نموذج رقم (1)

إقــــــرار

أنا الموقع أدناه مقدم الرسالة التي تحمل العنوان:

optimal Emergency Ambulance Locations in Gaza Strip

المكان الأمثل لسيارات الإسعاف والطوارئ في قطاع غزة.

أقر بأن ما اشتملت عليه هذه الرسالة إنما هو نتاج جهدي الخاص، باستثناء ما تمت الإشارة إليه حيثما ورد، وإن هذه الرسالة ككل أو أي جزء منها لم يقدم من قبل لنيل درجة أو لقب علمي أو بحثي لدى أي 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: عماد حرب عوض أبو رضي

Signature: التوقيع:

Date: التاريخ: ٢٨/١٢/٢٠١٥

بسم الله الرحمن الرحيم

Islamic University of Gaza
Deanery of Higher Studies
Faculty of Commerce
Department of Management

Optimal Emergency Ambulance Locations in Gaza Strip

Prepared by:

Emad H. Abu Nasier

Supervised by:

Prof. Dr. Yousif H. Ashour

A thesis submitted in partial fulfillment of the requirement for the degree of MBA

February/2015

بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

الجامعة الإسلامية – غزة
The Islamic University - Gaza

مكتب نائب الرئيس للبحث العلمي والدراسات العليا   هاتف داخلي 1150

الرقم: ج س غ/35/ Ref

التاريخ: 2015/02/25 Date

نتيجة الحكم على أطروحة ماجستير

بناءً على موافقة شئون البحث العلمي والدراسات العليا بالجامعة الإسلامية بغزة على تشكيل لجنة الحكم على أطروحة الباحث/ **عماد حرب عوض أبو نصير** لنيل درجة الماجستير في **كلية** *التجارة* قسم إدارة الأعمال وموضوعها:

المكان الأمثل لسيارات الاسعاف والطوارئ في قطاع غزة

Optimal Emergency Ambulance Locations in Gaza Strip

وبعد المناقشة التي تمت اليوم الاثنين 06 جمادى أولى 1436 هـ، الموافق 2015/02/25م الساعة الثانية مساءً، اجتمعت لجنة الحكم على الأطروحة والمكونة من:

أ.د. يوسف حسين عاشور	مشرفاً و رئيساً	....
أ.د. فارس محمود أبو معمر	مناقشاً داخلياً	....
أ.د. سامي سليم أبو ناصر	مناقشاً خارجياً	....

وبعد المداولة أوصت اللجنة بمنح الباحث درجة الماجستير في **كلية** *التجارة*/ قسم إدارة الأعمال.

واللجنة إذ تمنحه هذه الدرجة فإنها توصيه بتقوى الله ولزوم طاعته وأن يسخر علمه في خدمة دينه ووطنه.

والله ولي التوفيق ،،،

نائب الرئيس لشئون البحث العلمي والدراسات العليا

أ.د. عبدالرؤوف على المناعمة

P.O. Box 108, Rimal, Gaza, Palestine fax: +970 (8) 286 0800 فاكس Tel: +970 (8) 286 0700 هاتف ص.ب. 108 الرمال. غزة. فلسطين
public@iugaza.edu.ps www.iugaza.edu.ps

Abstract

When an incident occurs and acute health care is needed, the emergency number 101 should be called. After such a call, an ambulance should be within 10 minutes in the place.

There are ambulance stations in all Gaza Strip region, from where ambulance can depart to the scene of an incident. The study goal is to identify the optimal locations of these stations and the maximum response time (or maximum service distance) to reach the accident. The Location Set Covering Model (LSCM) is applied to the Palestinian Red Crescent Society (PRCS), which is the responsible of the Emergency Medical Service (EMS) stations. The optimal locations are firstly achieved by locating these stations so the maximum expected demand may be reached within a specified target time.

The LSCM determines the minimal number of location sites needed to cover all demand points using three different maximal response time of 7 , 10 and 12 minutes, As a result when Gaza Strip considered as one region the optimal output of the model is 5 , 3 and 3 location sites respectively. If each governorate considered as a separate region then 6 location sites needed with a maximal response time of 7 minutes.

The study proposes an approach to find out a location problem solution based on the model formulation as an integer linear program problem and solved using LINDO-language program.

The optimal solution of the study model makes reduction of the number of location sites by a percentage 25%, decreasing the maximal response time by 30% , reducing the average traveling distance by 38% and finally, increasing the maximum expected coverage by 12%.

أفضل الأماكن لإنشاء محطات الإسعاف و الطوارئ في قطاع غزه

ملخص الرسالة Abstract in Arabic

عندما يحدث حادث و نكون بحاجه لعناية طبية عاجلة نقوم بالإتصال على رقم الطوارئ 101. بعد إجراء المكالمة، لابد لسيارة الإسعاف من أن تكون متواجدة عندنا في غضون 10 دقائق. يوجد هناك محطات إسعاف موزعه على كل منطقة قطاع غزه، وذلك من أجل أن تخلي سيارة الإسعاف الإصابة من مكان الحادث. في هذه الدراسة نحاول أن نجد أفضل الأماكن لإنشاء هذه المحطات. نموذج مشكلة مجموعة تغطية المواقع "LSCM" تطبقت على جمعية الهلال الأحمر الفلسطيني، و التي بدورها مسئولة عن محطات خدمات الإسعاف و الطوارئ في قطاع غزه. إن الأماكن المثالية يمكن تحقيقها عندما تغطي مواقع هذه المحطات أكبر قدر من الطلب المتوقع عليها مع تحقيق الوصول لمكان الحدث في الوقت المطلوب و المحدد.

من أجل أن نصل إلى هذه الأماكن التي تغطي نقاط الطلب عليها قمنا بإستخدام ثلاثة أوقات كأعلى معدل زمني للإستجابة وهي 7 ، 10 ، 12 دقيقة.

من خلال النتائج نرى أنه عندما فرضنا أن قطاع غزه منطقة واحدة نحتاج إلى 5 ، 3 ، 3 محطات إسعاف مقابل كل زمن إستجابه من المذكورة أعلاه على الترتيب.

إذا فرضنا أن كل محافظة في القطاع هي عبارة عن منطقة مستقلة عن باقي المحافظات فإننا بذلك نحتاج إلى ما مجموعه 6 محطات إسعاف في كل القطاع للوصول إلى أفضل نتيجه في عملية توزيع المحطات بحيث يكون أقصى زمن للإستجابه في هذه الحالة هو 7 دقائق.

الدراسة إعتمدت على نظام البرمجة الخطية ذات قيم العدد الصحيح لحل المعادلات و إيجاد أفضل الأماكن و بإستخدام لغة برمجة يطلق عليها LINDO لحل مثل هذه المشاكل.

إن النتائج التي تم التوصل إليها من خلال هذه الدراسة تقوم على تقليل عدد أماكن تواجد محطات الإسعاف بنسبة 25% و تقليص أقصى زمن للإستجابة بنسبة 30% و كذلك خفض متوسط المسافات المقطوعة بنسبة 38% و أخيراً زيادة القيمة القصوى لتغطية نقاط الطلب بنسبة 12%.

Dedication

Especially dedicated

to my beloved family

especially my father (God's mercy)

Acknowledgments

I would like to express my sincere gratitude to my Prof. Dr. Yousif Ashour for his supervision and guidance. I also would like to express my thanks to Prf. Dr. Faris Abu Mouamer and Prof. Dr. Samy Abu Naser for their help, guidance and revising this thesis.

I also would like to express my thanks to my friend Eng. Ahmed Al Afeefy for his help in this thesis.

I would like to thank the Palestinian Red Crescent Society staff for providing me with a lot of information required for this thesis. I would like to express my gratitude to the experts who help me in this thesis.

Last, but not least, I would like to thank my family and friends for their continuous support throughout this thesis.

Table of Contents

List of Tables

List of Figures:

List of Appendices:

List of abbreviations:

ACS	American Community Survey
AMEXCLP	Adjusted Maximum Expected Covering Location Problem
AMS	Ambulance Management System
BACOP	Backup Coverage Formulation
BB	Branch and Bound
CCLP	Coherent Covering Location Problem
CCR	Central Communication Room
CEMSAA	County Emergency Medical Service Ambulance Allocation
CRCR	Central Radio Communication Room
D	Distance
DSM	Double Standard Model
EMS	Emergency Medical Services
FAST	Fire and Ambulance Service Technique
FLEET	Facility-Location, Equipment-Emplacement Technique
FS	Fire Station
GIS	Geographical Information System
GPS	Global Positioning System
GSM	Global System for Mobile Communications
HOSC	Hierarchical Objective Set Covering
IT	Information Technology
ILP	Integer Linear Programming
LSCM	Location Set Covering Model
MALP	Maximum Availability Location Problem
MCLP	Maximal Covering Location Problem
MCM	Maximal Covering Model
MEXCLP	Maximum Expected Covering Location Problem
MGLC	Multilevel, Goal-Oriented Location Covering Model
MOCCP	Multiobjective Conditional Covering Problem
MOH	Ministry of Health
MOLG	Ministry of Local Government
MRLP	Maximum Reliability Location Problem
NP	Non Polynomials

OPT	Occupied Palestine Territory
PBDSM	Reliability Based Double Standard Model
PLASC	Probabilistic Location-Allocation Set Covering Model
P-MED	P-Median Model
PRCS	Palestinian Red Crescent Society
QM-CLAM	Queueing Maximal Covering Location-Allocation Model
Q-PLSCP	Queueing Probabilistic LSCP
Rel-P	Reliability Model
SARCS	Saudi Arabia Red Crescent Society
SCM	Set Covering Model
T	Time
TEAM	Tandem Equipment Allocation Model
TTM	Two-Tiered Model
US	United States

Chapter One: General Background

1. **Introduction**
2. **Study Problem**
3. **Study Objectives**
4. **Study Importance**
5. **Study Methodology**
6. **Study Structure**
7. **Previous Studies**
8. **Summary of Previous Studies**

1. Introduction:

In case of accidents or other life-threatening emergency situations, it is important for health care to be provided within a short time, since this can be different between life and death.

Gaza Strip is under the Israel occupation and exposed to different emergency situations. Three wars occurred in the last six years, first in December/2008, second in November/2012 and the last in July/2014 which caused high numbers of emergency cases that needed to served. From this the emergency services has the more importance. The PRCS provided the emergency service to **2529** cases in September/2013, while in August/2014 during the last war has been served **12,185** cases in fifty days [32].

Rapid response to an incident is one important to measurement of the emergency services system success which mean a vital emergency ambulance service because a few minutes difference in the time of its arrival may make the difference between life and death for a patient [1].

Health services and a part of it emergency ambulance services are among most important services that required to be developed and improved its performance to achieve the aim of emergency services to reduce the mortality and health deterioration caused by emergency incidents or illness in general [15].

However, the location of emergency ambulance is critical and should be stationed to minimize the response time to emergency call and this is reason why organizing and planning emergency ambulance location and relocation is important [4]. In current practice the standard is that after a call, ambulance is at the scene in less than 15 minutes(US ACS, 1963) and this goal should be achieved in at least 95% of the regular cases, while resuscitation cases should be treated immediately within 4 minutes called "golden period" for cannot breathe case [37].

Gaza Strip,

Gaza Strip lies on the eastern coast of the Mediterranean Sea that borders Egypt on the southwest for 11 kilometers, with a total area of 65 square kilometers. The population of Gaza Strip is more than 1,850,000 million with population density 4,118 person per one kilo meter square. Gaza Strip consisting of five governates shown in Figure 3.1:The north, Gaza, The middle, Khan Yunis and Rafah. There are twenty five municipalities listed in the Table 3.1 with covering area about 45kilometers, in length by 6 to 12 kilometers in width [49].

Palestinian Red Crescent Society

In Gaza Strip the number one sector organization for ambulance care is Ambulances of Palestinian Red Crescent Society. The Palestinian Red Crescent Society (PRCS) was founded in 1968, and become member of the International Red Cross Society in 2006. Emergency Medical Services (EMS) constitutes essential health services provided by PRCS to all individuals in need under normal and extraordinary conditions. Considering the importance of this humanitarian service, PRCS was entrusted by the Palestinian National Authority in 1996, by virtue of a presidential decree, with full responsibility for these services in the West Bank and Gaza. EMS services are offered by PRCS 24/7 through the **101** hotline[47].

Figure 1.1: Emergency ambulance providing the service.

PRCS emergency services now encompass 14 main centers, including one in East Jerusalem, and 26 subsidiary centers in the Occupied Palestine Territory (OPT). These centers are currently assisted by a fleet of 140 ambulances and are manned by 348 paramedics and 200 volunteers. Moreover, PRCS runs its own EMS Institute, which is unique in Palestine and is specialized in providing EMS training to prepare basic and general paramedics through its two branches in Al Bireh and Gaza. In Gaza Strip there are five main ambulance stations and three substations as branches for the PRCS and one main center provide the emergency service assisted by a fleet of 37 ambulances. The Central Communication Room (CCR) in the station which geographically nearest to the calling position is the first part in the Emergency Services system receives the demand call. When the station room receives a call it assigns to responsible for serving that call and dispatches one of its ambulances. If the call is no available, then the room assigns the call to nearest other station based on their judgment. Calls are served on a first come first served basis [47].

2. Study Problem:

Ambulance stations should be organized and planned based on a scientific method and models that minimize the response time of the emergency incident and to be able to provide the best coverage with the least number of stations [15]. The problem arises here from determining the optimal locations of these stations, In 2014 there were **8** ambulance stations in Gaza Strip which covered 88% of demand with maximal response time 10 minutes. In urban areas, the most widely used ambulance response time standard is to respond to 90% of calls within 8 minutes and 59 seconds as compared to responding to 90% of calls within 14 minutes and 59 seconds in rural areas [10].

The problem that are treated in this study are about the location of ambulance stations to finding the "optimal" configuration / distribution of locations of ambulance stations. The main question that will be in mind :

What is the optimal distribution of ambulance stations in Gaza Strip.

It is possible to give definite answer to this question, because what is optimal depends on the objective and constraints imposed.

3. Study Objectives:

The main objective of this study is to find the optimal location of ambulance stations in Gaza Strip that can cover any point in Gaza Strip within a limited time.

The study also includes the following sub objectives:

- ✓ How many locations needed to cover all areas of Gaza Strip?
- ✓ What is the maximal travel time that the ambulance it takes to arrive to the patient?
- ✓ Find the maximal response time for the emergency cases from the call and the maximal travelling distance from the site to the scene.
- ✓ Is there another alternatives to relocating the existing station to be the optimal.

4. Study Importance:

The importance of this study lies in selecting a vital subject that is most important and critical logistic decisions because the poor location decision increase the mortality (death) and morbidity (disease) can result by increasing the response time of emergency incidents [15].

The big motivation of this study is because of its high importance which can be explained in the following points:

- **a.** Ensure that the ambulance arrives to the patient within the target time.
- **b.** Ensure that the ambulances stations covering all areas of Gaza Strip.
- **c.** Find the optimal location and allocations of the limited resources of the EMS.
- **d.** Measure the performance of the emergency ambulance and establish the standard response time of it.
- **e.** Find how many stations should be added if we need and where they should be located.
- **f.** Find the alternatives to relocating the existing stations to be optimal?

5. Study Methodology:

The study methodology explains the road map needed to reach the study goal. Starting with goal definition, then data collection, in which, the real work of EMS in Gaza, in which include the application of basic facilities locations models.

I. Goal Definition:

The goal of this study is to determine the optimal locations of ambulance stations in Gaza Strip using basis for almost facility location models that are used in health care applications . The basis models of facility location are the Set Covering Model (SCM), the Maximal Covering Model (MCM), and the P-Median model (P-MED).

II. Data Collection:

The data needed for the study are: emergency ambulance stations positions, number of ambulances in each station, number of cases served by EMS, number of called to 101, average time response served the emergency cases.

The required data was collected from:

1. Ministry Of Local Government (MOGL).
2. Palestinian Red Crescent Society (PRCS).

6. Study Structure:

Chapters are organized as follows:

- Chapter one: presents the study background including introduction about the Emergency Medical services (EMS) in Gaza strip, study problem, objectives, importance, methodology, structure and end with the previous studies.
- Chapter two: presents literature review of the previous related studies in ambulance location models and the mathematical formulation of these models.
- Chapter three: presents the methodology followed in the study, which is the input data to applying LSCM model.
- Chapter four: presents the results with the model introduced in chapter four are given and discussed.
- Chapter five: presents the conclusions, recommendations and future study.

7. Previous Studies:

There are a lot of related studies, these studies are used the models of facility location to optimization models and another making a simulation to these models with real data. Another studies used the GIS system to management the ambulance locations.

The study of Ramashe and others, (2014) titled "**A Bi-Objective Model for Locating and Sizing Emergency Stations**"

This paper presented a bi-objective model within the integer linear programming framework to determine the location of emergency stations, the regions covered by each of these stations and location of ambulance to these stations. Objectives of this model are minimizing the cost of locating the stations and ambulances as well as the maximum time it takes to sever the demands. In this model, service time is the interval between dispatching the ambulance and transporting the patient to the closest hospital. The model solved by the epsilon –constraint method, provides with a set of Pareto optimal solutions. The presented algorithm is able to solve problem instances containing up to 150 regions within period of less than 12 seconds which is a reasonable time. Population and demand density, distances between the regions, number of times a region needs to be served (coverage) by neighboring stations and positions of existing hospitals are the models inputs. All of the demand nodes are covered with consider the two goals of minimizing the cost and minimizing the maximum service time simultaneously [54].

The study of Looije, (2013) titled "**Optimal Ambulance Locations in the Netherlands**"

The objective of this study is to determine the optimal locations of ambulance stations in Netherlands, to be able to provide the best coverage with the least number of stations. In 2010 there were 203 ambulance stations in the country. The study consider the Netherlands as a directed graph, where the nodes represent four-digit postal code area and the arcs represent the road network, and each arc has a value corresponding to the travel time between the tail node and the head node of the arc.

Two based models used. The first model is the Location Set Covering Model (LSCM), which determines the minimal number of location sites needed to cover all demand points. The second model is the Maximal Coverage Location Problem (MCLP), which determines the maximal coverage that can be achieved with a fixed number of location sites.

The result with LSCM model using deferent maximal travel times of 8, 12 and 15 minutes was 302, 165 and 100 location sites respectively if we consider the Netherlands as one region. If Netherlands consider as a separate region(25 region) the needed is to 203 location sites with a maximal travel time of 12 minutes. Using the results from LSCM, the MCLP used to determine the percentage of the residents can still cover with less ambulance stations than the outcomes from the LSCM with the same three different travel time the stations still cover approximately 95% of the residents with 225, 95 and 60 location sites respectively [39].

The study of Limpattanasiri and others, (2013) titled "**Solving a Maximal Covering Model of Emergency Ambulance Location Problem in Urban Areas by Dynamic Programming Technique**"

The objective of this study is to consider the maximal covering ambulance location problem for regular traffic situation and heavy traffic congestion situation in urban area. A two hierarchical objectives model for planning level based on MCLP model is proposed and exact searching algorithm based on Dynamic Programming technique is developed for its solution. The traffic behavior is assumed to be normally distribution. The stochastic traveling speed is derived to be a static variable using inverse cumulative function by given percentage rank. The model defines regular traveling speed with 0.50 percentile of distribution and speed for heavy traffic congestion situation with 0.05 percentile of distribution. The proposed model solved by proposed searching algorithm is compared with the MCLP model solved by CPLEX and proposed searching algorithm. Computational results using both randomly generated data and real data of Osaka city confirm the efficiency of the proposed approach. Comparing with the MCLP model, the MCLP-htc maintains maximal covering for standard response time (15 minutes) and increases level of population covered within short response time (8 minutes and 4 minutes) by the first solution [37].

The study of Rabello and others, (2012) titled "**Optimization Models in the Location of Healthcare Facilities: a Real Case in Brazil**"

The objective of this paper is to is to find the optimal solutions proposed by the location models of the healthcare facilities and carried out as real experiment in Brazilian city to confront the current sites configuration. After applied the most important location models: p-median model, set and maximal covering model and p-center, the results showing the effectiveness of the models and permitting the highlight of the strong points of each approach.

The most interesting finding in the experiment the trend of increasing the proportional saving in distance generated by the models as these is an increasing in the population of the area under study. In order to develop a more comprehensive analysis, comparison was developed with all four models result and the see clearly the advantage of each model. The results showed the effectiveness of the models, in all criteria considered: minimization of distance, minimization of cost, maximization of coverage and minimization of maximal distance. The four types of models tested showed total demand coverage with a better service (large reductions in the distance of facilities) and all the results were compared. From the result the first best model is the p-median which has a performance more than 85% of the population served by facility located at distance less than 2km, the second best model is the set covering, which has a performance, with a considerable portion of the population located at the same distance (77.9%). The third best model set covering with solution of this model 77.7% of the population at the same distance, the fourth best model is the p-center, which presented solution were 76% of the population would be located at less than 2km of its nearest health facility [51].

The study of Chanta and others, (2011) titled "**Improving Emergency Service in Rural Are: a Bi-Objective Covering Location Model for EMS Systems**"

The objective of this study is to balance the level of first-response ambulatory service provided to patient in urban and rural areas by locating ambulances at appropriate stations. The objective of covering location model is to minimize demand that can be covered. Consequently, these models favor locating ambulances in more density populated areas. To address the issue of fairness in semi-rural/semi-urban communities, the study propose the bi-objective covering location models that directly consider fairness. The three bi-objective models for locating EMS ambulance is the traditional covering problem objective of maximizing expected coverage while the second objective aims to improving service in rural area. The study proposed three alternatives to be the second objective are: (1) minimizing the maximum distance between each uncovered demand zone and its closet opened station, (2) minimize the number of uncovered rural demand zones, and (3) minimize the number of uncovered demand zones. These three models are formulated as integer programs. Non-dominated solutions to each bi-objective model are generated using the epsilon constraint approach. The key contribution of this paper is that it provides a model for reducing the geographic disparities in service between different demographic. The study used data from the Hanover Fire/EMS department which located in Virginia, the EMS department response to 911 calls 24 hours a day and serves a country of 474 square miles, which the population nearing 100,000 individuals with 16 EMS ambulance stations, the population density information captured from GIS data. The input data to the model are the number of requested calls (or call volume) in the each demand zone, the geographical coordinates of the 122 demand zones (ignore the zones that have no demand during 2007) and 16 potential locations, and the demand zone classification, as either rural or urban. The Hanover standard to response-time threshold of 9 minutes for the covering objective. The results of a single objective model is there are 5 ambulances, this single objective covering location model locates 4 ambulances in urban areas and 1 in the rural area, thus the majority of the uncovered demand zones are rural. The results of the bi-objective model provide decision makers with more alternative to reduce the disparity between service in urban and rural areas. With 5 ambulances to be located , the maximum expected demand that can be covered is 1260.3 calls (73.66% off calls), and the maximum distance between uncovered rural demand zones are 18,63 and 69 miles [10].

