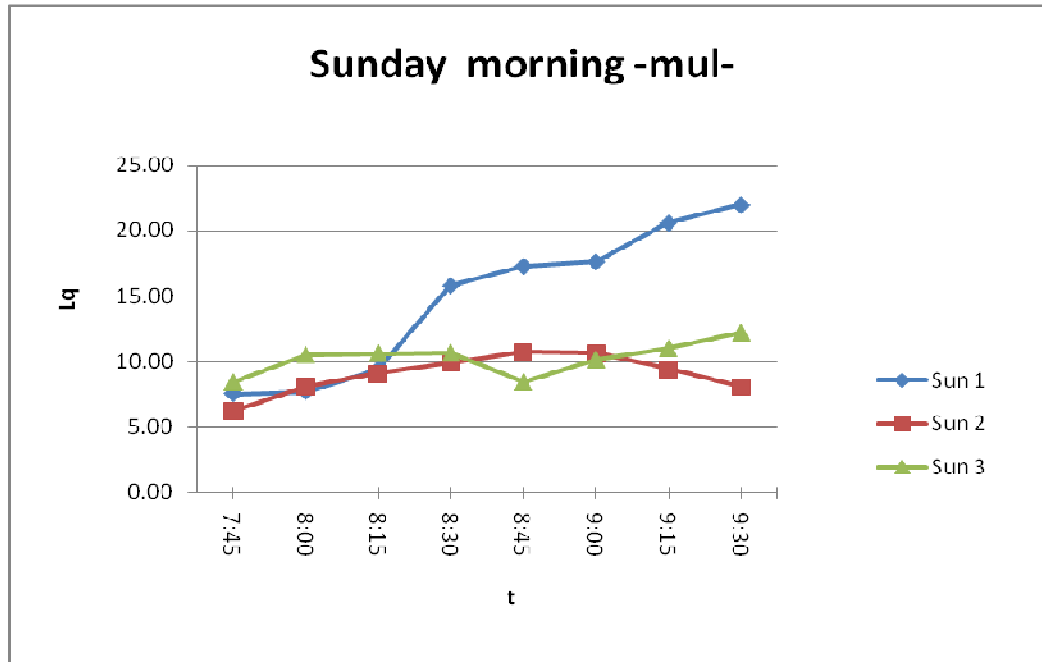
Women and men over forty departing Nablus on Sunday morning, waiting time in the queue vs t.



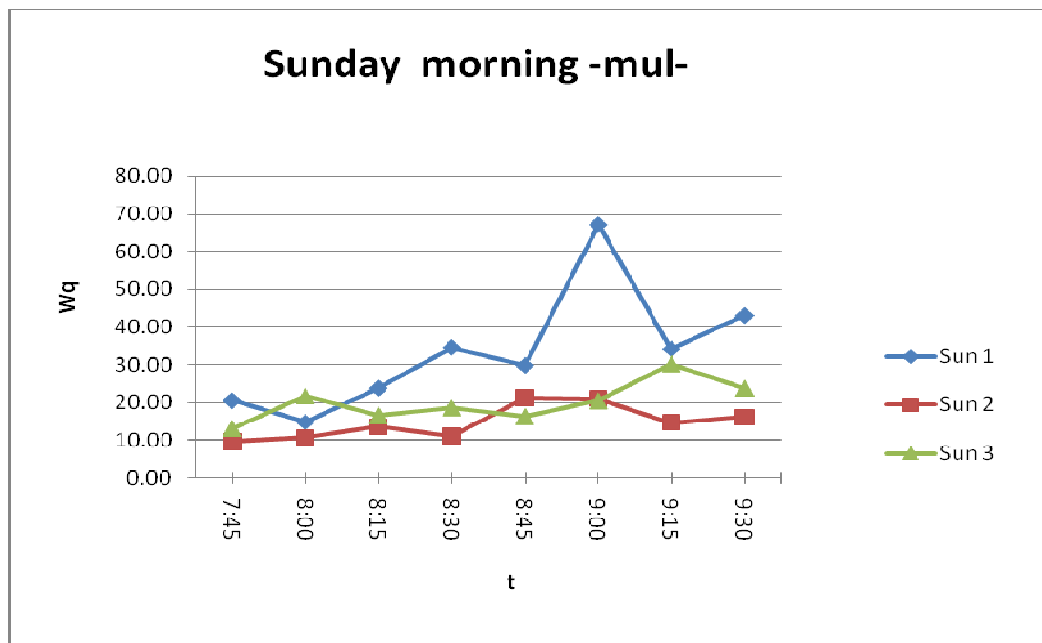
Women and men over forty departing Nablus on Sunday evening, the length of the queue vs t.



Women and men over forty departing Nablus on Sunday evening, the waiting time in the queue vs t.

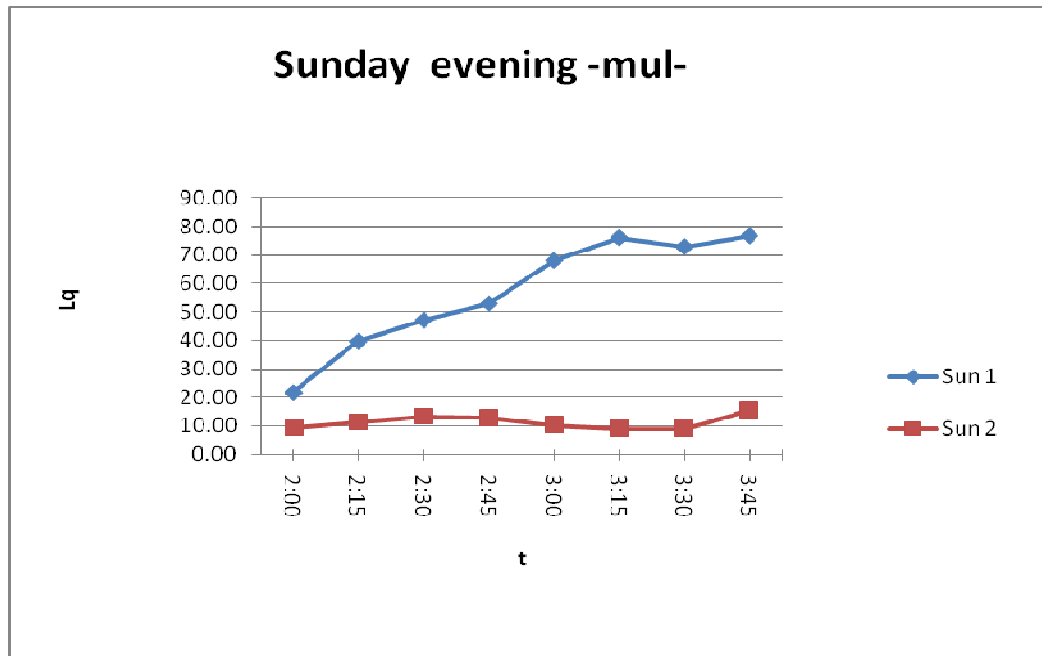


Men under forty departing Nablus on Sunday morning, the length of the queue vs t.

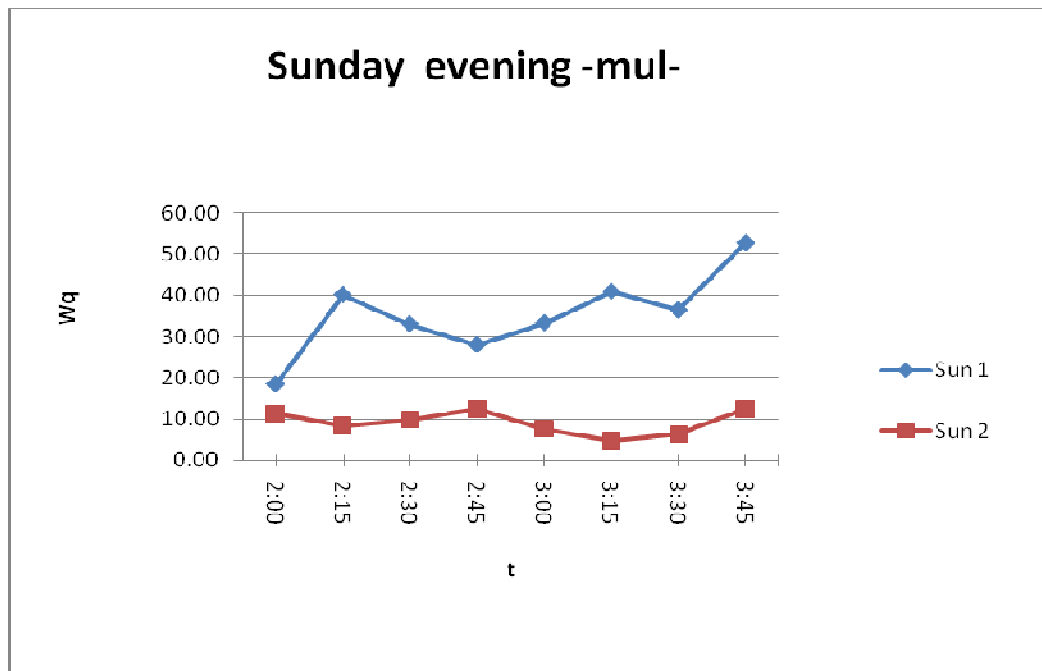


Men under forty departing Nablus on Sunday morning, waiting time in the queue vs t.

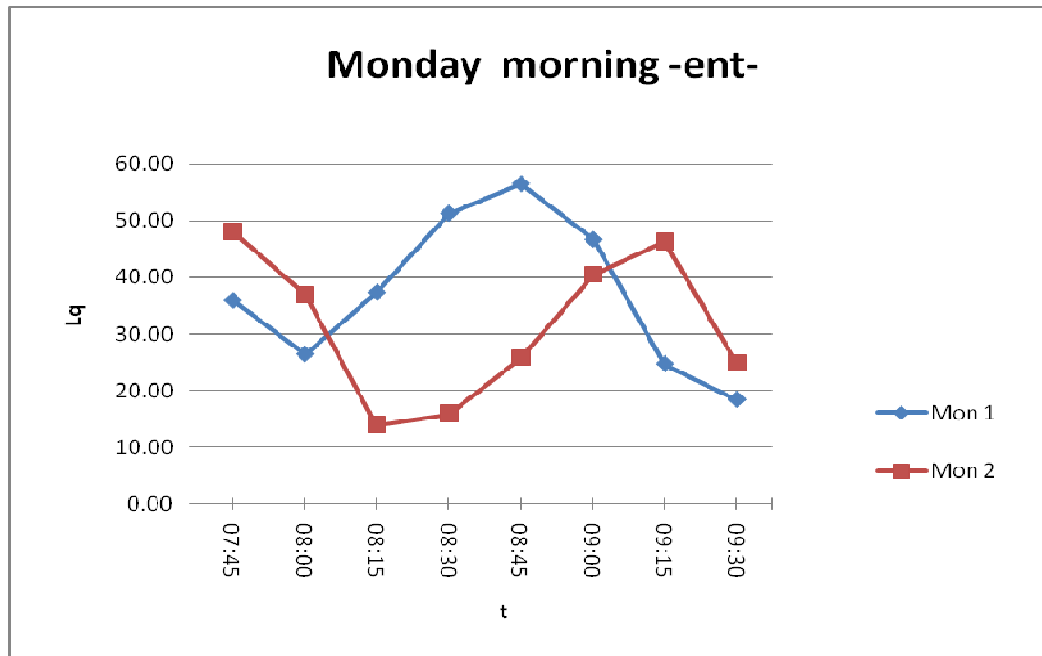




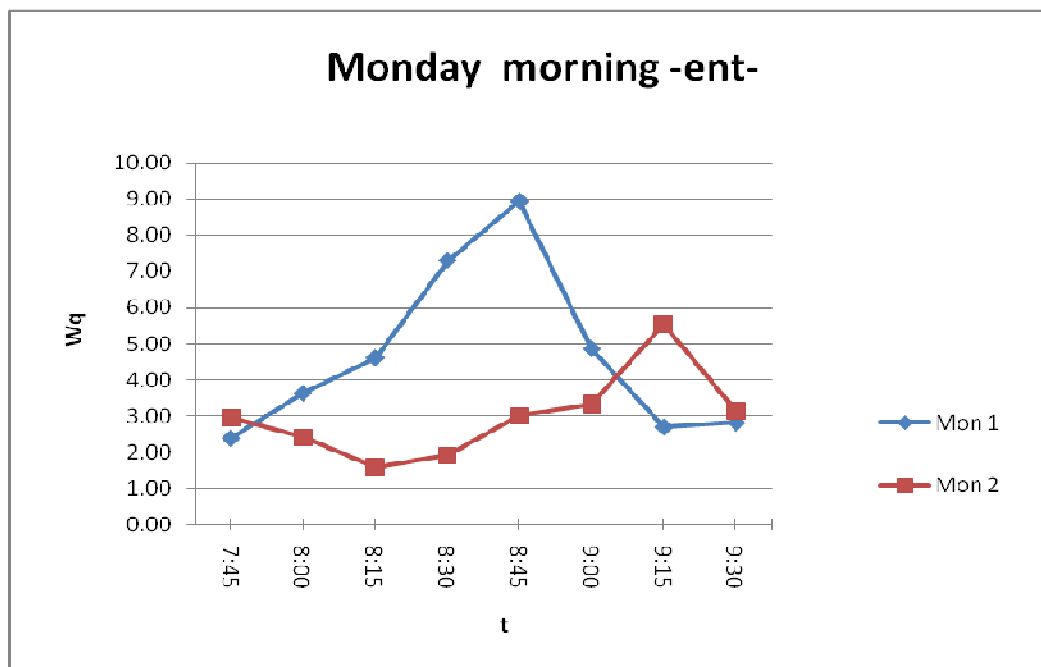
Men under forty departing Nablus on Sunday evening, the length of the queue vs t.



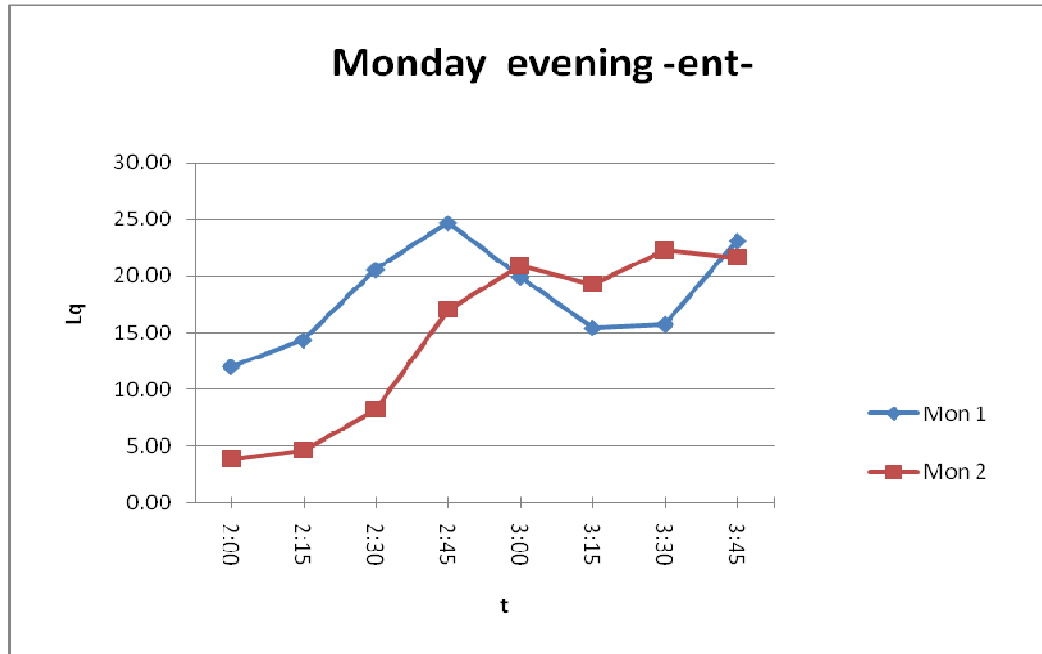
Men under forty departing Nablus on Sunday evening, waiting time in the queue vs t.



