A THREE-LEVEL HIERARCHICAL LOCATION-ALLOCATION MODEL FOR REGIONAL ORGANIZATION OF PERINATAL CARE

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ŞAKİR KARAKAYA

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submitted by **ŞAKİR KARAKAYA** in partial fulfillment of the requirements for the degree of **Master of Science in Industrial Engineering, Middle East Technical University** by,

Prof. Dr. Canan Özgen ___________________
Dean, Graduate School of **Natural and Applied Sciences**

Prof. Dr. Nur Evin Özdemirel ___________________
Head of Department, **Industrial Engineering**

Assist. Prof. Dr. Sedef Meral ___________________
Supervisor, **Industrial Engineering Dept., METU**

Examining Committee Members:

Prof. Dr. Sinan Kayalıgil ___________________
Industrial Engineering Dept., METU

Assist. Prof. Dr. Sedef Meral ___________________
Industrial Engineering Dept., METU

Assist. Prof. Dr. Z.Pelin Bayındır ___________________
Industrial Engineering Dept., METU

Dr. İsmail Serdar Bakal ___________________
Industrial & Systems Engineering Dept., University of Florida

Asst. Prof. Dr. Bahar Özyörük ___________________
Industrial Engineering Dept., Gazi University

Date: ___________________

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Name, Last name: Şakir Karakaya

Signature :

ABSTRACT

A THREE-LEVEL HIERARCHICAL LOCATION-ALLOCATION MODEL FOR REGIONAL ORGANIZATION OF PERINATAL CARE

Karakaya, Şakir
M.S., Department of Industrial Engineering
Supervisor: Assist. Prof. Dr. Sedef Meral

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While the concept of regional organization (regionalization) of perinatal care aimed at reducing perinatal mortality has remained at the agenda of developed countries since 1970's, Turkey is one of the countries that does not have such a system yet. In this study, a three-level hierarchical location-allocation model is developed for the regionalization of perinatal care in an attempt to have a better distribution of maternal and perinatal health care services in Turkey. Since the mathematical model developed is difficult to solve in a reasonable time, we propose three heuristic approaches: top-down, modified top-down and Lagrangean relaxation based heuristics. These heuristics are computationally tested on a set of problem instances for networks ranging from 10 to 737 vertices. A significant result is that Lagrangean relaxation based heuristic outperforms the other two heuristics in terms of solution quality. In most of the test problems, the modified top-down heuristic outperforms the top-down heuristic in terms of solution quality. Using the proposed approaches, we solve a real life problem corresponding to the Eastern and South Eastern Anatolian Regions (the East Region) of Turkey.

Keywords: Regionalization, perinatal care, hierarchical location-allocation model, top-down heuristics, Lagrangean relaxation.

ÖZ

PERİNATAL BAKIMIN BÖLGESELLEŞTİRİLMESİ İÇİN ÜÇ-BASAMAKLI HİYERARŞİK BİR YERSEÇİMİ-ATAMA MODELİ

Karakaya, Şakir
Yüksek Lisans, Endüstri Mühendisliği Bölümü
Tez Yöneticisi: Y. Doç. Dr. Sedef Meral

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Perinatal mortaliteyi azaltmayı amaçlayan perinatal bakımın bölgeselleştirilmesi olarak tanımlanan düzenleme, gelişmiş ülkelerde 1970'li yıllardan beri uygulanmakta iken, Türkiye bu uygulamanın henüz başlatılamadığı ülkelerden birisidir. Bu çalışmada, Türkiye'de maternal ve perinatal bakım hizmetlerinin daha iyi dağılımını sağlayabilmek amacıyla, perinatal bakımın bölgeselleştirilmesine yönelik olarak üç-basamaklı hiyerarşik bir yer seçimi-atama modeli önerilmiştir. Bu matematiksel modelin uygun sürede çözümünün zor olması nedeniyle, sezgisel yöntemler geliştirilmiştir: yukarıdan-aşağıya adım adım çözme yöntemi, modifiye edilmiş yukarıdan-aşağıya adım adım çözme yöntemi ve Lagrange gevşetmesine dayalı çözüm yöntemi. Bu yöntemler 10'dan 737'ye kadar değişen sayıda potansiyel tesis yerini içeren değişik problemler ile test edilmiştir. Buna göre, Lagrange gevşetmesine dayalı sezgisel yöntem, çözüm kalitesi bakımından diğer iki yöntemden daha iyi sonuç vermiştir. Problemlerin birçoğunda, çözüm kalitesi bakımından modifiye edilmiş yukarıdan-aşağıya adım adım çözme yöntemi, yukarıdan-aşağıya adım adım çözme yönteminden daha iyi sonuç vermiştir. Geliştirilen yöntemler kullanılarak, Türkiye'nin Doğu ve Güneydoğu Anadolu Bölgesini içeren bir gerçek hayat problemi için çözüm sunulmuştur.

Anahtar Kelimeler: Bölgeselleştirme, perinatal bakım, hiyerarşik yerseçimi-atama modeli, yukarıdan-aşağıya adım adım çözme yöntemi, Lagrange gevşetmesi.

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H	Hierarchical
LB	Lower Bound
LRH	Lagrangean Relaxation Based Heuristic
LRP	Lagrangean Relaxation Problem
MCLP	Maximal-Covering Location Model
MIP	Mixed Integer Programming
MMR	Maternal Mortality Rate
MTDH	Modified Top-Down Heuristic
OFV	Objective Function Value
PNMR	Perinatal Mortality Rate
S	Singular
3-HLM	Three Level Hierarchical Location Model
TDH	Top-Down Heuristic
TDHS	Turkish Demographic and Health Survey
UB	Upper Bound

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Health indicators are standardized measures used for evaluating a health system's effectiveness, and the state of health of both individuals and the overall population, and comparing the health status and health system performance. Among these indicators, for instance, there are death rates such as premature mortality, infant mortality and perinatal mortality rates; incidence rates of diseases such as tuberculosis, cancer and AIDS; psychological well-being, fertility rates, etc. Indicators related to the perinatal period of pregnancy (i.e. perinatal and maternal mortality rates, premature mortality, fertility rates, etc.), which applies to the last months of pregnancy and the first week after delivery (i.e., perinatal period = post prenatal period + natal + early neonatal period), are very important in the health care environment, because these rates denote the level of health of pregnant women and their infants as well as the standard of health care provided for delivery and neonatal health care. "The perinatal mortality rate is also one of the best indicators of the socio-economic status of a community, a region or a country. Communities with a high perinatal mortality rate also have a high maternal mortality rate as both reflect poor living conditions and inadequate health care services. Following the perinatal mortality rate over a number of years gives a good idea of the progress of a community" (www.pepcourse.co.za, 23 January 2007).

According to the World Health Organization (WHO), the *perinatal period* commences at the end of 22nd week (154 days) of gestation and ends after seven completed days from birth, as shown in Figure 1.1.

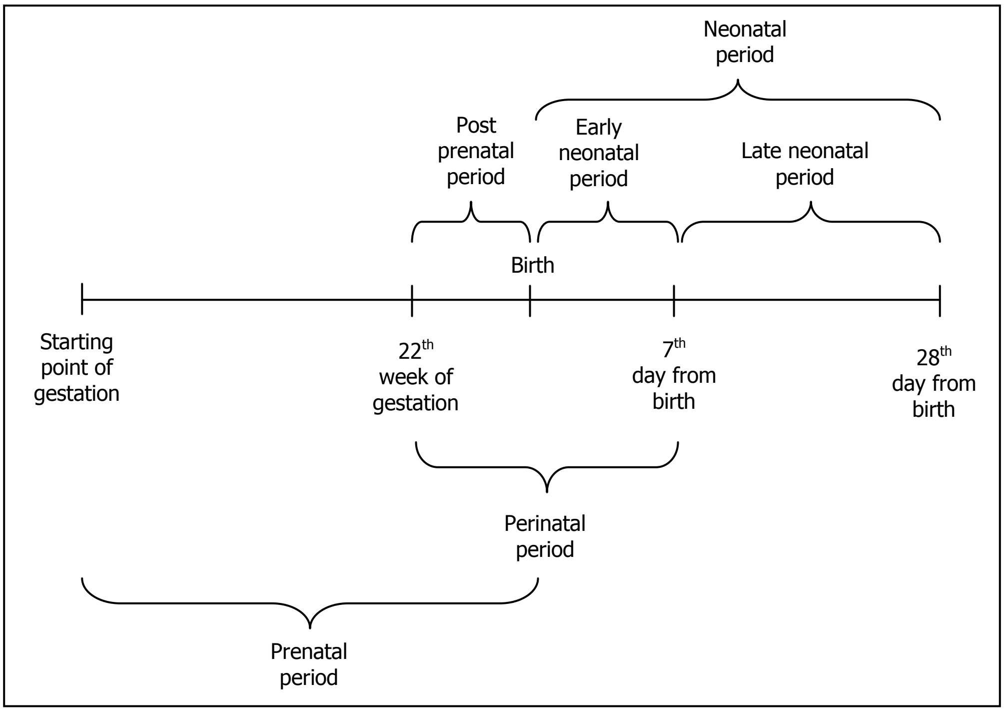

Figure 1.1. Prenatal, perinatal and neonatal periods

It should be noted that it is the period in which the effects of the problems related to gestational and natal can be seen distinctly on new born and so in this period, maternity welfare and new born care are vitally important. Number of deaths occurring during the perinatal period, i.e. total number of babies born dead and babies born alive but die within the first 7 days after delivery (stillbirths), is used to determine *the perinatal mortality rate (PNMR)* over a specific time period. PNMR is calculated as follows:

$$PNMR = \frac{\text{Number of stillbirths} + \text{number of early neonatal deaths}}{\text{Number of liveborn} + \text{Number of stillborn infants}} * 1{,}000$$

Another good indicator used for assessing both the standard of health of pregnant women and standard of care being provided to mothers after delivery is *maternal mortality (i.e. the death of a woman during pregnancy)*. This is used to determine the maternal mortality rate (MMR) which is defined over a specific time period and per 100,000 deliveries. The maternal mortality rate is calculated as follows:

$$MMR = \frac{\text{Number of maternal deaths}}{\text{Number of deliveries}} * 100{,}000$$

WHO pointed out that according to statistics of the year 2000, the perinatal mortality rate is five times higher in developing regions than in developed regions: 10 deaths per 1000 total births in developed regions; 50 per 1000 in developing regions and over 60 per 1000 in least developed countries. It is the highest in Africa, with 62 deaths per 1000 births, and especially in middle and western Africa, which have rates as high as 75 and 76 per 1000. The perinatal mortality rate in Asia is 50 per 1000 total births, with a peak of 65 per 1000 in South-central Asia, the third highest rate among the regions, lower than only those of Middle and Western Africa. Oceania's rate of 42 per 1000 falls between the rates of Asia and those of the Latin America and Caribbean region. Differences in the latter region are nevertheless significant, with a rate of 31 in the Caribbean and around 20 in Central and South America. The lowest values are from Northern America and Europe with 7 and 13 per 1000, respectively (WHO, 2006a).