The study of Amponsah and others, (2011) titled "**<u>Location of Ambulance Emergency Medical Service in the Kumasi Metropolis, Ghana</u>**"

This paper presented a case study of the ambulance location problem in an urban setting as the Kumasi metropolis in Ghana is solved. The Non-linear Maximum Expected Covering Location Problem (MEXCLP) was implemented. Kumasi is the second largest city of Ghana with population of 1,517,000. There are 5 ambulances currently located in the area. To solve the maximum expected covering problem, Genetic Algorithms (Gas) which is a computational method inspiring by evolution used as approach to compared the performance. The application instance is fully defined by the number of nodes, the distance matrix, the coverage radius of the servers, the number of servers, distribution calls among the nodes, and the system wide probability of a server being busy when is called to service. The network consist of 54 nodes among which ambulance going to be located and these nodes were selected based on a Geographic Information System (GIS) buffering technique. The edge matrix used in the work is based on real distance and not Euclidean distance. The average response time which is an important parameter in EMS in the study was 12 minutes and the coverage radius calculated from the 5-month data in time 12 minutes is 8km and in 10(response time set by US EMS 1973) minutes 7km, the system-wide probability (p)=0.02. the results of optimal solution show that the solution three is the optimal solution to locate seven ambulances at the submetro centers of Kumasi metropolis [3].

The study of Koc and others, (2011) titled " **<u>A Reliability Based Solution to an Ambulance Location Problem Using Fuzzy Set Theory</u>**"

In this study, the Reliability Based Double Standard Model (RBDSM) was proposed to address the travel time uncertainty associated with the determination of the coverage. This new coverage model was applied to solve the ambulance location problem of the province of Sivas, Turkey. The reliability analysis were performed between all demands as a function of the fuzzy shortest travel time and fuzzy target travel time. The results indicate that the fuzzy travel times may be appropriate to handle the uncertainty investigated here and have a good potential to be used for the ambulance location problems. The surface are of the province of Sivas, Turkey is about 35.715km2 and a population of 283233 inhabitants. It distributed among 60 zones. From results the RBDSM addresses the travel time uncertainty in determining the coverage of the demand points and a fuzzy approach (fuzzy shortest travel time and fuzzy target travel time) can be useful to handle the travel time uncertainty in the ambulance location problem. It may provide a flexible and efficient alternative to estimate the travel time and these travel times may also serve as a reference for future measures by EMS staff or other health providers in an emergency [36].

The study of Ates and others, (2011) titled "**<u>Determining Optimum Ambulance Locations for Heart Attack Cases With GIS</u>**"

The objective of this paper is to provide optimum distribution of ambulance stations without exceeding standard heart attack response time in Istanbul. In this context, existing ambulance service areas are determined with ArcGIS Network Analysis in order to understand which areas remained out service zone. The area of study (Istanbul) selected because of its different socio-demographic structure, high population and containing 40 municipalities. Geographic data used in the scope of study are composed of 4 different groups; Health , Administrative unit, Transportation, and Land Cover. Administrative boundaries of the study area (province, country, district), road network, locations of existing ambulance stations, population and acute myocardial infarction (AMI) patient data are the basis of database design. Final distribution of ambulance stations provide an ambulance for every 50,000 people in built-up area with respect to the Regulation of Emergency Medical Services. In the study the optimum locations of the ambulance are determined at district level. As a result of optimization process , 1 station is completely removed, 4 stations locations are changed from existing 120 ambulance station and 41 new ambulance are recommended. In this contest, the new system has 160 ambulance stations which will provide 279 new ambulance vehicles added in the scope of regulation [5].

The study of Inakawa and others, (2010) titled "**<u>Effect of Ambulance Stations Locations and Number of Ambulances to the Quality of the Emergency Service</u>**"

The objective of this paper is to consider ambulance system by the aspect of their response time using queueing simulation to introduce the actual situation for ambulance system of Seto City in Japan, and proposed queueing simulation model to compute mean response time , loss ratio and other several important indices. The study present two simulation experiment, one is about the decision-making for restructuring of the ambulance system , other one is about relation between ambulance locations and the number of ambulance.

The number of calls in 2007 was about 5.29 million that mean one of the 26 people in Japan is transported by the ambulance with a year. Every city in Japan runs own ambulance system. The results of the simulation model of the two experiment was to constructing a new station is twice as effective as adding a new ambulance for Seto City, this mean that is important to evaluate restructuring plans concretely. In the second simulation experiment show that lower bound of mean response time the value of this bound greatly influences for an efficient system improvement [31].

The study of Morohosi, (2008) titled "**<u>A Case Study of Optimal Ambulance Location Problem</u>**"

This paper presented to give a comparison (actual location and optimal solution) of the optimization models of ambulance stations through actual patient call data from Tokyo metropolitan area to show the characteristics of each model and investigate a possible improvement in ambulance service. Coverage model and median model is approaches proposed to this problem (ambulance stations). Coverage model looks for the location to maximize the (deterministic or probabilistic) demand of ambulance calls and this model can be thought of reliability oriented model. The median model the objective is to minimize the total traveling distance of the ambulance form the station to the scene of call. This model gives more weight to the efficiency of ambulance operations. The results shows that the optimal solution can achieve improvement in both models, and suggests the possibility of more efficient and reliable location. The most distinctive feature of the problem is to stochastic property demand. The data to analyze of ambulance system of Tokyo special word area in 2002, the number of days is 300, the number of dispatch is 397242 calls, the ambulance number is 145 ambulance and the town divided to 3115 blocks. The standard response-time to achieve is five minutes and the vehicle speed in Tokyo is approximately 350m/min, that mean the distance should be 1750m (Euclidean distance measure) or 1250m (Manhattan distance). The optimal solution by LSCM model found that 85 ambulances are needed to in the distance of 1750m while the actual number of ambulance is 145 when D=1500 and D=1250, necessary number of ambulances are 132 and 153, respectively. This result encouraging to try to find more reliable and efficient location for ambulance. By the apply median model the average traveling distance computed from objective value of optimal location is 667m while the average traveling distance from the actual location(the actual traveling distance measured on the real road network) is 2100m [45].

The study of Aringhieri and others, (2007) titled "**Ambulance Location through Optimization and Simulation: the Case of Milano Urban area**"

This paper presented three step approach to deal with the problem of locating ambulance posts over an urban area. First real life data on the considered system behavior are analyzed. Then integer linear programming model are considered with the aim of finding new post locations. The third is simulation framework for testing the behavior of the proposed solutions that respect to the real life situation. The paper deal with the problem of locating the ambulances in agreement with the official Emergency Medical Service, called Also 118. The Italian law states that the response to emergency calls has to be performed within a mandatory time of 8 minutes in the urban areas (LA time). In Milano urban area only around 60% of the emergency calls are served within LA time. The aim of this work is to is to analyze the data on the system behavior to point out possible criticality and then to provide, through optimization and simulation, suggestions for the emergency service management. In 2005 The amount of calls received and of required ambulance were 145844 and 96094, respectively with 29 ambulance posts and divided the demand area using square grid with a side per element of about 593 meters. The study focus on static deterministic models such as LSCM to optimizing the optimal location of the ambulance and developed a new model tailored Milano case. The model is static one and does not consider the arriving calls from a dynamic point of view. The model considers the dimensioning of the ambulance post, the number of ambulance to be located in each post, to satisfy the total demand and consider a second time limit less than the LA time [4].

The study of Takeda and others, (2007) titled "**Analysis of Ambulance Decentralization in an Urban Emergency Medical Service using the Hypercube Queueing Model**"

This paper presented studies the application of the hypercube queueing model to SAMU-192, the urban Emergency Medical Service of Campinas in Brazil. The hypercube is a powerful descriptive model to represent server-to-customer systems, allowing the evaluation of a wide variety of performance measures for different configurations of the system. In its original configuration, SAMU-192 had all ambulances centralized in its central base.

This study analyzes the effects of decentralizing ambulances and adding new ambulances to the system, comparing the results to the ones of the original situation. It is shown that, as a larger number of ambulances are decentralized, mean response times, fractions of calls served by backups and other performance measures of the system are improved, while the ambulance workloads remain approximately constant. However, total decentralization as suggested by the system operators of SAMU-192 may not produce satisfactory results.

The mean travel time of the system reduces from 13.6 min (centralized configuration) to 11.4min (six ambulances decentralized). The fraction of advanced calls assisted by backups (BSVs) also decreases from 19% to 11% [69].

The study of Pasha, (2006) titled " **Ambulance Management System Using GIS**"

This study present the problems of study area faced by emergency service providers on road network are identified. In this study Geographical Information System (GIS)/Global Positioning System (GPS)/Global Communication System (GSM)based prototype system has been developed for routing of ambulance on road network of Hyderabad city (AMS). This prototype is designed such that it finds the accident location on the road network and locates the nearest ambulance to incident site using the real-time technologies (GPS/GSM). AMS create the fastest route from nearest ambulance to accident site, and from there to nearest hospital. Congestion on the roads during peak hour is considered, and the fastest route on both major and minor roads is created. AMS user interface has been developed using VBA, ArcGIS (network analyst) [37].

The study of Alsalloum and Rand, (2003) titled " **A goal –Programming Model Applied to the EMS System at Riyadh City, Saudi Arabia**"

This paper presented applied of Maximal Covering Location Problem (MCLP) as approach model of facility location to the Saudi Arabian Red Crescent Society (SARCS), Riyadh City.

The proposed is to identify the optimal locations of emergency medical services (EMS) stations and this is achieved by locating these stations so the maximum expected demand may be reached within a pre-specified target time and by ensuring that any demand located within the target time will find at least one ambulance available. The EMS receives more than 13000 calls on average a year (36 calls a day) using 7 stations and 35 ambulance. The EMS system is self-contained system, because each station is responsible only for those demands within its boundary. The area divided to 92 quarters, as in the CRCR records. Detailed information for more than 3800 incidents was collected for comparing the results from the model. The existing 7 stations only cover 74% of the population with 10 minutes and to cover a whole city at least 17 station are needed, therefore , about 24 ambulance are needed to ensure that any call find at least an idle ambulance within 20 minutes driving to serve it [1].

8. Summary of Previous studies

Each study has research gap. Table 1.1 provided the comparison between the research gap of each previous study are listed in this chapter.

Table 1.1: Summary of the research gap in previous studies

No.	Researcher	Research title	Research gap
1.	Alsalloum and Rand, (2003)	A goal –Programming Model Applied to the EMS System at Riyadh City, Saudi Arabia"	applied of Maximal Covering Location Problem (MCLP) as approach model of facility location to the Saudi Arabian Red Crescent Society (SARCS), Riyadh City
2.	Pasha, (2006)	Ambulance Management System Using GIS"	Geographical Information System (GIS)/Global Positioning System (GPS)/Global Communication System (GSM)based prototype system has been developed for routing of ambulance on road network of Hyderabad city (AMS).
3.	Takeda and others, (2007)	Analysis of Ambulance Decentralization in an Urban Emergency Medical Service using the Hypercube Queueing Model	the application of the hypercube queueing model to SAMU-192, the urban Emergency Medical Service of Campinas in Brazil.
4.	Aringhieri and others, (2007)	Ambulance Location through Optimization and Simulation: the Case of Milano Urban area	three step approach to deal with the problem of locating ambulance posts over an urban area
5.	Morohosi, (2008)	A Case Study of Optimal Ambulance Location Problem	comparison (actual location and optimal solution) of the optimization models of ambulance stations through actual patient call data from Tokyo metropolitan area to show the characteristics of each model and investigate a possible improvement in ambulance service
6.	Inakawa and others, (2010)	Effect of Ambulance Stations Locations and Number of Ambulances to the Quality of the	consider ambulance system by the aspect of their response time using queueing simulation to introduce the actual situation for ambulance system of Seto City in Japan, and

No.	Researcher	Research title	Research gap
		Emergency Service	proposed queueing simulation model to compute mean response time , loss ratio and other several important indices.
7.	Chanta and others, (2011)	Improving Emergency Service in Rural Are: a Bi-Objective Covering Location Model for EMS Systems	balance the level of first-response ambulatory service provided to patient in urban and rural areas by locating ambulances at appropriate stations
8.	Amponsah and others, (2011)	Location of Ambulance Emergency Medical Service in the Kumasi Metropolis, Ghana	case study of the ambulance location problem in an urban setting as the Kumasi metropolis in Ghana is solved
9.	Koc and others, (2011)	A Reliability Based Solution to an Ambulance Location Problem Using Fuzzy Set Theory	Reliability Based Double Standard Model (RBDSM) was proposed to address the travel time uncertainty associated with the determination of the coverage
10.	Ates and others, (2011)	Determining Optimum Ambulance Locations for Heart Attack Cases With GIS	provide optimum distribution of ambulance stations without exceeding standard heart attack response time in Istanbul
11.	Rabello and others, (2012)	Optimization Models in the Location of Healthcare Facilities: a Real Case in Brazil	find the optimal solutions proposed by the location models of the healthcare facilities and carried out as real experiment in Brazilian city to confront the current sites configuration
12.	Looije, (2013)	Optimal Ambulance Locations in the Netherlands	determine the optimal locations of ambulance stations in Netherlands, to be able to provide the best coverage with the least number of stations
13.	Limpattanasiri and others, (2013)	Solving a Maximal Covering Model of Emergency Ambulance Location Problem in Urban Areas by Dynamic Programming Technique	consider the maximal covering ambulance location problem for regular traffic situation and heavy traffic congestion situation in urban area
14.	Ramashe and others, (2014)	A Bi-Objective Model for Locating and Sizing Emergency Stations	presented a bi-objective model within the integer linear programming framework to determine the location of

No.	Researcher	Research title	Research gap
			emergency stations, the regions covered by each of these stations and location of ambulance to these stations. Objectives of this model are minimizing the cost of locating the stations and ambulances as well as the maximum time it takes to sever the demands

Comments on the previous studies:

There is large number of foreign studies regarding to the ambulance location problems and the optimization solution by using different models or simulation framework.

These studies provides multiple models and the effective of application these model on the real world of EMS by reducing time response and relocating the ambulance stations to increase the covering area.

The studies are one of the three types, first use direct models and implement with real data. Second use the data to find optimization solution and formulate simulation framework to ensure the results given by the optimization solution. Last type which using the GIS technique to find the optimal ambulance location by using the geographical data.

There is no local studies talk about this subject and this study is the first.

This study is important to implement the location models used in the decision of ambulance location sites in Gaza Strip to measure the performance of the EMS and improving the performance.

Chapter Two: Literature Review

1. Introduction
2. Ambulance Location Models
3. Heuristic Optimization Methods
4. Exact Optimization Methods
5. Simulation models
6. Geographic Information System (GIS) technique
7. Summary

1. First: Introduction:

The location of facilities is critical in both industry and in healthcare , in healthcare the poor location means increase in death and disease [15].

The location problems of EMS facilities are an active study area. Most studies are on model development and solution methods rather than being application-oriented studies [5]. The literature on the ambulance positioning system truly to reflects the evolution of ambulance location and relocation models proposed over the past 30-years [16]. This chapter focus on the models that have been developed for ambulance locations and optimization methods using to find optimal solution, last the using of Simulation and GIS in ambulance location problem.

2. Ambulance Locations Models:

The Ambulance location problem is a decision problem to locate ambulance stations for optimizing the objective function. There have been 100's of journal paper covering models of EMS. The reason for the large amount of work that the system is very important to the public and hence designing and operating them well leads to a clear sense of purpose for the researcher [38].

Brotcorne et al. (2003) classified ambulance location models into 3 categories. The static and deterministic models are used for planning state and ignore stochastic considerations regarding the availability of ambulances. The probabilistic models reflect the fact that ambulances operate as servers in a queuing system and cannot always answer a call. And the dynamic models are the models that have been developed to repeatedly relocate ambulance throughout the day. List of models classified by Brotcorne et al. (2003) are presented in Table 2.1.

Table 2.1: Ambulance location models classified by (Brotcorne et al. 2003).

Deterministic models	
1.	Toregas *et al*. (1971), the location set covering model (LSCM)
2.	Church and ReVelle (1974), the maximum covering location problem (MCLP)
3.	Schilling *et al*. (1979), the tandem equipment allocation model (TEAM)
4.	Schilling *et al*. (1979), the facility-location, equipment-emplacement technique (FLEET)
5.	Daskin and Stern (1981), the hierarchical objective set covering (HOSC)
6.	Hogan and ReVell (1986), the backup coverage formulation 1 (BACOP1)
7.	Hogan and ReVell (1986), the backup coverage formulation 2 (BACOP2)
8.	Gendreau *et al*. (1997), the double standard model (DSM)
Probabilistic models	
1.	Daskin (1983), the maximum expected covering location problem (MEXLP)
2.	ReVelle and Hogan (1989a), the maximum availability location problem I (MALP I/ MALP II)
3.	Batta *et al.* (1989), the adjusted MEXCLP (AMEXCLP)
4.	Ball and Lin (1993), the reliability model (Rel-P)
5.	Repede and Bernardo (1994), the time dependent MEXCLP (TIMEXCLP)
6.	Marianov and ReVlle (1994), the queueing probabilistic LSCP (Q-PLSCP)
7.	Mandell (1998), the two-tiered model (TTM)
Dynamic models	
1.	Gendreau *et al*. (2001), the dynamic DSM (DSM)

Goldberg (2004) classified ambulance location models into 5 categories. The static models used a single set of demand and travel time data. The multiple objectives models combined these objectives into a single objective. If f(x) and g(x) are objective functions, w is between 0 and 1, and then $w \cdot f(x) + (1-w) \cdot g(x)$ is a combined objective (this is called the "weighting method"). The back-up coverage model concerned the level of demand covered at least twice. The multiple vehicle type's models handle more one type of vehicle. The dynamic models are re-positioning model for real time. List of models classified by Goldberg are presented in Table 2.2.

Table 2.2: Ambulance location models classified by Goldberg (Goldberg,2004).

Static models	
1.	Toregas *et al*. (1971), the location set covering model (LSCM)
2.	Church and ReVelle (1974), the maximal covering location problem (MCLP)
Multiple objectives models	
1.	Daskin and stern (1981), the hierarchical objective set covering (HOSC)
2.	Baker *et al*. (1989), the county emergency medical service ambulance allocation (CEMSAA)
3.	ReVelle *et al.*(1996), the multiobjective conditional covering problem (MOCCP)
	Back-up coverage models
4.	Daskin (1983), the maximal expected covering location problem (MEXCLP)
5.	Hogan and ReVelle (1986), the backup coverage formulation 1 (BACOP1)
6.	Hogan and ReVelle (1986), the backup coverage formulation 2 (BACOP2)
7.	ReVelle and Hogan (1989a), the maximum availability location problem (MALP I/ MALP II)
8.	ReVelle and Hogan (1989b), the maximum reliability location problem (MRLP)
9.	Ball and Lin (1993), the reliability model (Rel-P)
10.	Marianov and ReVelle (1994), the queueing probabilistic LSCP (Q-PLSCP)
11.	Marianov and ReVelle (1994), the queueing MALP (Q-MALP)
12.	Gendreau *et al.* (1997), the double standard model (DSM)
13.	Marianov and Serra (1998), the queueing maximal covering location-allocation model (QM-CLAM)
14.	Marianov and Serra (2002), the probabilistic location-allocation set covering model (PLASC)
	Multiple vehicle types models
1.	Schilling *et al*. (1979), the tandem equipment allocation model (TEAM)
2.	Schilling *et al*. (1979), the facility-location, equipment-emplacement technique (FLEET)
3.	Charnes and Storbeck (1980), the multilevel, goal-oriented location covering model (MGLC)
4.	ReVelle and Snyder (1995), the fire and ambulance service technique (FAST)
5.	Serra (1996), the coherent covering location problem (CCLP)
6.	Mandell (1998), the two-tiered model (TTM)
	Dynamic models
1.	Gendreau *et al*. (2001), the dynamic DSM (DSM)

The ambulance location models can be placed into three kinds of problems are the set covering problem (SCP), the maximum coverage problem (MCP), and the p-median problem (PMED). SCP aims to minimize the number of facilities that covered all demand nodes. MCP aims to maximize demand covered by given number of facilities. PMED aims to minimize summation of distance between facilities and demand nodes that covered by the facility. Ambulance location models are defined on graph $G = (I \cap J, E)$ where I is a node set representing aggregated demand nodes, J is a set of potential ambulance location sites, and $E = \{(i,j): i \in I \; and \; j \in J\}$ is a set of edges. With each edge (i,j) is associated a travel time t_{ij}. Demand node $i \in I$ id covered by site $j \in J$ if and only if $t_{ij} \leq r$, where r is a preset coverage standard. Let $J_i = \{j \in J: t_{ij} \leq r\}$ be the set of location sites covering demand node i. Let x_j is binary variable be 1 if and only if demand node $i \in I$ is covered by at least one ambulance station. The maximum number of stations denoted to s. The maximum number of ambulances denotes to n. Denote d_i is demand at demand node i. The existing ambulance location models are presented below. An overview of the notation and the mathematical formulation of the models described in this section can be found in Appendix C.