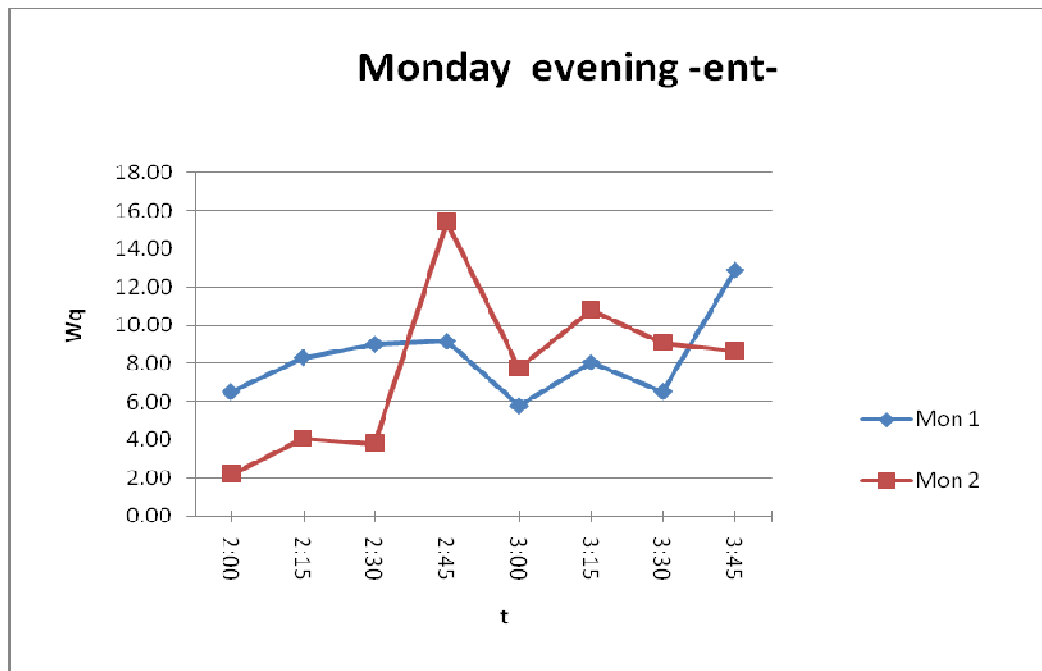
People arriving to Nablus on Monday morning, the length of the queue vs t.



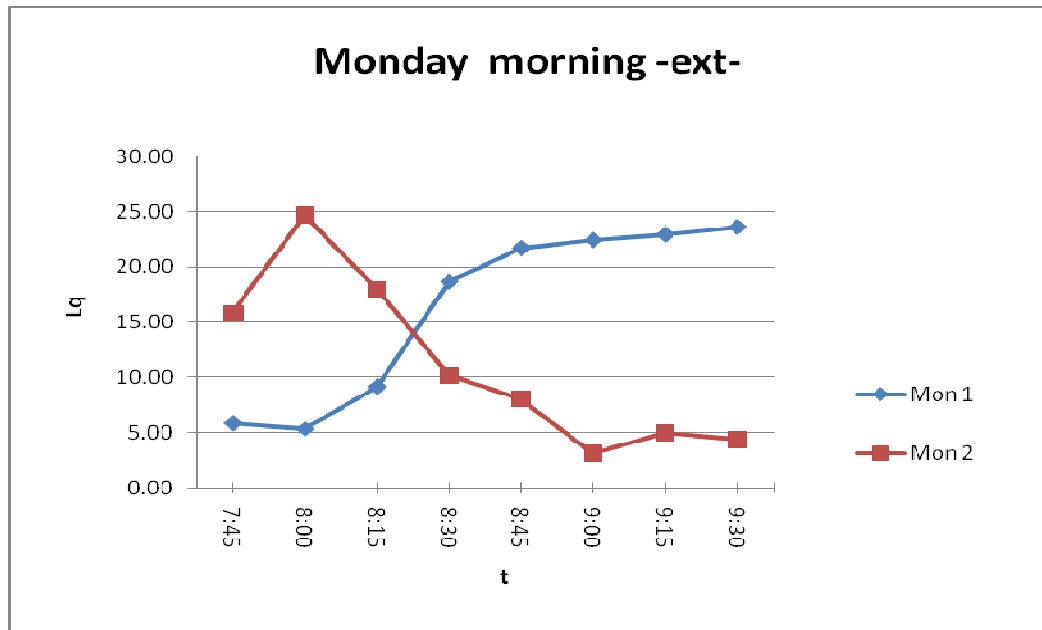
People arriving to Nablus on Monday morning, waiting time in the queue vs t.



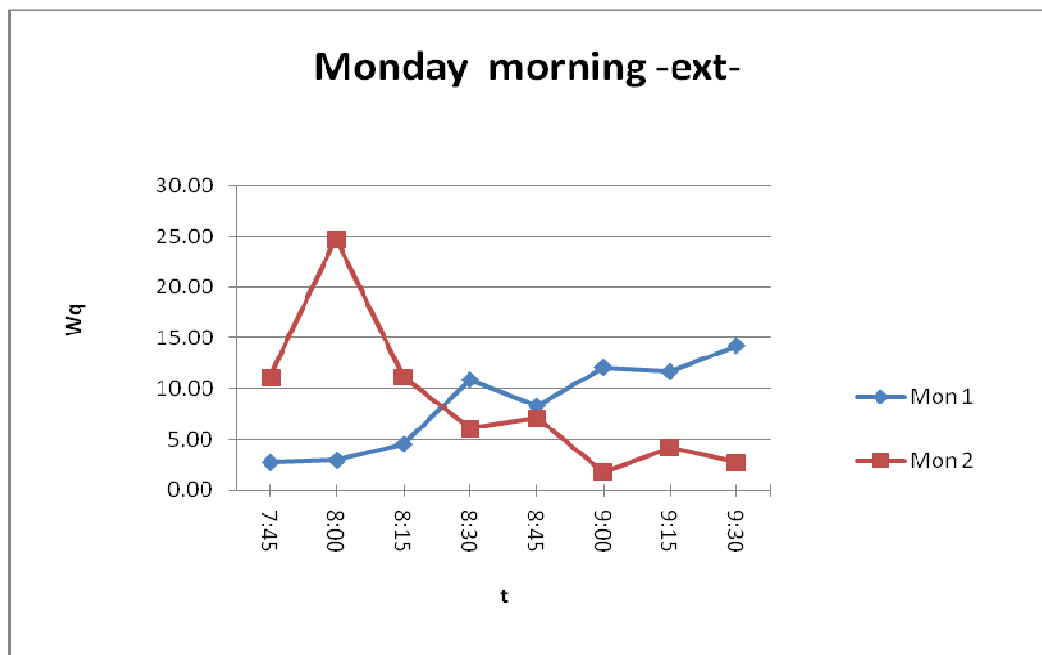
People arriving to Nablus on Monday evening, the length of the queue vs t



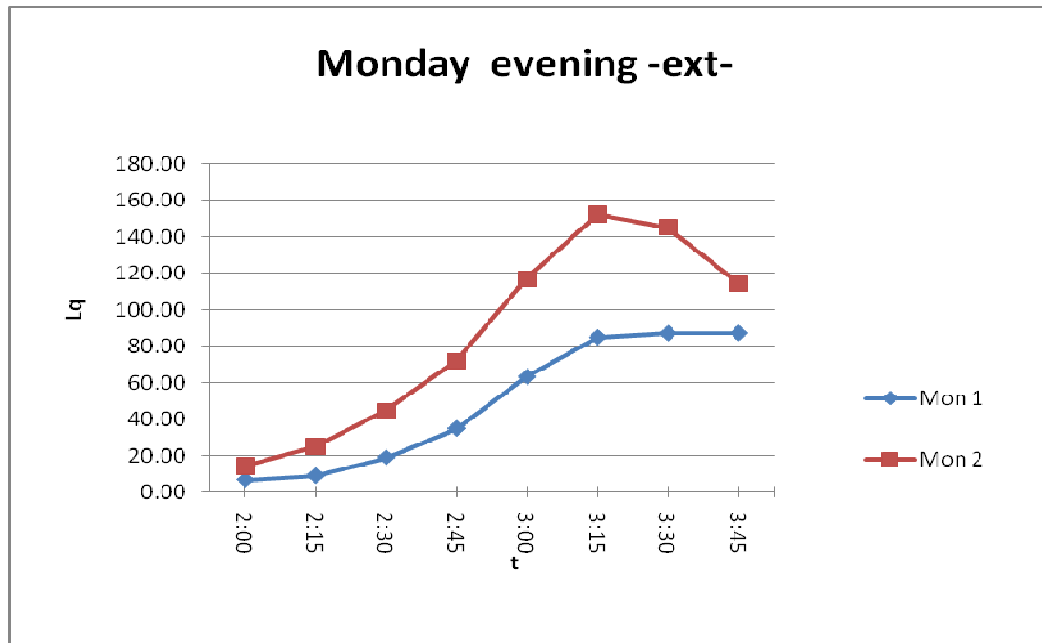
People arriving to Nablus on Monday evening, the waiting time in the queue vs t.



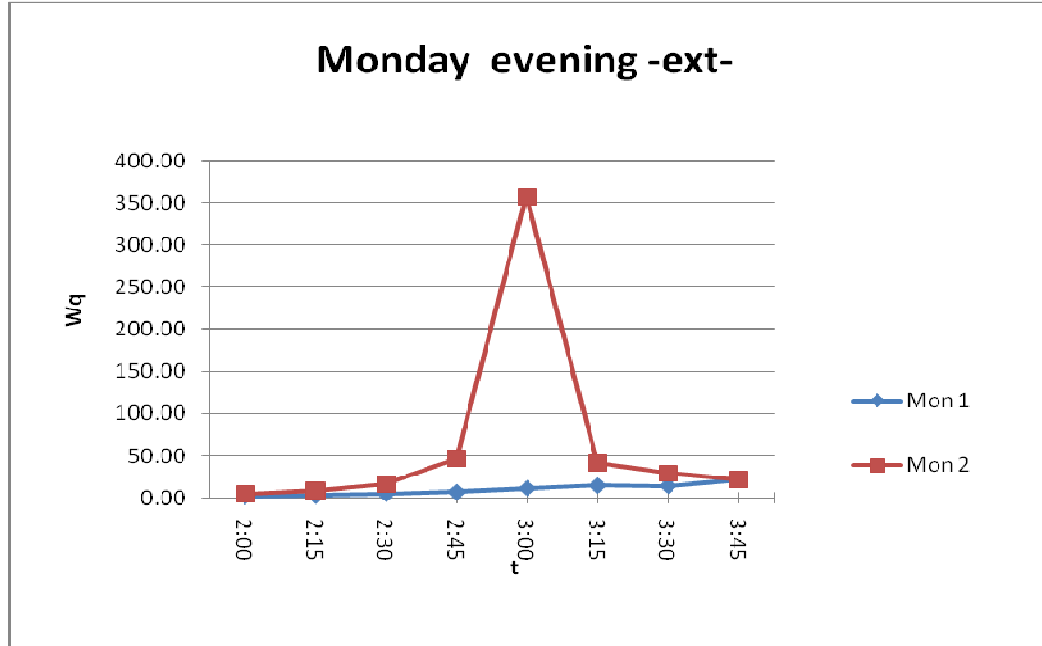
Women and men over forty departing on Monday morning, the length of the queue vs t.



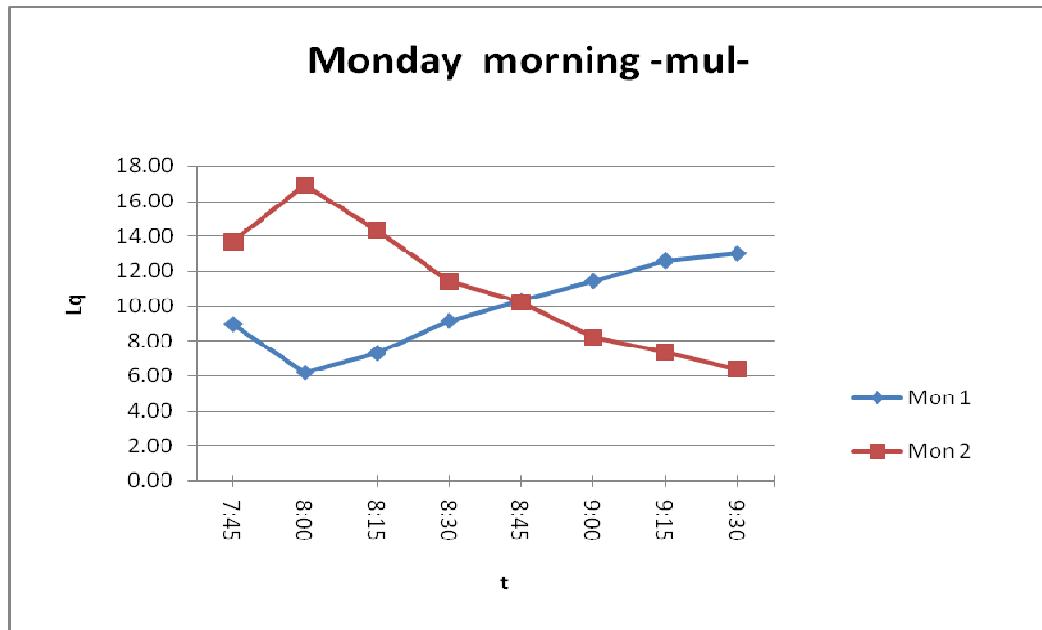
Women and men over forty departing on Monday morning, the waiting time in the queue vs t.