In many developing countries the maternal mortality rate is also high. Worldwide, most of the maternal deaths occur in poor countries where the death is usually related to poverty and inadequate access to good health care services (www.pepcourse.co.za, 23 January 2007).

The perinatal mortality rates reflect the quality of obstetric and pediatric care available and play an important role in providing the information needed to improve the health status of pregnant women, mothers and newborns. That information allows decision-makers to identify problems, track temporal and geographical trends and disparities and assess changes in public health policy and practice (WHO, 2006a).

When we analyze this situation for Turkey, it can be seen that both perinatal and maternal mortality rates are high. According to WHO perinatal mortality rate is 36 per 1000 for Turkey (year 2000). It can be compared, for example, to the mortality rate of 6 for Canada (year 2000), rate of 5 for Sweden (year 2000), rate of 8 for Denmark (year 2000), rate of 7 for Japan and rate of 8 for The Netherlands (year 2000) (WHO, 2006a). Besides these data introduced by WHO, the first comprehensive study is conducted by Erdem (2003) to investigate the perinatal mortality rate, the stillbirth rate and the early neonatal mortality rate in 29 centers throughout Turkey between January 1, 1999 and December 31, 1999. Perinatal mortality rate is *34.9 per 1000*, stillbirth rate *18 per 1000* and early neonatal death rate *17.2 per 1000*. Perinatal mortality rates are highest with 71.9 and 62.9 per 1000 in the Black Sea, Eastern and Southeastern Anatolia Regions respectively that have low socio-economic status and are predominantly rural and semi-urban. The rate is lowest (27.3 per 1000) in the Aegean Region that is economically more developed. Moreover, these rates are 40.6 in the Mediterranean Region, 35.8 in Marmara Region and 29.6 in Middle Anatolia Region. In 23 out of 29 centers, the causes of death are clearly determined. In conclusion, it is noted that reduction in the perinatal mortality rate in Turkey is likely to be possible only with the co-ordination of the government, universities, obstetricians and neonatologists and improvement of antenatal, delivery and postnatal care and prevention of prematurity (Erdem, 2003).

A timely study, Turkey Demographic and Health Survey (year 2003), is conducted by Hacettepe University (TDHS, 2003). According to the results of this survey, the perinatal mortality rate is estimated as **24 per thousand** births during the 5 years preceding the survey. Perinatal mortality rate in rural regions (29 per thousand) is higher than in urban regions (21 per thousand). Estimated perinatal mortality rate of Southern (27 per thousand) and Eastern Anatolia Regions (33 per thousand) is higher than the average rate (24 per thousand) of Turkey. According to the Health Statistics in Turkey (year 2006), published by the Turkish Medical Association, perinatal conditions cause almost 3.5 % of all deaths in Turkey, while this percentage is 1 % in the EU countries (WHO, 2006a). Moreover, the maternal mortality rate is 70.0 per 100,000 (year 2000) in Turkey, while this rate is 5 per 100,000 in Canada, 7 per 100,000 in Denmark, 8 per 100,000 in Sweden and 10 per 100,000 in Japan (WHO, 2006b).

In Turkey, there are some problems encountered in efforts made for reducing the perinatal mortality rate. These are (Yurdakök, 2005):

- Deficiency of strategies for reducing the perinatal-neonatal deaths,
- Insufficient organization and distribution of perinatal-neonatal care services,
- Lack of multidisciplinary approach to perinatal care,
- Inefficient neonatal intensive care units,
- Lack of organized neonatal referral transportation system
- Centralization and over-medication of services.

"On the other hand, rapid developments in neonatal intensive care units and advances in the number of neonatal specialists during the last years have helped reduce the neonatal mortality and morbidity rates. But reduction in these rates depends not only on the technological developments, but also on the good organization and high quality of perinatal care services. These services should be built up according to the needs of the society and be coordinated well enough" (Tekinalp, 2003).

Over the last years, attempts are made for reducing the perinatal mortality rate in most of the US states (New York, California, Wisconsin, Iowa) and European countries such as France, Portugal, Germany, Sweden, Australia and United Kingdom to develop a regional approach to perinatal care, and to establish regional centers to care for high-risk mothers and their infants. In these countries, regional perinatal care systems are developed and successful results in reducing the infant mortality are acquired by improving both the quality and availability of perinatal services to geographically defined populations in the regions (See Hein, 2004; Mullem et al., 2004; Pasquier et al., 2005; Paul and Singh, 2004; Yeast et al., 1998; Yu and Dunn, 2004; Zeitlin et al., 2004).

1.2 REGIONALIZATION OF PERINATAL CARE

Regionalization is a regulatory approach to rationalization of resource allocation, especially for highly specialized medical services or technologies. Proposals to encourage regionalization have come in sight over the years. A major argument in favor of regionalization is the possibility of achieving better patient outcomes (Chang and Klitzner, 2002). Regionalization of health care services is an important component of systems planning and is common in countries such as the United Kingdom and Italy (Pierskalla and Brailer, 1994). Experiences in perinatal and neonatal care regionalization have resulted in improved outcomes for mothers and infants by providing appropriate services to them as close to their homes as possible and through a better distribution of health care facilities. According to Ryan (1977) (as cited in Galvão et al., 2006a), regionalization provides modern technologies to the majority of the population. The supply of technologies by the health units of a given area should take account of the given profile of needs of mothers and babies (as detected by clinical-epidemiological criteria). That is, a reference system must be built according to the needs of the patients.

Regionalization of any health care facilities is based on the organization of health care services defined in a hierarchical structure. "Such hierarchical systems distinguish the level of assistance from level of the health unit: a health unit is seen as a centre that can offer more than one level of medical assistance. This may imply, for instance, developing a hierarchical system composed of three levels of assistance (service) and three levels of units, in which health units of level-2 offer services of levels-1 and level-2, and health units of level-3 offer all three types of services (service levels-1, -2 and -3). The existence of units of level-1 must have a geographical justification, being located for example in rural or isolated areas. In metropolitan areas these units should be gradually integrated with units of level-2" (Ryan, 1977; as cited in Galvão et al., 2006).

Regionalized perinatal care is first advocated in Canada 40 years ago. In 1968, when the Department of National Health and Welfare in Canada published the 'Recommended Standards for Maternity and Newborn Care', the philosophy of the regionalized perinatal care had appeared with the following statement (Yu and Dunn, 2004):

"It is recognized that certain mothers and infants, because of past pregnancy experience or present complications, are at high risk for development of difficulties and require for their optimum care facilities and services which may not be found in all hospitals providing maternity care. When these mothers and babies can be recognized and their problems are anticipated, there is a growing appreciation of the value of ensuring that they be cared for in hospitals with the best facilities even though this may require referral to another institution."

After Canada's efforts, in 1977 the Committee on Perinatal Health in USA described the concept of regionalized perinatal care as follows (Mullem et al., 2004):

"Regionalization implies the development, within a geographic area, of a coordinated, cooperative system of maternal and perinatal health care in which, by mutual agreements between hospitals and physicians and based upon population needs, the degree of complexity of maternal and perinatal care each hospital is capable of providing is identified so as to accomplish the following objectives: quality care to all pregnant women and newborns, maximal utilization of highly trained perinatal personnel and intensive care facilities, and assurance of reasonable cost effectiveness." In USA, from that year to early 1980's regional perinatal centers are established, and they developed formal relationships with smaller community hospitals; arrangements are made to transfer high-risk women antenatally, or newborn infants if they required a higher level of care (Mullem et al., 2004).

Two goals of regionalization are described in the American Medical Association document (1971) (as cited in Yu and Dunn, 2004): (1) 'Programs to identify the high-risk pregnancy in sufficient time to allow for delivery at those hospitals which are staffed, equipped, and organized for optimal perinatal care'; and (2) 'Programs for the early recognition of high-risk infants not identified during the prenatal period, which provide for the prompt transfer of a distressed infant to a more appropriately equipped facility when indicated; i.e. arrangements for transport should be an integral part of the regional perinatal care planning'.