LSCM (1971)

The location set covering model (LSCM) of Toregas *et al.* (1971) aims to minimize the number of ambulance needed to cover all demand nodes. The formulation of LSCM is:

$$\text{Minimize} \quad \sum_{j \in J} x_j \tag{2.1}$$

$$\text{Subject to} \quad \sum_{j \in J_i} x_j \geq 1 \qquad \forall \, i \in I \tag{2.2}$$

$$x_j = 0, 1 \qquad \forall \, j \in J \tag{2.3}$$

$$\text{where} \quad x_j = \begin{cases} 1 \text{ if station } j \text{ is allocated} \\ 0 \text{ otherwise} \end{cases}$$

For LSCM model, the objective function (2.1) minimize the number of facilities to be located. Constraint (2.2) ensures that each demand node is covered by at least one facility. Constraint (2.3) enforces the yes or no of the siting decision.

MCLP (1974)

The maximal covering location problem (MCLP) proposed by Church and ReVelle (1974). Denoted the demand of node i by d_I and s is the number of stations to be located. The MCLP aims to maximize demand covered with s number of stations. The model of MCLP is:

$$\text{Maximize} \quad \sum_{i \in I} d_i y_i \tag{2.4}$$

$$\text{Subject to} \quad \sum_{j \in J_i} x_j \geq y_i \qquad \forall\, i \in I \tag{2.5}$$

$$\sum_{j \in J} x_j = s \tag{2.6}$$

$$x_j, y_i = 0, 1 \tag{2.7}$$

where
$$x_j = \begin{cases} 1 \text{ if stations located at site } j \\ 0 \text{ otherwise} \end{cases}$$

$$y_i = \begin{cases} 1 \text{ if demand node } i \text{ is covered} \\ 0 \text{ otherwise} \end{cases}$$

For MCLP model, the objective function (2.4) maximizes demand covered. Constraint (2.5) mean that demand node is covered only if at least an ambulance station is located in J_i . Constraint (2.6) control the number of allocated stations in solution. Constraint (2.7) enforces the yes or no nature of the siting decision and covering of demand nodes.

TEAM (1979)

Schilling *et al.* (1979) proposed the tandem equipment allocation model (TEAM) to allocate maximum coverage location for two types of ambulance. The formulation is:

$$\text{Maximize} \quad \sum_{i \in I} d_i y_i \tag{2.8}$$

$$\text{Subject to} \quad \sum_{j \in J_i^A} x_j^A \geq y_i \qquad \forall\, i \in I \tag{2.9}$$

$$\sum_{j \in J_i^B} x_j^B \geq y_i \qquad \forall\, i \in I \tag{2.10}$$

$$\sum_{j \in J} x_j^A = n^A \tag{2.11}$$

$$\sum_{j \in J} x_j^B = n^B \tag{2.12}$$

$$x_j^A \quad \leq x_j^B \qquad \forall\, j \in J \tag{2.13}$$

$$x_j^A, x_j^B, y_i = 0, 1 \tag{2.14}$$

where $x_j^A, x_j^B \quad = \begin{cases} 1 \text{ if ambulance type A, B locate at site } j \\ 0 \text{ otherwise} \end{cases}$

$y_i \quad = \begin{cases} 1 \text{ if node } i \text{ covered 2 types of ambulance} \\ 0 \text{ otherwise} \end{cases}$

n^A, n^B = number of ambulance type A and type B

r^A, r^B = standard coverage time of ambulance type A and type B

$J_i^A \quad = \{ j \in J : \ t_{ij} \leq r^A \}$

$J_i^B \quad = \{ j \in J : \ t_{ij} \leq r^B \}$

For TEAM model, the objective function (2.8) maximizes demand covered. Constraint (2.9) and (2.10) ensure that a demand node is covered only if it is covered by both type B and type A. constraints (2.11) and (2.12) control total number of ambulance type A and type B. Constraint (2.13) ensures that type A is located only at nodes possessing type B. Note that the service distance standard for type A need not be the same as that for type B. Constraint (2.14) enforces the yes or no nature of the siting decision and covering of demand nodes.

FLEET (1979)

Schilling *et al.* (1979) proposed the facility- location, equipment-emplacement technique (FLEET) to allocate maximum coverage location for several types of ambulance. The FLEET model locates several type of ambulance to provide the best service without the restrictions imposed by a required ordering. The formulation is:

$$\text{Maximize} \quad \sum_{i \in I} d_i y_i \qquad (2.15)$$

$$\text{Subject to} \quad \sum_{j \in J_i^A} x_j^A \geq y_i \qquad \forall\, i \in I \qquad (2.16)$$

$$\sum_{j \in J_i^B} x_j^B \geq y_i \qquad \forall\, i \in I \qquad (2.17)$$

$$\sum_{j \in J} x_j^A = n^A \qquad (2.18)$$

$$\sum_{j \in J} x_j^B = n^B \qquad (2.19)$$

$$\sum_{j \in J_N} z_j = s^z \qquad (2.20)$$

$$x_j^A \leq z_j \qquad \forall\, j \in J_N \qquad (2.21)$$

$$x_j^B \leq z_j \qquad \forall\, j \in J_N \qquad (2.22)$$

$$x_j^A, x_j^B, y_i, z_j = 0, 1 \qquad (2.23)$$

where

$x_j^A, x_j^B = \begin{cases} 1 \text{ if ambulance type A, B locate at site } j \\ 0 \text{ otherwise} \end{cases}$

$y_i = \begin{cases} 1 \text{ if node } i \text{ covered 2 types of ambulance} \\ 0 \text{ otherwise} \end{cases}$

$z_j = \begin{cases} 1 \text{ if a facility located at site } j \\ 0 \text{ otherwise} \end{cases}$

n^A, n^B = number of ambulance type A and type B

s^z = number of new facilities to be built

r^A, r^B = standard coverage time of ambulance type A and type B

$J_i^A = \{j \in J : \; t_{ij} \leq r^A\}$

$J_i^B = \{j \in J : \; t_{ij} \leq r^B\}$

J_N = set of potential new facility locations; $J_N \subset J$

For FLEET model, Constraints (2.15)-(2.19) followed the constraints (2.8)-(2.12) of TEAM. Constraint (2.20) control number of new facilities to be built. Constraints (2.21) and (2.22) prohibit the emplacement of equipment at nodes where facilities have not been located. This formulation assumes that those nodes in J but no in J_{N} have facilities already in place and are eligible for equipment emplacement. Note that FLEET model can be considered also as a special case of TEAM model which $J_{\mathrm{N}} = \emptyset$ and constraint (2.21) to constraint (2.22) are vacuous. Constraint (2.23) enforces the yes or no nature of the sitting decision and covering of demand nodes.

MGLC (1980)

Charnes and Storbeck (1980) proposed the multilevel, goal-oriented location covering (MGLC) model to minimize the number of uncovered call for two types of ambulance.

The MGLC formulation is:

$$\text{Minimize} \quad \sum_{i \in I} c_i^1 y_i^{\alpha-} + c_i^1 y_i^{\beta-} + c_i^2 y_i^{\theta-} \tag{2.24}$$

$$\text{Subject to} \quad \sum_{j \in J} a_{ij}^1 x_j^1 - y_i^{\alpha-} = 1 \qquad \forall\, i \in I \tag{2.25}$$

$$\sum_{j \in J} a_{ij}^1 x_j^2 - y_i^{\alpha-} - y_i^{\beta+} + y_i^{\beta-} = 0 \qquad \forall\, i \in I \tag{2.26}$$

$$\sum_{j \in J} a_{ij}^2 x_j^2 - y_i^{\theta+} + y_i^{\theta-} = 1 \qquad \forall\, i \in I \tag{2.27}$$

$$\sum_{j \in J} x_j^1 = n^1 \qquad \forall\, j \in J \tag{2.28}$$

$$\sum_{j \in J} x_j^2 = n^2 \qquad \forall\, j \in J \tag{2.29}$$

$$a_{ij}^1, a_{ij}^2, x_j^1, x_j^2, y_i^{\alpha-}, y_i^{\beta-}, y_i^{\theta-} = 0, 1 \qquad \forall\, i, j \tag{2.30}$$

$$y_i^{\alpha+}, y_i^{\beta+}, y_i^{\theta+} \geq 0 \qquad \forall\, i \in I \tag{2.31}$$

where c_i^1 = number of critical call at node i

c_i^2 = number of non-critical call at node i

$a_{ij}^1 = \begin{cases} 1 \text{ if travel time from } j \text{ to } i \text{ is within standard for critical call} \\ 0 \text{ otherwise} \end{cases}$

$a_{ij}^2 = \begin{cases} 1 \text{ if travel time from } j \text{ to } i \text{ is within standard for non-critical call} \\ 0 \text{ otherwise} \end{cases}$

$x_j^1 = \begin{cases} 1 \text{ if station } j \text{ is allocated ambulance type A} \\ 0 \text{ otherwise} \end{cases}$

$x_j^2 = \begin{cases} 1 \text{ if station } j \text{ is allocated ambulance type B} \\ 0 \text{ otherwise} \end{cases}$

$y_i^{\alpha-} = \begin{cases} 1 \text{ if critical call of demand node } i \text{ is uncovered by type A} \\ 0 \text{ otherwise} \end{cases}$

$y_i^{\beta-} = \begin{cases} 1 \text{ if critical call of demand node } i \text{ is uncovered by type B} \\ 0 \text{ otherwise} \end{cases}$

$y_i^{\theta-} = \begin{cases} 1 \text{ if non-critical call of demand node } i \text{ is uncovered by type B} \\ 0 \text{ otherwise} \end{cases}$

$y_i^{\alpha+}$ = number of type A covered critical call of demand node $i - 1$

$y_i^{\beta+}$ = number of type B covered critical call of demand node $i - 1$

$y_i^{\theta+}$ = number of type B covered non-critical call of demand node i - 1

n^1 = number of ambulances type A

n^2 = number of ambulances type B

For MGLC model, the objective function (2.24) minimize the number of uncovered calls. Constraint (2.25) ensures that at least an ambulance type A covered critical call of demand node i if travel time between station j and demand node i within standard of critical call. Constraint (2.26) implements backup coverage for critical call by ambulance type B. It ensures that at least an ambulance type B covered critical call of demand node i if travel time between station j and demand node i within standard of critical call. Constraint (2.27) ensures that at least an ambulance type B covered non-critical call of demand node i if travel time between station j and demand node i within standard of non-critical call. Constraints (2.28) and (2.29) control total number of ambulance type A and type B. Constraint (2.30) enforces the yes or no nature of the sitting decision and covering of demand nodes. Constraint (2.31) enforces demand nodes is covered by at least an ambulance.

Later, the backup coverage problem (BACOP) 1 and 2 were developed in 1986. The BACOP models try to cover as many demand points as possible twice. The most important difference between these models is that the first version has the constraint that every demand point has to be covered once and the objective is to maximize the demand covered twice, whereas in the second version there is no constraint on coverage, but the objective is to maximize both the demand covered once, as well as the demand covered twice. The objective function for BACOP2 is a combination of the demand covered once and the demand covered twice, where the coefficient can be specified. The next model will be described is the double standard model (DSM), published in 1997 by Gendreau et al. The DSM model looks for a solution that covers all demand points at least once, within a time r1 and α percent within a time r2 (where r2 < r1). Simultaneously it tries to cover as many demand points as possible twice within a time r1. The last model will be described is multi-period the double standard model (mDSM), published in 2010 by Schmid and Doerner for relocation strategy based on the DSM model.

3. Heuristic Optimization Methods:

The models that are discussed in this chapter are (binary) integer linear programs. The location problem is NP-Hard (Non-deterministic Polynomial hard) problem, Generally, (mixed) or large integer programming models are used to formally describe combinatorial optimization problem. When it is possible, linear models are used. Optimization methodologies can be classified in **exact or heuristic** [58].

Constructive heuristics are often designed ad-hoc to exploit the characteristic of each problem. The most popular methodology is the Greedy Adding Algorithm. The most popular metaheuristic are Tabu Search, Simulated Annealing, Evolutionary Algorithms, Variable Neighborhood Search, Ant Colony Systems [34].

4. Exact Optimization Methods:

Both exact and meta-heuristic algorithms have been practices for solving location problems. However, effectiveness of the exact algorithms is limited to small size problem. There are four exact optimization methods, first Linear Programming, second Branch and Bound Method , third is A Constraint Programming and the last Dynamic Programming [34].

5. Simulation models:

With help simulation, one can try to evaluate solutions and get insight for improvement. There is also quite some literature considering simulation for ambulance planning because determining the number of needed ambulances highly depends on the time-dependent demand and travel time. Several of simulation studies use simulation to evaluate location policies determined by optimization models. Some studies use simulation in combination with a form of branch-and bound to determine the location of ambulances. The assigned number of ambulances per base is set sufficiently high to serve all request, and after the simulation it is determined how many ambulances are needed to guarantee availability [28].

6. Geographic Information System (GIS) Technique:

Geographic Information System (GIS) can be used as Decision Support System for planning and managing the health services. Referencing data related to health geographically is possible with the using of GIS. Collecting, storage, presentation, and analysis of geo-based spatial and attribute data are provided in the scope of GIS and by its way a new approach to render the spatial decisions related to health has constituted for complex situations. Today different disciplines use Information Technology (IT) to process the geographic information (remote sensing, geography, civil engineering, cartography, topology, geodesy, photogrammetry, ecology, computer science etc.).

GIS is mostly employed today in operational research as a one way data for mathematical models and successfully provides distance and time for their emergency services districting and location problems [47].

7. Summary

The ambulance location problem was focus since 1970s. The problems based on three paradigms are SCP, MCP, and PMED. Table 2.3 and Table 2.4 summary existing ambulance location models into those three categories.

Table 2.3: List of ambulance location

No.	SCP (8)	No.	SCP (8)
1.	LSCM (Toregan *et al.*, 1971)	**5.**	Q-PLSCP (Marianov and ReVelle , 1994)
2.	HOSC (Daskin and Stern, 1981)	**6.**	HiQ-LSCP (Marianov and Serra, 2001)
3.	PLSCP (ReVelle and Hongan, 1988)	**7.**	PLASC (Marianov and Serra, 2002)
4.	Rel-P (Ball and Lin, 1993)	**8.**	DACL (Rajagopalan *et al.*, 2008)
No.	**PMED (3)**		
1.	MRLP (ReVelle and Hogan, 1989b)		
2.	MERLP (Rajagopalan and Saydam, 2009)		
3.	SQM (Geroniminis *et al.*, 2009)		

Table 2.4: List of ambulance location models (MCP).

No.	MCP (22)	No.	MCP (22)
1.	MCLP (ReVelle, 1974)	**2.**	TIMEXCLP (Repede and Bernardo, 1994)
3.	TEAM (Schilling et al., 1979)	**4.**	FAST (ReVelle and Snyder, 1995)
5.	FLEET (Schilling et al., 1979)	**6.**	CCLP (Serra, 1996)
7.	MGLC (Charnes and Storbeck, 1980)	**8.**	Q-MALP (Marianov and ReVelle, 1996)
9.	MEXCLP (Daskin, 1983)	**10.**	DSM (Gendreau et al., 1997)
11.	BACOP1/2 (Hogan and ReVelle, 1986)	**12.**	TTM (Mandell, 1998)
13.	MOFLEET (Bianchi and Church, 1988)	**14.**	QM-CLAM (Marianov and Serra, 1998)
15.	CEMSAA (Baker et al., 1989)	**16.**	Hi-MCLP (Marianov and Serra, 2001)
17.	CMCLP (Prikul and Schilling, 1989)	**18.**	DDSM (Gendreau et al., 2001)
19.	MALP-I/II (ReVelle and Hogan, 1989)	**20.**	MECRP (Gendreau et al., 2006)
21.	MCMCLP (Prikul and Schilling, 1992)	**22.**	mDSM (Schmid and Doerner, 2010)

In the real world, the ambulance location problems are dynamic. Researchers identified the dynamic variables with mathematics methods. The stochastic variables of ambulance location problem are the amount of demand, the location of emergency cases, the availability of ambulance, the reliability of service, and the travel speed of ambulance. The optimization methods for ambulance location problems are heuristics method and exact method. The simulation method and GIS used in ambulance location problem.

Chapter Three: Methodology

First: Introduction

Second: Data Collection

1. **PRCS regions**
2. **Twenty five municipality**
3. **Distance travel model**
4. **Demand**
5. **Maximal response time**
6. **Current ambulance locations**
7. **PRCS emergency services**

Third: LSCM Application

1. **Model description**
2. **LSCM formulation**

Fourth: Summary

First: Introduction

In this chapter the data has been described which used in the model and another data give an overview of the current organization of ambulance service in Gaza Strip. The sets of demands points, (potential) location sites and traveling distance between (coverage standard area D) those points are based on the ambulance vehicle speed in Gaza strip and the achieve or standard arrival time to the scene (7,10 and 12 minutes as response time). The reference for ambulance vehicle speed in Gaza strip was 1100 m\min which described in previous study of Eljamassi [19]. The study considered every municipality area (quarter) as a demand point, based on the division of Gaza strip by both local governmental ministry and PRCS.

Second: Data Collection

The main required data for this study are the parameters or input data to the model and the others for comparison the performance in the current locations and the optimal which collected from the MOLG and the PRCS management with more explain and details in this chapter.

1. PRCS regions

For the organization of ambulance service and local governmental ministry, Gaza Strip is divided into five governorates (Rafah- Khan Yunis -Middle-Gaza-North). As shown In Figure 3.1. Every governorate consist of a main ambulance station and some consist of substation (Rafah and Khan Yunis). Every station is legally responsible for the ambulance service in its governorate.

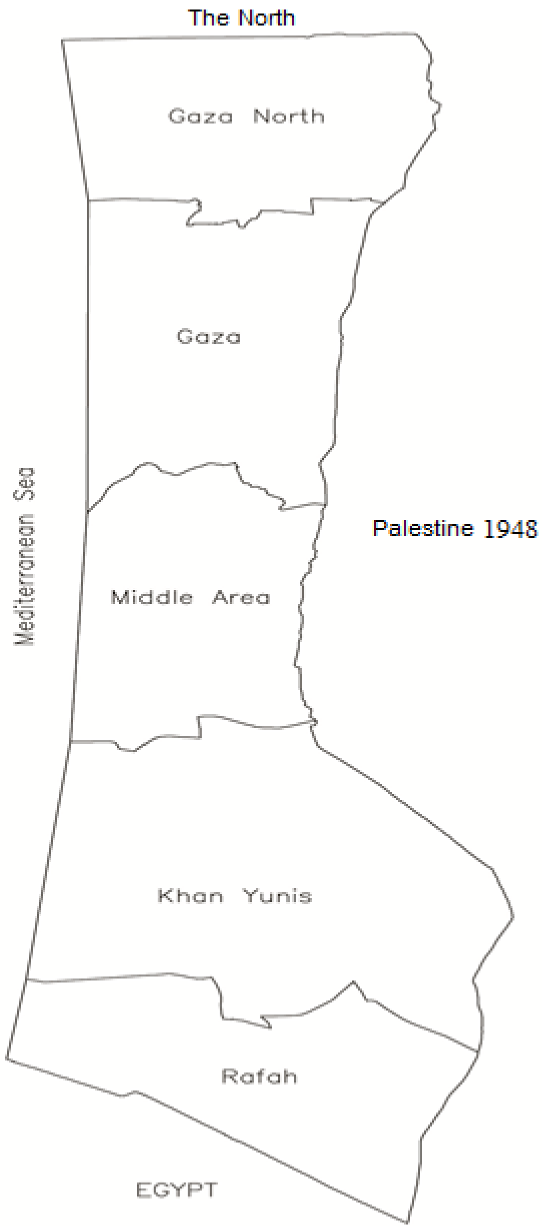

Figure 3.1: Gaza Strip Governorates

2. Twenty five municipality

In Gaza Strip each governorate region divided into municipality areas(quarter). The model considered each quarter as a region which mean a demand point. Table 3.1 and Figure 3.2 show each governorate and the municipality (quarter) which consist of it.

Table 3.1: Number of quarter per municipality.

Governorate	Municipality name	Quarter number
Rafah	Rafah	1
	Al-Naser	2
	Shoka	3
Khan Yunis	Khan Yunis	4
	Al Qarar	5
	Bani Suheila	6
	Abasan Al Kabira	7
	Abasan al Jadida	8
	Khuza’a	9
	Al fukhari	10

Governorate	Municipality name	Quarter number
Middle	An Nuseirat	11
	Al Buraij	12
	Az Zawayda	13
	Al Maghazi	14
	Deir al Balah	15
	Al Musaddar	16
	Wadi Al Salqa	17
Gaza	Gaza	18
	Madinat Ezahra	19
	Al Mughraqa	20
	Juhor ad Dik	21
North	Um Al-Naser	22
	BeitLahiya	23
	Beit Hanun	24
	Jabalya	25

Figure 3.2: The division of Gaza strip in 25 municipalities (quarters).

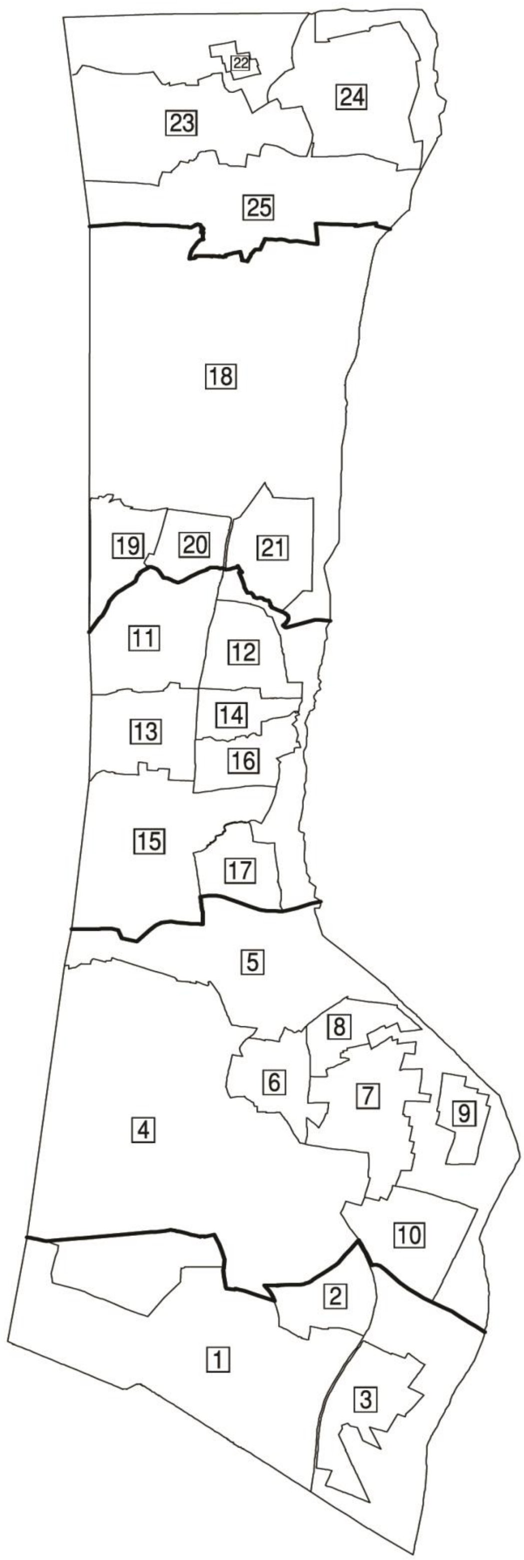

Figure 3.2: The division of Gaza strip in 25 municipalities (quarters).