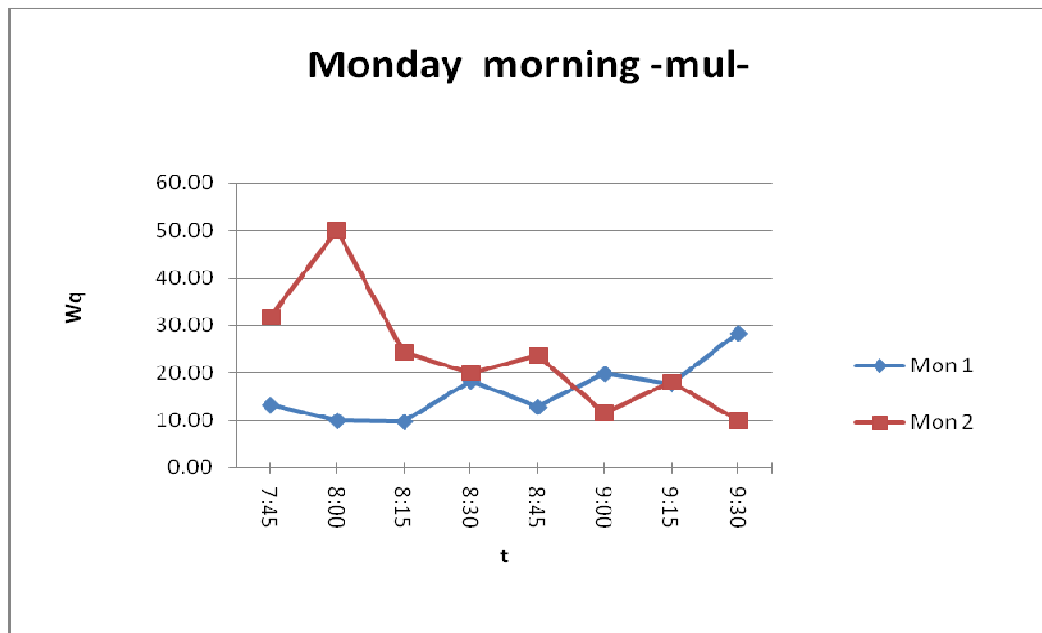
Women and men over forty departing on Monday evening, the length of the queue vs t.



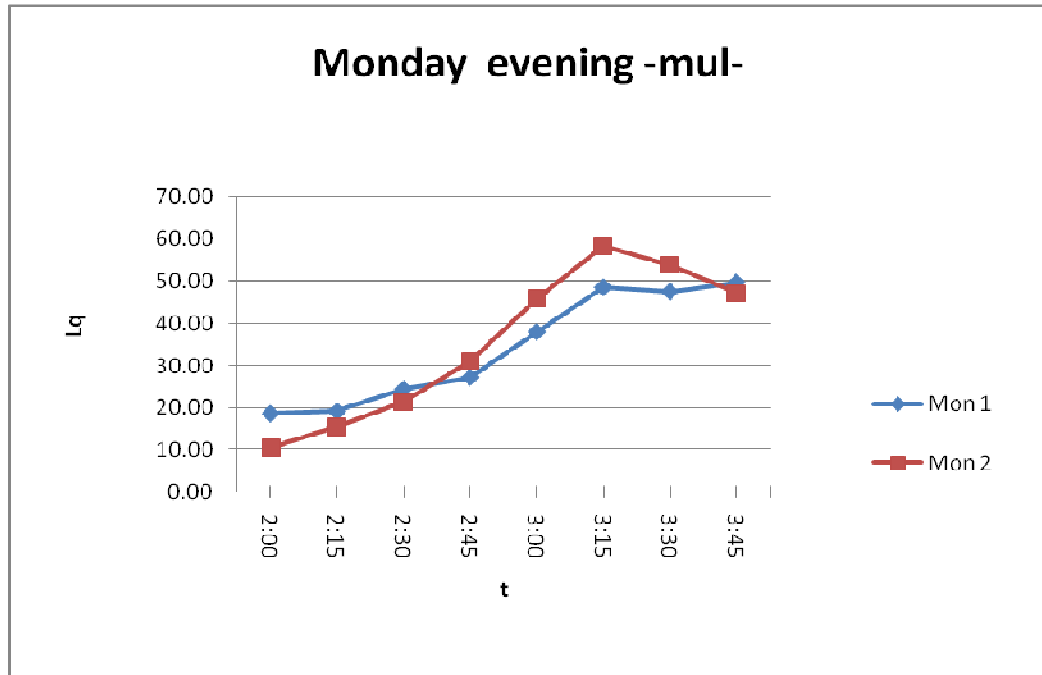
Women and men over forty departing on Monday evening, waiting time in the queue vs t.



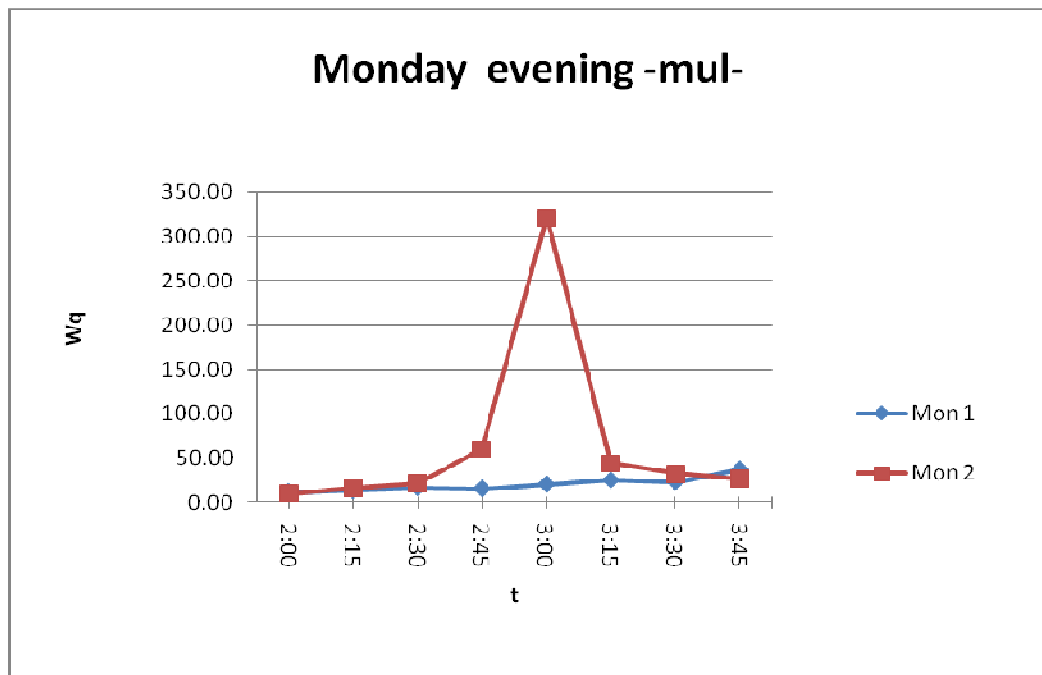
Men under forty departing on Monday morning, the length of the queue vs t.



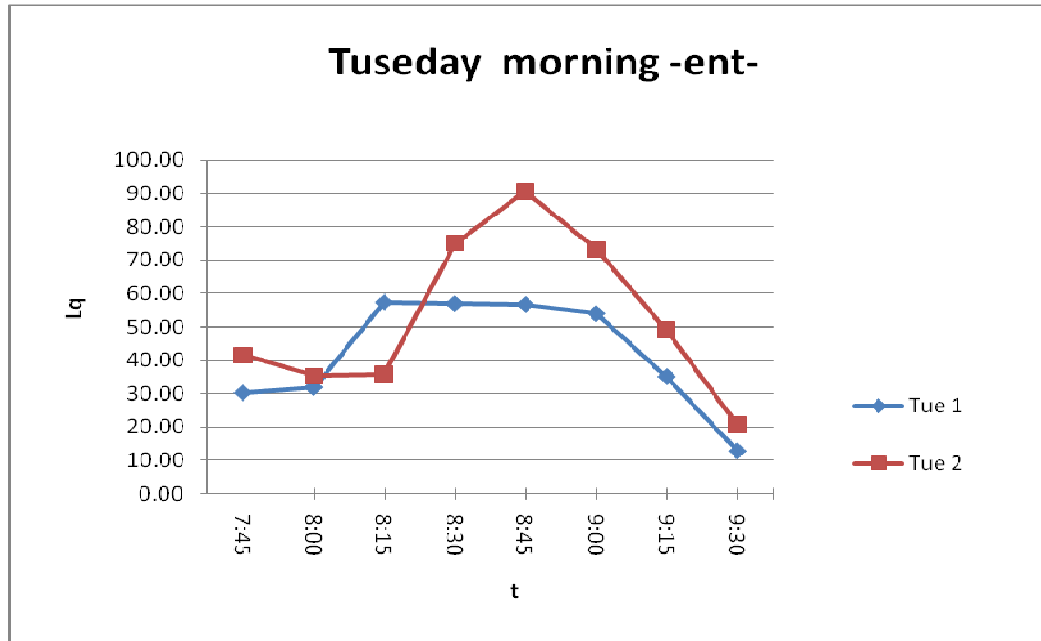
Men under forty departing on Monday morning, waiting time in the queue vs t.



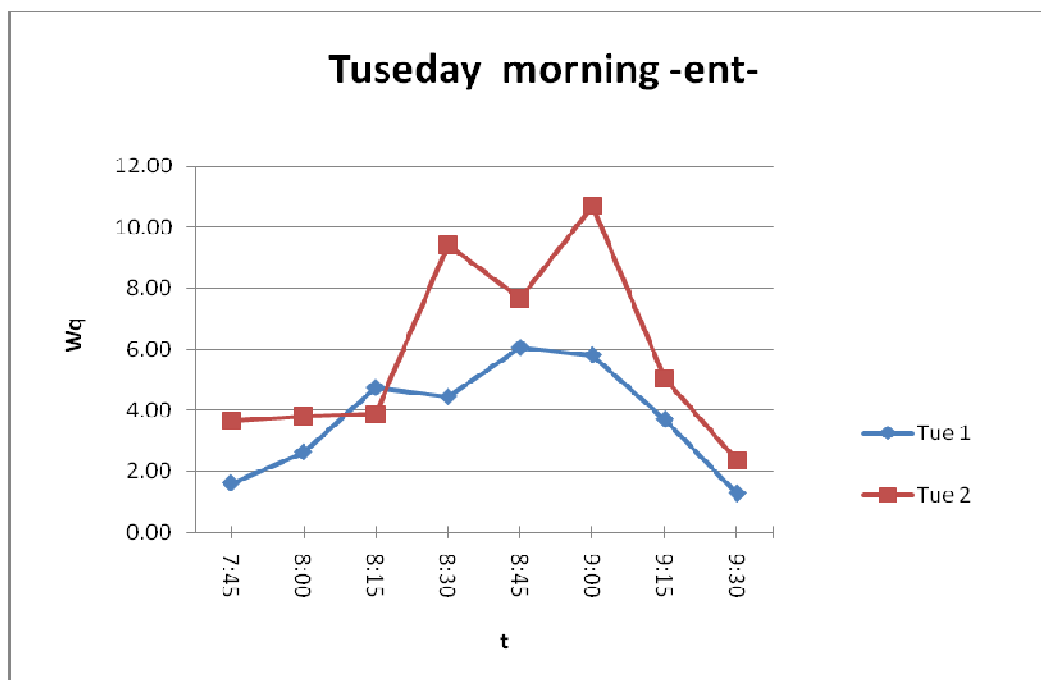
Men under forty departing on Monday evening, the length of the queue vs t.



Men under forty departing on Monday evening, waiting time in the queue vs t.

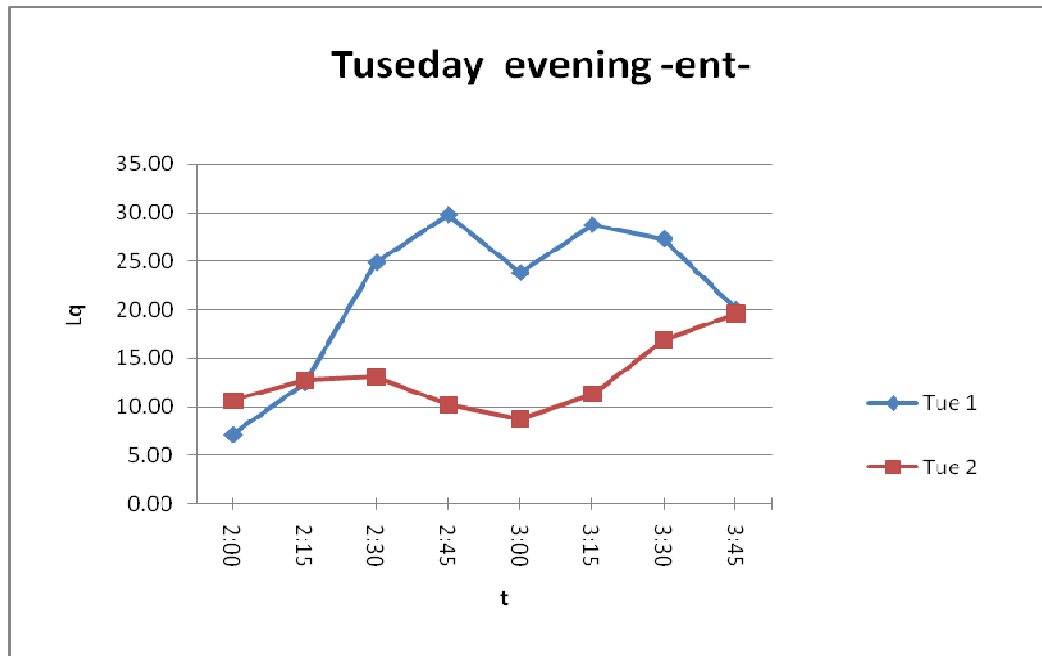


People arriving to Nablus on Tuseday morning, the length of the queue vs t.

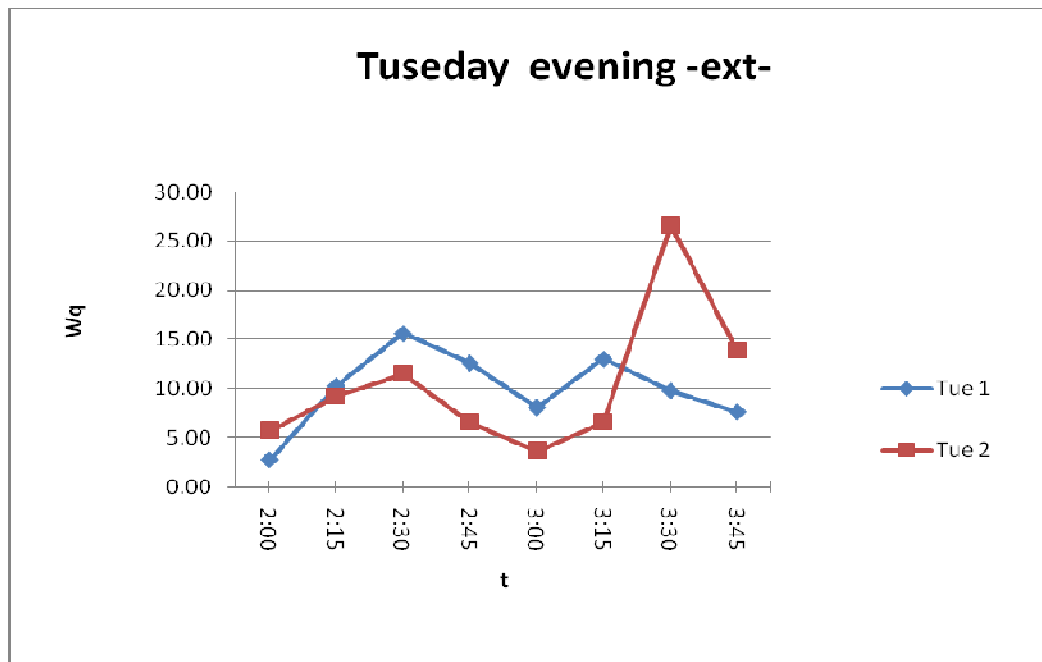


People arriving to Nablus on Tuseday morning, waiting time in the queue vs t.