Perinatal regionalization promotes the creation of perinatal care networks. "These networks are meant to optimize the management of pregnant women taking into account their pregnancy risks and their possible delivery site equipped with the expertise and technology needed for their optimal care. In fact, regionalization is one means of enhancing the inborn rate in cases of high-risk pregnancies and the concept is developed to replace a centralized system under which the same facilities are used to manage low- and high-risk pregnancies as well." (Pasquier et al., 2005) Regionalization also includes a broad array of regional services including maternal-risk evaluation, consultation referral and transport, neonatal transport, outreach education, back transfer, regional statistics and long-term follow-up (Zeitlin et al., 2004).

Regionalization of perinatal care facilities is based on the organization of health care services defined in a hierarchical structure. This hierarchy connects the health care centers serving to pregnancy, birth and neonatal health care assistance at different levels. When levels of care are defined in a regionalized system, most are based on a three-tiered system which includes tertiary care centers, called level-3 units, other neonatal units, called level-2 units, and maternity units without neonatal units, called level-1 units. There are some variants on this general scheme (Zeitlin et al., 2004). Portugal, for instance, has a regionalized system that consists of local health centers caring for normal pregnancies and normal newborn babies; first-level hospitals without deliveries; second-level hospitals caring for normal pregnancies and normal babies, with intermediate care units and with the ability to ventilate newborns whilst awaiting neonatal transport; and third-level hospitals with neonatal intensive care units, caring for high-risk pregnancies and high-risk newborns (Neto, 2002). “In Belgium, because all maternity units are required by law to have an adjoining neonatal unit, there are no level-1 maternity units. In The Netherlands, only level-3 units have an official definition. Moreover, levels of care are defined differently in different places. The greatest heterogeneity in definitions is observed for level-2 units, which cover a broad range of intermediary care settings. Some countries, including Sweden and France, define two tiers of level-2 units” (Zeitlin et al., 2004).

As discussed above, while there are countries with officially defined levels of care for regionalization including Belgium, France, The Netherlands, Poland, Portugal and Sweden, Turkey doesn’t use any official health policies to regulate the care of moderate- and high-risk pregnancies and births. Instead, some national scientific people make recommendations, generally, on the importance of neonatal transfer and birth in level-3 centers for preterm babies.

Since birth rate and perinatal-maternal mortality rates are high in Turkey, antenatal care, delivery and neonatal intensive care services should be designated in compliance with the principles of regionalization of perinatal care; the neonatal transport needs to be incorporated into this system; and it is needed to optimize the distribution of neonatologists and neonatal intensive care units in accordance with the regional requirements. Within this scope, it is suggested that the regionalized hierarchical structure implemented successfully in developed countries since 1970's for maternal and perinatal health care services should be considered for implementation in Turkey. Besides the reflection of regionalization strategy for perinatal care to improved health indicators in the community; it can provide maximum usage of the limited resources, since maternal-fetal medicine and neonatal intensive care are high-cost and low-volume specialties (Mullem et al., 2004). Furthermore, in this system, all pregnant women in the region are almost guaranteed to access the system, and the requisite level of care to her and her baby is assured depending upon the clinical needs (Paul and Singh, 2004). For that purpose, in the next chapter, we have proposed a mathematical model devoted to designing a regional perinatal care system in Turkey.

1.3 SOME WORLD APPLICATIONS ON REGIONALIZATION OF PERINATAL CARE

In this section, we give some successful regional perinatal care implementations in the world. New York State, California, Portugal and Southwestern Ontario are selected for this purpose.

New York State, USA (www.health.state.ny.us)

New York State is committed to ensuring that a pregnant woman and her baby will have ready access to the services they need to improve the chances they will be healthy and that a health care team with the necessary knowledge, skills and technology, will be available to handle any problems they might have.

Perinatal regionalization ensures that there are hospitals that can provide a full range of services for pregnant women and their babies in a geographic region. This means parents-to-be can be sure that there are hospitals near where they live that can provide everything from a basic, uncomplicated delivery to those that can serve mothers and babies with the most complex, critical problems.

With perinatal regionalization, each hospital receives a designation indicating the level of care they can provide. As a result they can focus on improving the skills needed for those services. Because the pregnant women and babies they see tend to be similar, they become even more expert in delivering the care needed. And, when a mother or baby has problems that require more expert care than the level of care they can provide, they know they can turn to other hospitals, including their Regional Perinatal Center (RPC) in the region for specialized consultation on the complicated cases, or to assume care for patients who need more specialized care.

New York State's system of regionalized perinatal services includes four levels of perinatal care provided by the hospitals within a region (called affiliate hospitals) and led by a Regional Perinatal Center (RPC), which provides the most sophisticated care and provides education, advice and support to their affiliate hospitals.

The regional system is led by an RPC that is capable of providing all the services and expertise required by the most acutely sick or at-risk pregnant women and newborns. The concentration of high-risk patients makes it possible to enhance and maintain the level of expertise in the care of high-risk obstetric and neonatal patients, as well as justify the substantial expense required to establish and maintain neonatal intensive care units and attending-level subspecialty consultation. RPCs provide or coordinate maternal-fetal and newborn transfers of high-risk patients from their affiliate hospitals to the RPC, and are responsible for support, education, consultation and improvements in the quality of care in the affiliate hospitals within their region.

The four levels of perinatal care within the regionalization system vary by the types of patients that are treated, availability of sub-specialty consultation, qualifications of staff, types of equipment available and volume of high-risk perinatal patients treated. Besides the RPC, there are three other levels of care:

- Level-1 hospitals provide care to normal and low-risk pregnant women and newborns, and they do not operate neonatal intensive care units (NICU);
- Level-2 hospitals provide care to women and newborns at moderate risk and operate NICUs;
- Level-3 hospitals care for patients requiring increasingly complex care and operate NICUs.

California, USA (www.perinatal.org)

The Regional Perinatal Programs of California (RPPC) evolved from the need for comprehensive, cooperative networks of public and private health care providers within geographic areas to promote the well-being of pregnant women and their babies. In the early 1980s the California Legislature mandated the development of a statewide network of perinatal regionalization. The goal is to match the needs of high risk perinatal patients with the appropriate type of care by developing a multi-tiered network of care providers and facilities within specific geographic areas.

There are now 14 RPPCs providing services to all areas of the State. The programs are designed to assist the California State Department of Health Services, Maternal and Child Health Branch (MCH) to ensure that pregnant women and newborns have access to appropriate levels of high quality care, to provide for safe and effective treatment of women and their babies before, during and after delivery, to meet the needs of the infants at risk for neonatal complications and to reduce the incidence of maternal death due to obstetric complications. The regional programs serve as facilitators in coordinating and supporting perinatal quality improvement within their regions. RPPC staff obtain and disseminate needs assessment and outcome data; consult with individual facilities regarding perinatal programs and services; collaborate with county and state maternal and child health departments, manage care plans, and other perinatal and professional groups and agencies on how best to meet the needs of the perinatal community; develop methods, models and materials for use by perinatal providers; create and support education programs to address the needs of high risk mothers and infants in their regions; represent their regions in regional and state task forces; and work with other perinatal regions and the state to respond to needs identified across the regions.

The RPPCs have the flexibility, neutrality and credibility to bridge public and private sectors and to cross geographic boundaries. These programs offer the opportunity for multiple districts, hospitals, clinics, individual providers and health care plans to work collaboratively to identify common concerns.

Services and linkages can then be planned cooperatively to address the needs of perinatal patients within each region.

Goals

RPPC programs address four basic Statewide Perinatal Goals:

- All children born healthy to healthy mothers.
- No difference in health status among racial/ethnic, gender, economic and regional groups.
- A safe and healthy environment for women, children and their families.
- Equal access for all women, children and their families to appropriate and needed care within an integrated system.

Roles of the Perinatal Programs

- Promote quality, seamless perinatal systems of care through information exchange and collaboration among services providers, facilities, health plans, as well as State and local MCH programs.
- Perform perinatal assessment of regional and statewide significance (e.g. Perinatal Facilities Interviews) on evaluation of delivery sites of very low-birth-weight infants in California.
- Develop community networks among agencies, providers and individuals.
- Provide resource directories and referral services.
- Develop, publish, disseminate and/or provide technical assistance to interpret pertinent perinatal data to assist with program/service planning and evaluation (e.g. The Perinatal Profiles of California Regions and Hospitals).
- Develop statewide guidelines and tools to promote high quality, risk appropriate perinatal care (e.g. current task forces on In-Utero and

Neonatal Transport, Education and Competency Assurance, and Clinical Quality Review).

- Develop and administer programs for priority populations such as the California Diabetes and Pregnancy Program.

Portugal (Neto, 2006)

In 1989, perinatal care in Portugal is reformed based on regionalization: the closure is proposed of maternity units with less than 1500 deliveries per year; hospitals are classified as level-1 (no deliveries), level-2 (low-risk deliveries, intermediate care units) or level-3 (high-risk deliveries, intensive care units), and functional coordinating units responsible for liaison between local health centers and hospitals are established. Nationwide systems of neonatal transport began in the year 1987, and in the year 1990 postgraduate courses on neonatology are initiated. With this reform, in-hospital deliveries increased from 74 % before the reform to 99 % after the reform. Maternal death rate decreased from 9.2/100 000 deliveries in the year 1989 to 5.3 in the year 2003 and, in the same period, the perinatal mortality rate decreased from 16.4 to 6.6/1000 (live births + stillborns with greater than 22 week gestational age), the neonatal mortality rate decreased from 8.1 to 2.7/1000 live births, and the infant mortality rate from 12.2/1000 live births to 4/1000.

Southwestern Ontario, Canada (www.lhsc.on.ca)

In Southwestern Ontario, the National Guidelines divide maternity and newborn care into two major parts:

- Ambulatory Prenatal Care; and
- Birth, Postpartum, and Newborn Care.