3. Distance travel model

The maximum response time (or maximum service distance) is measured from the point at which the server is stationed to the point of demand [69].

The travel distance in other mean coverage standard distance D used in the modeling are determined within the Eljamassi study [19].

It consist of the estimated vehicle emergency speed in order to get from an ambulance location site to an emergency call. These vehicle speed determined using a questioning some of ambulance drivers, which observed ambulance vehicle speed in Gaza Strip metropolis is approximately 1100 m/min. to achieve 7,10 or 12 minutes maximal response time to scene (this is desirable response time for the rescue of serious patient in PRCS standard response time) D should be the multiple of the speed (1100 m/min) and standard response time form PRCS (7,10 and 12 minutes).

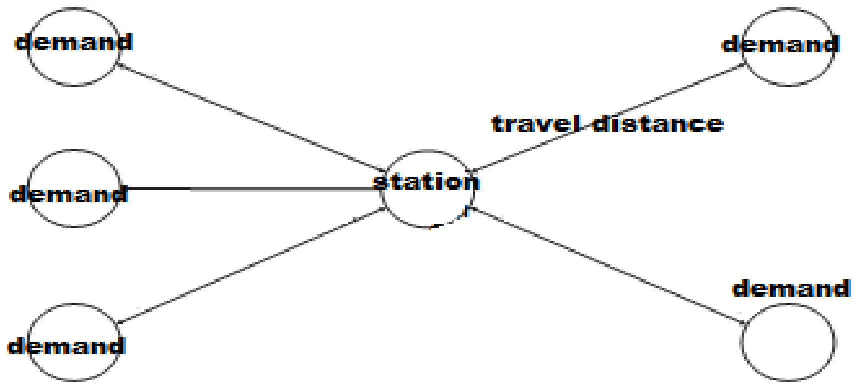

Figure 3.3: Traveling distance from the station to the demand point.

4. Demand

As the demand for each municipality quarter, the number of residents in 2014 determined by Ministry of Local Government (MOLG). This a choice made the number of residents as the demand. Table 3.2 given an indication of the distribution of the number of residents per municipality quarter.

Table 3.2: Overview of the distribution of the number of residents per quarter(2014).

Quarter number	Number of resident	Quarter number	Number of resident
1	20,190	14	27,297
2	7,235	15	79,417
3	10,367	16	2,068
4	231,000	17	5,238
5	19,025	18	700,000
6	42,854	19	2,849

Quarter number	Number of resident	Quarter number	Number of resident
7	24,408	20	2,849
8	6,340	21	3,592
9	10,869	22	3,277
10	4,178	23	76,460
11	82,415	24	51,833
12	40,772	25	227,786
13	17,404		
Total	**1,853,533**		

5. Maximal response time

A rapid response time by EMS can mean the difference between

life and death. The response time of an ambulance is defined as the time between the moment that the call is taken at the call center and the arrival of the ambulance at the scene of an incident. The aim of the PRCS ambulance services, is to reach the scene within maximal response time less than 10 minutes under normal circumstances [32]. In urban areas, the most widely used ambulance response time standard is to respond to 90% of calls within 8 minutes and 59 seconds as compared to responding to 90% of calls within 14 minutes and 59 seconds in rural areas [10].

This time is divided into three steps: first the time of handling the call, second the time to get the ambulance ready and depart from the station and third the travel time to the scene. Using information from PRCS data, it is assumed the first steps takes about 1 minute and the second step takes 1 minute. This leaves 3 or 8 minutes for the ambulance to drive to the scene.

6. Current ambulance locations

In 2014 there are 8 location sites for ambulances, which are occupied 24/7. These location sites are spread over the 8 different regions with 10 ambulances vehicles as indicated in Table 3.3, a visual overview is given in Figure 3.3

Table 3.3: Current ambulance stations per quarter.

No.	Quarter number	Location name	No. of vehicles in the station	Type of station
1.	1	Rafah	1	Substation
2.	2	Al-Naser	1	Main station
3.	4	Khan Yunis	1	Main station
4.	5	Al Qarara	1	Substation
5.	7	Abasan Al Kabira	1	Substation
6.	15	Deir al Balah	1	Main station
7.	18	Gaza	2	Main station
8.	25	Jabalya	2	Main station
Total		**8**	**10**	**Main (5) sub(3)**

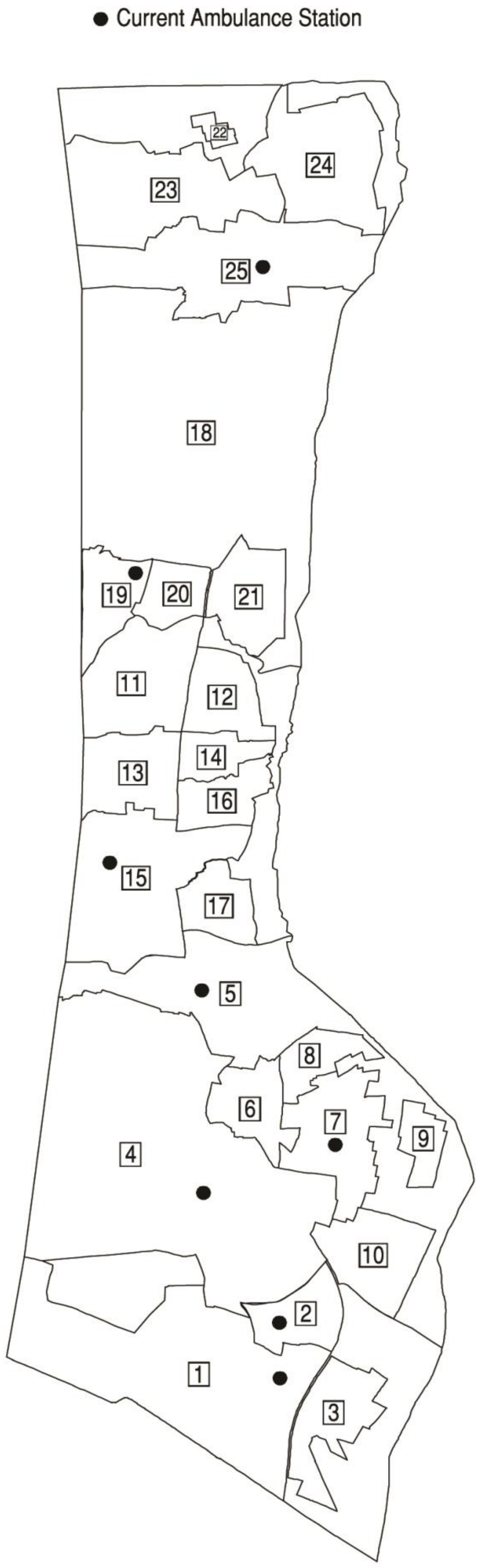

Figure 3.4: Current locations of ambulance stations per quarter.

7. PRCS emergency services

In 2013 PRCS served 31,773 cases in all Gaza Strip region. The ambulance vehicle moved more than 44,5956 kilometers with 12415 liters of fuel which total cost for each case served approximately 20$ for each case and average traveling distance 6.2 km [32]. Table 3.4 summarized the performance of PRCS services.

Table 3.4: Performance of PRCS services in 2013.

Number of station	Number of dispatch	Distance(km)	Number of residents	% of residents served	Average travel distance per dispatch (km)
2	6,038	98,552	192,498	3.14	13.3
4	8,022	109,606	314,700	2.55	12.3
15	6,037	81,347	234,811	2.58	12.7
18	7,145	97,089	587,852	1.22	12.6
25	4,531	59,362	313,356	1.45	11.0
Total	**31,773**	**445,956**	**1,625,017**	**1.96**	**12.4/2=6.2**

Third: LSCM Application

As the basic requirements for LSCM including the objective functions and the constraints and alternatives are identified, the application of the process is as explained in the following steps with the reasons to use this model.

1. Model description

The main step in this study was to work with simple existing model. So the study looking at the first model described in chapter 2, which was the Location Set Covering Model (LSCM). All of the models described in chapter two has some of their input in common:

- The set of demand points I.
- The set of potential location sites J.
- The travel distance d_{ij} from $j \in J$ to $i \in I$.
- A maximal travel distance D an ambulance may traveling to get to the scene of an incident within standard response time and as coverage standard.

Using this input can be determined for each demand point $i \in I$ which potential location sites $j \in J$ can cover it, we define:

$$J_i = \{j \in J \big| d_{ij} \leq D\}.$$

The sets I and J are the same, they consist of all 25 quarters as described in chapter 3. The two sets are the same because the study assumed that can build an ambulance station at every location point have. The travel distance are given by the travel distance model as described in chapter 3 with the table of the d_{ij} for each quarter to the other in Appendix A . The maximal travel distance has different cases depend on different response time (7 , 10 and 12) minutes.

For the LSCM model, the study started with a greenfield scenario:

- Assume that there are no existing ambulance stations in the area and find optimal location site in each governorate.
- Using the main station site in real work to find the substation that achieve the optimal location site that support the main station (where must build new substation to achieve the objectives).

2. LSCM formulation

Recall the formulation of the LSCM from chapter 2:

LSCM

Minimize $\sum_{j \in J} \boldsymbol{x_j}$

Subject to $\sum_{j \in J_i} \boldsymbol{x_j} \geq \mathbf{1} \qquad \boldsymbol{i} \in \boldsymbol{I}$

$\boldsymbol{x_j} \in \{\mathbf{0}, \mathbf{1}\} \qquad \boldsymbol{j} \in \boldsymbol{J}$

Apart from the general input, the maximal traveling distance (coverage standard) has been specified, which is used to define the sets J_i, $i \in I$. Three different maximal traveling distance chosen to solve the model which depend on three different response time : 5 minutes, 8 minutes and 10 minutes which is driving time without setting up the vehicle and the time to receive the call.

This will consider two cases for this model:

- Consider all quarters as one region and solve the model, which given one solution for all of Gaza Strip.
- Consider all of the five governorates separately and solve the model for each governorate, then take the union of all these solutions as a solution for all of Gaza Strip.

As the results, the solution in the second case is better than the first solution, while the first is good especially near boundaries.
The model is formulated and solved by LINDO software and the results are shown in chapter 4. The LINDO API software can easily create optimization applications. The model has been solved by using a free trial version of LINDO API 6.1. The limitations on this trial version include the solution of only 150 constraints, 300 variables, 50 integer variables and 2000000 non-zeros. The ILP model of the study includes 25 binary (0,1) variables.. The constraints of the ILP model of the study are 25 constraints for each travel distance. (Appendix (B) shows the ILP model).
The results of this model are discussed in chapter 4.

Fourth: Summary:

The methodology used in this study was described in this chapter, required data was collected, in which the scenarios and the alternatives are identified, followed by the LSCM formulation. The chapter finished with the application of ILP model to find the optimal location sites.

Chapter Four: Results

First: Introduction

Second: LSCM model

1. **Gaza Strip as one region**
2. **PRCS Separate regions**

Third: comparison between study results

Fourth: Summary

First: Introduction

This chapter describes the results obtained from the model described in chapter 3. The study used LINDO-language program. Two scenarios are considered in the study, first Gaza Strip as one region and the second the five governorates each one legally responsible which the PRCS providing the emergency services in it.

Second: LSCM Model

The model introduced is the Location Set Covering Model, which compute the minimal number of location sites needed to cover all demand points. This model was run for two different scenarios:

- **A.** The minimal number of locations sites needed to cover all demand points in the area. This is the Gaza Strip as one region when large area of the region demand, no legally responsibility, centralization of communication control room, no boundaries between the regions or governorates responsibility and last the presence of a limited hospitals.
- **B.** The minimal number of locations sites needed to cover all demand points for each governorate separately. This scenario used if there legally responsibility, separate CCR, small area of the regions with boundaries and last the existence of hospitals in each region.

The results of these cases are discussed in section 4.1 and 4.2 respectively. The first scenario requires less location sites in total than the second scenario. On the other hand, it can occur that the PRCS has less location sites when it is considered as one region, than when it is considered in the separate region case. The second scenario is closed to reality of location sites with the legally responsibility and the management of the PRCS ambulance stations in Gaza Strip.

1. Gaza Strip as one region

First the model used to compute the minimal number of locations sites needed to cover all demand point, considering Gaza strip as one region. This was done for three different maximal travel time 5 , 8 and 10 minutes and this time mean driving time to reach to the scene. To observed ambulance vehicle speed in Gaza Strip metropolis is approximately 1100m/min. To achieve 5,8 and 10 minutes maximal travel time to arrival to scene D should be =5500m, =8800m and =11000m. The results are summarized in Table 4.1. With the solutions, 5 ambulances (stations) are needed in coverage standard D=5500m and 3 ambulances in the coverage standard D=8000m and D=11000m.

While the actual number of ambulances (stations) in Gaza Strip are 8 stations.

Table 4.1: Results of different coverage standard D,T and the optimal number of sites.

Coverage standard distance (m)	5500	8800	11000
Maximal travel time (minutes)	5	8	10
Number of location sites needed	5	3	3

From the results in Table 4.1 and the coverage standard D=5500m are achieving the objective function of the study, which the maximal response time is 7 minutes and maximum expected demands covered.

Table 4.2: optimal locations of the model when gaza strip one region with maximal response time 7 minutes.

No.	Location identification number	Location name	Coverings
1.	2	Al-Naser	1,2,3,10
2.	8	Abasan al Jadida	1,4,5,6,7,8,9,10
3.	16	Al Musaddar	11,12,13,14,15,16,17
4.	19	Madinat Ezahra	11,12,13,19,20,21
5.	25	Jabalya	18,22,23,24,25

From the Table 4.2 results of the model, the optimal 5 stations are as follows:

Al-Naser (2), Abasan al Jadida (8), Al Musaddar (16), Madinat Ezahra (19), Jabalya (25). can cover 100% of the population within **7** minutes. If PRCS wish to implement these results they have to relocate the existing **8** stations to give specific service level from 96% to 100% covered population and from 88% to 100% maximum expected demand covered. The results for these options can be found in Table 4.3 and shown in Figure 4.1

Table 4.3: The optimal locations and their objective values in one region at 7 minutes maximal response time.

No. of locations	Locations	Maximum Expected demands covered	% Of residents covered
1	2	0.16	0.1184
2	2,8	0.40	0.3120
3	2,8,16	0.68	0.4534
4	2,8,16,19	0.80	0.7129
5	2,8,16,19,25	1.00	100%

To cover the region, at least 5 stations are needed to satisfy the minimum requirement that any node can be served from a station within maximal response time 7 minutes. Relocating the existing stations will maximize the demands within the target time and will reduce the operation cost by decreasing the number of stations from 8 to 5 stations and the average traveling distance . The following is the optimal set of five stations: Al-Naser (2), Abasan al Jadida (8), Al Musaddar (16), Madinat Ezahra (19), Jabalya (25). By relocating the existing 8 stations to 5 stations in the same quarters, the demand covered will about 100% of the residents and the expected demand points.

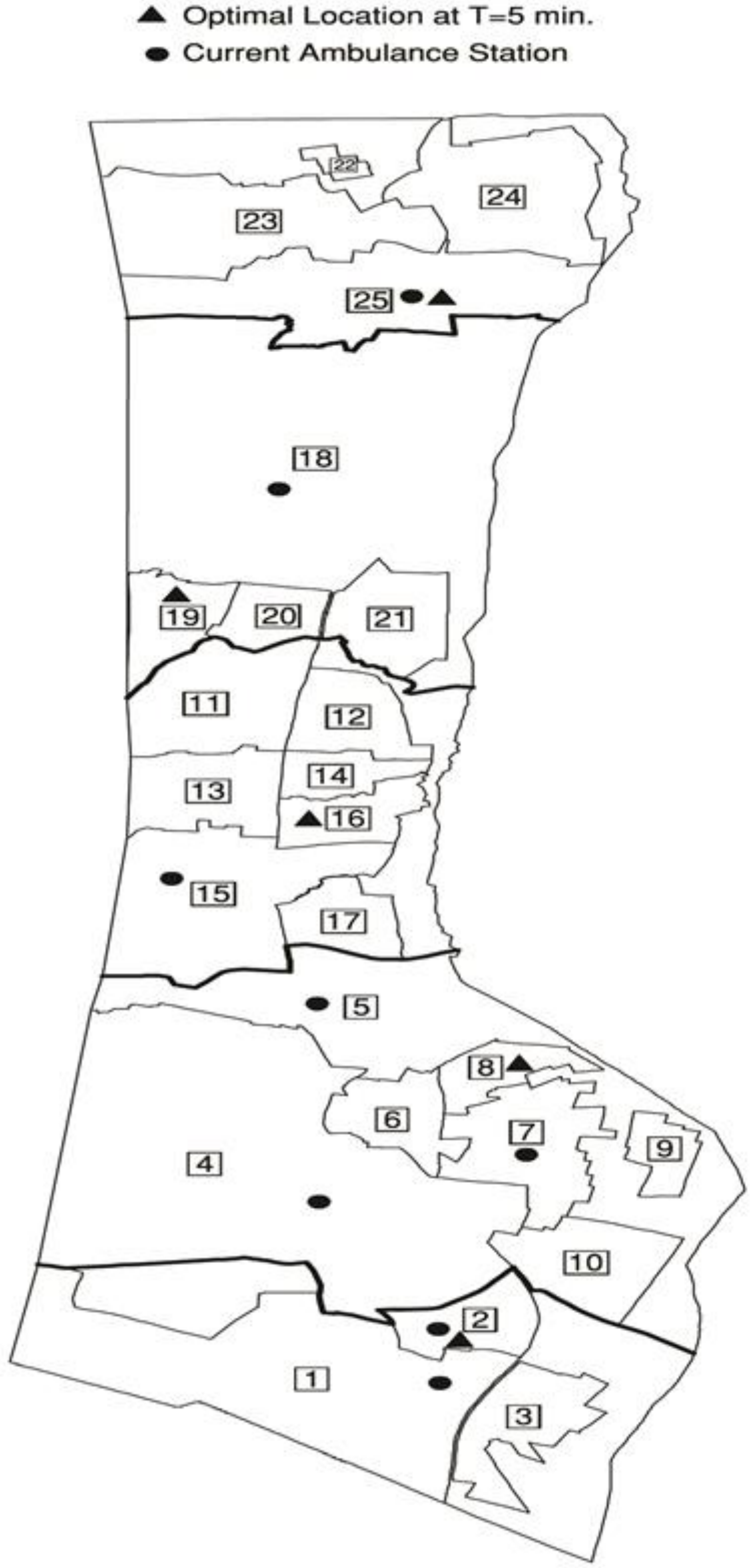

Figure 4.1: Current and optimal locations model for 7 minutes maximal response time in one region.

2. PRCS separate regions

The current practice is that each PRCS station try to cover their 'own' demand points in the legally responsible region. A better indication of this scenario is given the current organizational situation with PRCS can be found by running the LSCM for every PRCS separately. This was only done for a maximal travel time of 5 minutes, since it is the current norm in practice. The result of this run can be found in Table 4.4, Table 4.5 and shown in Figure 4.2, where the number of locations needed in the both scenarios are reported. As expected , the number of location sites in case of each PRCS is considered as a separate region is **6** location sites needed to cover all demand points. This scenario is closed to current and reality of **8** location sites.

Table 4.4: optimal locations of the model when gaza strip separate region with maximal response time 7 minutes

No.	Location identification number	Location name	Coverings
1.	2	Al-Naser	1,2,3
2.	7	Abasan Al Kabira	4,5,6,7,8,9,10
3.	14	Al Maghazi	11,12,13,14,15,16,17
4.	18	Gaza	18,22,25
5.	21	Juhor ad Dik	19,20,21
6.	25	Jabalya	18,22,23,24,25

From Table 4.5 To cover each separate region, at least 6 stations are needed to satisfy the minimum requirement that any node can be served from a station within at maximal response time 7 minutes.

Table 4.5: The optimal locations and their objective values in separate regions.