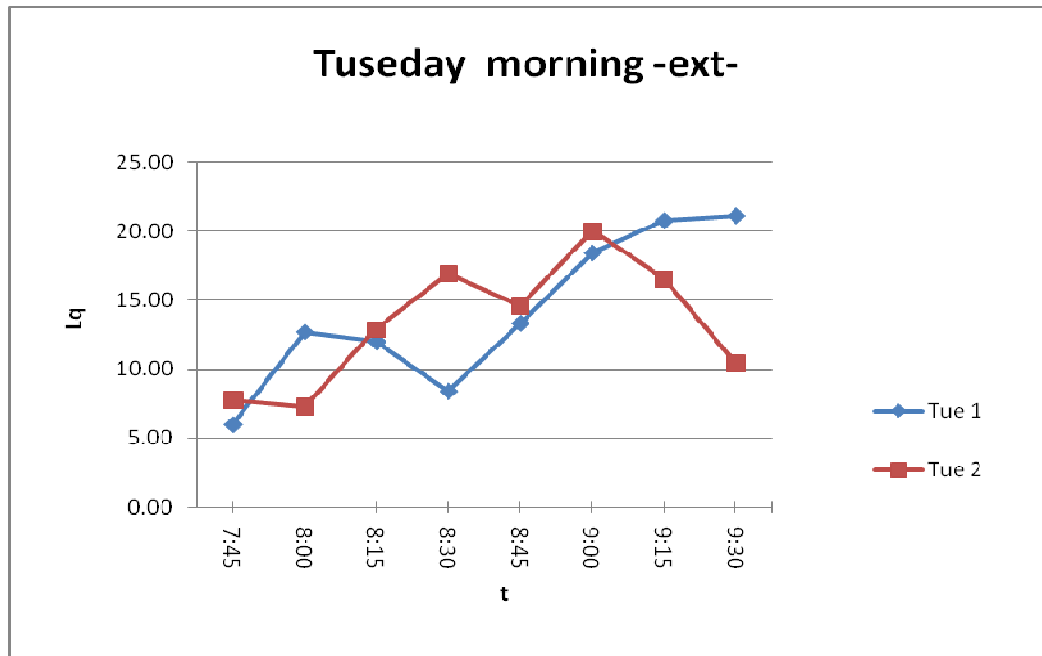




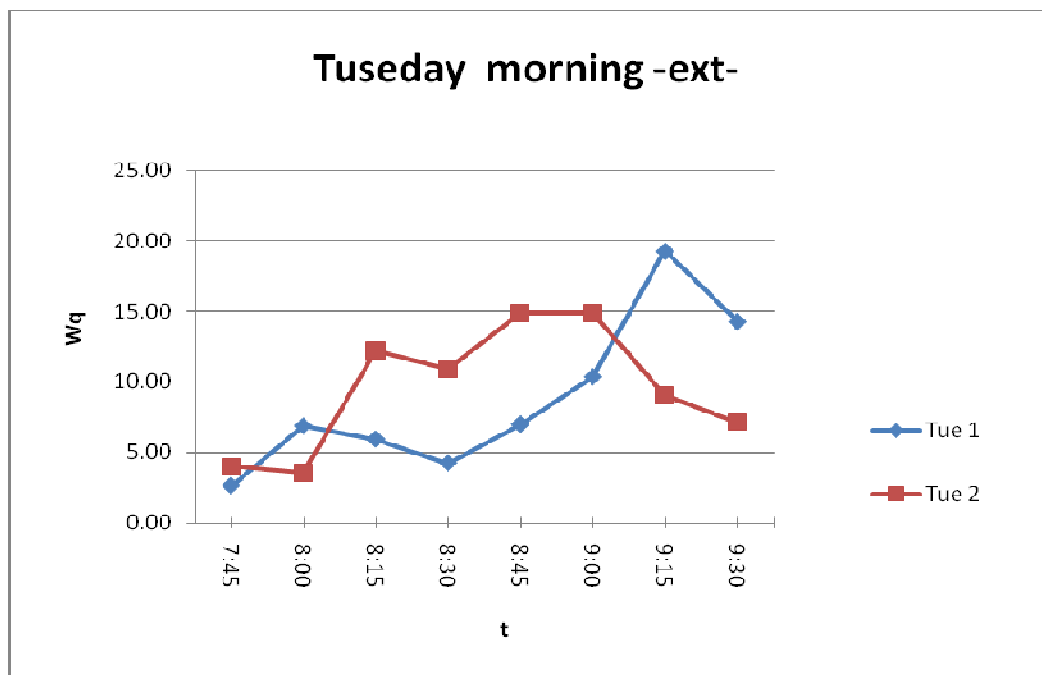
People arriving to Nablus on Tuseday evening, the length of the queue vs t.



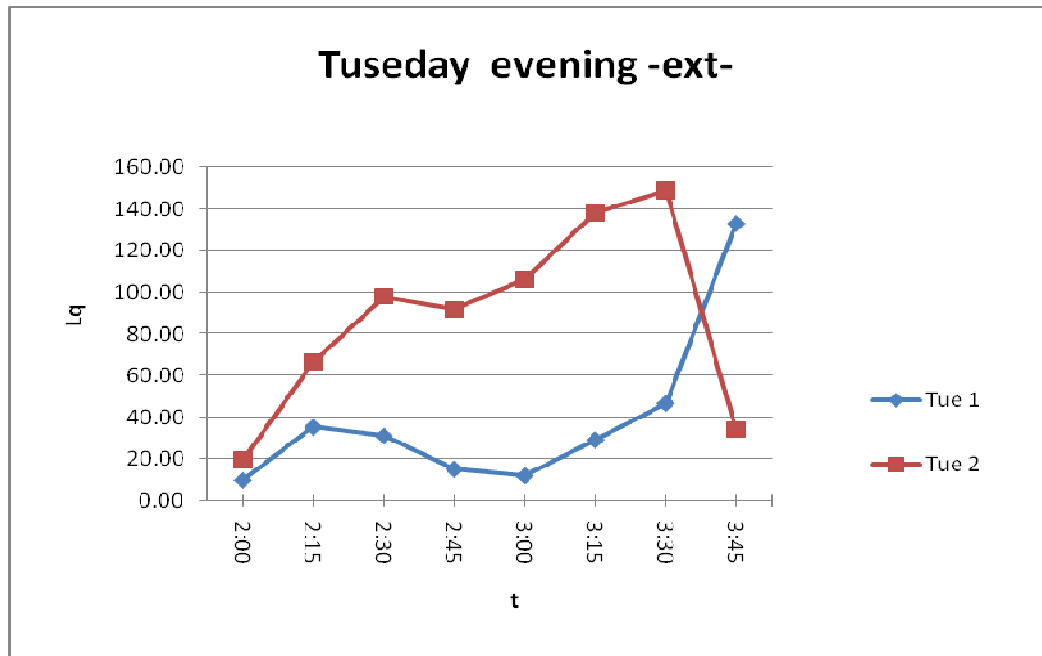
People arriving to Nablus on Tuseday evening, waiting time in the queue vs t.



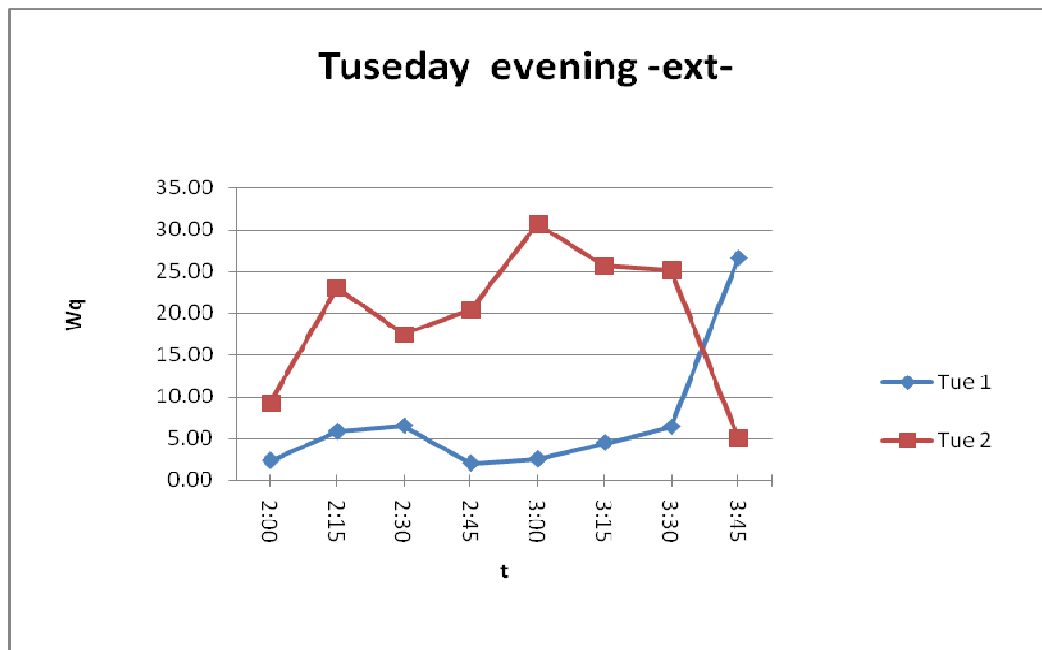
Women and men over forty departing Nablus on Tuesday morning, the length of the queue vs t.



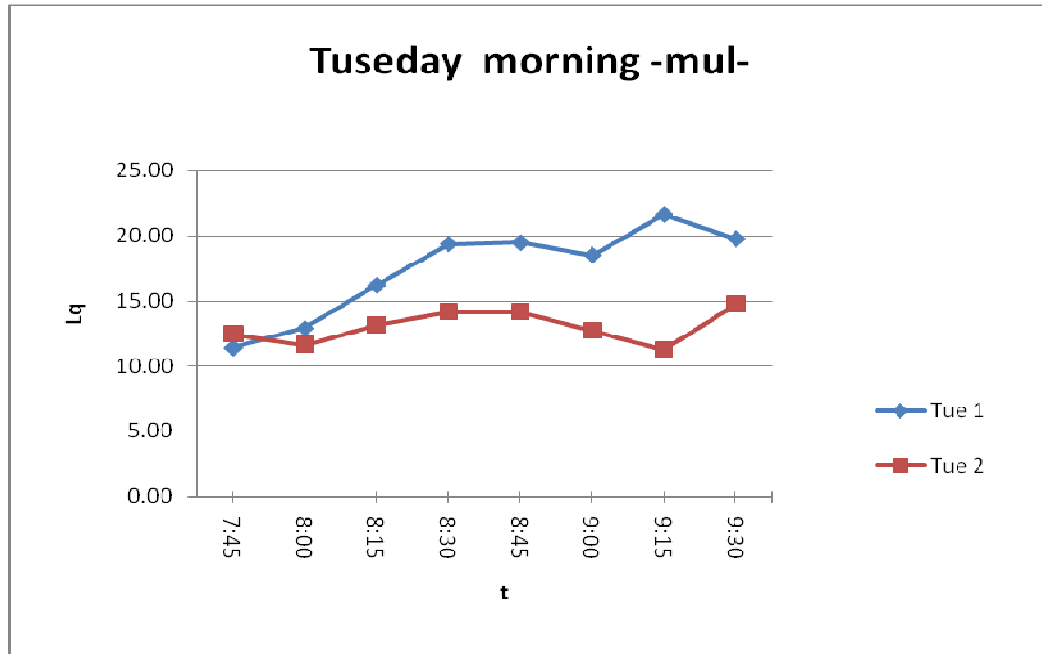
Women and men over forty departing Nablus on Tuesday morning, the waiting time in the queue vs t.



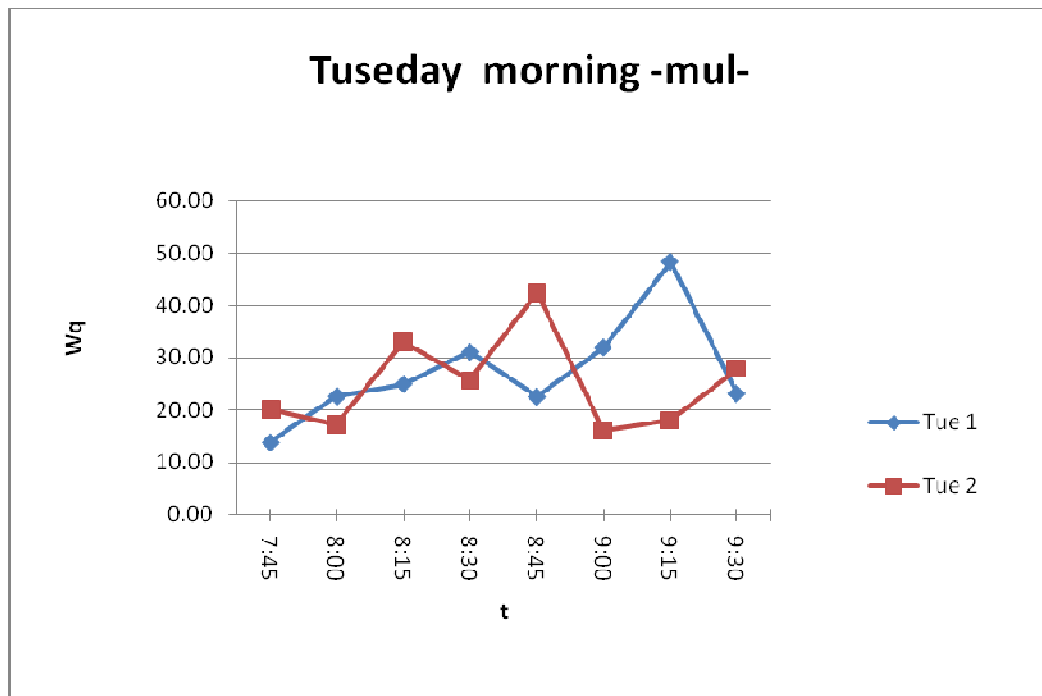
Women and men over forty departing Nablus on Tuesday evening, the length of the queue vs t.



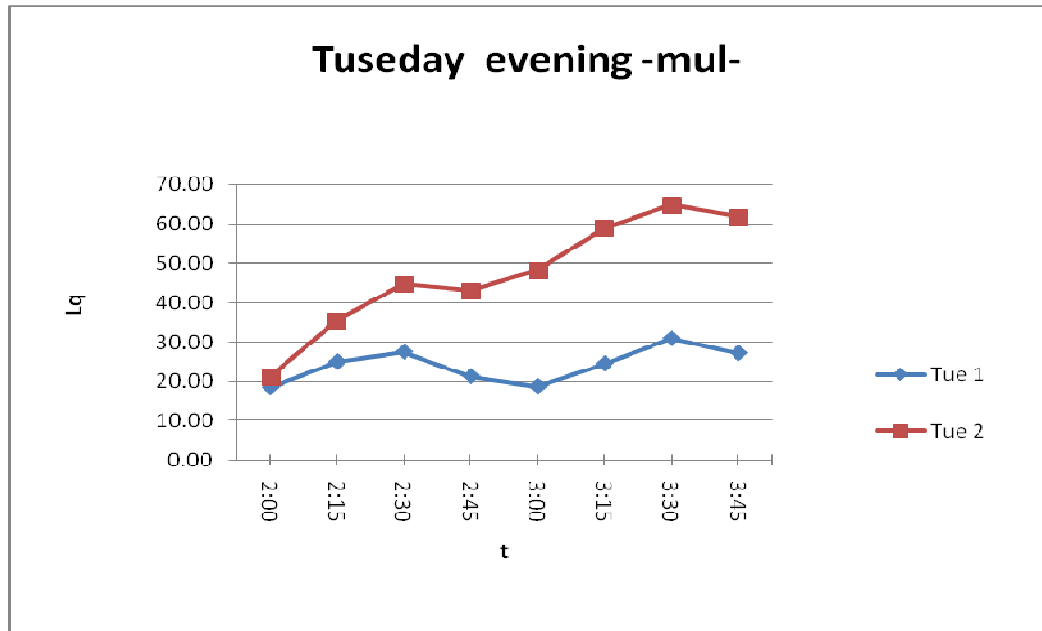
Women and men over forty departing Nablus on Tuesday evening, waiting time in the queue vs t.