Ambulatory Prenatal Care focuses on pregnancy and it is provided in a variety of settings by a variety of providers—physicians, midwives, public health nurses and others. The second part, labor and birth, postpartum, and newborn care focuses on hospitals and birthing centers and the care provided immediately before, during and after the birthing experience. The term 'perinatal care' refers to prenatal care as well as birth, postpartum and newborn care.

The National Guidelines (4th edition, 2000) propose that family centered maternity and newborn care be organized on a regional basis. 'Regionalization of Services' is described as follows:

Regionalization of maternal and newborn services brings together a comprehensive organization of services to provide optimal care for women, babies and families. Central to this concept is risk assessment combined with referral to risk-appropriate services. The system of care is broadly focused on meeting the needs for appropriate services, professional education, research and evaluation (March of Dimes Birth Defects Foundation, 1993).

The National Guidelines go on to say: Regionalization of maternal and newborn care implies the development of a coordinated, cooperative system of care within a defined geographic area.

The goals of this system are:

- Provision of quality care for all women, newborns, and their families;
- Appropriate use of personnel and facilities;
- Coordination of services;
- Provision of referral mechanisms;
- Provision of professional education; and
- Incorporation of research and evaluation.

Also central to a regionalized system of care are the mutual relationships and responsibilities of the agencies providing care. The goal here is to provide appropriate care as close to home as possible for mothers, babies, and families. The rationale for addressing perinatal care from a regional perspective is clear. First, not every community or hospital provides the same level of perinatal care. Second, there is an important and significant interdependence among the centers that provide perinatal care. This interdependence is reflected in the different levels of care, and by definition, the levels of complexity different centers have the capacity to address. Third, by looking at perinatal care from a regional perspective, it is reasonable to expect that within a region the full gamut of skills and resources would be available. Only in exceptional circumstances would women or newborns have to be transferred outside the region. As a regionally-based system of care, therefore, it is important that the process of delivering care is coordinated among sites of care and that there are clear expectations regarding the roles of different sites. Within the province of Ontario, a voluntary partnership has been established called the Ontario Perinatal Partnership. The Ontario Perinatal Partnership is designed to be a forum for partner communication, networking, and the development of new approaches to perinatal care delivery. It is also designed to be a resource to members, government, and professional organizations. As well, it is a forum to continually assess the impact of the changing health care environment, and a liaison with other provincial and national organizations.

CHAPTER 2

STUDIES ON LOCATION OF HEALTH CARE FACILITIES

2.1 INTRODUCTION

Location of health care delivery facilities and services has much in common with the location aspects of many types of facilities or services which have a geographically dispersed customer base, and where there is a need to be close enough to customers for ease of access and/or speed of access, as well as a need for low cost of siting and operations (Pierskalla and Brailer, 1994).

"The implications of poor location decisions in health care extend well beyond cost and customer service considerations. If too few facilities are utilized and/or if they are not located well, increases in mortality (death) and morbidity (disease) can result. Thus, facility location modeling takes on an even greater importance when applied to the siting of health care facilities" (Daskin and Dean, 2004).

Locational analysis is a widely used approach to planning where to locate services and the types of service for national and/or regional development. The role of locational analysis in planning services for regional development is well known. One of the tools for such analysis is quantitative location-allocation modeling. It provides a framework for investigating service accessibility problems and involves simultaneously selecting a set of locations for facilities and assigning spatially distributed sets of demands to these facilities to optimize some specified measurable criteria (Rahman and Smith, 2000).

There are several ways of classifying health care location models and problems. A good taxonomy of this type of problems can be found in Daskin and Dean (2004). They examine the health care location literature in three major classes, which are referred to as *accessibility*, *adaptability* and *availability*. By accessibility they mean the ability of patients to reach the health care facility or, in the case of emergency services, the ability of the health care providers to reach patients. Adaptability models consider multiple future conditions, try to find good compromise solutions and tend to take a long-term view of the world. Availability models focus on the short-term balance between the ever-changing demand for services and the supply of those services.

Rahman and Smith (2000) review several health facility location-allocation studies conducted in the context of developing nations. These studies are designed: (1) to find a set of optimal sites, (2) to locate optimal sites in a new area, (3) to measure the effectiveness of past location decisions, (4) to improve existing location patterns.

Another classification is given by Pierskalla and Brailer (1994). They state that siting or location problems usually fall into one of five categories with somewhat distinctive characteristics. The first category is the regionalization of health care facilities. The second category is the siting or removal of a single facility, such as an acute care hospital or a central blood bank which needs to be geographically close to its customer bases. The third category is the location of ambulatory neighborhood clinics, which are primarily used for routine outpatient medical and/or surgical care and for preventive care. The location of health maintenance organization facilities, surging-centers, diagnostic centers such as CT-scanner centers and poly-clinics fall into this category. The fourth category comprises the location of specialized long-term care facilities such as nursing homes, psychiatric hospitals, skilled nursing facilities and rehabilitation centers. The fifth category of health care location problems is the siting of emergency medical services (EMS), involving determination of the number and placement of locations, number and type of emergency response vehicles and of personnel.

Besides the studies mentioned above, in the next section we review several health facility location-allocation studies conducted in the context of health service development planning and develop a classification scheme for these studies in Section 2.2.

2.2 CLASSIFICATION SCHEME

In this section, we give a classification scheme for location of health care facilities including: regionalization, location of specialized long-term care facilities, location of ambulatory neighborhood clinics and siting or removal of a single facility. Our classification scheme is based on several attributes of single and hierarchical systems of facilities. The main structure is built on nine attributes, as indicated in Table 2.1.

Table 2.1. Our classification scheme

Levels of Service Provided	• Single • Hierarchical
Objective Functions of Mathematical Formulations	• Single-objective o P-Median o P-Center o Set-Covering o Maximal-Covering o Uncapacitated Fixed-Charge Location o Others • Multi-objective
Aim of the Studies	• Finding a Set of Optimal Sites • Improving Existing Location Pattern
Nesting Property for Hierarchical Models	• Successively Inclusive • Successively Exclusive • Locally Inclusive
Flow Type for Hierarchical Models	• Discriminating • Integrated
Referral Pattern for Hierarchical Models	• Referral • Non-referral
Network Structure	• Discrete • Continuous
Capacity Constraints	• Capacitated • Uncapacitated
Solution Methodology	• Solution Methods for Hierarchical Models o Stepwise Strategy o Integrated Strategy • Solution Methods for Singular Models

Levels of Service Provided (Singular (S) vs. Hierarchical (H))

Health care facility location models usually fall into one of these two categories. Some studies have been directed towards the location of components of a health care system in which facilities are considered to be of one type (with respect to the level of service provided). These models are referred to as *single-level location-allocation models*. Mulvihill (1979), Okafor (1981), Mehretu et al. (1983), Berghmans et al. (1984), Mehrez et al. (1996), Cho (1998), Rahman and Smith (1999) and Harper et al. (2005) are some examples of single-level location-allocation models. However, it is widely recognized that most health care systems, especially in developing and industrialized countries, are organized as hierarchical systems. These systems are called *hierarchical location-allocation models*. The studies conducted by Banerji and Fisher (1974), Hodgson (1984), Okabe et al. (1997), Galvão et al. (2002) and Şahin et al. (2007) are some examples of hierarchical location-allocation models.

Hierarchical location models generally consist of k (≥ 2) distinct types of facility that are hierarchically related to each other. At least three factors need to be considered in hierarchical location problems (Narula, 1986). The first is whether a level m facility can provide only level m service or whether or not it can also provide services at all lower levels (1, …, m). The second issue is, in a successively inclusive service, whether a level m facility can provide all m levels of service to *all* demand nodes, or a level m facility can provide all m levels of service only to demands at the node at which the facility is located and level m service only to other nodes. The former is referred to as a successively inclusive service hierarchy while the latter is termed a locally inclusive service hierarchy. A successively exclusive service hierarchy is one in which a level m facility provides only level m service to all nodes. Finally, there will generally be fewer high level facilities (e.g., regional hospitals) than low level facilities (e.g., local clinics). If high-level facilities can only be located at sites housing a lower level facility, the system is termed nested; otherwise it is not nested (Daskin and Dean, 2004).

For example, health care systems may consist of clinics and hospitals; higher education systems may consist of technical schools and universities; production-distribution systems may consist of factories and warehouses, with a given product shipped to a client directly from the factory or through one of the warehouses (Galvão, 2004).

Objective Function Types of Mathematical Formulations

Single Objective

P-Median

One of the most popular models for public facility location problems is the p-median problem. The problem can be defined in the following manner: given discrete demand centers, locate a number (p or less) of facilities so that the total weighted travel distance or time between facilities and demand centers is minimized. It is assumed that all users of the facility choose to travel to the closest one. The objective of the p-median problem is to locate a given number of facilities so that the total travel distance (or time) between facilities and demand points is minimized (Rahman and Smith, 1999).

P-Center

The p-center problem addresses the problem of minimizing the maximum distance that demand is from its closest facility given that we are siting a pre-determined number of facilities.

Set-Covering (SC)

The set-covering problem can be defined as: find the minimum number of facilities and their locations such that each and every demand centre is covered by at least one facility within a given maximal service distance (time). This formulation has been used in a developed country for locating kidney dialysis machines, a form of treatment for which the patient must make frequent, repeated journeys (Eken-Chaine and Pliskin, 1986; as cited in Rahman and Smith, 2000). A related problem, known as the pq-median problem, is concerned with finding an efficient set of facility locations which can be associated with districting the catchment areas for two or more levels of facility (Rahman and Smith, 1999). Shortly, the set covering model tries to minimize the cost of the facilities selected in order to ensure that all demand nodes are covered.