No. of locations	Locations	Maximum Expected demands covered	Of % residents covered
1	2	0.12	0.1184
2	2,7	0.35	0.3120
3	2,7,14	0.68	0.4534
5	2,7,14,18,21	0.84	0.8028
6	2,7,14,18,21,25	1.0	100%

To cover all the regions, at least 6 stations are needed to satisfy the minimum requirement that any node can be served from a station within maximal response time 7 minutes. Relocating the existing stations will maximize the demands within the target time and will reduce the operation cost by decreasing the number of stations from 8 to 6 stations and the average traveling distance. The following is the optimal set of five stations: Al-Naser (2), Abasan al Kabira (7), Al Maghazi (14), Gaza (18), Juhor ad Dik (21), Jabalya (25). By relocating the existing 8 stations to 6 stations in the same quarters, the demand covered will about 100% of the residents and the expected demand points

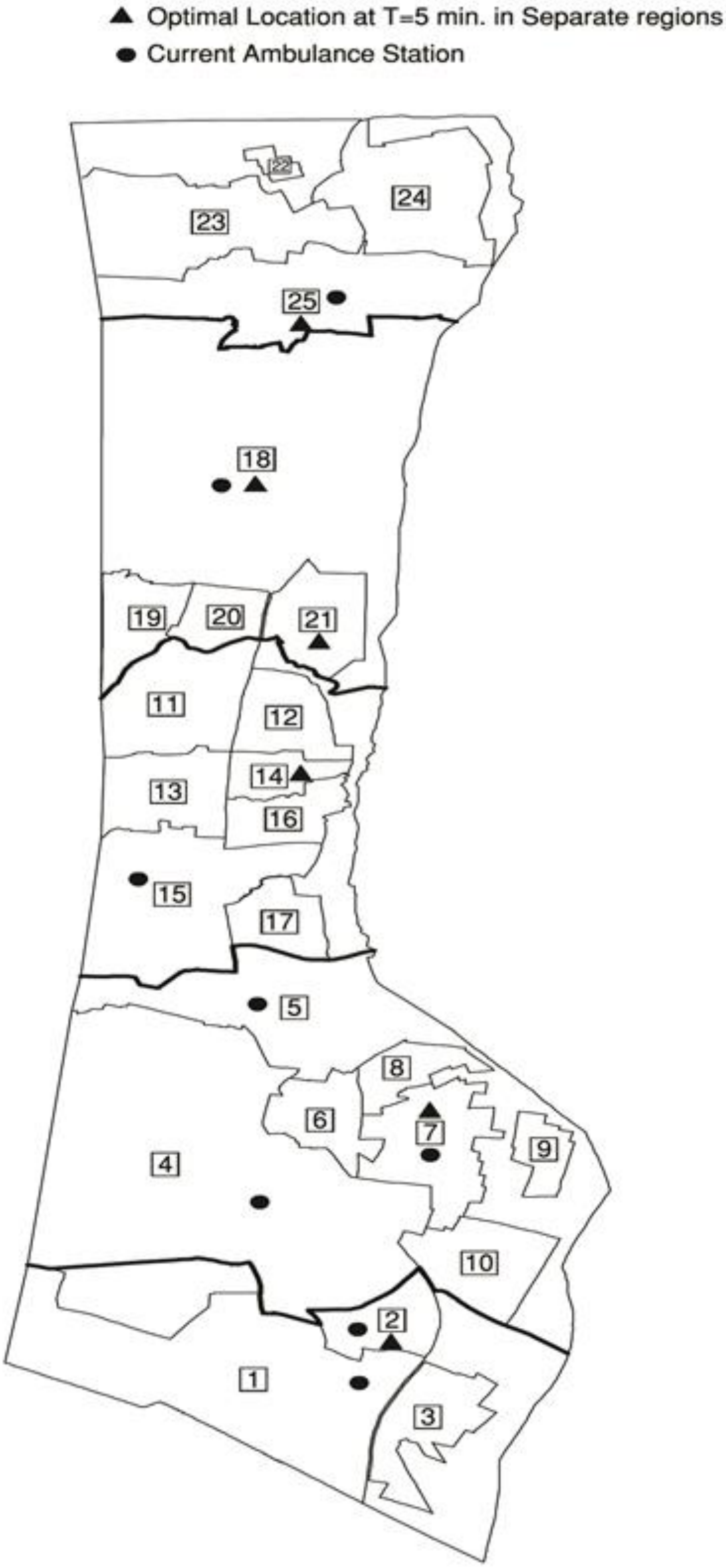

Figure 4.2: Optimal locations for 7 minutes maximal response time in separate regions.

Third: Comparison between the study results

To compare the results, the maximal traveling distance computed from the objective function model to the actual average traveling distance which is calculated based on the data collected from January/2013 to December/2013 shown in Table 3.4. However, this result implies the possibility of improving the access traveling distance to the scene by modifying the location of ambulance stations as in Table 4.5.

Table 4.6: Average traveling distance computed from objective value of optimal location.

	Optimal location	**Current location**
Average traveling distance (km)	3.8	6.2

Relocating the existing stations will maximize the demands within the target time and will reduce the operation cost by decreasing the number of stations from 8 to 6 stations and the average traveling distance in second scenario. The following is the optimal set of six stations: Al-Naser (2), Abasan Al Kabira (7), Al Maghazi (14), Gaza (18) and Juhor ad Dik (21), Jabalya (25). By relocating the existing eight stations to six stations in the same region, the demands covered will be about from 96% to 100% of the residents, which is an improvement of 4% and The maximum expected coverage from %88 to 100% of expected demand points which is an improvement of 12% and reducing of the average traveling distance from 6.2km to 3.8km, which is an improvement of 38%.

Finally the optimal location sets in Gaza strip is six station which is closed to the current reality as follow:

Al-Naser (2), Abasan Al Kabira (7), Al Maghazi (14), Gaza (18) and Juhor ad Dik (21), Jabalya (25). With 100% of maximum coverage demand expected and the residents covered in maximum travel distance 5.5km. However, the model can indicate the actual ambulances location is optimal or not and This is summarized in Table 4.7

Table 4.7: Current and optimal locations sites in separate regions.

Region	**Current locations**	**Optimal locations**
Rafah	1,2	2
Khan Yunis	4,5,7	7
Middle	15	14
Gaza	18	18,21
The North	25	25
Total	**8**	**6**

In the end of this chapter the results of the optimal locations are summarized and the improvements of their objective values in Table 4.8 and Figure 4.3.

Table 4.8: Improvement of the objectives values at optimal locations in separate regions.

N0.	Optimal objectives	Current value	Optimal value	% of Improvement
1.	no. of location sites	8	6	**25%**
2.	maximal response time (minute)	10	7	**30%**
3.	average traveling distance (km)	6.2	3.8	**38%**
4.	maximum expected coverage	88%	100%	**12%**
5.	% of residents covered	96%	100%	**4%**

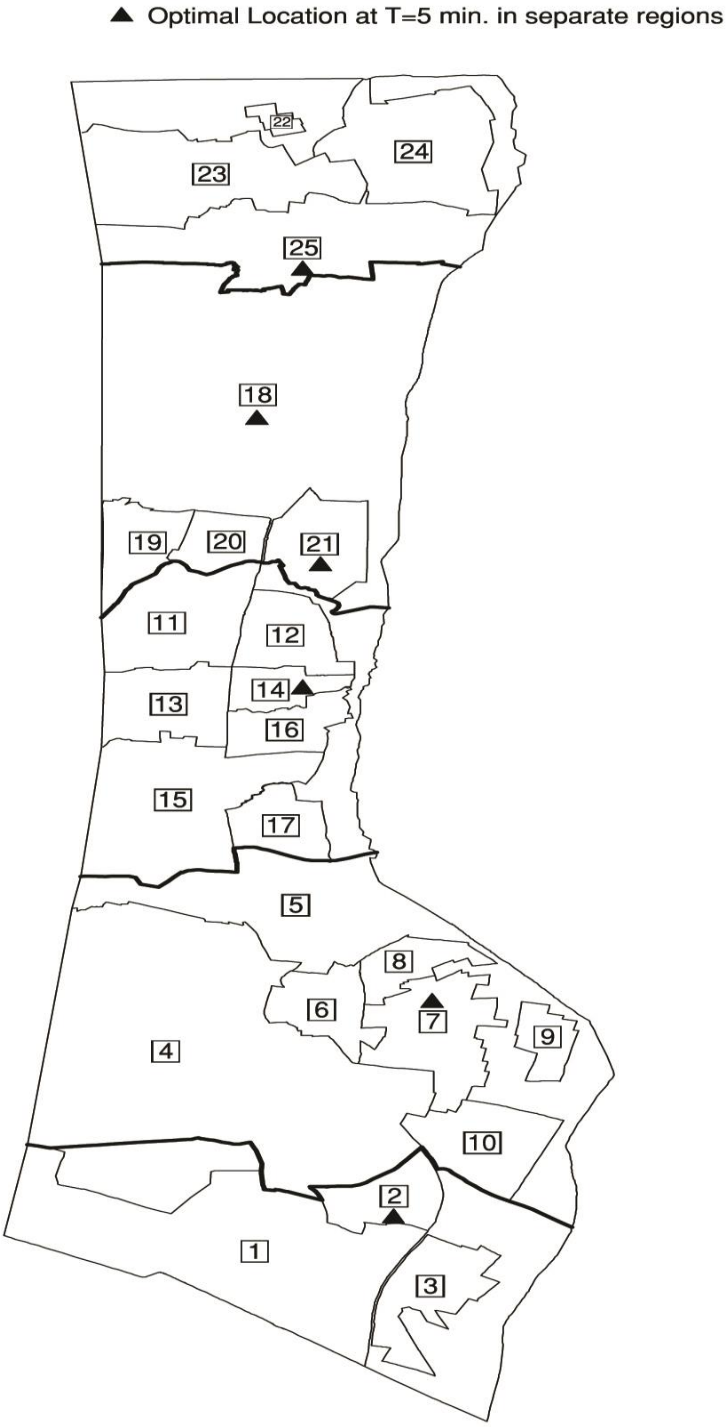

Figure 4.3: The optimal location sets of the model

Fourth: Summary:

The results and the analysis of the study was presented in this chapter. The model output shows that the optimal solution improve the performance of the EMS system by reducing the maximal response time and average traveling distance and increasing the expected coverage demand and in the last reducing the number of location sites. All results with each case are summarized in Table 4.9.

Table 4.9: Comparison between the Current locations and the optimal locations results in each scenario.

No.	Objective	Current location	Optimal location (one region)	Optimal location (separate regions)
1.	no. of location sites	8	5	6
2.	maximal response time (minute)	10	7	7
3.	% Of residents covered	96%	100%	100%
4.	average traveling distance (km)	6.2	3.8	3.8
5.	maximum expected coverage	88%	100%	100%
6.	Common sites with current locations	1,2,4,5,7,15,18,25	2,25	2,7,18,25

Chapter Five: Conclusion, Recommendations and Future Study

First: Conclusion

Second: Recommendations

Third: Future study

In this final chapter, answer the study question "what is the optimal location" and suggest ideas for future studies with some recommendation about the EMS in PRCS.

First: Conclusions

- Gaza Strip divided into 5 PRCS regions, which all consist of one ambulance station excepted Rafah and Khan Yunis has two and three stations.
- Every PRCS station is legally responsible for the ambulance care in its region.
- In 2104, there were 8 stations for ambulances with 37 ambulance vehicle, just of 10 of them are occupied 24/7 and the other are only occupied during the emergency situations like the war.
- The target to reach to the scene (response time) within 10 minutes after an emergency calling are received.
- The study started by considering the constraint that 8 minutes maximal driving time to resident.
- The model introduced for this purpose is the LSCM (Location Set Covering Model).
- The result of this model is the minimal number of locations needed to cover all demand points which was determined for three different maximal travel times, namely 5,8 and 10 minutes.
- The results found that the minimal number of location site is 5 sites in one region scenario and 6 sites in second for maximal travel distance 5.5km in maximal traveling time 5 minutes.
- The current of actual number of location sites is 8 sites, which is significantly close to 6 sites with maximal travel time 5 minutes and 5.5 km maximal travel distance.
- The study found that needed at least 6 locations, which is quite close to the current reality in number of 8 location sites and the responsibility of PRCS in separate regions with maximal response time 7 minutes.

The results of the optimal solution are summarized as follow:

- When fixing the existing 8 stations and relocating some of them as in the results of the model to be 6 stations, with decreasing the number of location sites, ,maximal response time, average traveling distance and last the maximum expected coverage, which is an improvement of 25% , 30% , 38% and 4% respectively.

Second: Recommendations

There are some recommendations in this subject about the emergency services system in PRCS as follow:

- Enhancing the use of this model applications to locate the best locations for civil defense stations.
- Promote the communication companies to corporate with ambulance stations to improve their services and to reduce the quarrels problems.
- Create an emergency operation center to handle with all emergency stations to handle with all emergency actors.
- Supply the emergency operation center with the needed computers, radios and transmission towers.
- Using the GIS and GPS applications in EMS management.
- Enhancing the use of locations models to determine the best number for ambulance vehicles in stations for availability .
- Publish the awareness about the importance of the addressing and mapping system for the regions to reducing the response time in emergency situations.
- Create a coordinating channel between the EMS and the hospitals which provide the health care in the same region.
- Enhancing the MOLG to mapping and addressing the quarters with unique system over all the area.

Third: Future study

Even though there has been a considerable amount of OR work applied in EMS and FS planning and operation, potentially fruitful areas for future research remain. The major area of needed work is the real-time operation of EMS and FS systems. The decisions involved in vehicle relocation and dispatch are complex and simulation and analytic modeling can be used to help consider the impact of such decisions.

Future study direction will focus on developing efficient models which can identify near optimal solution for determine the optimal ambulance vehicle number in each station depending on the demand density population , dispatching number and the travelling distance to nearest hospital of the scene.

Another area for the future study is shift scheduling. It is not difficult to estimate the required number of vehicles needed per day, however they must staff those days with vehicles and crews. Final expand this study to cover all areas of Palestine.

References

1. Alsallom, O., and Rank, GK. (2003). "A Goal Programming Model Applied to the EMS System at Riyadh City, Saudi Arabia". Lancaster University Management School, UK. See working paper 2003/035.
2. Alsallom, O., and Rank, GK. (2006). "Extensions to Emergency Vehicle Location Models". Computer and Operations Research, Vol. 33, pp.2725-2743.
3. Amponsah, S., Amoaka, G., Darkwah, K., and Agyeman, E. (2011). " Location of Ambulance Emergency Medical Service in the Kumasi Metropolis, Ghana". African Journal of Mathematics and Computer Science Research, vol. 4, No. 1, pp 18-26.
4. Aringhieri, R., Carello, G., and Morale, D. (2007). " Ambulance Location through Optimization and Simulation: the Case of Milano Urban are". University of Milano, 15 October 2007.
5. Ates, S., Cagda, A., and Coskun, M. (2011). " Determining Optimum Ambulance Locations for Heart Attack Cases With GIS". 2011 Esri International User Conference, July 11-15, San Diego, USA
6. Baker, J., Clayton, E., Taylor, B. (1989). "A Non-Linear Multi-Criteria Programming Approach for Determining County Emergency Medical Service Facilities Location Problems". Opt Res. Soc., Vol. 29, No. 12, pp.1167-1179.
7. Ball, M., Lin, F. (1993). "A Reliability Model Applied to Emergency Service Vehicle Location". Operations Research, Vol. 41, No. 1, pp.18-36.
8. Bianchi, G., Church, R. (1988). "A Hybrid FLEET Model for Emergency Medical Service system Design". Social Science and Medicine, Vol. 26, pp.163-171.
9. Brotcorne, L., Laporte, G., Semet, F. (2003). "Ambulance Location and Relocation Models". European Journal of Operational Research, Vol. 147, pp.451-463
10. Chanta, S., Mayorga, M., and Mclay, L. (2011). " Improving Emergency Service in Rural Are: a Bi-Objective Covering Location Model for EMS Systems" . New York: Springer. Published on line: 27 September 2011.
11. Charnes, A., Storbeck, J., (1980). "A Goal Programming Model for Sitting Multi-Level EMS System". Socio-Economic Planning Sciences, Vol. 14, pp.155-161.
12. Church, R., ReVelle, C. (1974). "The Maximal Covering Location Problem". Paper of the Regional Science association, Vol. 32, pp.101-118.
13. Cromley, E., McLaffert, L. (2002). " GIS and Public Health". The Guildford Press, New York, London
14. Daskin, M. (1983). "A Maximum Expected Covering Location Model: Formulation, Properties and Heuristic Solution". Transportation Science, Vol. 17, pp48-70.
15. Daskin, M., Dean, L. (2004). "Location of Health Care Facilities". Chapter 3 in the Handbook of OR/MS in Health Care. Department of Industrial Engineering and Management Sciences, Northwestern University, Evanston.
16. Daskin, S., Stern, H. (1981). "A Hierarchical Objective set Covering Model for Emergency Medical Service Vehicle Deployment". Transportation Science, Vol. 15, pp.137-152.

17. De Maio, V., Stiell, I., Wells, G., and Spaite, D. (2003). "Optimal Defibrillation Response Intervals For Maximum Out-of-Hospital Cardiac Arrest Survival Rates". Annals of Emergency Medicine, Vol. 42, pp.242-250.
18. Dorigo, M. (1992)."Optimization Natural Algorithms". Ph.D. thesis, Politecnico di Milano, Italy.
19. Eljamassi, A. (2012). " Emergency Management Systems Using GIS (Geographic Information Systems) in Gaza City-Palestine". International Journal of Engineering and Innovative Technology (IJEIT), Vol. 2, Issue. 6, pp.377-385.
20. Fitch, J. (2005). "Response time: Myths, Measurement and Management". Journal of Emergency Medical Services. Vol. 42, pp.242-250.
21. Garey, M., Johnson, D. (1979). "Computes and Intractability: A Guide to the Theory of NP-Completeness". W.H. Freeman and Co., New York.
22. Gendreau, M., Laporte, D., Semet, F. (1997). "Solving an Ambulance Location Model by Tabu Search". Location Science, Vol. 5, pp.75-88.
23. Gendreau, M., Laporte, D., Semet, F. (2001). "A Dynamic Model and Parallel Tabu Search Heuristic for real-time Ambulance Relocation". Parallel Computing, Vol. 27, pp.1641-1653.
24. Gendreau, M., Laporte, D., Semet, F. (2006). "The Maximal Expected Coverage Relocation Problem for Emergency Vehicles". Journal of the Operational Research Society, Vol. 57, pp.22-28.
25. Geroniminis, N., Karlaftis, M. (2009). "A Spatial Queueing Model for the Emergency Vehicle Districting and Location Problem". Transportation Research Part B, Vol. 43, pp.798-811.
26. Glover, F. (1986). "Future Paths for Integer Programming and Links to Artificial Intelligence". Computer and Operations Research, Vol. 9, pp.849-859.
27. Goldberg, B. (2004). " Operations Research Models for the Deployment of Emergency Services Vehicles". EMS Management Journal, Vol. 1, No.1, pp.20-39.
28. Hansen, P., Mlademovic, N. (2001). "Developments of Variable neighborhood Search, in Meta-Heuristic". Advances and Trends in Local Search Paradigms for Optimization, Kluwer Academic Publishers, pp.433-458.
29. Hogan, K., ReVelle, C. (1986). "Concept s and Applications of Backup Coverage". Management Science, Vol. 34, pp.1434-1444.
30. Holland, J. (1975). "Adaptation in Natural and Artificial Systems". University of Michigan Press, USA.
31. Inakawa, K., Furuta, T., and Suzuki, A. (2010). " Effect of Ambulance Stations Locations and Number of Ambulances to the Quality of the Emergency Service". The Ninth International Symposium on Operations Research and Its Applications, vol. 19, No. 23, pp 340-347.
32. Interview Dr. Pashar Morad. Gaza Strip. Palestine.20/05/2014.
33. Joana, P., Maurici, P. (2003). "Geographical Information System and Intelligent Transporting System: technologies used to form new communication networks". NETCOM, Vol. 17, No. 1-2.
34. Karakaneva, J.(2003). " A location Problem Modeling and Solving". Trakia Journal of Sciences, Vol. 1, No. 4, pp.1-7.
35. Kirpatrick, S., Gelatt, C., Vecchi, M. (1983). "Optimization by Simulated Annealing". Science , Vol. 200, pp.671-680.

36. Koc, M., Bostancioglu, M. (2011). " A Reliability Based Solution to an Ambulance Location Problem Using Fuzzy Set Theory". International Journal of Natural and Engineering Science, Vol. 5, No. 1, pp13-17.
37. Limpattanasiri, W., Taniguchi, E. (2013). " Solving a Maximal Covering Model of Emergency Ambulance Location Problem in Urban Areas by Dynamic Programming Technique" a research paper proceedings of the Eastern Asia Society for Transportation Studies, vol. 9, 2013.
38. Limpattanasiri, W., Taniguchi, E. (2013). " Solving a Maximal Covering Model of Emergency Ambulance Location Problem in Urban Areas by Dynamic Programming Technique". PhD Thesis. Kyoto University, KURENAI. 2013.
39. Looije, D., (2013). "Optimal Ambulance Locations in the Netherlands". (Unpublished Master's Thesis). Delft University of Technology, Netherlands. 2013.
40. Mandell, M. (1998). "Covering Models for Two-Tiered Emergency Medical Services Systems". Location Science, Vol. 6, pp.355-368.
41. Marianov, V., and Serra, D. (1998). "Probabilistic, Maximal Covering Location-Allocation Models for Congested Systems". Journal of Regional Science, Vol. 38, No. 3, pp.401-424.
42. Marianov, V., and Serra, D. (2001). "Hierarchical Location-Allocation Models of Congested Systems". European Journal of Operational Research, Vol. 135, pp.195-208.
43. Marianov, V., and Serra, D. (2002). "Location-allocation of Multiple-Server Service Centers With Constrained queues or waiting times". Annals of Operations Research, Vol. 111, pp.35-50.
44. Marianov, V., ReVelle, C. (1996). "The Queueing Maximal Availability Location Problem: a Model for the Sitting of Emergency Vehicles". European Journal of Operational Research, Vol. 93, pp.110-120.
45. Morohosi, H. (2008)."A Case Study of Optimal Ambulance Location Problem ". The seventh International Symposium on Operations Research and Its Applications, October 31-November 3, 2008, pp 125-130.
46. Palestinian News & Info Agency. (WAFA website), Available: http://www.wafainfo.ps, (Accessed: 2014, January 2)
47. Palestinian Red Crescent Society.(PRCS website), Available: http://www.palestinercs.org, (Accessed: 2014, May 12)
48. Pasha, I. (2006). " Ambulance Management System Using GIS". Department of Computer and Information Science, Linkoping University, Sweden
49. Prikul, H., Schilling, D. (1989). "The Capacitated Maximal Covering Location Problem with Backup Service". Annals of Operations Research, Vol. 18, pp.141-154.
50. Prikul, H., Schilling, D. (1992). "Capacitated Emergency Facility Siting with Multiple Levels of Backup". Annals of Operation Research, Vol. 40, pp.323-337.
51. Rabello, A., Vallim, A., and Mota, I. (2012). "Optimization Models in the Location of Healthcare Facilities: a Real Case in Brazil". Journal of Applied Operational Research, vol. 4, No. 1, pp 37-50.
52. Rajagopalan, H., Saydam, C. (2009). "A Minimum Expected Response Model: Formulation, Heuristic Solution, and Application". Socio-Economic Planning Sciences, Vol. 43, pp.253-262.