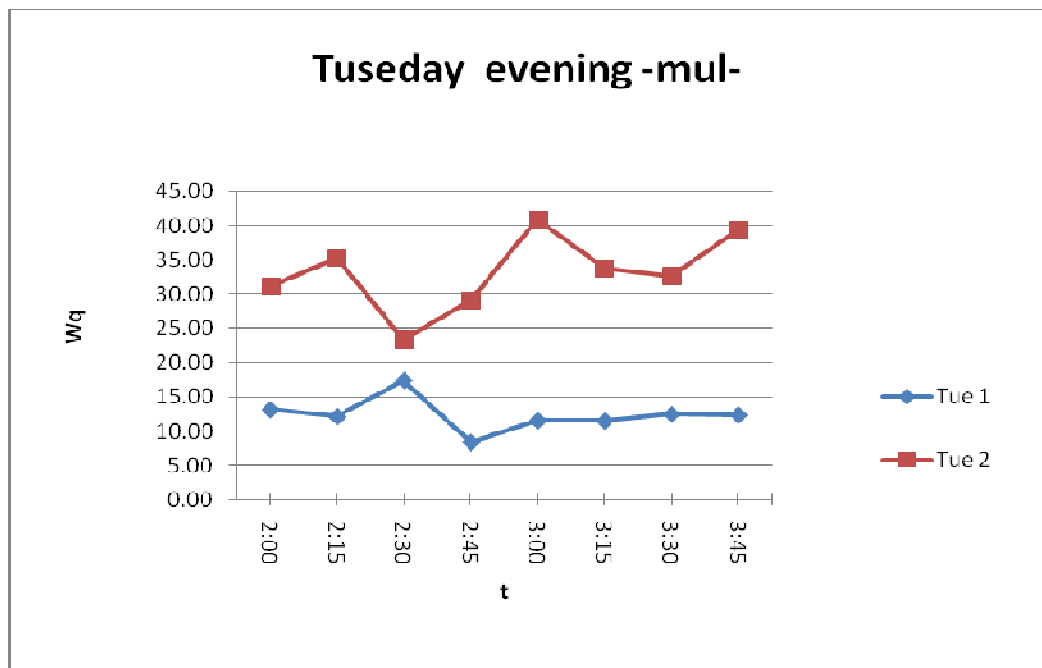
Men under forty departing Nablus on Tuseday morning, the length of the queue vs t.



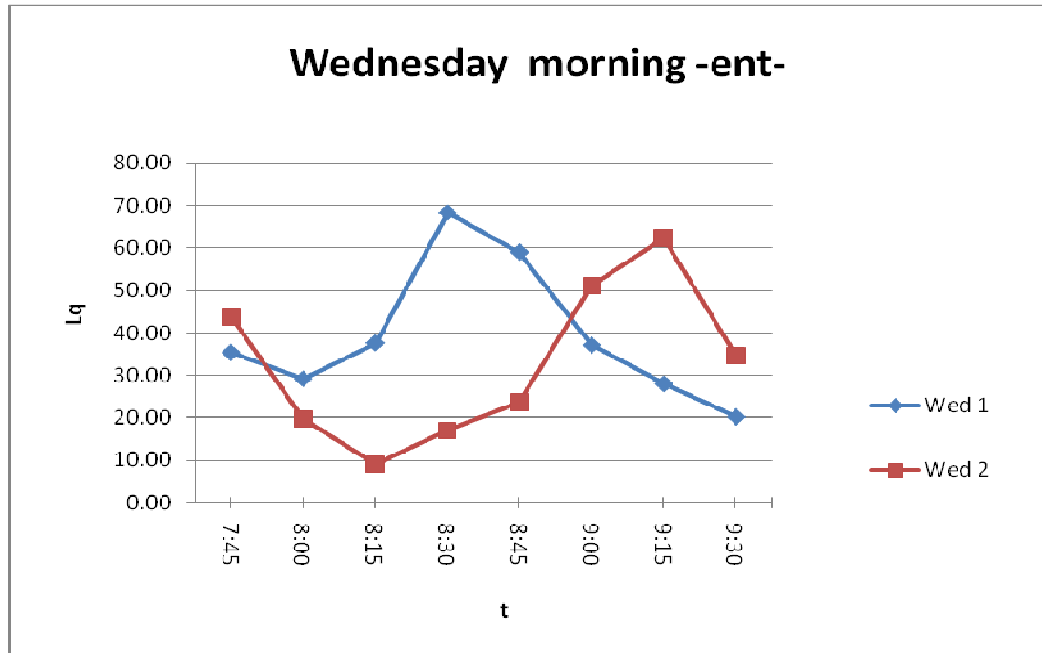
Men under forty departing Nablus on Tuesday morning, waiting time in the queue vs t.



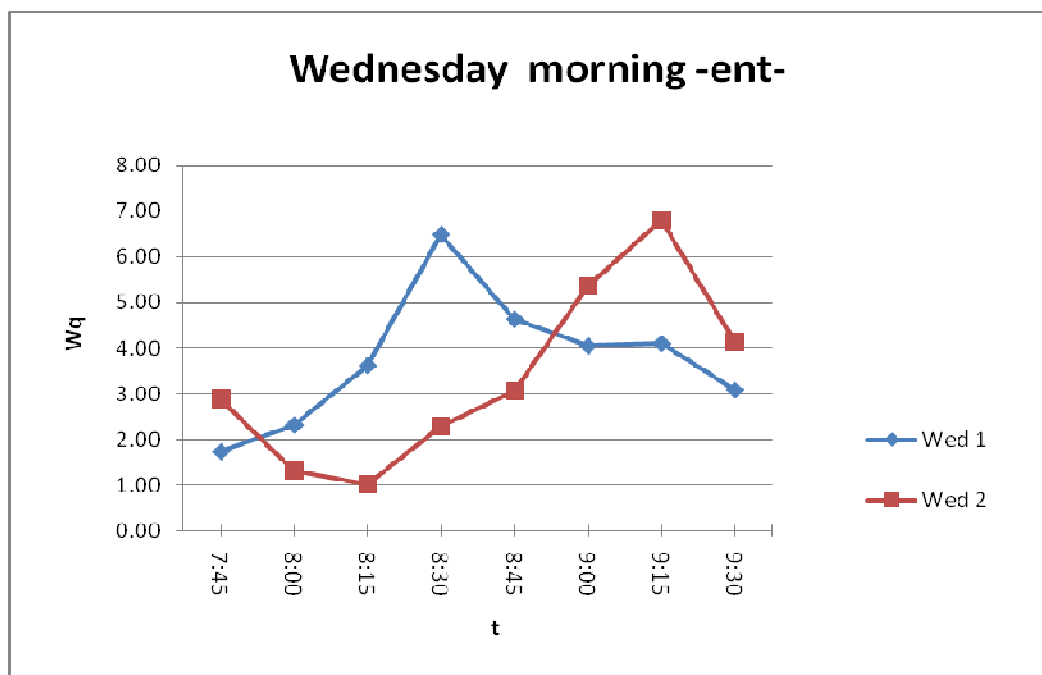
Men under forty departing Nablus on Tuesday evening, the length of the queue vs t.



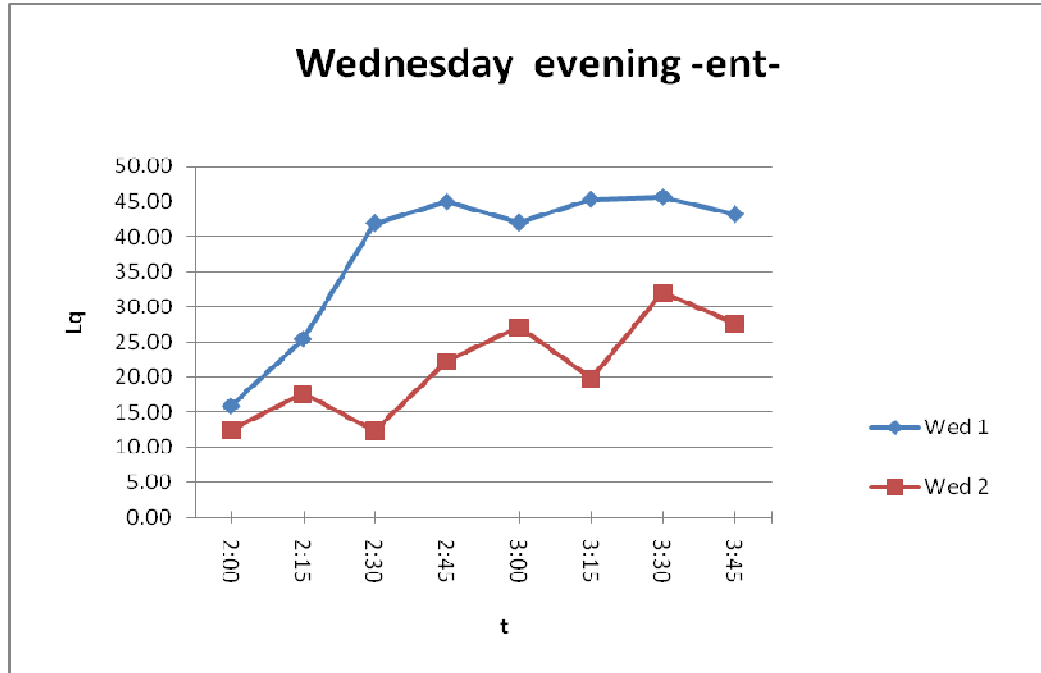
Men under forty departing Nablus on Tuesday evening, waiting time in the queue vs t.



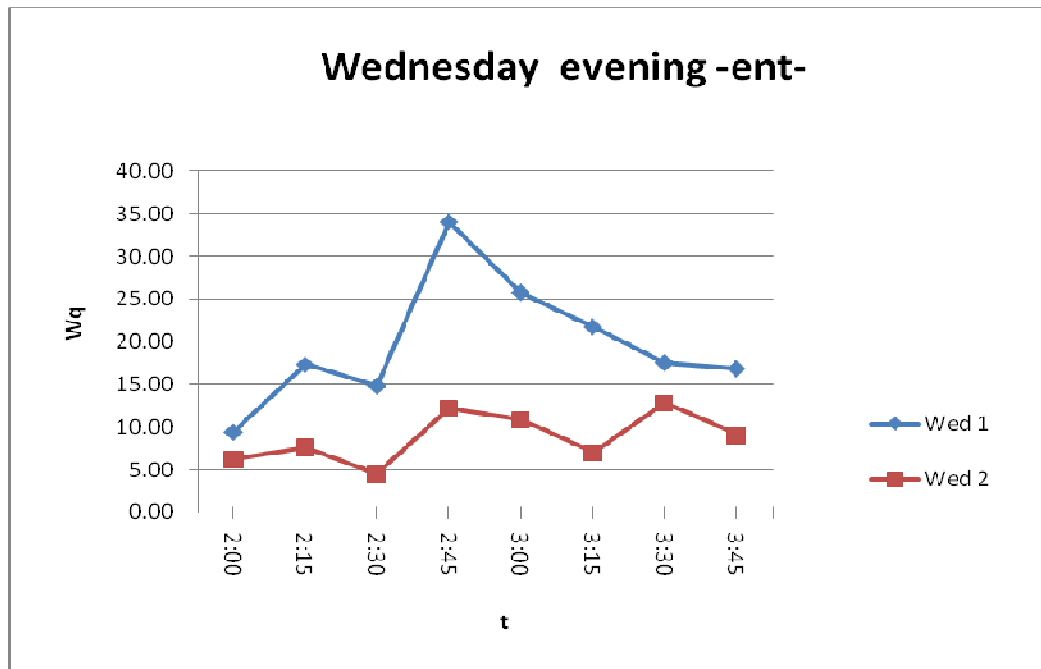
People arriving to Nablus on Wednesday morning, the length of the queue vs t.



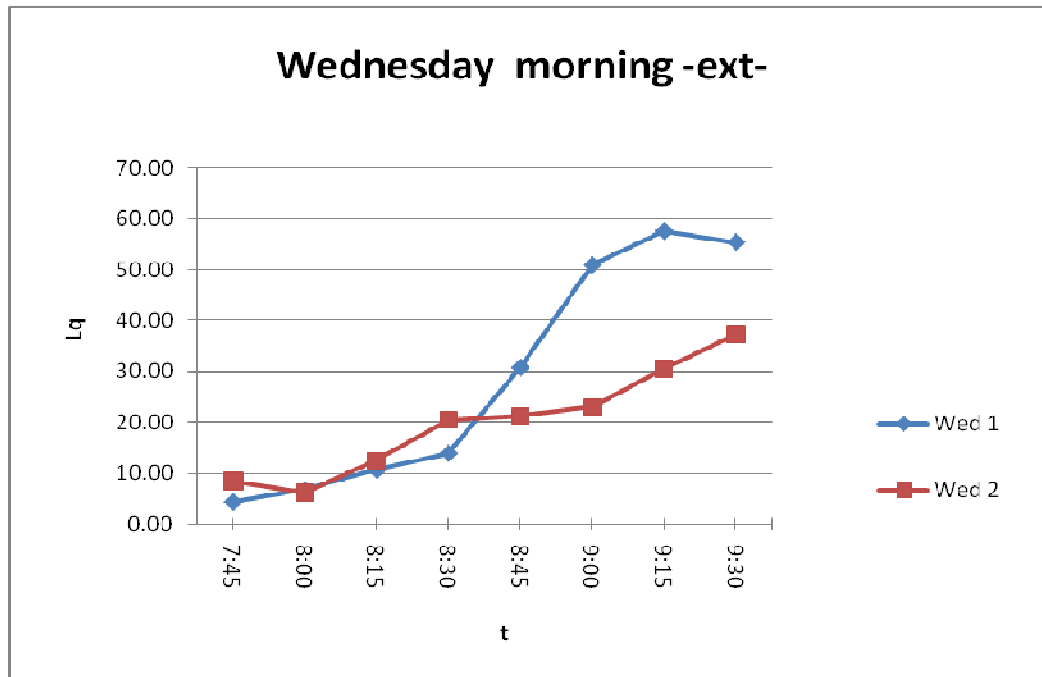
People arriving to Nablus on Wednesday morning, waiting time in the queue vs t.