Maximal-Covering (MCLP)

When compared with set-covering modeling, the decision maker may abandon the goal of total coverage and attempt instead to locate the facilities in such a way that as few people as possible lie outside the desired service distance. This means the problem is to maximize coverage within a desired service distance by locating a fixed number of facilities. This problem is referred to as the maximal covering location problem (MCLP) (Rahman and Smith, 1999). The objective of MCLP location problem is to locate a fixed number of facilities to maximize the total demand within a maximum service criterion (distance or time).

Uncapacitated Fixed-Charge Location (UFC)

The uncapacitated fixed charge location problem is a close cousin of the *P*-median problem. The UFC problem is derived from the *P*-median problem and aims to determine the optimal number of facilities as well as their locations and the allocation of demands to those facilities in order to minimize the combined fixed facility location costs and the transport costs (Daskin and Dean, 2004).

Multi-Objective (M-Obj)

Most of studies reviewed have used some kind of single criterion objective functions. A few of them consider multiple criteria objective functions. For instance, Mitropoulos et al. (2006) propose a method based on a bi-objective mathematical programming model for locating hospitals and primary health care centers for semi-rural and rural population. In the model, two objectives are considered: (1) minimization of distance between patients and facilities (efficiency objective), (2) equitable distribution of the facilities among citizens (equity objective). Other examples are Mehrez et al. (1996) and Cho (1998).

Aim of the Studies

Finding a Set of Optimal Sites (FSOS)

These studies consist of finding a set of locations for facilities and assigning spatially distributed sets of demands to these facilities to optimize some specified measurable criterion in a new area or locating the existing facilities without considering their current locations. Schultz (1970), Narula and Ogbu (1979), Tien and El-Tell (1984), Boffey et al. (2003) and Mitropoulos et al. (2006) are some examples of this group of studies.

Improving Existing Location Pattern (IELP)

These studies compare the effectiveness of previous locational decisions and generate alternatives in order to improve the performance of the service system. Aim is to make an assessment of the effectiveness of past locational decisions which can provide information regarding what could be achieved using the same resources. This type of study has limited use (for instance, Dökmeci (1977), Mulvihill (1979), Oppong and Hodgson (1994), Rahman and Smith (1999)), since relocations in an existing system to improve efficiency may be infeasible both politically and economically in developing nations (Rahman and Smith, 2000).

Nesting Property for Hierarchical Models

Based on the relationship between various levels of hierarchies, Tien et al. (1984) recommended three types of service hierarchies. These are: *successively inclusive*, *successively exclusive* and *locally inclusive* hierarchies, which are defined as follows:

Successively Inclusive

A hierarchical system in which the facilities at any level offer all the services offered by the facilities of a lower level is said to have a successively inclusive hierarchy, namely, a facility at level m (m = 1,2....,k) offers services of type 1 , . . . ,m. Higher level service facilities are only located at a site or in a community if facilities of all lower level services are also located there. The various levels of facilities may or may not be physically distinct (in the above examples the different level schools would likely be in separate buildings whereas both levels of warehouses could well be located in the same building complex) (Weaver and Church, 1991). In health care systems it is generally assumed that the facility hierarchy is successively inclusive.

Successively Exclusive

In a successively exclusive hierarchy a facility at level m offers only type m services to all locations. Tien et al. (1983), Hodgson (1984), and Tien and El-Tell (1984) are examples of successively exclusive hierarchies.

Locally Inclusive

In a locally inclusive hierarchy a facility at any level offers all services only to the location where it is located and only the highest order service to all other locations. For instance, in a 3_level hierarchical system, the level-3 facility offers type 1, 2 and 3 services to its location and offers only type 3 service to all other locations. Likewise, the level-2 facility offers type 1 and 2 services to its location and offers only type 2 services to other locations (Rahman and Smith, 2000).

Flow Type (Discriminating vs. Integrated) for Hierarchical Models

Narula (1984) proposes a classification scheme based upon the number of types of facilities in a hierarchy and the flow of service between locations and types of facilities. The flow can be divided into two categories. The flow may be *integrated* or *discriminating*. A flow is said to be integrated if it occurs from any lower level (0, 1, 2, ….. , f-1) facility to any higher level (1, 2, ….,f) facility. A flow is discriminating when it occurs from any lower level facility m to the next higher level facility m + 1 only (Rahman and Smith, 2000).

Referral Pattern for Hierarchical Models

Systems defined in hierarchical models can be classified as *referral* or *non-referral* systems. In a referral system, a proportion of customers served at each level are referred to higher levels. The latter systems do not consider referrals between levels (Marianov and Serra, 2001).

Network Structure (Discrete vs. Continuous Location Models)

Discrete location models assume that demands can be aggregated to a finite number of discrete points. Thus, we might represent a city by several hundred or even several thousand points or nodes (e.g., census tracts or even census blocks). Similarly, discrete location models assume that there is a finite set of candidate locations or nodes at which facilities can be sited. Continuous location models assume that demands are distributed continuously across a region. These models do not necessarily assume that demands are uniformly distributed, though this is a common assumption. Likewise, facilities can generally be located anywhere in the region in continuous location models (Daskin and Dean, 2004).

Capacity Constraints

Most of the location models for health facilities are assumed to be uncapacitated, i.e. each has an infinite capacity to serve consumer demand (See, for example, Schultz, 1970; Mehretu et al., 1983 and Boffey et al., 2003).

Calvo and Marks (1973), Dökmeci (1977), Narula and Ogbu (1979), Mulvihill (1979), Okafor (1981), Moore and Revelle (1982), Mehrez et al. (1996), Okabe et al. (1997), Cho (1998), Galvão et al. (2006a) and Mitropoulos et al. (2006) study the capacitated models. For example, in Galvão et al.

(2006a), it is noted that the lack of capacity constraints means that the capacity of each facility in each of the three levels of the hierarchy is sufficient to cope with any foreseeable demand at the corresponding level. The use of large standard facilities, however, is inefficient, especially in the resource intensive level-3 of the hierarchy. Thus, in the paper they extend the Basic Model, defined in Galvão et al. (2002), to include capacity constraints in level-3 of the hierarchy.

Solution Methodology

Solution Methods for Hierarchical Models

Stepwise Solution Strategy (Top-down / Bottom-up)

While the procedure for the top-down solution strategy locates the highest-level facility first and then moves down the hierarchy, the bottom-up approach locates the lowest-level facility first and then moves up the hierarchy to locate higher-level facilities. In the bottom-up strategy, the solution space for higher-level facility locations is restricted to location sets which are determined only through consideration of lower-level service requirements. In the top-down strategy, lower-level facilities must contain locations thrust upon them through consideration of only higher-order needs. Hodgson (1986) demonstrates that overall hierarchical sub optimization can result from either of these approaches. Narula (1981) and Hodgson (1984) demonstrate that this approach of locating hierarchical facilities would generally produce inferior results to those of integrated solution locating all levels.

Integrated Solution Strategy

Hodgson (1984) finds out that the top-down and the bottom-up strategies consistently produces sub-optimal solutions. The integrated approach produces better solutions than both stepwise strategies, and the bottom-up approach generally out-performs the top-down procedure. Hodgson (1986) observes that this could be due to the much higher weighting applied to the usage of low-level facilities. Furthermore, the spatial quality of the solution depends upon the solution procedure. The bottom-up strategy assures optimality for the lowest-order, resulting in a relatively uniform spread of potential higher-order locations, forcing a peripheral location on the highest-order center. In contrast, the top-down strategy selects a central location for the highest-order center, which prevents an optimal spread of facilities at a lower order. The integrated strategy provides a compromise between the top-down and the bottom-up strategies (Narula, 1986). The integrated strategy produces better solutions than either the top-down or the bottom-up strategy as discussed in Hodgson (1984) and Galvão et al. (2002). Lagrangean Relaxation, LP Relaxation, Genetic Algorithm and Greedy Interchange are some examples of methods using integrated solution strategy.

Solution methods for the hierarchical models are explained in detail in Chapter 4.

Solution Methods for Singular Models

Most of the studies conducted in the context of singular health services use various heuristic methods. LP Relaxation, Lagrangean Relaxation, Decomposition, Teitz and Bart Heuristic Method, Genetic Algorithm, Greedy Interchange, Garfinkel and Nemhauser Heuristic are some examples of these methods. In a few of them, the problems are solved optimally (e.g., Mehrez et al., 1996).

2.3 STUDIES IN THE LITERATURE

In this section, we give brief information about the studies on health care locational analysis through classifying them into two main parts -singular and hierarchical location models- and summarize them in a table (Table 2.2).

Singular Location Models

Mulvihill (1979) conducts a study that evaluates the locational efficiency of a set of primary health centers in Guatemala City. He studies a capacity-constrained location-allocation model that identifies an optimal set of service locations through an iterative process using heuristic solution procedures. This process first allocates users to a set of predetermined facility locations of specified capacity, using the criteria of transport-cost minimization; it then calculates the population centers of the districts given by the first iteration and assigns the central facilities to these points. The process continues until no further relocations occur.

Okafor (1981) conducts a study to find a site (from four possible sites) for a hospital which is to be added to an existing health delivery system with three hospitals in Bendel state, Nigeria. The problem is solved as a transportation problem and the capacities of the existing hospitals are included in the transportation formulation. However, it appears from the study that a p-median type formulation would have been more appropriate.

Mehretu et al. (1983) conducts a study to locate rural health clinics in the Eastern Region of Upper Volta. The objective is to locate clinics such that the total weighted travel distance between clinics and villages is minimized subject to the constraint that no one would travel more than a maximum distance of 5 km. Their problem is a modified p-median problem, defined as the p-median problem with maximum distance constraints. First, 635 villages in the study area are arbitrarily grouped into 94 village clusters referred to as programming units. Then the facilities are located in each programming unit separately (a geographically constrained problem) using the Teitz and Bart algorithm.