53. Rajagopalan, H., Saydam, C., and Xiao, J. (2008). "A Multiperiod Set Covering Location Model for Dynamic Redeployment of ambulances". Computers and Operations Research, Vol. 235, pp.814-826.
54. Ramashe, N., and Amiri, E. (2014). "A Bi-Objective Model for Locating and Sizing Emergency Stations" a research paper proceedings of the 2014 International Conference on Industrial Engineering and Operations Management Bali, Indonesia, January 7-9, 2014.
55. Repede, J., Bernardo, J. (1994). "Developing and Validating a Decision Support System for Locating Emergency Medical Vehicles in Louisville, Kentucky". European Journal of Operational Research, Vol. 75, No. 3, pp.567-581.
56. ReVelle, C., Hogan, K. (1988). "A Reliability-Constrained Sitting Model With Local Estimates of Busy Fractions". Environment and Planning B, Vol. 15,pp.143-152.
57. ReVelle, C., Hogan, K. (1989a). " The Maximum Availability Location Problem". Transportation Science, Vol. 23, pp.192-200.
58. ReVelle, C., Hogan, K. (1989b). " The Maximum Reliability Location Problem and α-Reliable P-Center Problem: Derivatives of the Probabilistic Location Set Covering Problem". Annals of Operations Research, Vol. 19, pp.155-174.
59. ReVelle, C., Marianov, V. (1991). "Probabilistic FLEET Model With Individual Vehicle Reliability Requirements". European Journal of Operational Research, Vol. 53, pp.93-105.
60. ReVelle, C., Schweitzer, J., and Snyder, S. (1996). "The Maximal Conditional Covering Problem". INFOR, Vol. 34, No. 2. Pp.77-91.
61. ReVelle, C., Snyder, S. (1995). "Inter Fire and Ambulance Sitting: A Deterministic Model". Socio-Economic Planning Science, Vol. 29, No. 4, pp.261-271.
62. Revelle, C., Toregas, C., Falkson, L. (1976). " Applications of the Location Set-covering Problem". Geographical Analysis, Vol. 9, (January, 1976), pp.65-76.
63. Richard, B. (1957). "Dynamic Programming". Princeton University Press, Princeton, New Jersey, USA.
64. Schmid, V., Doerner, K. (2010). " Ambulance Location and Relocation problems with Time-Dependent Travel Times". European Journal of Operational Research, Vol. 207, pp.1293-1303.
65. Serra, D. (1996). "The Coherent Covering Location problem, Paper in Regional Science". The Journal of the RSAI, Vol. 75, No. 1, pp.79-101.
66. Shilling, D., Elzing, D., Cohon, R., Church, R., ReVelle, C. (1979). "The TEAM/FLEET Models for Simultaneous Facility and Equipment sitting". Transportation Science, Vol. 13, pp.163-175.
67. Sorensen, P., Church, R. (20101). "Integrating expected coverage and local reliability for emergency services location problems" Socio-Economic Planning Science, Vol. 44. pp.8-18.
68. Swoveland, C., Uyeno, D., Vetinsky, I., Vickson, R. (1973). "A Simulation-based Methodology for Optimization of Ambulance Service Policies". Socio-Economic Planning Science, Vol. 7, No. 6, pp.697-703.
69. Takeda, R., Widmer, J., Morabito, R. (2007). " Analysis of Ambulance Decentralization in an Urban Emergency Medical Service using the Hypercube Queueing Model". Computer and Operations Research, Vol. 34, pp727-741.

70. Toregas, C., Swain, R., ReVelle, C., and Bergman, L. (1971). "The Location of Emergency Service Facilities". Operations Research, Vol. 19, pp.1363-1373.
71. Volz, R. (1971). "Optimum Ambulance Location in Semi-Rural Areas". Transportation Science, Vol. 5, No. 3,pp.193-203.

Appendix A: Integer Linear Programming Model (ILPM)

First Case (one region)

Parameters: a quarter = x , D= 5.5 km. , d_{ij} given in the appendix A.

Min

x1+x2+x3+x4+x5+x6+x7+x8+x9+x10+x11+x12+x13+x14+x15+x16+

x17+x18+x19+x20+x21+x22+x23+x24+x25

subject to

x1+x2>=1

x1+x2+x3+x10>=1

x1+x3>=1

x4+x5+x6+x7+x8>=1

x4+x5+x6+x7+x8+x15+x17>=1

x4+x5+x6+x7+x8+x10>=1

x4+x5+x6+x7+x8+x9+x10>=1

x4+x5+x6+x7+x8+x9+x10+x17>=1

x7+x8+x9+x10 >=1

x2+x6+ x7+x8+x9+x10>=1

x11+x12+x13+x14+x15+x16+x19+x20>=1

x11+x12+x13+x14+x15+x16+x17+x19>=1

x11+x12+x13+x14+x15+x16+x17>=1

x5+ x11+x12+x13+x14+x15+x16+x17>=1

x5+x8+ x13+x14+x15+x16+x17>=1

x18+x22+x25>=1

x11+x12+x13+x19+x20+x21>=1

x11+x12+x19+x20+x21>=1

x19+x20+x21>=1

x18+x22+x23+x24+x25>=1

x22+x23+x24+x25>=1

D= 8.8 km.

Min

x1+x2+x3+x4+x5+x6+x7+x8+x9+x10+x11+x12+x13+x14+x15+x16+

x17+x18+x19+x20+x21+x22+x23+x24+x25

subject to

x1+x2+x3+x4+x10>=1

x1+x2+x3+x4+x6+x7+x8+x9+x10>=1

x1+x2+x3+x10>=1

x1+x2+x3+x4+x5+x6+x7+x8+x9+x10+x15>=1

x4+x5+x6+x7+x8+x9+x10+x13+x14+x15+x16x+x17>=1

x2+x4+x5+x6+x7+x8+x9+x10+x15+x17>=1

x2+x4+x5+x6+x7+x8+x9+x10+x17>=1

x2+x4+x5+x6+x7+x8+x9+x10+x15+x16+x17>=1

x2+x4+x5+x6+x7+x8+x9+x10>=1

x1+x2+x3+x4+x5+x6+x7+x8+x9+x10>=1

x11+x12+x13+x14+x15+x16+x17+x19+x20+x21>=1

x5+x11+x12+x13+x14+x15+x16+x17+x19+x20+x21>=1

x4+x5+x6+x8+x11+x12+x13+x14+x15+x16+x17+x19+x20>=1

x5+x8+ x11+x12+x13+x14+x15+x16+x17+x19+x20>=1

x5+x6+x7+x8+x11+x12+x13+x14+x15+x16+x17>=1

x18+x19+x20+x21+x22+x23+x24+x25>=1

x11+x12+x13+x14+x15+x16+x18+x19+x20+x21>=1

x11+x12+x13+x14+x15+x16+x18+x19+x20+x21+x25>=1

x11+x12+x13+x14+x18+x19+x20+x21+x25>=1

x18+x22+x23+x24+x25>=1

x18+x20+x21+x22+x23+x24+x25>=1

D= 11 km.

Min

x1+x2+x3+x4+x5+x6+x7+x8+x9+x10+x11+x12+x13+x14+x15+x16+

x17+x18+x19+x20+x21+x22+x23+x24+x25

subject to

x1+x2+x3+x4+x6+x7+x10>=1

x1+x2+x3+x4+x6+x7+x8+x9x10>=1

x1+x2+x3+x7+x9+x10>=1

x1+x2+x4+x5+x6+x7+x8+x9+x10+x15+x16+x17>=1

x2+x4+x5+x6+x7+x10+x11+x12+x13+x14+x15+x16+x17>=1

x1+x2+x3+x4+x5+x6+x7+x8+x9+x10+x15+x16+x17>=1

x2+x4+x5+x6+x7+x8+x9+x1+x13+x14+x15+x16+x17+x18>=1

x2+x3+x4+x5+x6+7+x8+x9+x10+x17>=1

x1+x2+x3+x4+x5+x6+x7+x8+x9+x10+x17>=1

x5+x11+x12+x13+x14+x15+x16+x17+x18+x19+x20+x21>=1

x5+x7+x11+ x12+x13+x14+x15+x16+x17+x18+x19+x20+x21>=1

x5+x6+x8+x11+ x12+x13+x14+x15+x16+x17+x18+x19+x20+x21>=1

x4+x5+x6+x7+x8+x11+ x12+x13+x14+x15+x16+x17+x18+x19+x20>=1

x4+x5+x6+x7+x8+x11+ x12+x13+x14+x15+x16+x17+x18+x19+x20+x21>=1

x11+x12+x18+x19+x20+x21+x22+x23+x24+x25>=1

x11+x12+x13+x14+x15+x16+x17+x18+x19+x20+x21+x25>=1

x11+x12+x13+x14+x16+x18+x19+x20+x21+x22+x23+x25>=1

x18+x21+x22+x23+x24+x25>=1

x18+x22+x23+x24+x25>=1

x18+x19+x20+x21+x22+x23+x24+x25>=1

Second Case (separate regions)

D=5.5 km

1. Rafah Governorate

Min

x1+x2+x3

Subject to

x1+x2>=1

x1+x2+x3>=1

x2+x3>=1

2. Khan Yunis Governorate

Min

x4+x5+x6+x7+x8+x9+x10

subject to

x4+x5x+x6+x7+x8>=1

x4+x5x+x6+x7+x8+x10>=1

x4+x5x+x6+x7+x8+x9+x10>=1

x6+x7+x8x+x9+x10>=1

3. The Middle Governorate

Min

x11+x12+x13+x14+x15+x16+x17

subject to

x11+x12+x13+x14+x15+x16>=1

x11+x12+x13+x14+x15+x16+x17>=1

x13+x14+x15+x16+x17>=1

4. Gaza Governorate

Min

x18+x19+x20+x21

subject to

x18>=1

x19+x20+x21>=1

5. The North Governorate

Min

x22+x23+x24+x25

Subject to

x22+x23+x24+x25>=1

Appendix B: Models from Literature

An overview of the mathematical formulations of the models described in Chapter 2.

LSCM (1971)

$$\text{Minimize} \quad \sum_{j \in J} x_j \tag{2.1}$$

$$\text{Subject to} \quad \sum_{j \in J_i} x_j \geq 1 \qquad \forall\, i \in I \tag{2.2}$$

$$x_j = 0, 1 \qquad \forall\, j \in J \tag{2.3}$$

$$\text{where} \quad x_j = \begin{cases} 1 \text{ if station } j \text{ is allocated} \\ 0 \text{ otherwise} \end{cases}$$

MCLP (1974)

$$\text{Maximize} \quad \sum_{i \in I} d_i y_i \tag{2.4}$$

$$\text{Subject to} \quad \sum_{j \in J_i} x_j \geq y_i \qquad \forall\, i \in I \tag{2.5}$$

$$\sum_{j \in J} x_j = s \tag{2.6}$$

$$x_j, y_i = 0, 1 \tag{2.7}$$

$$\text{where} \quad x_j = \begin{cases} 1 \text{ if stations located at site } j \\ 0 \text{ otherwise} \end{cases}$$

$$y_i = \begin{cases} 1 \text{ if demand node } i \text{ is covered} \\ 0 \text{ otherwise} \end{cases}$$

TEAM (1979)

$$\text{Maximize} \quad \sum_{i \in I} d_i y_i \tag{2.8}$$

$$\text{Subject to} \quad \sum_{j \in J_i^A} x_j^A \geq y_i \qquad \forall\, i \in I \tag{2.9}$$

$$\sum_{j \in J_i^B} x_j^B \geq y_i \qquad \forall\, i \in I \tag{2.10}$$

$$\sum_{j \in J} x_j^A = n^A \tag{2.11}$$

$$\sum_{j \in J} x_j^B = n^B \tag{2.12}$$

$$x_j^A \leq x_j^B \qquad \forall\, j \in J \tag{2.13}$$

$$x_j^A, x_j^B, y_i = 0, 1 \tag{2.14}$$

where $x_j^A, x_j^B = \begin{cases} 1 & \text{if ambulance type A, B locate at site } j \\ 0 & \text{otherwise} \end{cases}$

$y_i = \begin{cases} 1 & \text{if node } i \text{ covered 2 types of ambulance} \\ 0 & \text{otherwise} \end{cases}$

n^A, n^B = number of ambulance type A and type B

r^A, r^B = standard coverage time of ambulance type A and type B

$J_i^A = \{ j \in J : t_{ij} \leq r^A \}$

$J_i^B = \{ j \in J : t_{ij} \leq r^B \}$

FLEET (1979)

Maximize $\sum_{i \in I} d_i y_i$ (2.15)

Subject to $\sum_{j \in J_i^A} x_j^A \geq y_i \quad \forall\, i \in I$ (2.16)

$\sum_{j \in J_i^B} x_j^B \geq y_i \quad \forall\, i \in I$ (2.17)

$\sum_{j \in J} x_j^A = n^A$ (2.18)

$\sum_{j \in J} x_j^B = n^B$ (2.19)

$\sum_{j \in J_N} z_j = s^z$ (2.20)

$x_j^A \leq z_j \quad \forall\, j \in J_N$ (2.21)

$x_j^B \leq z_j \quad \forall\, j \in J_N$ (2.22)

$x_j^A, x_j^B, y_i, z_j = 0, 1$ (2.23)

where $x_j^A, x_j^B = \begin{cases} 1 \text{ if ambulance type A, B locate at site } j \\ 0 \text{ otherwise} \end{cases}$

$y_i = \begin{cases} 1 \text{ if node } i \text{ covered 2 types of ambulance} \\ 0 \text{ otherwise} \end{cases}$

$z_j = \begin{cases} 1 \text{ if a facility located at site } j \\ 0 \text{ otherwise} \end{cases}$

n^A, n^B = number of ambulance type A and type B

s^z = number of new facilities to be built

r^A, r^B = standard coverage time of ambulance type A and type B

$J_i^A = \{ j \in J : \ t_{ij} \leq r^A \}$

$J_i^B = \{ j \in J : \ t_{ij} \leq r^B \}$

J_N = set of potential new facility locations; $J_N \subset J$

MGLC (1980)

$$\text{Minimize} \quad \sum_{i \in I} c_i^1 y_i^{\alpha-} + c_i^1 y_i^{\beta-} + c_i^2 y_i^{\theta-} \tag{2.24}$$

$$\text{Subject to} \quad \sum_{j \in J} a_{ij}^1 x_j^1 - y_i^{\alpha-} = 1 \qquad \forall\, i \in I \tag{2.25}$$

$$\sum_{j \in J} a_{ij}^1 x_j^2 - y_i^{\alpha-} - y_i^{\beta+} + y_i^{\beta-} = 0 \qquad \forall\, i \in I \tag{2.26}$$

$$\sum_{j \in J} a_{ij}^2 x_j^2 - y_i^{\theta+} + y_i^{\theta-} = 1 \qquad \forall\, i \in I \tag{2.27}$$

$$\sum_{j \in J} x_j^1 = n^1 \qquad \forall\, j \in J \tag{2.28}$$

$$\sum_{j \in J} x_j^2 = n^2 \qquad \forall\, j \in J \tag{2.29}$$

$$a_{ij}^1, a_{ij}^2, x_j^1, x_j^2, y_i^{\alpha-}, y_i^{\beta-}, y_i^{\theta-} = 0, 1 \qquad \forall\, i, j \tag{2.30}$$

$$y_i^{\alpha+}, y_i^{\beta+}, y_i^{\theta+} \geq 0 \qquad \forall\, i \in I \tag{2.31}$$

where c_i^1 = number of critical call at node i

c_i^2 = number of non-critical call at node i

$a_{ij}^1 = \begin{cases} 1 \text{ if travel time from } j \text{ to } i \text{ is within standard for critical call} \\ 0 \text{ otherwise} \end{cases}$

$a_{ij}^2 = \begin{cases} 1 \text{ if travel time from } j \text{ to } i \text{ is within standard for non-critical call} \\ 0 \text{ otherwise} \end{cases}$

$x_j^1 = \begin{cases} 1 \text{ if station } j \text{ is allocated ambulance type A} \\ 0 \text{ otherwise} \end{cases}$

$x_j^2 = \begin{cases} 1 \text{ if station } j \text{ is allocated ambulance type B} \\ 0 \text{ otherwise} \end{cases}$

$y_i^{\alpha-} = \begin{cases} 1 \text{ if critical call of demand node } i \text{ is uncovered by type A} \\ 0 \text{ otherwise} \end{cases}$

$y_i^{\beta-} = \begin{cases} 1 \text{ if critical call of demand node } i \text{ is uncovered by type B} \\ 0 \text{ otherwise} \end{cases}$

$y_i^{\theta-} = \begin{cases} 1 \text{ if non-critical call of demand node } i \text{ is uncovered by type B} \\ 0 \text{ otherwise} \end{cases}$

$y_i^{\alpha+}$ = number of type A covered critical call of demand node $i - 1$

$y_i^{\beta+}$ = number of type B covered critical call of demand node $i - 1$

$y_i^{\theta+}$ = number of type B covered non-critical call of demand node i - 1

n^1 = number of ambulances type A

n^2 = number of ambulances type B

HOSC (1981)

Minimize $\quad w\sum_{j\in J} x_j - \sum_{i\in I} s_i \qquad (2.32)$

Subject to $\quad \sum_{j\in J_i} x_j - s_i \geq 1 \qquad \forall\, i \in I \qquad (2.33)$

$s_i \geq 0 \qquad \forall\, j \in J \qquad (2.34)$

$x_j = 0, 1 \qquad \forall\, i \in I \qquad (2.35)$

where $x_j = \begin{cases} 1 \text{ if station } j \text{ is allocated} \\ 0 \text{ otherwise} \end{cases}$

s_i = number of ambulances capable of responding to demand node i

w = some positive weight

MEXCLP (1983)

$$\text{Maximize} \quad \sum_{i \in I} \sum_{k=1}^{p} d_i (1-q) q^{k-1} y_{ik} \tag{2.36}$$

$$\text{Subject to} \quad \sum_{j \in J_i} x_j \geq \sum_{k=1}^{p} y_{ik} \qquad \forall\, i \in I \tag{2.37}$$

$$\sum_{j \in J} x_j \leq n \tag{2.38}$$

$$x_j \quad = \text{integer} \qquad \forall\, j \in J \tag{2.39}$$

$$y_{i,k} = 0, 1 \qquad \forall\, i \in I \tag{2.40}$$

where $y_{i,k} = \begin{cases} 1 \text{ if node } i \text{ is covered by the } k \text{ ambulance} \\ 0 \text{ otherwise} \end{cases}$

BACOP1/BACOP2 (1986)

$$\text{Maximize} \quad \sum_{i \in I} d_i u_i \tag{2.41}$$

$$\text{Subject to} \quad \sum_{j \in J_i} x_j - u_i \geq 1 \qquad \forall\, i \in I \tag{2.42}$$

$$\sum_{j \in J} x_j = s \tag{2.43}$$

$$x_j, u_i = 0, 1 \tag{2.44}$$

where $x_j = \begin{cases} 1 \text{ if stations located at site } j \\ 0 \text{ otherwise} \end{cases}$

$u_i = \begin{cases} 1 \text{ if demand node } i \text{ is covered at least twice} \\ 0 \text{ otherwise} \end{cases}$

The BACOP2 formulation is:

Maximize $\theta \sum_{i \in I} d_i y_i + (1-\theta) \sum_{i \in I} d_i u_i$ (2.45)

Subject to $\sum_{j \in J_i} x_j - y_i - u_i \geq 0 \quad \forall\, i \in I$ (2.46)

$y_i - u_i \leq 0 \quad \forall\, i \in I$ (2.47)

$\sum_{j \in J} x_j = n$ (2.48)

$x_j, u_i, y_i = 0, 1$ (2.49)

where $y_i = \begin{cases} 1 \text{ if demand node } i \text{ is covered at least once} \\ 0 \text{ otherwise} \end{cases}$

θ = weight chosen in [0, 1]

PLSCP (1988)

Minimize $\sum_{j \in J} x_j$ (2.51)

Subject to $\sum_{j \in J_i} x_j \geq b_i \quad \forall\, i \in I$ (2.52)

$x_j \geq 0 \quad \forall\, j \in J$ (2.53)

MOFLEET (1988)

Minimize $\sum_{i \in I} \sum_{k=1}^{p} d_i (1-q) q^{k-1} \bar{y}_{ik}$ (2.54)

Subject to $\sum_{j \in J_i} x_j + \sum_{k=1}^{M_p} y_{ik} \geq M_p \quad \forall\, i \in I$ (2.55)

$\sum_{j \in J} x_j \leq s$ (2.56)

$\sum_{j \in J} z_j \leq n$ (2.57)

$x_j \leq p_j \quad \forall\, j \in J$ (2.58)

$$x_j \quad = \text{integer} \qquad \forall\, j \in J \qquad (2.59)$$

$$z_j, \bar{y}_{i,k} = 0, 1 \qquad \forall\, i \in I \qquad (2.60)$$

where $\bar{y}_{i,k} = \begin{cases} 1 \text{ if node } i \text{ is not covered by the } k \text{ ambulances} \\ 0 \text{ otherwise} \end{cases}$

$z_j = \begin{cases} 1 \text{ if stations located at station } j \\ 0 \text{ otherwise} \end{cases}$

x_j = number of ambulance located at station j

p_j = available space for ambulance at station j

s = maximum number of stations to be located

M_p = maximum number ambulances necessary to completed coverage

CEMSAA (1989)

$$\text{Minimize} \quad \left\{ P_0\left(d^+ + \sum_{j \in J} d_j^+\right), P_1 d^+, P_2 d^+, P_3 \sum_{j \in J} d_j^+, P_4 \sum_{j \in J} d_j^- \right\} \qquad (2.61)$$

where x_j = number of ambulance located at station j

d^+ = overachievement of goal

d^- = underachievement of goal

Detail each goal-constraints see in Baker *et al.* (1989).