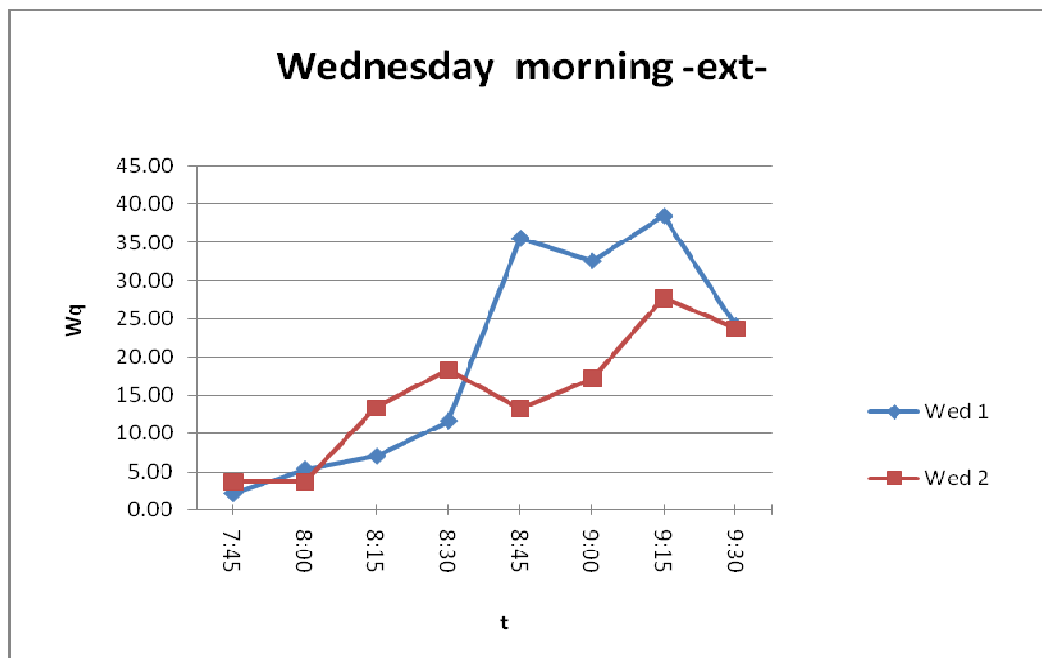
People arriving to Nablus on Wednesday morning, the length of the queue vs t.



People arriving to Nablus on Monday evening, waiting time in the queue vs t.

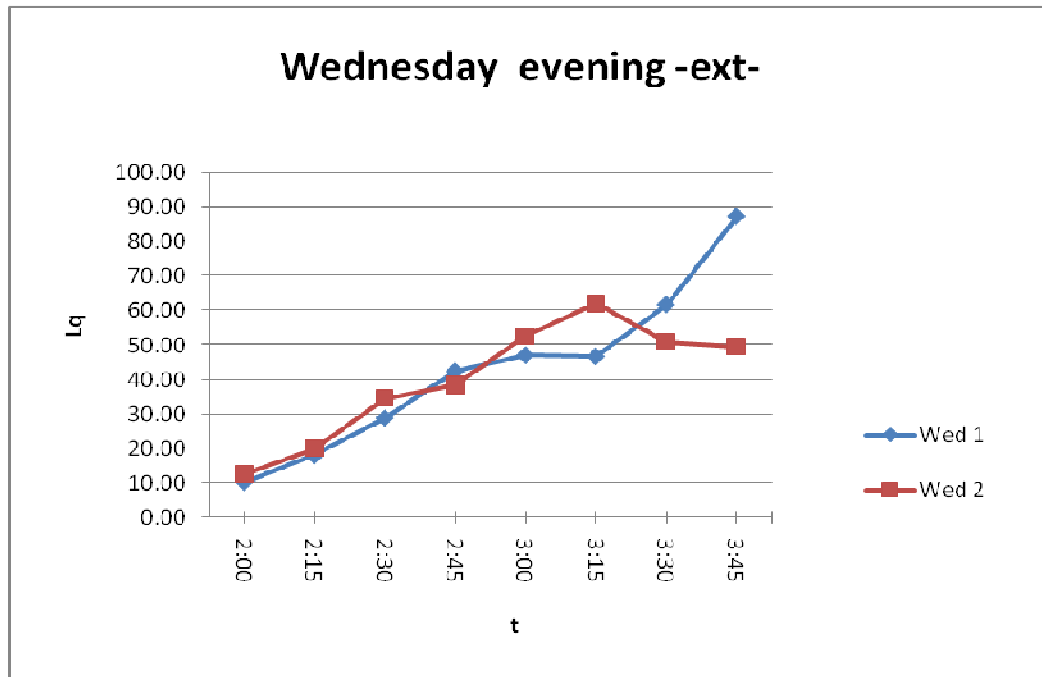


Women and men over forty departing Nablus on Wednesday morning, the length of the queue vs t.

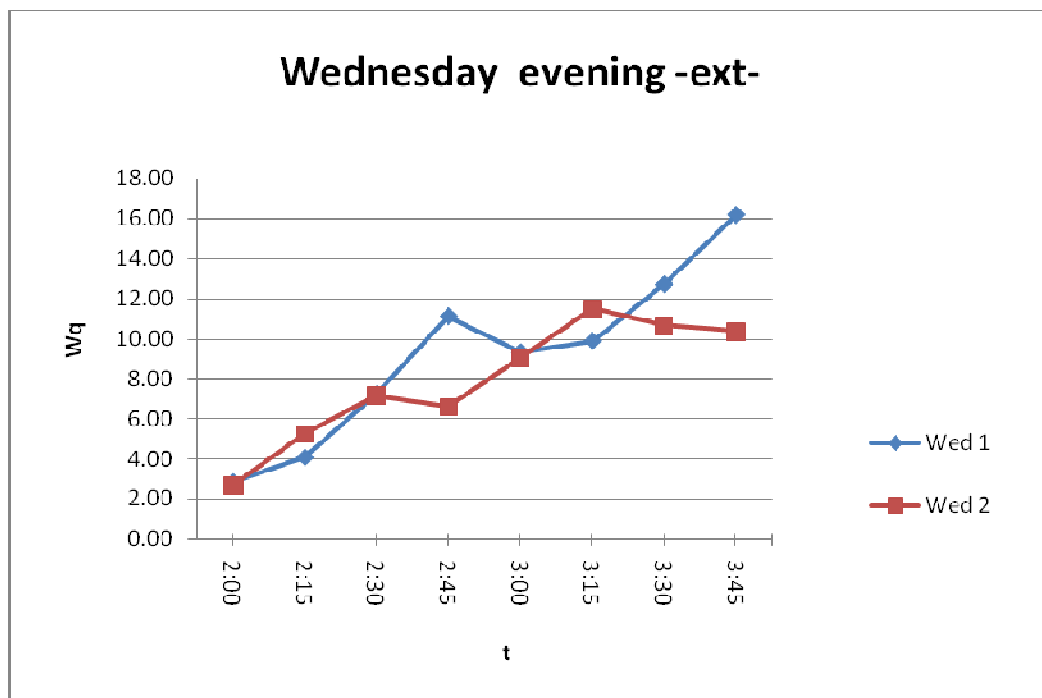


Women and men over forty departing Nablus on Wednesday morning, waiting time in the queue vs t.

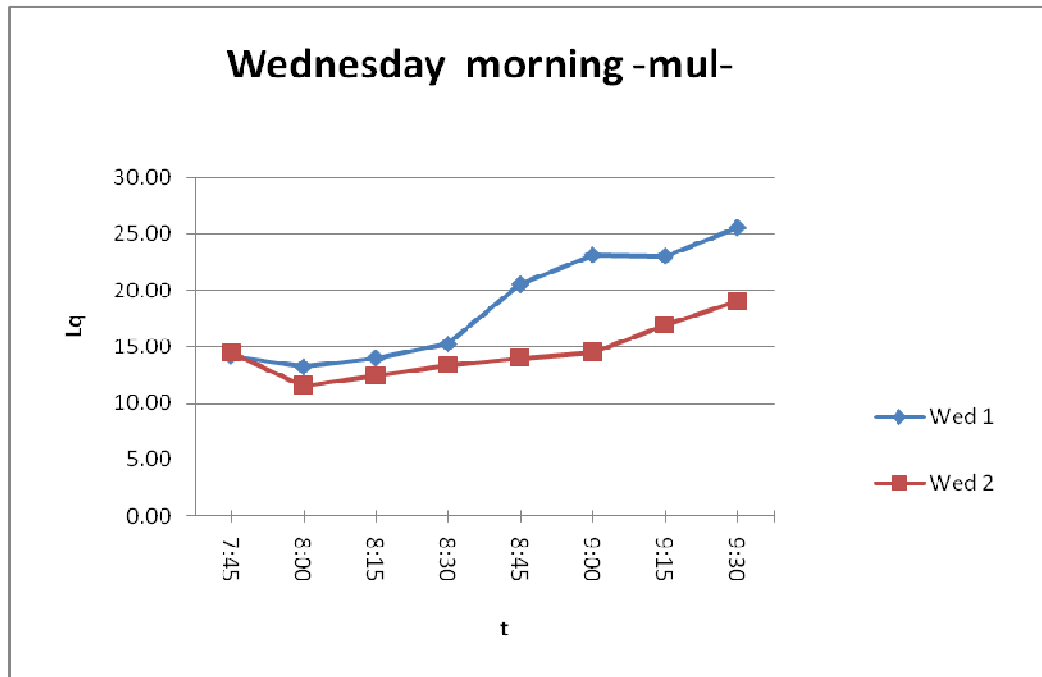




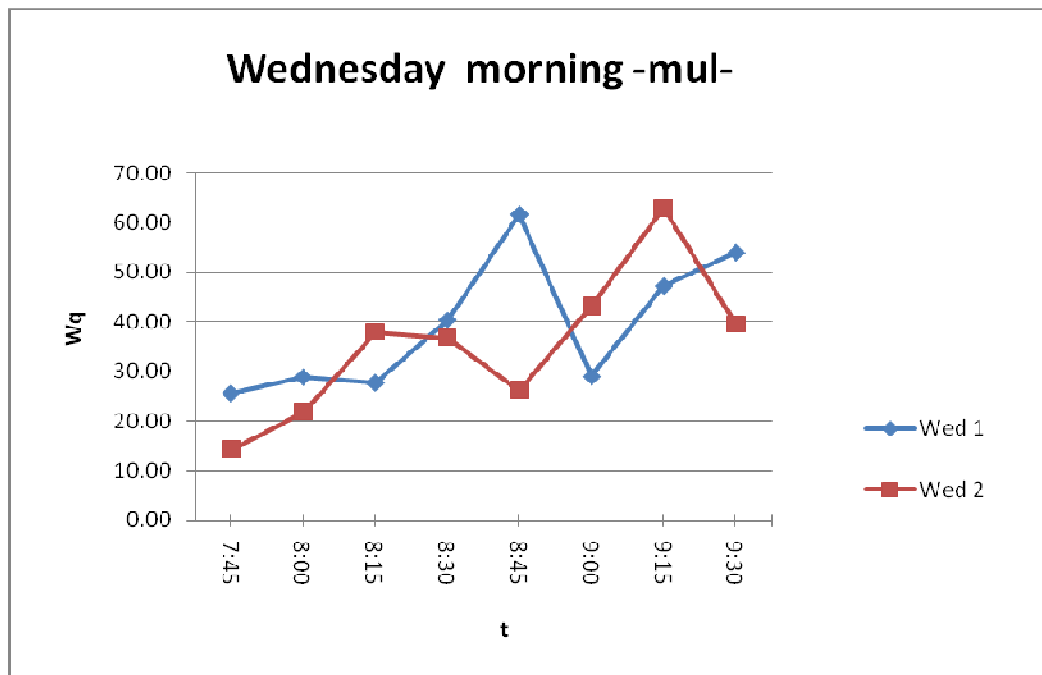
Women and men over forty departing Nablus on Wednesday evening, the length of the queue vs t.



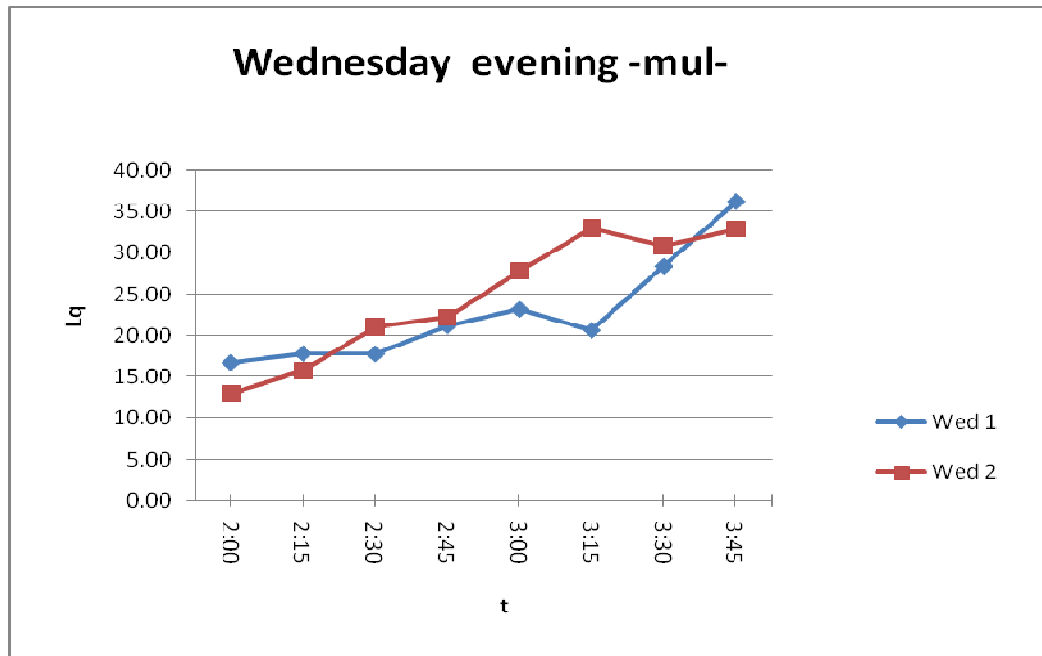
Women and men over forty departing Nablus on Wednesday evening, waiting time in the queue vs t.



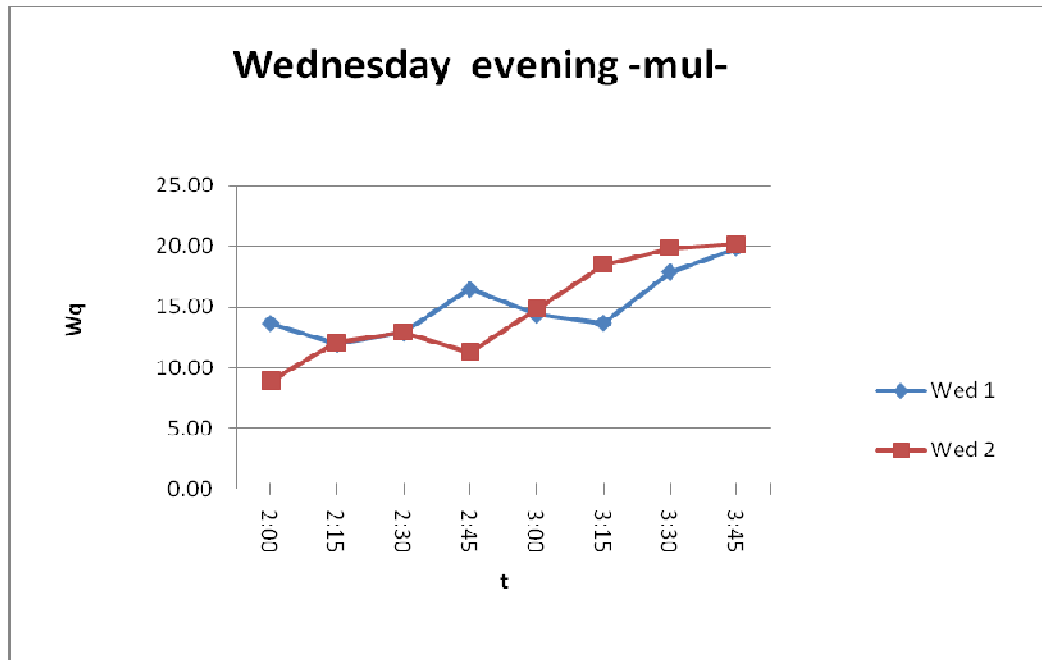
Men under forty departing on Wednesday morning, the length of the queue vs t.