Berghmans et al. (1984) reports on a study which deals with a problem of locating health centers in a completely new city (Yanbu al Sinaya) in Saudi Arabia. Taking into consideration four quantitative criteria, the problem is formulated as a p-center problem which consists of finding the number of centers and their location anywhere on the links of the graph so that all the vertices are contained within the maximum service distance S. The problem is solved using the Garfinkel and Nemhauser heuristic for different values of S. The results are compared with solutions of the problem which assume that all centers would be restricted to the existing vertices.

Mehrez et al. (1996) conducts a study to locate a new hospital in Israel using location-allocation models in conjunction with the Analytic Hierarchy Process (AHP) approach. First the problem is analyzed using the p-median and set-covering location model both on the plane and on networks. Then the AHP is applied to evaluate the optimal sites using a set of criteria which include: minisum (p-median) objective function; service availability to remote settlements; improving employment; contribution for population diversity; using the existing infrastructure.

Cho (1998) presents a location-allocation modeling approach to the location of medical facilities, which is called the equity-efficiency trade-off model. It is a multi-objective optimization structure, in which systems equity (measured by the opportunity to receive medical services) and efficiency (represented by consumer and producer welfare) are incorporated. The model is implemented in an effort to determine locations of medical facilities with non-referral pattern in the Chongju Metropolitan Area of Korea. Furthermore, the size of facilities is used as a proxy for their attractiveness. A solution approach is developed by combining the Monte Carlo integer programming technique with the augmented Lagrangean algorithm.

Rahman and Smith (1999) conduct a study to find suitable sites for additional facilities in rural Bangladesh. The problem is considered as a maximal covering location problem (MCLP) which is solved by a heuristic method (Teitz and Bart Heuristic). In the model no constraint is imposed on health facilities capacity. It is a discrete location model including a minimum population constraint for a village to be a potential center. Although they describe the problem as a 2-level hierarchical problem, they solve it by successively applying MCLP in a nonhierarchical context.

Harper et al. (2005) develop a stochastic discrete-event geographical location–allocation simulation model evaluating various options for the provision of health services. The simulation model is developed in a Delphi environment using a three-phase simulation shell. The model is applied through two case studies, one at a local planning level and the other at a wider regional level. These case studies demonstrate the benefits of a stochastic approach to complex real-life location–allocation problems.

Hierarchical Location Models

Schultz (1970) adopts a central place theory to analyze a successively inclusive *k*-hierarchical health care facility location problem. He gives a procedure to determine the optimal service radius for each type of facility. His model is designed to find the optimal pattern of healthcare facilities that maximizes net social benefits to homogeneous population centers. He does not consider referrals of the patients from the lower-level facilities to the higher-level facilities.

Calvo and Marks (1973) extend Schultz's work by considering heterogeneous population centers and the limited capacity of health care facilities. They describe a 3-level hierarchical health care delivery system in detail, and develop a multi-objective integer linear model to locate *k*-hierarchical health care facilities: the model minimizes distance, user costs, and maximizes demand or utilization, and utility. It is based on assumptions that (1) patients go to the closest appropriate level; (2) there is no referral to higher levels; and (3) all facilities offer lower level services (successively inclusive) (4) patients can be divided into *k* groups according to their health care needs. They formulate the problem as a zero-one integer programming problem; however, they do not propose a solution procedure.

Banerji and Fisher (1974) describe the application of hierarchical location analysis for integrated area planning in Andhra Pradesh, India. The problem of locating health facilities in rural villages is a part of the larger study. Here, a successively inclusive facility hierarchy and no referral pattern between levels are assumed. The proposed formulation is based on the *p-center* problem. First the set covering problem is solved to determine the number of facilities required at each level, for a given maximum allowable distance at each level of hierarchy. Then, given the number of facilities at each level, the p-median problem is solved to determine the optimal locations of the facilities. The solution procedure involved here is the top-down approach. The set covering problem and p-median problem are solved using the Banerji heuristic and the Teitz and Bart heuristic, respectively.

Dökmeci (1977) refines some earlier studies by taking into account the functional coordination and interdependency among different levels of the regional health care system. She presents a quantitative planning model to determine the optimal characteristics (number, size and locations) of a regional health facility system. The system consists of hierarchically coordinated 4-level facilities (i.e. a medical center, intermediate and local hospitals, and health centers). The quantitative model is based on the minimization of the total cost (sum of the transportation and facility costs) to the society. The optimal characteristics of the system are obtained using the bottom-up approach and a heuristic method which includes both interactions of sublevel hospitals and environmental conditions as well. For predicting demand for health care facilities a Markov process model is used.

Fisher and Rushton (1979) and Rushton (1984) (as cited in Marianov and Serra, 2002) use the average and maximum distance from any demand area to its closest health care center to study and compare actual and optimal hierarchical location patterns in India. The Teitz and Bart heuristic is used in three ways to determine hierarchies: constructing top-down hierarchical procedure, constructing a bottom-up hierarchical procedure, and constructing a hierarchical procedure where the first step is to locate a middle-level of the hierarchy optimally, and then proceed with the bottom-up heuristic for upper levels, and use the top-down heuristic for lower levels.

Moore and ReVelle (1982) extend the maximal covering location problem and apply it to a 2-level hierarchical health care delivery system in Honduras. The problem is simultaneously to locate a fixed number of clinics and hospitals and to maximize the population with clinic services available within a distance standard set for clinics, and with hospital services available within a hospital distance standard. Relaxed linear programming supplemented by branch and bound where necessary, is used to solve the resulting integer programming problem. The results are represented as a curve of population coverage versus the investment in facilities, instead of the number of facilities at each level. This is done in order to present the results in a two dimensional manner (coverage and investment). The hierarchy of the health system is considered to be successively inclusive.

Tien et al. (1983) correct two typographical errors in the paper by Calvo and Marks (1973) and point out that the corrected model allows only a locally inclusive service hierarchy. They further show that the corrected model could not be solved directly. However, to solve this model they first develop a model with successively exclusive facility and service hierarchies. They formulate and solve the problem as a zero-one integer programming problem. They also formulate and solve the problem of the health care delivery system with successively inclusive facility and service hierarchies as a zero-one integer programming problem. They illustrate the solutions to the three models with an example.

Hodgson (1984) demonstrates that the use of top-down or bottom-up techniques to locate hierarchical systems generally leads to suboptimal locational patterns. He uses both the p-median model with a simple objective function and an allocation rule based upon “Reilly's gravitational law” to compare both techniques with the simultaneous location of all hierarchies. He treats the simultaneous hierarchical location-allocation problem as a discrete-space combinatorial one in which facilities at three levels might be distinguished by the "size" of facility at that level.

Tien and El-Tell (1984) define a 2-level hierarchical model to locate village clinics and health centers and to identify a relationship between them. This relationship is based on the organizational attachment of one or more (village) clinics to every health centre and on the presence of a health centre-based physician at each clinic. It is necessary to locate the health centers at the most populated villages having the essential support services (electricity, water, telephone and good road transport). The problem is formulated as a zero-one integer programming problem with constraints which used the availability measure. It is a top-down formulation in the sense that the flow patterns start at the hospitals. That is, health professionals go from hospitals to village centers. Both village and regional clinics are located using a criterion of minimizing the weighted distance of assigning villages to clinics and village clinics to regional clinics. The model is applied to 31 villages in Jordan. It is solved on the MPSX package as a relaxed linear programme. The results demonstrate that by both reallocating the villages to the clinics and the clinics to the existing health centers, considerable improvement (in terms of coverage) could be made.

Oppong and Hodgson (1994) study the improvement of the existing location of primary health facilities in rural Ghana. They use the p-median and maximum coverage models to measure the level of accessibility (average travel distance for users for p-median model and the proportion of people covered for maximum coverage model) provided by the existing system of facilities and to determine if this level of accessibility could be provided without considerable additional resources. The analysis begins by evaluating, using the p-median criterion, the accessibility provided by the system of facilities in place. It demonstrates how accessibility might be improved, and evaluates the potential for improving accessibility by providing additional facilities. This is followed by an evaluation, using the maximum coverage criterion, of the ability of mid-level facilities to supervise low-level facilities. In this study, the system considered is based on a 3-level hierarchical structure with referral between levels. The modeling approach treats the three levels of service independently (bottom-up strategy) and locates an optimal system of thirty facilities in keeping with the successively inclusive nature of the system. For the solution, the Teitz and Bart heuristic algorithm is used.

Galvão et al. (2002) develop a 3-level successively inclusive hierarchical model for the location of maternal and perinatal health care facilities in the municipality of Rio de Janeiro. It is assumed that travel is always to a nearest facility of appropriate level and there is a referral between level-2 and level-3 facilities. Two basic heuristics are developed to solve the 3-level hierarchical model: a Lagrangean Heuristic (LH) and a heuristic based on the solution of three successive *p*-median problems (the 3 *p*-Median Heuristic). LH is then modified to include an initial upper bound calculated by the 3 *p*-median heuristic; new strategies are also tested to update the step size, resulting in a Modified Lagrangean Heuristic (MLH). These three heuristics are tested on problems available in the literature. The model is then tested in a case study that used real data for the municipality of Rio de Janeiro.

Boffey et al. (2003) proposes an alternative approach towards the location of the 3-level hierarchical prenatal-neonatal health care system in Galvão et al. (2002). They use a model that regards each facility as a collection of (*pseudo*) clinics, each providing just one 'level of service'. The objective function of their formulation includes a non-linear term and the authors develop a genetic algorithm to solve the problem. The results obtained with the genetic algorithm are of very similar quality to those obtained by Galvão, *et al.* (2002) with their Lagrangean heuristics. This added to the authors' confidence that both approaches yield near optimal solutions.