CMCLP (1989)

$$\text{Maximize} \quad \sum_{i \in I} \sum_{j \in J} \left(c_{ij}^p a_i^p y_{ij}^p + c_{ij}^b a_i^b y_{ij}^b\right) \qquad (2.62)$$

$$\text{Subject to} \quad \sum_{j \in J} x_j \leq s \qquad (2.63)$$

$$\sum_{j \in J} y_{ij}^p = 1 \qquad \forall\, i \in I \qquad (2.64)$$

$$\sum_{j\in J} y_{ij}^b = 1 \qquad \forall\, i \in I \qquad (2.65)$$

$$y_{ij}^p + y_{ij}^b \le x_j \qquad \forall\, i \in I, \forall\, j \in J \qquad (2.66)$$

$$\sum_{i\in I}\left(a_i^p y_{ij}^p + a_i^b y_{ij}^b\right) \le W_j \qquad \forall\, j \in J \qquad (2.67)$$

$$y_{ij}^p, y_{ij}^b, x_j = 0, 1 \qquad \forall\, i \in I, \forall\, j \in J \qquad (2.68)$$

where $x_j = \begin{cases} 1 \text{ if stations located at site } j \\ 0 \text{ otherwise} \end{cases}$

$y_{ij}^p = \begin{cases} 1 \text{ if station } j \text{ provides primary service to demand node } i \\ 0 \text{ otherwise} \end{cases}$

$y_{ij}^b = \begin{cases} 1 \text{ if station } j \text{ provides secondary service to demand node } i \\ 0 \text{ otherwise} \end{cases}$

a_i^p = the expected demand for primary service at node i

a_i^b = the expected demand for secondary service at node i

$c_{ij}^p = \begin{cases} 1 \text{ if travel time from } j \text{ to } i \text{ is within standard for primary service} \\ 0 \text{ otherwise} \end{cases}$

$c_{ij}^b = \begin{cases} 1 \text{ if travel time from } j \text{ to } i \text{ is within standard for secondary service} \\ 0 \text{ otherwise} \end{cases}$

W_j = the workload capacity on a station at site j

MALP-I/MALP-II (1989)

Maximize
$$\sum_{i\in I} d_i y_{i,b} \qquad (2.69)$$

Subject to
$$\sum_{k=1}^{b} y_{i,k} \le \sum_{j\in J_i} x_j \qquad \forall\, i \in I \qquad (2.70)$$

$$y_{i,k} \le y_{i,k-1} \qquad \forall\, i \in I, k=\{2,\ldots,b\} \qquad (2.71)$$

$$\sum_{j\in J} x_j = n \qquad (2.72)$$

$$x_j, y_{i,k} = 0, 1 \qquad (2.73)$$

where $x_j = \begin{cases} 1 \text{ if stations located at site } j \\ 0 \text{ otherwise} \end{cases}$

$y_{i,k} = \begin{cases} 1 \text{ if node } i \text{ is covered by the } k \text{ ambulances} \\ 0 \text{ otherwise} \end{cases}$

MRLP (1989b)

ReVelle and Hogan (1989b) introduced the α-reliable p-center problem by improving the PLSCP model (ReVelle and Hogan, 1988) named the maximum reliability location problem (MRLP). The MRLP aims to find the position of p facilities that minimize the maximum time (or distance) within which service is available with a given α reliability. The method of deriving busy fraction has modified.

MCMCLP (1992)

$$\text{Maximize} \quad \sum_{i \in I} \sum_{j \in J} \sum_{k \in K} c_{ij}^k a_i^k y_{ij}^k \tag{2.74}$$

$$\text{Subject to} \quad \sum_{j \in J} x_j \leq s \tag{2.75}$$

$$\sum_{j \in J} y_{ij}^k = 1 \qquad \forall\, i \in I, \forall\, k \in k \tag{2.76}$$

$$\sum_{j \in J} y_{ij}^b = x_j \qquad \forall\, i \in I, \forall\, k \in k \tag{2.77}$$

$$\sum_{i \in I} \sum_{k \in K} a_i^k y_{ij}^k \leq W_j \qquad \forall\, j \in J \tag{2.78}$$

$$y_{ij}^k, x_j = 0, 1 \qquad \forall\, i \in I, \forall\, j \in J, \forall\, k \in k \tag{2.79}$$

where k, K = the index and set of service levels

a_i^k = the expected demand of node i for level k service

d_{ij} = distance from site j to demand node i

s = number of station to be sited

S^k = maximum service distance for acceptable service at level k

W_j = the workload capacity on a station at site j

$$x_j = \begin{cases} 1 \text{ if stations located at site } j \\ 0 \text{ otherwise} \end{cases}$$

$$y_{ij}^k = \begin{cases} 1 \text{ if station } j \text{ provides service of level } k \text{ to demand node } i \\ 0 \text{ otherwise} \end{cases}$$

$$c_{ij}^k = \begin{cases} 1 \text{ if } d_{\text{ij}} \leq S^k \\ 0 \text{ otherwis} \end{cases}$$

Rel-P (1993)

$$\text{Minimize} \quad \sum_{j \in J} \sum_{1 \le k \le p_j} c_{jk} x_{jk} \tag{2.80}$$

$$\text{Subject to} \quad \sum_{1 \le k \le p_j} x_{jk} \le 1 \qquad \forall\, j \in J \tag{2.81}$$

$$\sum_{j \in J_i} \sum_{1 \le k \le p_j} a_{jk} x_{jk} \ge b_i \qquad \forall\, i \in I \tag{2.82}$$

$$x_{jk} = 0, 1 \qquad \forall\, j \in J \tag{2.83}$$

where $x_{jk} = \begin{cases} 1 \text{ if } k \text{ ambulance allocated at station } j \\ 0 \text{ otherwise} \end{cases}$

p_j = upper bound number of ambulance located at site $j \in J$.

c_{jk} = cost of locating k ambulances at site $j \in J$.

a_{jk} = probability that calls to station j can not served with k ambulances

b_i = probability of uncoverage at demand node i = -log(*failure probability*)

Q-PLSCP (1994)

Marianov and ReVelle (1994) proposed the queuing probabilistic location set covering problem (Q-PLSCP). They applied queuing theory into PLSCP. The key difference between Q-PLSCP and PLSCP is in how b_i is calculated. They assumed the behavior in each demand node as an $M/M/s/0$ – loss queuing system (a Poisson arrival, exponentially distributed service time, s server, loss system). With the assumption, let s be the number of ambulances in the neighborhood. If define the state k is computed by standard queuing theory steady-state equations for state 1, 2, 3, ……s is:

$$P[getting\ into\ state\ k] - P[getting\ out\ of\ state\ k] = 0$$

$$[p_{k-1}\lambda_i + (k+1)\mu_i p_{k+1}] - [p_k \lambda_i + k\mu_i p_k] = 0 \tag{2.84}$$

and for the stare 0 is: $$\mu_i p_1 - p_0 \lambda_i = 0 \tag{2.85}$$

Solution of these questions a steady-stare yields the probability of all s

servers being busy, p_s:

$$p_s = \frac{(1/s!)\rho_i^{b_i}}{1 + \rho_i + (1/2!)\rho_i^2 + \cdots + (1/s!)\rho_i^s} \tag{2.86}$$

This probability is a decreasing function of the parameter s. The recursive formula for p_s as a function of p_{s-1} illustrates as the tern in parentheses in the following equation is than one:

$$p_s = \left(\frac{1}{p_{s-1} + s\mu_i/\lambda_i}\right) p_{s-1} \tag{2.87}$$

Now, the probability of at least one server being in the region is $1 - p_s$. For each neighborhood around demand node i and each value of s, we can compute the value of p_s, and if for p_{s-1}that demand node, $1 - p_s \geq \alpha$, then we assume that node i will be reliability α. As p_s is a decreasing function of s, there always exist a nonnegative integer b_i, such that $s \geq b_i$, $1 - p_s > \alpha$. This integer $b_i$represents the minimum number of servers which must be located at demand node i for that node to be considered as covered with reliability α. The number of servers s required to achieve availability with probability α, must be greater than, or at least equal to b_i, the equation (2017) can be replaced with:

$$p_s = \frac{(1/b_i!)\rho_i^{b_i}}{1 + \rho_i + (1/2!)\rho_i^2 + \cdots + (1/b_i!)\rho_i^{b_i}} \leq 1 - \alpha \tag{2.88}$$

TIMEXCLP (1994)

$$\text{Maximize} \quad \sum_{t \in T} \sum_{i \in I} \sum_{k}^{p_t} (1 - q_t) q_t^{j-1} d_{t,i} y_{t,k,i} \tag{2.89}$$

$$\text{Subject to} \quad \sum_{k}^{p_t} y_{t,k,i} = \sum_{j \in J_i} x_{t,j}\, a_{t,j,i} \qquad \forall\, i \in I, \forall\, j \in J \tag{2.90}$$

$$\sum_{j \in J} x_{t,j} = n_t \qquad \forall\, t \in T \tag{2.91}$$

$$x_{t,j} \text{ is integer} \qquad \forall\, j \in J, \forall\, t \in T \tag{2.92}$$

$$y_{t,k,i}, a_{t,i,j} = 0, 1 \qquad \forall\, i \in I, \forall\, j \in J \tag{2.93}$$

where $\quad y_{t,k,i} = \begin{cases} 1 & \text{if } k \text{ ambulance covered node } i \text{ at time } t \\ 0 & \text{otherwise} \end{cases}$

$$a_{t,i,j} = \begin{cases} 1 & \text{if station } j \text{ covered node } i \text{ at time } t \\ 0 & \text{otherwise} \end{cases}$$

FAST (1995)

Maximize

$$Z_1 = \sum_{i \in I} a_i y_i^A \tag{2.94}$$

$$Z_2 = \sum_{i \in I} a_i y_i^F \tag{2.95}$$

Subject to

$$y_i^A \le \sum_{j \in J_i^A} x_j^A \qquad \forall\, i \in I \tag{2.96}$$

$$y_i^F \le \sum_{j \in J_i^T} x_j^T \qquad \forall\, i \in I \tag{2.97}$$

$$y_i^F \leq \sum_{j \in J_i^E} x_j^E \qquad \forall\, i \in I \tag{2.98}$$

$$x_j^T \leq z_j \qquad \forall\, j \in J \tag{2.99}$$

$$x_j^E \leq z_j \qquad \forall\, j \in J \tag{2.100}$$

$$x_j^A \leq z_j + n_j \qquad \forall\, j \in J \tag{2.101}$$

$$\sum_{j \in J} x_j^A = n^A \tag{2.102}$$

$$\sum_{j \in J} x_j^E + \sum_{j \in J} x_j^T = n^{E+T} \tag{2.103}$$

$$z_j + n_j \leq 1 \qquad \forall\, j \in J \tag{2.104}$$

$$\sum_{j \in J} z_j + b \sum_{j \in J} n_j = B \tag{2.105}$$

$$y_i^A, y_i^F, x_j^A, x_j^T, x_j^E, z_j, n_j = 0,1 \qquad \forall\, i \in I, \forall\, j \in J \tag{2.106}$$

where a_i = population at demand node i

n^A = number of ambulance to be sited

n^{E+T} = number of engines and trucks to be positioned

S^A = distance standard for ambulances

S^T = distance standard for trucks

S^E = distance standard for engines

d_{ji} = distance from site j to demand node i

J_i^A = $\{j \in J \mid d_{ji} \leq S^A\}$

J_i^T = $\{j \in J \mid d_{ji} \leq S^T\}$

J_i^E = $\{j \in J \mid d_{ji} \leq S^E\}$

B = budget

b = fraction of the cost of a fire station that an ambulance station incurs

$y_i^A = \begin{cases} 1 \text{ if demand node } i \text{ has at least one ambulance stationed within } S^A \\ 0 \text{ otherwise} \end{cases}$

$y_i^F = \begin{cases} 1 \text{ if demand node } i \text{ has at least one ambulance stationed within } S^T \\ 0 \text{ otherwise} \end{cases}$

$x_j^A = \begin{cases} 1 \text{ if an ambulance is stationed at site } j \\ 0 \text{ otherwise} \end{cases}$

$x_j^T \quad = \begin{cases} 1 \text{ if a fire truck is stationed at site } j \\ 0 \text{ otherwise} \end{cases}$

$x_j^E \quad = \begin{cases} 1 \text{ if a fire engine is stationed at site } j \\ 0 \text{ otherwise} \end{cases}$

CCLP (1996)

$$\text{Maximize} \quad \begin{aligned} Z_A &= \sum_{i\in I} a_i r_i \\ Z_B &= \sum_{i\in I} a_i s_i \end{aligned} \tag{2.107}$$

$$\text{Subject to} \quad r_i \le \sum_{j\in MA_i} u_j + \sum_{k\in MB_i} v_k \qquad \forall\, i \in I \tag{2.108}$$

$$s_i \le \sum_{k\in NB_i} v_k \qquad \forall\, i \in I \tag{2.109}$$

$$u_j \le \sum_{k\in O_j} v_k \qquad \forall\, j \in J \tag{2.110}$$

$$\sum_{j\in J} u_j = p \tag{2.111}$$

$$\sum_{k\in K} v_k = q \tag{2.112}$$

$$r_i, s_i, u_j, v_k = 0, 1 \qquad \forall\, i \in I, \forall\, j \in J, \forall\, k \in K \tag{2.113}$$

where a_i = population at demand node i

p = number of facility type A to be sited

q = number of facility type B to be sited

j, J = index and set of potential sites for type A facilities.

k, K = index and set of potential sites for type B facilities.

S^A = distance standard for type A offering type A services

S^B = distance standard for type B offering type A services

T^B = distance standard for type B offering type B services

d_{ij} = distance from site j to demand node i

S^{AB} = maximum distance from a type A to a type B facility

MA_i $= \{j \in J \mid d_{ij} \le S^A\}$

MB_i $= \{k \in K \mid d_{ik} \le S^B\}$

NB_i $= \{k \in K \mid d_{ik} \le T^B\}$

O_i $= \{k \in K \mid d_{ik} \le S^{AB}\}$

$r_i \quad = \begin{cases} 1 \text{ if demand node } i \text{ is covered by a type A facility} \\ 0 \text{ otherwise} \end{cases}$

$s_i \quad = \begin{cases} 1 \text{ if demand node } i \text{ is covered by a type B facility} \\ 0 \text{ otherwise} \end{cases}$

$u_j \quad = \begin{cases} 1 \text{ if a type a facility located st site } j \\ 0 \text{ otherwise} \end{cases}$

$$v_k = \begin{cases} 1 \text{ if a type a facility located at site } k \\ 0 \text{ otherwise} \end{cases}$$

Q-MALP (1996)

Maximize $\sum_{i \in I} d_i y_{i,b_i}$ (2.114)

Subject to $\sum_{k=1}^{b_i} y_{i,k} \leq \sum_{j \in J_i} \sum_{k=1}^{C_j} x_{kj}$ $\forall\, i \in I$ (2.115)

$y_{i,k} \leq y_{i,k-1}$ $\forall\, i \in I$, k={2,…,b} (2.116)

$\sum_{j \in J} \sum_{k=1}^{C_j} x_{kj} = n$ (2.117)

$x_{kj}, y_{i,k} = 0, 1$ (2.118)

where $x_{k,j} = \begin{cases} 1 \text{ if ambulance } k \text{ located at stations } j \\ 0 \text{ otherwise} \end{cases}$

$y_{i,k} = \begin{cases} 1 \text{ if node } i \text{ is covered by } k \text{ ambulances} \\ 0 \text{ otherwise} \end{cases}$

C_j = capacity of each station j

DSM (1997)

Maximize	$\sum_{i \in I} d_i y_i^2$		(2.119)
Subject to	$\sum_{j \in J_i^2} x_j \geq 1$	$\forall\, i \in I$	(2.120)
	$\sum_{i \in I} d_i y_i^1 \geq \alpha \sum_{i \in I} d_i$		(2.121)
	$\sum_{j \in J_i^1} x_j \geq y_i^1 + y_i^2$	$\forall\, i \in I$	(2.122)
	$y_i^2 \leq y_i^1$	$\forall\, i \in I$	(2.123)
	$\sum_{j \in J} x_j = n$		(2.124)
	$x_j \leq n_j$	$\forall\, j \in J$	(2.125)
	x_j is integer	$\forall\, j \in J$	(2.126)
	$y_i^1, y_i^2 = 0, 1$	$\forall\, i \in I$	(2.127)

where $y_i^1 = \begin{cases} 1 \text{ if demand node } i \text{ covered 1 time within } r_1 \\ 0 \text{ otherwise} \end{cases}$

$y_i^2 = \begin{cases} 1 \text{ if demand node } i \text{ covered 2 time within } r_1 \\ 0 \text{ otherwise} \end{cases}$

J_i^1 = set of stations that covered demand node i within r_1

J_i^2 = set of stations that covered demand node i within r_2

x_j = number of ambulances located at station j

n_j = available space for ambulance at station j

TTM (1998)

Maximize $\sum_{i\in I}\sum_{h=1}^{h_i}\sum_{k=0}^{k_i}\sum_{l=0}^{l_i} d_i\theta_{ihkl}y_{ihkl}$ (2.128)

Subject to $\sum_{h=1}^{h_i} h \sum_{k=0}^{k_i}\sum_{l=0}^{l_i} y_{ihkl} \le \sum_{j\in J_i^A} x_j^A \qquad \forall\, i \in I$ (2.129)

$\sum_{k=1}^{k_i} k \sum_{h=k}^{h_i}\sum_{l=0}^{l_i} y_{ihkl} \le \sum_{j\in J_i^B} x_j^A \qquad \forall\, i \in I$ (2.130)

$\sum_{l=1}^{l_i} l \sum_{h=1}^{h_i}\sum_{k=0}^{k_i} y_{ihkl} \le \sum_{j\in J_i^B} x_j^B \qquad \forall\, i \in I$ (2.131)

$\sum_{h=1}^{h_i}\sum_{k=0}^{k_i}\sum_{l=0}^{l_i} y_{ihkl} \le 1 \qquad \forall\, i \in I$ (2.132)

$\sum_{j\in J} x_j^A \le n^A$ (2.133)

$\sum_{j\in J} x_j^B \le n^B$ (2.134)

$x_j^A, x_j^B, y_{ihkl} = 0, 1$ (2.135)

where $x_j^A \quad = \begin{cases} 1 \text{ if ALS unit located at station } j \\ 0 \text{ otherwise} \end{cases}$

$x_j^B \quad = \begin{cases} 1 \text{ if BLS unit located at station } j \\ 0 \text{ otherwise} \end{cases}$

θ_{ihkl} = probability that at node i; h ALS units within r^A, k ALS units within r^B, and l BLS units within r^B is busy.

n^A = number ALS units to be located

n^B = number BLS units to be located

J_i^A = set of stations that covered demand node i within r^A

J_i^B = set of stations that covered demand node i within r^B

QM-CLAM (1998)

$$\text{Maximize} \quad \sum_{i \in I} d_i y_{ij} \tag{2.136}$$

$$\text{Subject to} \quad y_{ij} \le x_j \qquad \forall\, i \in I, \forall\, j \in J \tag{2.137}$$

$$\sum_{j \in J} y_{ij} \le 1 \qquad \forall\, i \in I \tag{2.138}$$

$$\sum_{j \in J} x_j = s \tag{2. 139}$$

$$\sum_{i \in I} f_i y_{ij} \le \mu_j \sqrt[b+2]{1-\alpha} \tag{2.140}$$

$$x_j, y_{ij} = 0, 1 \tag{2.141}$$

where $x_j = \begin{cases} 1 \text{ if center located at node } j \\ 0 \text{ otherwise} \end{cases}$

$y_{ij} = \begin{cases} 1 \text{ if demand node } i \text{ is allocated to station } j \\ 0 \text{ otherwise} \end{cases}$

f_i = request for service at demand node i

b = number of customer in queue

α = probability of number in queue is less than b

HiQ-LSCP (2001)

$$\text{Minimize} \quad \sum_{j \in J} C_j x_j + \sum_{k \in J} K_k z_k \tag{2.142}$$

$$\text{Subject to} \quad \sum_{j,k} y_{ijk} = 1 \qquad \forall\, i \in I \text{ with } j \in N_i^l, k \in N_i^h, k \in M_j \tag{2.143}$$

$$y_{ijk} \le x_j \qquad \forall\, i,j,k \tag{2.144}$$

$$y_{ijk} \le z_k \qquad \forall\, i,j,k \tag{2.145}$$

$$\sum_{i,k} f_i y_{ijk} \le \mu_j^L \cdot \sqrt[b+2]{1-\alpha} \qquad \forall\ j \tag{2.146}$$

$$\sum_{i,j} \beta_j f_i y_{ijk} \le \mu_j^H \rho_{\alpha k}^H \qquad \forall\, k \tag{2.147}$$

$$y_{ijk}, x_j, z_k = 0, 1 \qquad \forall\, i,j,k \tag{2.148}$$

where $y_{ijk} = \begin{cases} 1 \text{ if population at demand node } i \text{ is allocated to a low-level server} \\ \qquad\qquad \text{located at the high-level candidate node } k \\ 0 \text{ otherwise} \end{cases}$

$x_j = \begin{cases} 1 \text{ if a low-level server is locate at node } j \\ 0 \text{ otherwise} \end{cases}$

$z_k = \begin{cases} 1 \text{ if a high-level server is locate at node } k \\ 0 \text{ otherwise} \end{cases}$