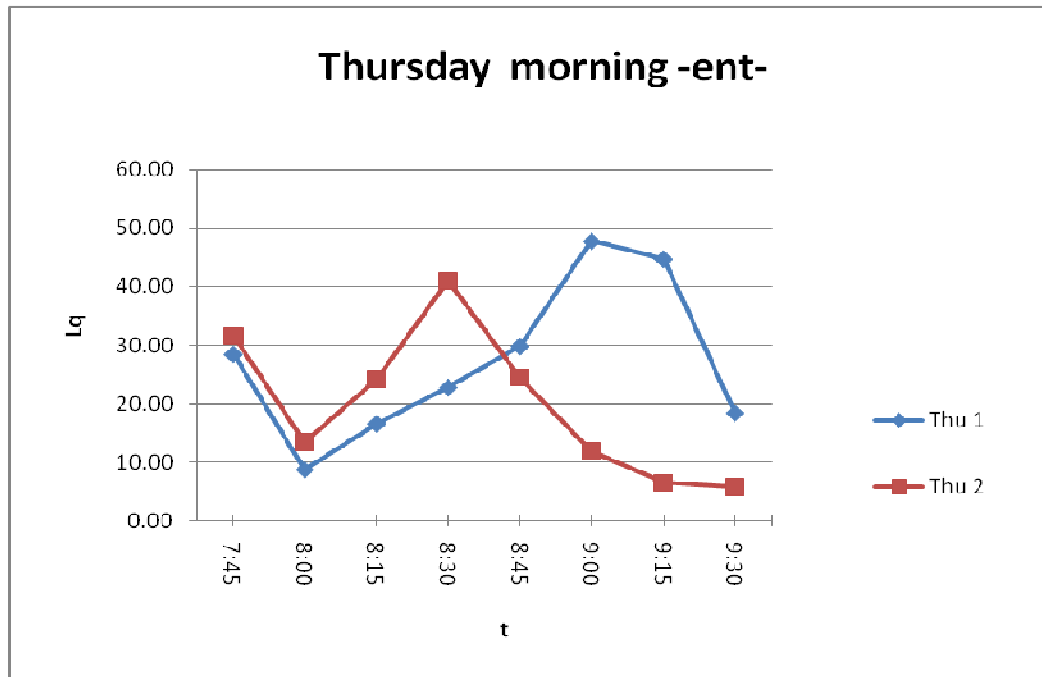
Men under forty departing on Wednesday morning, waiting time in the queue vs t.



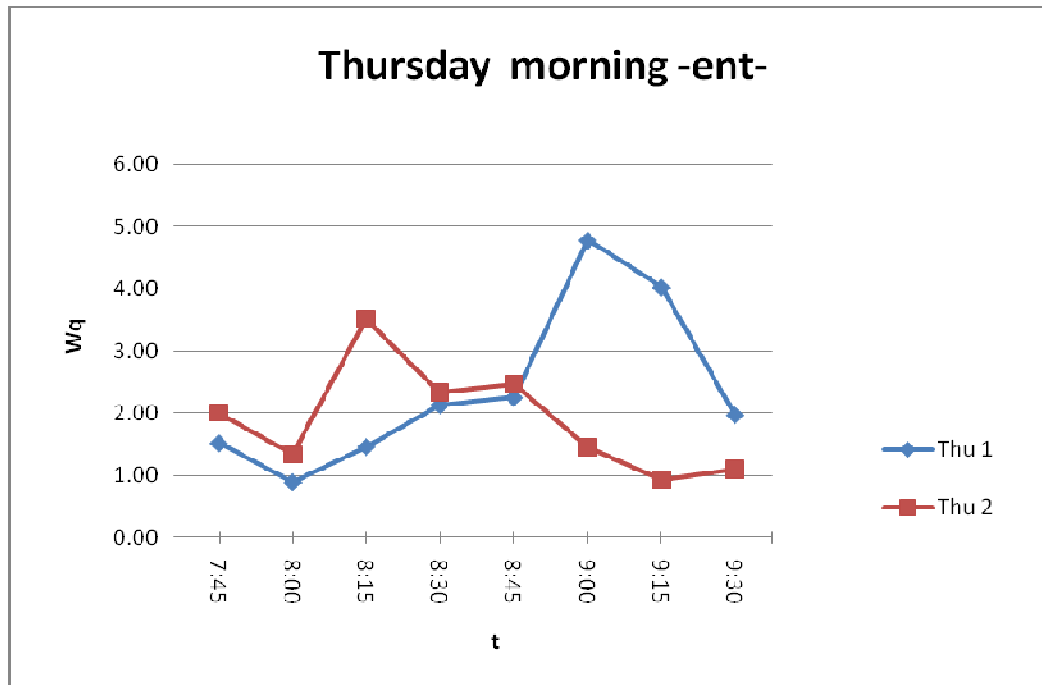
Men under forty departing on Wednesday evening, the length of the queue vs t.



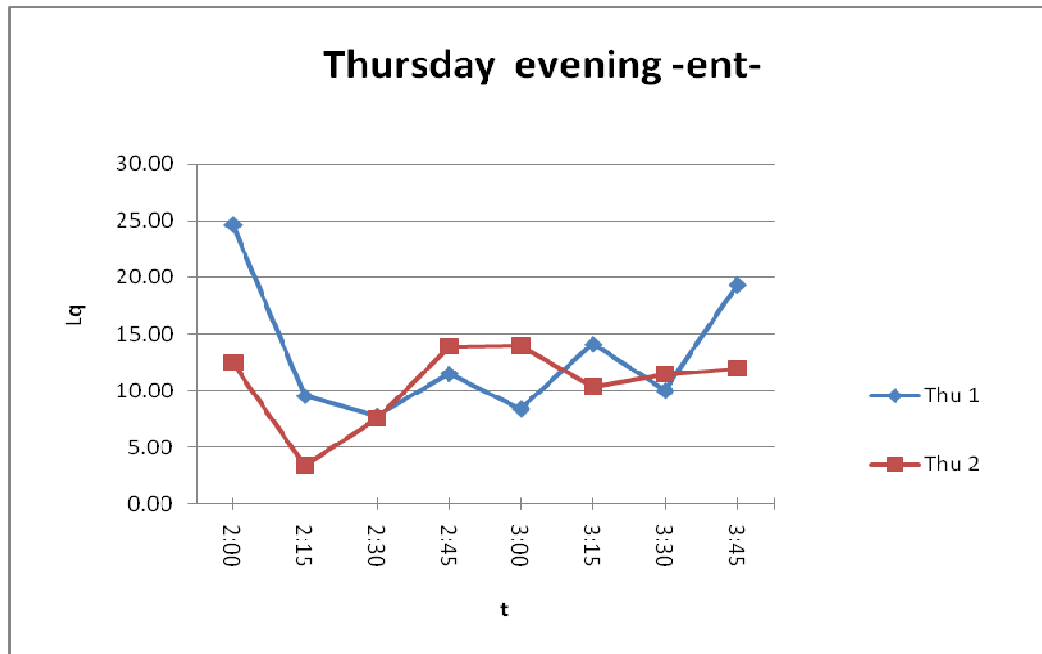
Men under forty departing on Wednesday evening, waiting time in the queue vs t.



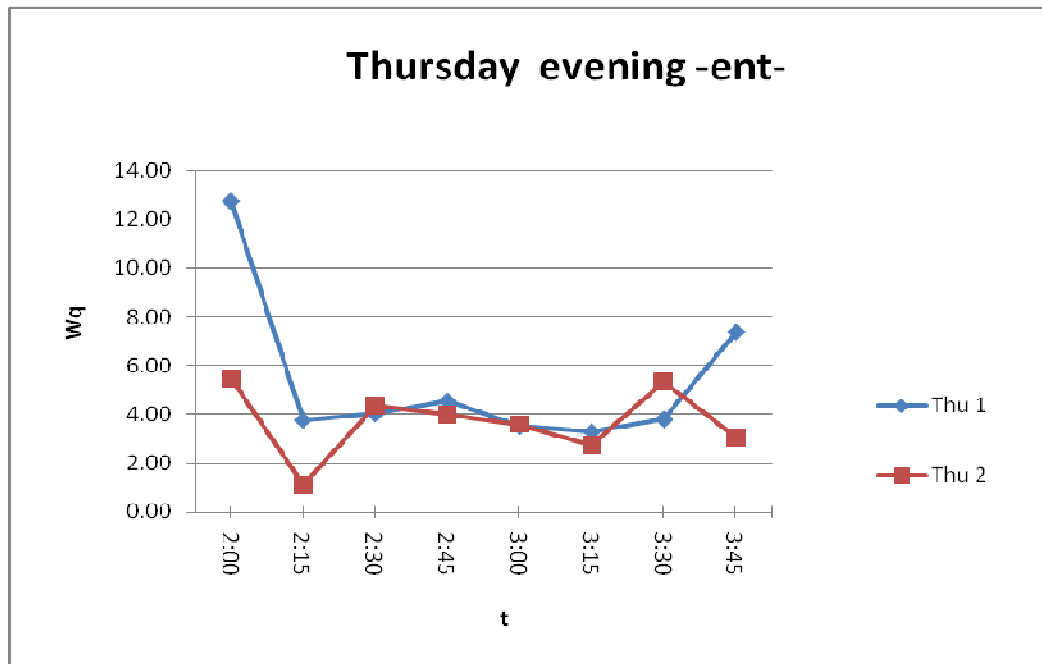
People arriving to Nablus on Thursday morning, the length of the queue vs t.



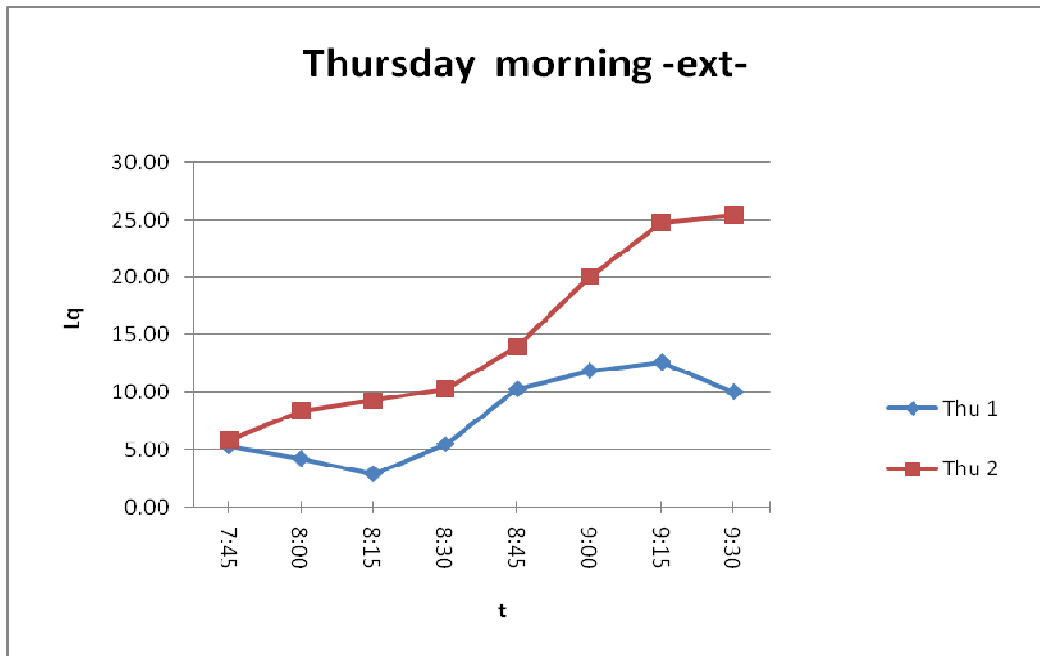
People arriving to Nablus on Thursday morning, waiting time in the queue vs t.



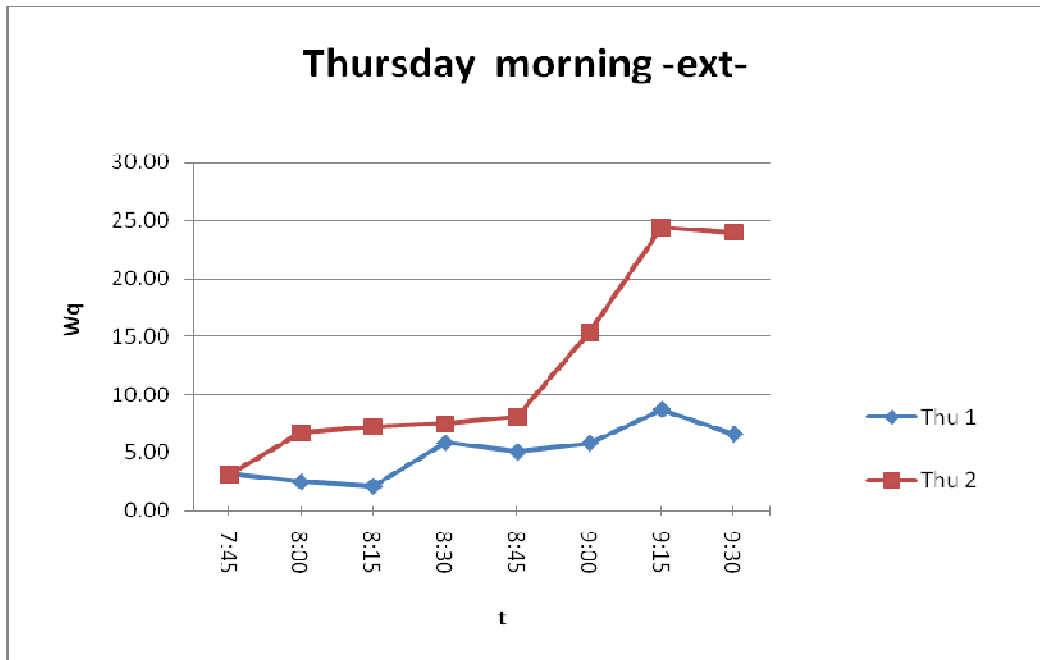
People arriving to Nablus on Thursday evening, the length of the queue vs t.