Galvão et al. (2006a) solved the 3-level hierarchical location model (defined in Galvão et al., 2002) including capacity constraints into the model, especially in the higher, resource intensive level of the hierarchy. In the capacitated model, two different situations arise in practice: (i) existing capacity at level-3 is appropriate, in which case the problem becomes one of load balancing among the level-3 services; (ii) existing capacity is insufficient; in this case the problem becomes one of how to locate these services and allocate with equity, among the population, the demand that can be met. In the case of situation (i) the problem takes the form of load balancing among level-3 services. The capacitated model is extended by

Galvão et al. (2006a) to deal with load balancing, taking the form of a bi-criterion model that seeks to minimize both total distance traveled and load imbalance among level-3 services. The capacitated model is solved using a Lagrangean heuristic and the bi-criterion model is solved using the Constraint Method through the use of CPLEX. An application is made using the real data for the municipality of Rio de Janeiro.

Galvão et al. (2006b) discuss some practical aspects associated with location planning in Galvão et al. (2002) and Galvão et al. (2006a) for perinatal and maternal assistance in Brazil. In this paper, the algorithmic aspects are detailed in Galvão et al. (2002) and Galvão et al. (2006a) and the emphasis is on practical issues and difficulties encountered. They note that the models developed are not implemented by the municipality health authorities. Then, they analyze the possible reasons for this outcome. Among the reasons they mention are the political motivations and the lack of a stable civil service in developing countries.

Mitropoulos et al. (2006) propose a method based on a bi-objective mathematical programming model for locating hospitals and primary health care centers for semi-rural and rural populations. The system considered is successively inclusive hierarchical structure. It has 2-levels (i.e. hospitals and health centers) that are located simultaneously. The health centers are capacitated. They formulate the problem as a mixed integer programming location model. In the model, two objectives are considered: (1) minimization of distance between patients and facilities (efficiency objective), (2) equitable distribution of the facilities among citizens (equity objective). In their analysis, first they determine the public preference between secondary and primary level (i.e., hospitals and health centers) of the current public health provision system. Thus they estimate a parameter (called patient preference parameter, ɑ) that represents patients' preference of hospitals rather than health centers. Then they use this parameter in the bi-objective location–allocation model to initiate a more appropriate planning process. The methodology is applied in a case study concerning the health care facilities in the region of Western Greece and solved optimally with XPRESS solver engine.

Şahin et al. (2007) construct a 2-level assignment-based model with referrals for the regionalization of blood services. They develop several mathematical models to solve the location-allocation decision problems in regionalization of blood services. The proposed system has a successively inclusive hierarchy and a coherent spatial configuration of the facilities at different levels. The primary objective in the study is to minimize the overall transportation cost of the system. Considering emergency blood demands as a critical issue for blood services, the second objective is to minimize the maximum service response time. They decompose the entire problem into three sub-problems. The first sub-problem is formulated as a pq-median location model that minimizes the total of population-weighted average distances among the service facilities, and between the service facilities and the demand points. The second sub-problem is formulated as a set-covering model that locates the supporting facilities and finally, the third sub-problem is to redistribute the mobile units to each service region. All mathematical models are solved using CPLEX-6. They report computational results, obtained by using real data, for the Turkish Red Crescent Society blood services.

Table 2.2 below summarizes all these studies based on our classification scheme described in Section 2.2.

Table 2.2. Summary of the studies conducted on the location of health care delivery facilities

Authors	**Level of Service**	**# of Levels**	**Objective**	**Aim of the Studies**	**Nesting Property**	**Flow Type**	**Referral Pattern**	**Discrete vs. Continuous**	**Capacity Constraints**	**Solution Methodology**
Schultz (1970)	H	3	Others (maximizes net social benefit)	FSOS	Successively Inclusive	Integrated	Nonreferral	Continuous	Uncapacitated	First use of central place theory, maximizes social benefit
Calvo and Marks (1973)	H	3	Multi-Objective	FSOS	Locally Inclusive	Integrated	Nonreferral	Discrete	Capacitated	Flow-based MIP formulation, proposed no solution procedure
Banerji and Fisher (1974)	H	2	p-center	FSOS	Successively Inclusive	Integrated	Nonreferral	Discrete	Uncapacitated	For set covering problem the Banerji Heuristic and for p-median Teitz and Bart Heuristic in a bottom-up procedure.
Dökmeci (1977)	H	3	UFC	IELP	Successively Inclusive	Integrated	Referral	Continuous	Capacitated	Heuristic using the bottom-up procedure.
Narula and Ogbu (1979)	H	2	p-median	FSOS	Successively Inclusive	Integrated	Referral Nonreferral	Discrete	Capacitated	Forward, Backward, Add, Drop, Greedy Interchange Heuristics. Facilities are located simultaneously.
Mulvihill (1979)	S	-	Others (Transportation)	IELP	-	-	-	Discrete	Capacitated	An iterative solution process using heuristic procedures
Okafor (1981)	S	-	Others (Transportation)	IELP	-	-	-	Discrete	Capacitated	Solved as a transportation problem
Moore and ReVelle (1982)	H	2	MCLP	FSOS	Successively Inclusive	Integrated	Nonreferral	Discrete	Capacitated	LP Relaxation Integrated solving procedure

Table 2.2. (continued)

Authors	**Level of Service**	**# of Levels**	**Objective**	**Aim of the Studies**	**Nesting Property**	**Flow Type**	**Referral Pattern**	**Discrete vs. Continuous**	**Capacity Constraints**	**Solution Methodology**
Tien et al. (1983)	H	k	p-median	FSOS	Successively exclusive, inclusive and locally inclusive	Integrated	Nonreferral	Discrete	Uncapacitated	No solution approach
Mehretu et al. (1983)	S	-	p-center	FSOS	-	-	-	Discrete	Uncapacitated	Teitz and Bart Heuristic
Hodgson (1984)	H	3	p-median + Reilly's Gravitational Law	FSOS	Successively Exclusive	Discriminating	Not explicit	Discrete	Uncapacitated	Heuristic, Integrated solving procedure.
Berghmans et al. (1984)	S	-	p-center	IELP	-	-	-	Continuous	Uncapacitated	Garfinkel and Nemhauser Heuristic
Tien and El-Tell (1984)	H	2	p-median	FSOS	Successively Exclusive	Discriminating	Referral	Discrete	Uncapacitated	LP Relaxation using the top-down procedure
Narula & Ogbu (1985)	H	2	p-median	FSOS	Successively Inclusive	Integrated	Referral	Discrete	Uncapacitated	Lagrangean Relaxation and Decomposition
Oppong & Hodgson (1994)	H	3	p-median MC	IELP	Successively Inclusive	Integrated	Referral	Discrete	Uncapacitated	Teitz and Bart Heuristic using the bottom-up procedure
Mehrez et al. (1996)	S	-	Multi-Objective	IELP	-	-	-	Discrete	Capacitated	Optimally solved
Okabe et al. (1997)	H	≤4	p-median	FSOS	Successively Inclusive	Integrated	Nonreferral	Continuous	Capacitated	Heuristic (combination of grid search and descent method)

Table 2.2. (continued)

Authors	**Level of Service**	**# of Levels**	**Objective**	**Aim of the Studies**	**Nesting Property**	**Flow Type**	**Referral Pattern**	**Discrete vs. Continuous**	**Capacity Constraints**	**Solution Methodology**
Cho (1998)	S	-	Multi-Objective	FSOS	-	-	-	Discrete	Capacitated	A solution approach of combining the Monte Carlo IP technique with the augmented Lagrangean algorithm
Rahman and Smith (1999)	S	-	MCLP	IELP	-	-	-	Discrete	Uncapacitated	Teitz and Bart Heuristic
Galvão et al. (2002)	H	3	p-median	FSOS	Successively Inclusive	Integrated	Referral	Discrete	Uncapacitated	Lagrangean relaxation heuristics and 3 p-median heuristic using the bottom-up strategy
Boffey et al. (2003)	H	3	p-median	FSOS	Successively Inclusive	Integrated	Referral	Discrete	Uncapacitated	Genetic algorithm
Harper et al. (2005)	S	-	Others (Simulation)	IELP	-	-	-	Discrete	Uncapacitated	Three phase simulation approach
Galvão et al. (2006:1)	H	3	p-median (for capacitated version) and multi-objective (for load balancing)	FSOS	Successively Inclusive	Integrated	Referral	Discrete	Capacitated	Lagrangean heuristic for capacitated model and Constraint Method through the use of CPLEX for bi-criterion model
Mitropoulos et. al. (2006)	H	2	Multi-objective	FSOS	Successively Inclusive	Integrated	Nonreferral	Discrete	Capacitated	Solved optimally with XPRESS solver engine.
Şahin et. al (2007)	H	2	p-median	IELP	Successively Inclusive	Integrated	Referral	Discrete	Uncapacitated	All mathematical models are solved using CPLEX-6

All in all, we have reviewed various studies conducted in literature into two groups. First group consists of the studies about the “perinatal regionalization” which are generally published in medical journals and other medical sources in Chapter 1. These studies generally define the concept of regionalization of perinatal care, justifications behind it and results of the applications in various developed and developing countries. The main contribution of this literature group has been to help us understand the ideal system for the regional perinatal system. The second group in our literature survey consists of health care locational analysis conducted at the strategic decision level and specifically on perinatal regionalization. Among the studies for health care facility location, only the study by Galvão et al. (2002) addresses the problem of locating perinatal care facilities.