C_j = cost of opening and operation a low-level service center at node j

K_k = cost of opening and operation a high-level service center at node k

b = length of queue that is not to be exceeded with a predefined probability

α = predefined probability of not exceeding the queue length b

f_i = rate of appearance of requests for service at node i

λ_j^L = arrival rate of requests to low-level server j

μ_j^L = service rate at low-level server j

ρ_j^L = λ_j^L / μ_j^L

λ_k^H = arrival rate of requests to high-level server k

μ_k^H = service rate at high-level server k

ρ_k^H = λ_k^H / μ_k^H

β_j = percentage of requests to low-level node j that request high-level service

p_s = probability of s customer in queue

d_{ij} = shortest network distance between node i and node j

S_{dl} = standard distance from demand node to low-level server

S_{dh} = standard distance from demand node to high-level server

S_{lh} = standard distance from low-level server to its high-level server

N_i^l = $\{j | d_{ij} \leq S_{dl}\}$

N_i^h = $\{k | d_{ij} \leq S_{dh}\}$

M_j = $\{k | d_{ij} \leq S_{lh}\}$

HiQ-MCLP (2001)

$$\text{Maximize} \quad \sum_{i}\sum_{j}\sum_{k} a_i y_{ijk} \tag{2.149}$$

$$\text{Subject to} \quad \sum_{j,k} y_{ijk} \le 1 \qquad \forall\, i,j,k \tag{2.150}$$

$$y_{ijk} \le x_j \qquad \forall\, i,j,k \tag{2.151}$$

$$y_{ijk} \le z_k \qquad \forall\, i,j,k \tag{2.152}$$

$$\sum_{i,k} f_i y_{ijk} \le \mu_j^L \cdot \sqrt[b+2]{1-\alpha} \qquad \forall\ j \tag{2.153}$$

$$\sum_{i,j} \beta_j f_i y_{ijk} \le \mu_j^H \rho_{\alpha k}^H \qquad \forall\, k \tag{2.154}$$

$$\sum_{j} x_j = P_l \tag{2.155}$$

$$\sum_{k} z_k = P_h \tag{2.156}$$

$$y_{ijk}, x_j, z_k = 0,1 \qquad \forall\, i,j,k \tag{2.157}$$

where $y_{ijk} = \begin{cases} 1 & \text{if population at demand node } i \text{ is allocated to a low-level server} \\ & \text{located at the high-level candidate node } k \\ 0 & \text{otherwise} \end{cases}$

$x_j = \begin{cases} 1 & \text{if a low-level server is locate at node } j \\ 0 & \text{otherwise} \end{cases}$

$z_k = \begin{cases} 1 & \text{if a high-level server is locate at node } k \\ 0 & \text{otherwise} \end{cases}$

a_i = population at demand node i

P_l = number of low-level station to be located

P_h = number of high-level station to be located

b = length of queue that is not to be exceeded with a predefined probability

α = predefined probability of not exceeding the queue length b

f_i = rate of appearance of requests for service at node i

λ_j^L = arrival rate of requests to low-level server j

μ_j^L = service rate at low-level server j

ρ_j^L $= \lambda_j^L / \mu_j^L$

λ_k^H = arrival rate of requests to high-level server k

μ_k^H = service rate at high-level server k

ρ_k^H $= \lambda_k^H / \mu_k^H$

β_j = percentage of requests to low-level node j that request high-level service

p_s = probability of s customer in queue

d_{ij} = shortest network distance between node i and node j

S_{dl} = standard distance from demand node to low-level server

S_{dh} = standard distance from demand node to high-level server

S_{lh} = standard distance from low-level server to its high-level server

N_i^l $= \{j | d_{ij} \leq S_{dl}\}$

N_i^h $= \{k | d_{ij} \leq S_{dh}\}$

M_j $= \{k | d_{ij} \leq S_{lh}\}$

DDSM (2001)

Maximize $$\sum_{i\in I} d_i y_i^2 - \sum_{j\in J}\sum_{l=1}^{p} M_{jl}^t x_{jl} \quad (2.158)$$

Subject to $$\sum_{j\in J_i^2}\sum_{l=1}^{p} x_{jl} \geq 1 \qquad \forall\, i \in I \quad (2.159)$$

$$\sum_{i\in I} d_i y_i^1 \geq \alpha \sum_{i\in I} d_i \quad (2.160)$$

$$\sum_{j\in J_i^1}\sum_{l=1}^{p} x_{jl} \geq y_i^1 + y_i^2 \qquad \forall\, i \in I \quad (2.161)$$

$$y_i^2 \leq y_i^1 \qquad \forall\, i \in I \quad (2.162)$$

$$\sum_{j\in J} x_{jl} = 1 \qquad (l = 1, \dots, n) \quad (2.163)$$

$$\sum_{l=1}^{p} x_{jl} \leq n_j \qquad \forall\, j \in J \quad (2.164)$$

$$x_{jl}, y_i^1, y_i^2 = 0, 1 \quad (2.165)$$

where $x_{jl} = \begin{cases} 1 \text{ if ambulance } l \text{ move to station } j \\ 0 \text{ otherwise} \end{cases}$

$y_i^1 = \begin{cases} 1 \text{ if demand node } i \text{ covered 1 time within } r_1 \\ 0 \text{ otherwise} \end{cases}$

$y_i^2 = \begin{cases} 1 \text{ if demand node } i \text{ covered 2 time within } r_1 \\ 0 \text{ otherwise} \end{cases}$

J_i^1 = set of stations that covered demand node i within r_1

J_i^2 = set of stations that covered demand node i within r_2

n_j = available space for ambulance at station j

PLASC (2002)

$$\text{Minimize} \quad \sum_{j\in J} x_j \tag{2.166}$$

$$\text{Subject to} \quad \sum_{j\in J_i} y_{ij} = 1 \qquad \forall\, i \in I \tag{2.167}$$

$$y_{ij} \le x_j \qquad \forall\, i \in I, \forall\, j \in J_i \tag{2.168}$$

$$P[\text{station } j \text{ has} \le b \text{ people in queue}] \ge \alpha \tag{2.169}$$

where

$$x_j = \begin{cases} 1 \text{ if station } j \text{ is allocated} \\ 0 \text{ otherwise} \end{cases}$$

$$y_{ij} = \begin{cases} 1 \text{ if demand node } i \text{ located to served by station } j \\ 0 \text{ otherwise} \end{cases}$$

α = reliability of service

MECRP (2006)

$$\text{Maximize} \quad \sum_{k=1}^{n} \sum_{i\in I} d_i q_k\, y_{ik} \tag{2.170}$$

$$\text{Subject to} \quad \sum_{j\in J_i} x_{jk} \ge y_{ik} \qquad \forall\, i \in I, \ (k = 0, \dots, n) \tag{2.171}$$

$$\sum_{j\in J} x_{jk} = k \qquad (k = 0, \dots, n) \tag{2.172}$$

$$x_{jk} - x_{j,k-1} \le u_{jk} \qquad \forall\, j \in J, (k = 1, \dots, n-1) \tag{2.173}$$

$$\sum_{j\in J} u_{jk} \le \alpha_k \qquad (k = 1, \dots, n-1) \tag{2.174}$$

$$x_{jk}, y_{ik}, u_{jk} = 0, 1 \tag{2.175}$$

where

$$x_{jk} = \begin{cases} 1 \text{ if } k \text{ ambulances available and ambulance located at station } j \\ 0 \text{ otherwise} \end{cases}$$

$$y_{ik} = \begin{cases} 1 \text{ if } k \text{ ambulances available and demand node } i \text{ is covered} \\ 0 \text{ otherwise} \end{cases}$$

$$u_{jk} = \begin{cases} 1 \text{ if } k \text{ ambulances available and station } j \text{ is changed} \\ 0 \text{ otherwise} \end{cases}$$

$$\alpha_k = \{0,1, \dots, n\}$$

DACL (2008)

$$Q(m, p_t, j) = \frac{\sum_{k=j}^{m-1}(m-j-1)!\,(m-k)(m^k)\left(p_t^{k-j}\right)P_0}{(k-j)!\,(1-P_m)^j m!\left(1-p_t(1-P_m)\right)} \quad \forall j = 0,1,\dots,m-1 \tag{2.176}$$

Also let,

$$y_{j,t} = \begin{cases} 1 \text{ if node } j \text{ is covered by at least one server with } \alpha_t \text{ reliability at time } t \\ 0 \text{ otherwise;} \end{cases} \tag{2.177}$$

$$a_{ij,t} = \begin{cases} 1 \text{ if node } i \text{ is within the distance threshold of station } j \\ \qquad \text{during time interval } t \\ 0 \text{ otherwise;} \end{cases} \tag{2.178}$$

The formulation of DACL is:

$$\text{Minimize} \quad \sum_{t=1}^{T}\sum_{k=1}^{n}\sum_{i\in k} x_{ik,t} \tag{2.179}$$

$$\text{Subject to} \quad \left[\left\{1 - \prod_{i=1}^{m_t} p_{i,t}^{\sum_{k=1}^{n} a_{ij}x_{ik,t}} Q\left(m_t, \rho_t, \sum_{j=1}^{n}\sum_{i=1}^{m_t} a_{ij}x_{ik,t} - 1\right) - \alpha_t\right\}\right] y_{j,t} \geq 0 \tag{2.180}$$

$$\sum_{j=1}^{n} h_{j,t} y_{j,t} \geq c_t \qquad \forall\, t \in T \tag{2.181}$$

$$x_{ik,t}, y_{j,t} = 0, 1 \qquad \forall\, i, k, t \tag{2.182}$$

MERLP I/MERLP II (2009)

$$\text{Minimize} \quad \sum_{i\in I}\sum_{k=1}^{n} Q(n,p,k-1) d_{ik} h_i y_{ik} (1-p_k) \prod_{l=1}^{k-1} p_l \tag{2.183}$$

$$\text{Subject to} \quad \sum_{k=1}^{n} x_{ik\in N_i} = \sum_{k=1}^{n} y_{ik} \qquad \forall\, i \in I \tag{2.184}$$

$$\sum_{i\in I}\sum_{k=1}^{n} Q(n,p,k-1) d_{ik} h_i y_{ik} (1-p_k) \prod_{l=1}^{k-1} p_l \geq c \tag{2.185}$$

$$\sum_{i\in I}\sum_{k=1}^{n} x_{ik} = n \tag{2.186}$$

$$x_{ik}, y_{ik} = 0,1 \tag{2.187}$$

where $x_{ik} = \begin{cases} 1 \text{ if ambulance } k \text{ locate at node } i \\ 0 \text{ otherwise} \end{cases}$

$y_{ik} = \begin{cases} 1 \text{ if node } i \text{ is covered by ambulance } k \\ 0 \text{ otherwise} \end{cases}$

d_{ik} = response distance of ambulance k to node i

h_i = number of demand at node i

p_k = busy fraction of ambulance k

Q = correction factor approximate by Javis's hypercube (Jarvis, 1985)

c = pre-specified required coverage

N_i = set of all ambulances can covered node i

$$y_i = \begin{cases} 1 \; if \; node \; i \; is \; coverd \; with \; \alpha \; reliability \\ 0 \; otherwise \end{cases}$$

Followed the notation of MERLP I model, available coverage version, the formulation of MERLP II is:

Minimize $$\sum_{i\in I}\sum_{k=1}^{n} Q(n,p,k-1)d_{ik}h_i y_i(1-p_k)\prod_{l=1}^{k-1} p_l \tag{2.188}$$

Subject to $$\left[\left\{1-\prod_{k=1}^{n} p_k^{x_{ik\in N_i}}\, Q\left(n,p,\sum_{k=1}^{n} x_{ik\in N_i}-1\right)\right\}-\alpha\right] y_i \geq 0 \tag{2.189}$$

$$\sum_{i\in I} h_i y_i \geq c \tag{2.190}$$

$$\sum_{i\in I}\sum_{j\in I} x_{ij} = n \tag{2.191}$$

$$x_{ij}, y_i = 0,1 \tag{2.192}$$

where $y_i = \begin{cases} 1 \text{ if node } i \text{ is covered with } \alpha \text{ reliability} \\ 0 \text{ otherwise} \end{cases}$

SQM (2009)

Minimize $$\sum_{n=1}^{N}\sum_{j=1}^{J}(\rho_{nj}t_{nj}) \tag{2.193}$$

Subject to $$\sum_{j=1}^{J} f_j y_j \geq c_{cov} \tag{2.194}$$

$$\sum_{i \in W_j} x_i \geq y_j \tag{2.195}$$

$$\sum_{i=1}^{I} x_i = n \tag{2.196}$$

$$x_j, y_i = 0,1 \tag{2.197}$$

$$\rho_{nj} = f_j \frac{\sum_{B_i \in E_{kj}} P\{B_i\}}{(1 - P\{B_{2^n-1}\})} \tag{2.198}$$

$$P\{B_j\}\left[\sum_{\{B_i \in C_n : d_{ij}^- = 1\}} \lambda_{ij} + \sum_{\{B_i \in C_n : d_{ij}^+ = 1\}} \mu_{ij}\right] = \sum_{\{B_i \in C_n : d_{ij}^- = 1\}} \mu_{ij} P\{B_i\} + \sum_{\{B_i \in C_n : d_{ij}^+ = 1\}} \lambda_{ij} P\{B_i\} \tag{2.199}$$

$$\sum_{i=0}^{2^n-1} P\{B_i\} = 1 \tag{2.200}$$

mDSM (2010)

Maximize $$\sum_{t\in T}\left(\sum_{i\in I} d_i y_i^{2,t} - \beta \sum_{i,j\in J} r_{ij}^t\right) \qquad (2.201)$$

Subject to $$\sum_{j\in J_i^{2,t}} x_j^t \geq 1 \qquad \forall\, i \in I, t \in T \qquad (2.202)$$

$$\sum_{i\in I} d_i y_i^{1,t} = \alpha \sum_{i\in I} d_i \qquad \forall\, t \in T \qquad (2.203)$$

$$y_i^{2,t} \geq y_i^{1,t} \qquad \forall\, i \in I, t \in T \qquad (2.204)$$

$$\sum_{j\in J} x_j^t = n \qquad (2.205)$$

$$x_j^t \leq n_j \qquad \forall\, j \in J, t \in T \qquad (2.206)$$

$$x_j^t + \sum_{i,j\in J} r_{ij}^t - \sum_{i,j\in J} r_{ji}^t = x_j^{t+1} \qquad \forall\, j \in J, t \in T' \qquad (2.207)$$

$$x_j^T + \sum_{i,j\in J} r_{ij}^T - \sum_{i,j\in J} r_{ji}^T = x_j^1 \qquad \forall\, j \in J \qquad (2.208)$$

$$\sum_{i\in I_j^{2,t}} z_{ij}^t \leq \omega n_j \qquad \forall\, j \in J, t \in T \qquad (2.209)$$

$$\sum_{j\in J_i^{2,t}} z_{ij}^t = d_i \qquad \forall\, i \in I, t \in T \qquad (2.210)$$

$$x_j^t = \text{integer} \qquad (2.211)$$

$$y_i^{k,t}, r_{ij}^t = 0, 1 \qquad (2.212)$$

where x_j^t = number of ambulances locate at station j at period t

$y_i^{k,t} = \begin{cases} 1 \text{ if demand node } i \text{ is covered } k \text{ time at period } t \\ 0 \text{ otherwise} \end{cases}$

$r_{ij}^t = \begin{cases} 1 \text{ if relocate ambulance from location } i \text{ to location } j \text{ at period } t \\ 0 \text{ otherwise} \end{cases}$

z_{ij}^t = number of demand at node i cover by station j at period t

n_j = available space for ambulance at station j

Appendix C: Distances Between Quarters

		Rafah	Al-Naser	Shokat	Khan Yunis	Al Qarara	Bani Suheila	Abasan Al Kabira	Abasan al Jadida	Khuza'a	Al fukhkhari	An Nuseirat	Al Buraij	Az Zawayda	Al Maghazi	Deir al Balah	Al Musaddar	Wadi Al Salqa	Gaza	Madinat Ezahra	Al Mughraqa	Juhor ad Dik	Um Al-Naser	Beit Lahiya	Beit Hanun	Jabalya
1.	Rafah	0	5.5	7.0	9.0	13.0	10.0	10.5	11.5	11.5	9.0	23.0	22.5	21.0	20.0	17.0	18.5	17.5	30.0	25.0	25.5	27.0	40.0	38.0	39.0	35.0
2.	Al-Naser	5.5	0	4.0	8.0	11.0	7.5	6.5	8.5	6.5	4.0	21.0	20.5	19.0	18.0	16.0	17.0	16.0	31.0	27.5	27.0	25.5	36.0	36.5	37.0	33.0
3.	Shoka	7.0	4.0	0	11.5	15.5	12.0	11.0	12.0	10.5	8.0	25.5	25.0	23.5	22.5	20.5	21.5	20.5	35.0	32.0	31.5	30.0	40.5	40.0	41.5	37.5
4.	Khan Yunis	9.0	8.0	11.5	0	5.0	3.0	5.5	5.0	8.0	7.0	14.5	14.0	12.5	11.5	9.0	10.5	10.0	24.5	17.0	17.5	20.0	29.5	30.0	31.0	27.0
5.	Al Qarara	13.0	11.0	15.5	5.0	0	4.0	5.5	3.5	8.0	8.5	10.0	9.5	8.0	7.0	5.5	6.0	4.0	20.0	13.0	13.5	15.0	25.0	25.5	26.5	22.0
6.	Bani Suheila	10.0	7.5	12.0	3.0	4.0	0	3.0	2.5	6.0	5.5	13.5	13.0	11.0	10.5	7.0	9.5	6.5	23.5	16.5	17.0	18.5	28.5	29.5	30.0	25.5
7.	Abasan Al Kabira	10.5	6.5	11.0	5.5	5.5	3.0	0	2.0	3.0	3.5	15.0	14.0	13.0	12.0	11.0	10.5	7.5	24.5	18.0	18.0	19.0	29.5	30.0	30.0	26.5
8.	Abasan al Jadida	11.5	8.5	12.0	5.0	3.5	2.5	2.0	0	4.5	5.0	13.0	12.0	11.0	10.0	8.5	9.0	5.5	23.0	16.0	16.5	17.5	28.0	28.0	28.5	24.5
9.	Khuza'a	11.5	6.5	10.5	8.0	8.0	6.0	3.5	4.5	0	2.5	17.0	16.0	15.0	14.0	13.0	13.0	10.0	26.5	20.0	19.0	20.5	31.5	31.0	31.5	28.0
10.	Al fukhari	9.0	4.0	8.0	7.0	8.5	5.5	3.5	5.0	2.5	0	18.0	17.5	16.0	15.0	13.5	14.0	11.0	28.0	21.0	20.5	22.0	33.0	33.0	33.5	29.5
11.	An Nuseirat	23.0	21.0	25.5	14.5	10.0	13.5	15.0	13.0	17.0	18.0	0	2.0	2.5	3.5	5.5	4.5	7.5	10.0	3.0	3.5	6.5	15.0	16.0	17.0	12.0
12.	Al Buraij	22.5	20.5	25.0	14.0	9.5	13.0	11.0	15.0	16.0	17.0	2.0	0	2.5	2.5	5.5	3.5	6.5	10.5	4.0	4.0	6.0	15.5	16.0	17.0	12.5
13.	Az Zawayda	21.0	19.0	23.5	12.5	8.0	11.0	13.0	11.0	15.0	16.0	2.5	2.5	0	1.5	3.5	2.0	5.0	12.0	5.0	6.0	8.0	17.5	18.0	19.0	14.5
14.	Al Maghazi	20.0	18.0	22.5	11.5	7.0	10.5	12.0	10.0	14.0	15.0	3.5	2.5	1.5	0	2.0	1.5	4.0	13.0	6.0	6.5	8.5	18.0	19.0	19.5	15.0
15.	Deir al Balah	17.0	16.0	20.5	9.0	5.5	7.0	11.0	8.5	13.0	13.5	5.5	5.5	3.5	2.0	0	2.5	3.5	15.5	8.0	9.0	11.5	20.5	21.5	22.5	17.5
16.	Al Musaddar	18.5	17.0	21.5	10.5	6.0	9.5	10.5	9.0	13.0	14.0	4.5	3.5	2.0	1.5	2.5	0	3.0	14.5	7.0	7.5	9.5	19.5	20.0	20.5	16.5
17.	Wadi Al Salqa	17.5	16.0	20.5	10.0	4.0	6.5	7.5	5.5	10.0	11.0	7.5	6.5	5.0	4.0	3.5	3.0	0	17.0	10.0	10.5	12.0	22.5	23.0	23.5	19.0
18.	Gaza	30.0	31.0	35.0	24.5	20.0	23.5	24.5	23.0	26.5	28.0	10.0	10.5	12.0	13.0	15.5	14.5	17.0	0	7.0	6.5	7.0	5.5	6.5	8.0	2.5
19.	Madinat Ezahra	25.0	27.5	32.0	17.0	13.0	16.5	18.0	16.0	20.0	21.0	3.0	4.0	5.0	6.0	8.0	7.0	10.0	7.0	0	2.0	5.0	12.0	13.0	14.5	9.5
20.	Al Mughraqa	25.5	27.0	31.5	17.5	13.5	17.0	18.0	16.5	19.0	20.5	3.5	4.0	6.0	6.5	9.0	7.5	10.5	6.5	2.0	0	3.5	12.0	12.5	13.5	8.5
21.	Juhor ad Dik	27.0	25.5	30.0	20.0	15.0	18.5	19.0	17.5	20.5	22.0	6.5	6.0	8.0	8.5	11.5	9.5	12.0	7.0	5.0	3.5	0	11.0	11.0	11.5	8.0
22.	Um Al-Naser	40.0	36.0	40.5	29.5	25.5	28.5	29.5	28.0	31.5	33.0	15.0	15.5	17.5	18.0	20.5	19.5	22.5	5.5	12.0	12.0	11.0	0	2.5	5.5	3.5
23.	BeitLahiya	38.0	36.5	40.0	30.0	25.5	29.5	30.0	28.0	31.0	33.0	16.0	16.0	18.0	19.0	21.5	20.0	23.0	6.5	13.0	12.5	11.0	2.5	0	3.0	3.5
24.	Beit Hanun	39.0	37.0	41.5	31.0	26.5	30.0	30.0	28.5	31.5	33.5	17.0	17.0	19.0	19.5	22.5	20.5	23.5	8.0	14.5	13.5	11.5	5.5	3.0	0	5.5
25.	Jabalya	35.0	33.0	37.5	27.0	22.0	25.5	26.5	24.5	28.0	29.5	12.0	12.5	14.5	15.0	17.5	16.5	19.0	2.5	9.5	8.5	8.0	3.5	3.5	5.5	0