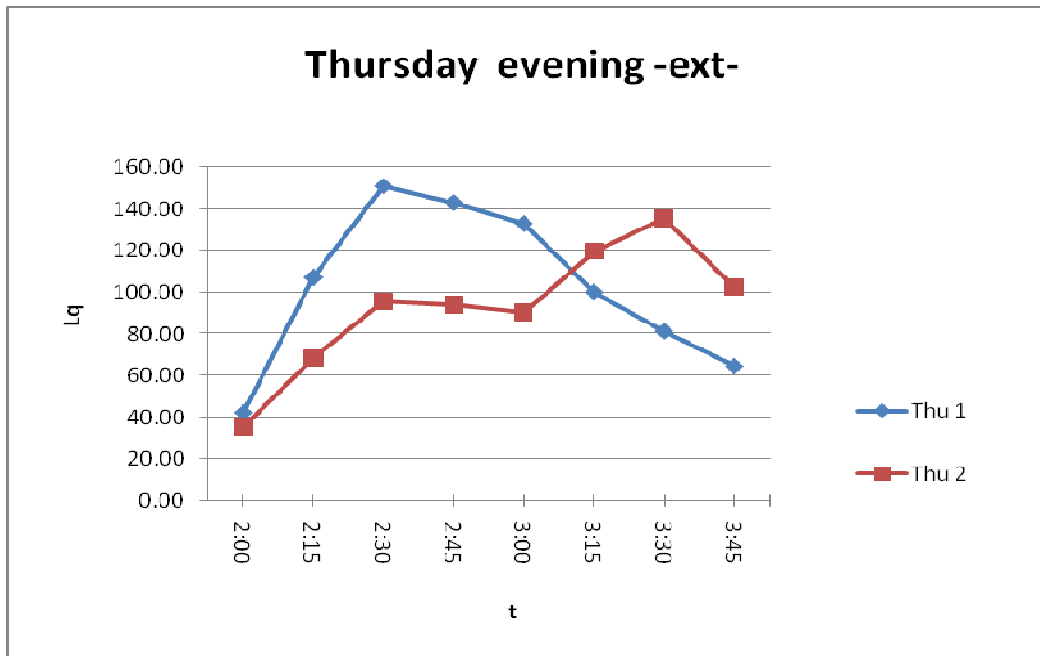
People arriving to Nablus on Thursday evening, waiting time in the queue vs t.



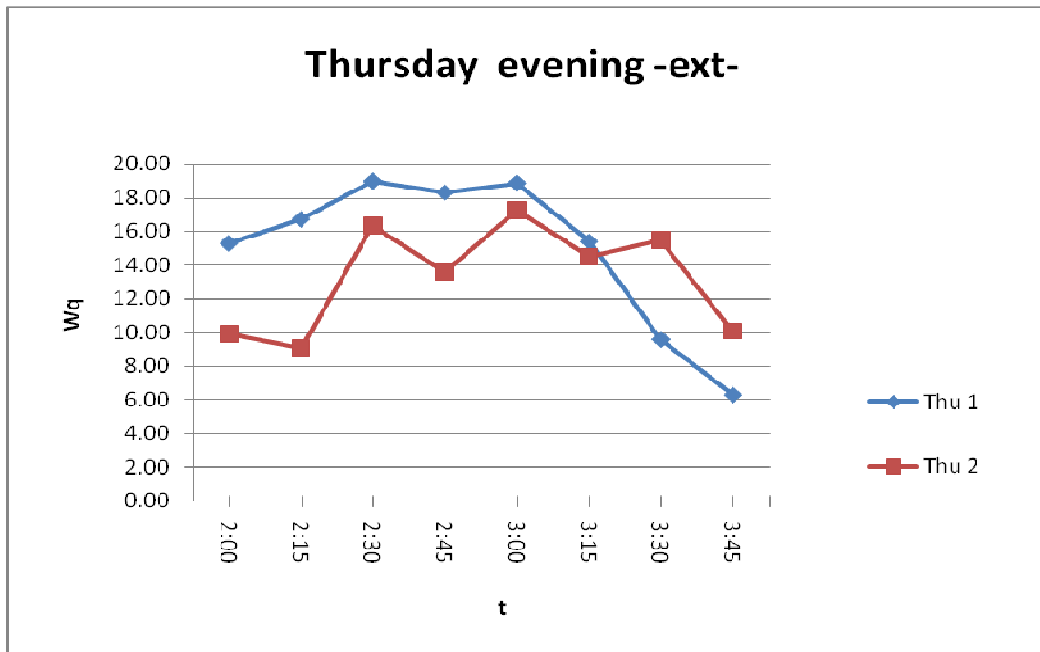
Women and men over forty departing Nablus on Thursday morning, the length of the queue vs t.



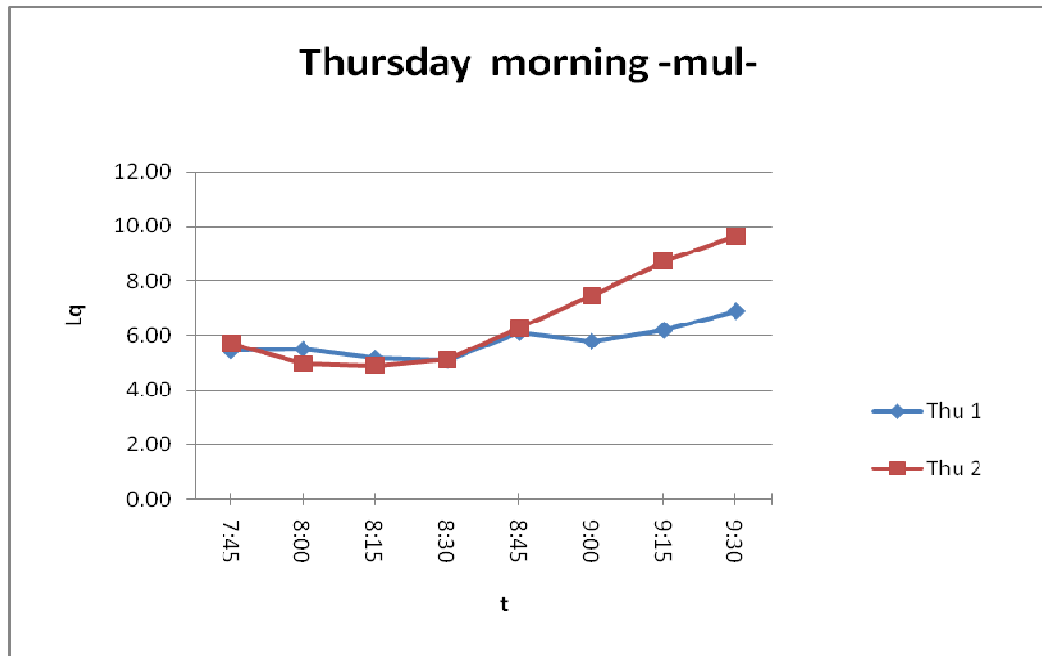
Women and men over forty departing Nablus on Thursday morning, waiting time in the queue vs t.



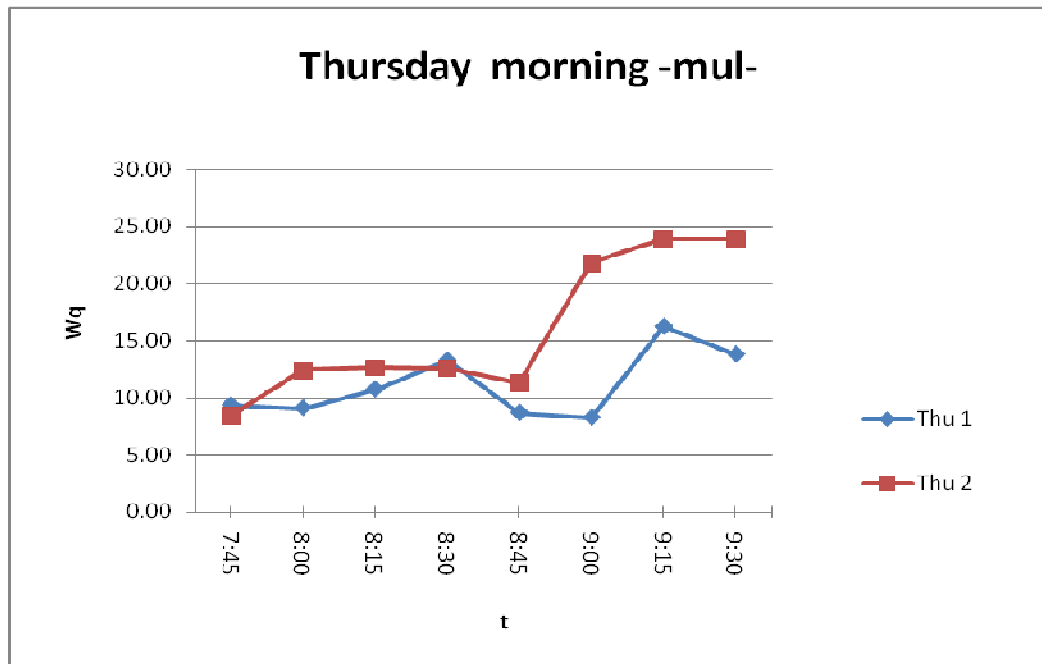
Women and men over forty departing Nablus on Thursday evening, the length of the queue vs t.



Women and men over forty departing Nablus on Thursday evening, waiting time in the queue vs t.

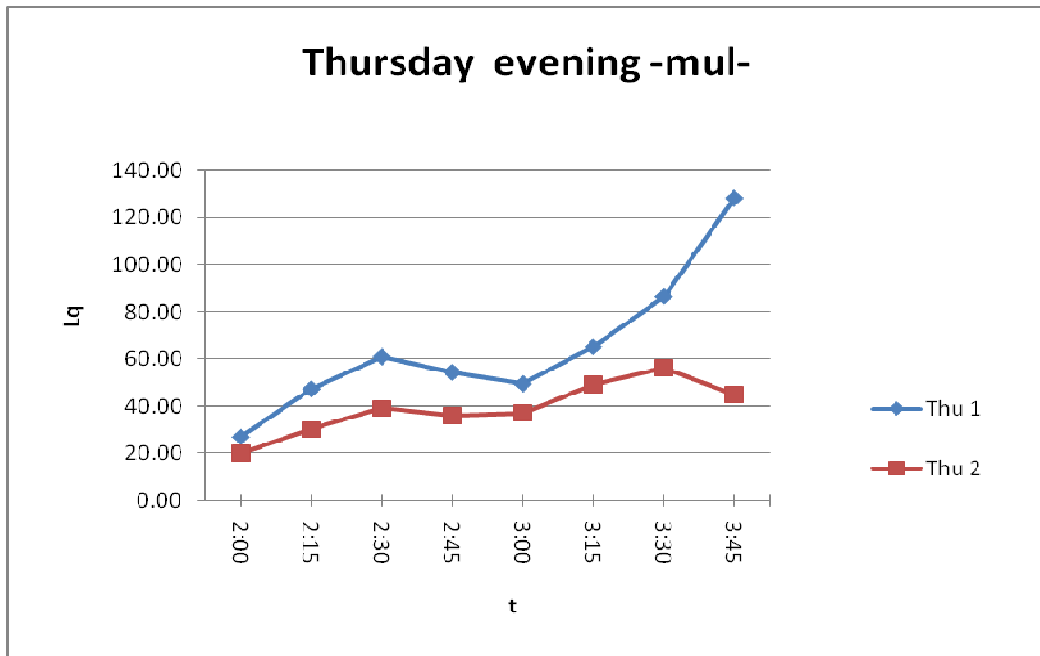


Men under forty departing Nablus on Thursday morning, the length of the queue vs t.

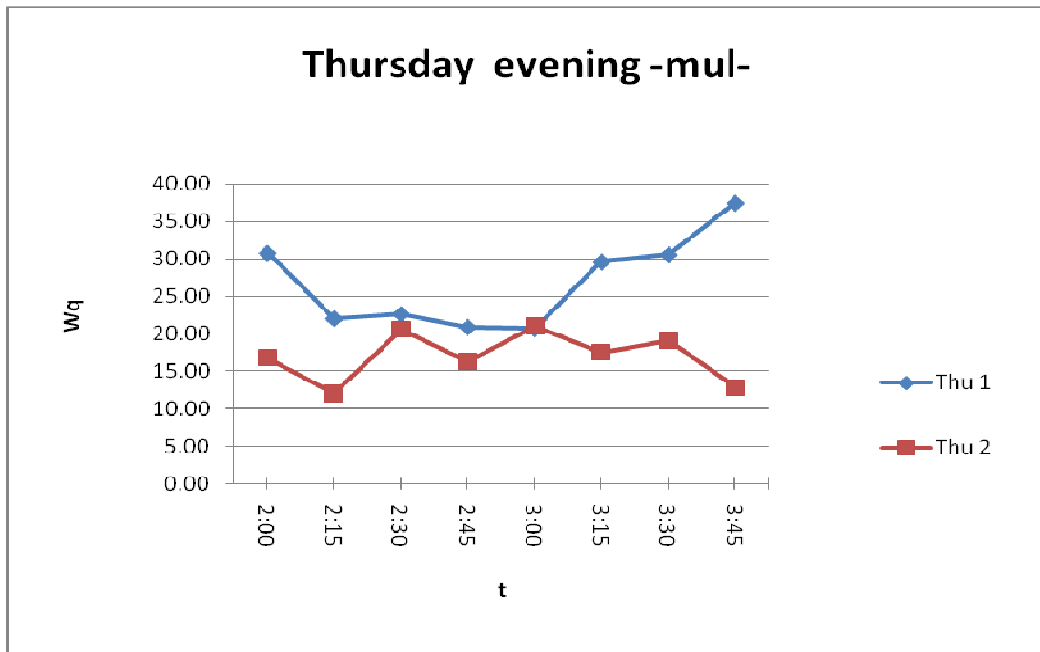


Men under forty departing Nablus on Thursday evening, waiting time in the queue vs t.





Men under forty departing Nablus on Thursday evening, the length of the queue vs t.



Men under forty departing Nablus on Thursday evening, the waiting time in the queue vs t.

## محاكاة أنظمة الطوابير: استخدام المحاكاة عند نقطة التفتيش بيت ايبا

اعداد

فاطمة يوسف عبد الله برهم

اشراف

د . محمد نجيب

د . لؤي ملحيس

قدمت هذه الأطروحة استكمالاً لمتطلبات الحصول على درجة الماجستير في الرياضيات المحوسبة ، بكلية الدراسات العليا في جامعة النجاح الوطنية في نابلس - فلسطين.

## محاكاة أنظمة الطوابير

إعداد

فاطمة يوسف عبد الله برهم

إشراف

د. محمد نجيب

د. لؤي ملحيس

### الملخص

هذه الدراسة "محاكاة أنظمة الطوابير" تهدف الى تحديد مقاييس الأداء في الطوابير ( أهمها مدة الأنتظار في الطابور، و طول الطابور ) عند نقطة التفتيش الموجودة عند بيت ايبا للقادمين و المغادرين لمدينة نابلس .

ومن اجل تحديد افضل نموذج تمت المقارنة بين نموذجين افتراضيين و النموذج الحقيقي على ارض الواقع باستخدام برنامج لمحاكاة أنظمة الطوابير "SimQuick" وهو برنامج يعتمد على برنامج الجداول الألكترونية اكسل .

ومن اجل التأكد من صحة النتائج التي حصلنا عليها ، تم طرح مشكلة افتراضية في أنظمة الطوابير في البداية ، ثم حلها اولا باستخدام نظرية الطوابير التي تعتمد على صيغ رياضية ، و ثانيا باستخدام محاكاة أنظمة الطوابير و التي تعتمد على برنامج الكمبيوتر " SimQuick " ، و كانت النتائج متقاربة بشكل جيد .

هذه الدراسة خلصت الى ان استخدام النظام المسمى " single channel-queue " اكثر فاعلية من " multiple channel-queue " .