CHAPTER 3

A LOCATION MODEL FOR PERINATAL FACILITIES

3.1 INTRODUCTION

A health system aims to offer care services to its beneficiaries on time, at the right place, at a high quality and appropriate cost level, and in this way to improve and protect individual's and community's health. In order to realize this aim, the health systems have to be managed and designed in accordance with the productivity principles. Productivity level of health care systems depends on the efficient usage of resources during the service process and the effectiveness of this process.

Providing services in the best facility locations contributes to increasing the performance and productivity of health system by improving two criteria. These are: efficiency that is defined as the capability of beneficiaries (patients) to access the health facilities or emergency services and as the capacity of health facilities to access their patients, and effectiveness that is defined as the value-added of services on community and as the possibility of benefitting from complete and equal health care services for the patients.

Benefitting from health facilities at the maximum level and getting effective outputs in an efficient way depend on appropriate planning of the system. In other words, these depend on whether hierarchical relations are defined right or not among the different levels of the system and also on the optimal distribution of these facilities over the country and/or a region.

On the other hand, with the help of the analysis of the existing conditions including the number and the capacity of neonatal intensive care units, rate of utilization of the antenatal care services and neonatal transportation system, and the undesirable perinatal and maternal mortality rates in Turkey, the possible reasons that give rise to such a condition from the point of locational analysis can be stated as follows (State Planning Organization, 2005; TDHS, 2003; Erdem, 2003, Beşer et al., 2007):

- The low frequency (or application rate) of community’s benefitting from perinatal care services (e.g., the number of periodic visits to get antenatal care from any health institution in pregnancy is lower than the worldwide norms.)
- Lack of consideration of demographic, social, geographic, cultural and environmental issues during the planning process of health systems,
- Inadequate personnel and equipment in health service presenting processes and unbalanced distribution of those,
- Lack of the referral transportation mechanism between the levels of hierarchical structure of the health system (i.e. neonatal transportation)
- Sub-optimal distribution (in terms of number and capacity) of perinatal care facilities at the country and/or regional level,
- Inadequate resource allocation for these services and inefficient usage of these resources.

In order to cope with these problems and decrease the perinatal and maternal mortality rates in our country, first of all, regional perinatal care system must be planned in an optimal way. Here, the aim is to develop a better distribution of the required/existing resources about perinatal care and to improve the planning studies of this health system. It has been shown in several studies that the geographical accessibility of health facilities is a strong determinant of the service utilization by the public (Bergmans, 1984). Within this scope, the problem of determining the types, locations and capacities of health facilities in the framework of geographical accessibility of health facilities is to be solved. A mathematical model, formulated in the next section, is proposed for developing regional perinatal care facilities.

3.2 GENERAL STRUCTURE OF THE SYSTEM MODELLED

In the context of regionalization of perinatal care, the system is designed to organize health services for maternity and new born according to population needs and the degree of complexity of maternal and perinatal care. In order to define the degree of complexity, mothers-to-be and babies are classified into different risk categories based upon certain medical criteria. It is proposed that babies are categorized in low, medium and high risk classes and mothers-to-be are categorized in low and high risk classes (Galvão, 2002). In this context, we can define three types of perinatal care services in relation to medical expertise and technology level needed for mothers-to-be and babies' optimal care:

Level-1 (l =1): antenatal medical care for pregnant women in any risk-category.

Level-2 (l=2): routine (in normal circumstances) births and neonatal assistance for low and moderate-risk mothers and for low and medium risk babies.

***Level-3 (l=3)**:* non-routine births (in high-risky circumstances) and neonatal assistance for high risk mothers and high-risk newborns.

There are three main levels of facilities associated with service levels in regional perinatal care system. These are:

Primary Units (Level-1-k=1): These are low technology units, responsible for providing antenatal care to pregnant women. Namely, mothers-to-be attend to *primary units* in order to receive guidance and basic health care. These units do not operate delivery and neonatal intensive care units. A pregnant woman makes multiple visits ("z" times on average) to a primary unit to have her progress monitored (pregnancy follow-up in antenatal term). It is taken into account by weighing the assignment variable for level-1 service in the objective function of the mathematical model. The number of visits to a level-2 facility and/or directly to a level-3 facility is considered as one visit only, since travels to these units are performed only for delivery.

Secondary Units (Maternity Homes) (Level-2-k=2): Maternity homes provide the basic care of level-1 units, plus antenatal care to pregnant women and newborns at intermediate risk. They are also responsible for routine (in normal circumstances) births and neonatal assistance to low risk mothers and babies and to medium risk babies. If a risky case during the pursuing process at this level appears, mother or newborn could be transferred from this level to higher level units (level-3) in hierarchy. So, a transportation (referral) system is organized between level-2 and level-3 type facilities in the regional system.

Tertiary Units (Neonatal Centers) (Level-3-k=3): They have the technological capability of level-1 and level-2 units, plus that needed for non-routine births and neonatal assistance to high risk babies. These levels have neonatal intensive care units for newborns. This may arise from earlier advice received at a primary unit during pregnancy or, if complications are detected when a woman is in a maternity clinic, she is *referred to the nearest tertiary unit* by ambulance from there (Arsan, 2003).

Considering the description of the different types of services and facilities above, we develop a *successively inclusive* model (See Figure 3.1) *with referral* between level-2 and level-3 of the hierarchy. In a successively inclusive facility hierarchy, a level-k facility offer services unique to itself as well as services available at a level-(k-1) facility, for k=2,…,K (Eitan et al., 1991). For perinatal health care hierarchical system, level-1 service can be given by a primary unit, secondary unit or tertiary unit; level-2 service can be given by a secondary unit or tertiary unit; level-3 service can only be given by a tertiary unit. Thus, a tertiary unit may be modeled as the combination of a level-1, a level-2 and a level-3 facility; and a secondary unit may be modeled as the combination of a level-1 and a level-2 facility.

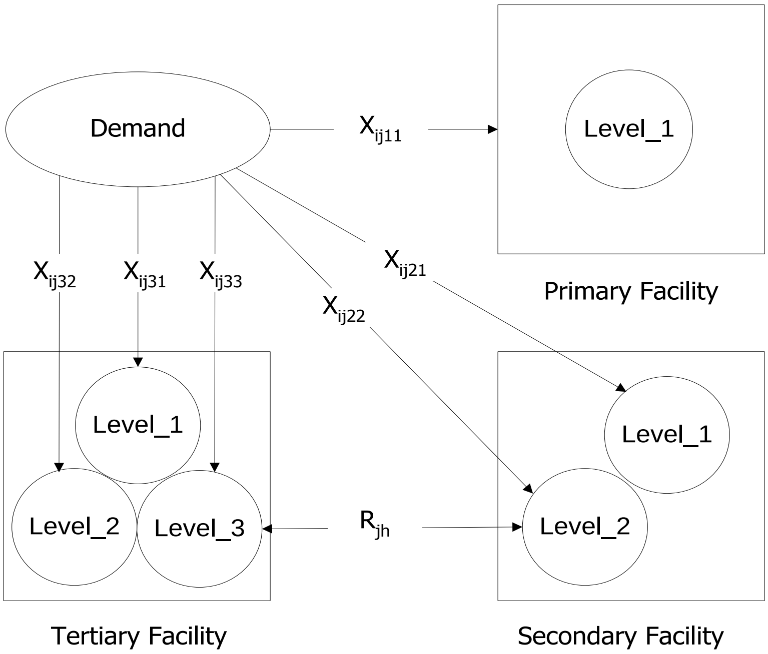

Figure 3.1. Flow diagram of mothers

3.3 BASIC ASSUMPTIONS AND MATHEMATICAL FORMULATION OF THE MODEL

The basic assumptions of the mathematical model are as follows:

- Each pregnant woman goes to a level-1, level-2 or level-3 unit to take level-1 service.
- Each low and normal risk pregnant woman goes to a level-2 or level-3 unit to give birth.
- Each high risk pregnant woman goes to a level-3 unit to give birth and to take neonatal intensive care.
- If a pregnant woman demands level-1 service, she goes to the nearest facility among the facilities providing level-1 service.
- Travels to level-2 and level-3 services are not always to the nearest facility, since level-2 service generates referrals to level-3 service.
- If complications after delivery are detected when a woman is in level-2 facility, she will be referred to a higher level unit (level-3) in

hierarchy for neonatal intensive care and will be transported by ambulance.

- A proportion of *referred* mothers (patients) from level-2 to level-3 goes back by ambulance to a lower level unit (level-2) from which she came, after her intensive care is completed (but she needs level-2 care service for a time period).
- It is considered that all types of facilities have no capacity limitations, they are uncapacitated.
- In-facility service costs for different types of services are the same for different types of facilities; i.e. costs of level-1 service given by a level-1 facility, a level-2 facility or a level-3 facility are the same. Similarly, cost of level-2 service given by a level-2 facility or a level-3 facility is the same.
- All population within a district is concentrated at the district "centroid" and district centroids provide the demand points. Each demand point is also a potential facility site.
- Those pregnant women who give birth at a secondary facility and need to attend a tertiary facility for neonatal intensive care must all be assigned to one and the same facility belonging to the 3rd level of the hierarchy (coherency structure).

Within the location modeling framework, the mathematical formulation is presented with the following indices, inputs, parameters and decision variables.

Indices

k: index for facility types, k=1, 2, 3,
l: index for demand (or service) types, l = 1, 2 ,3,
n: number of potential facility sites/demand points
i: index for demand locations, I= $\{i \mid i=1,2,...,n\}$

j: index for facility sites, J= $\{ j \mid j = 1, 2, ..., n \}$

Parameters

d_{ij} : shortest distance (cost) between demand point $i \epsilon I$ and facility site $j \epsilon J$

d_{jh} : shortest distance (cost) between facility site $j \epsilon J$ and facility site $h \epsilon J$,

W_i : demand (number of pregnant women) at location $i \epsilon I$,

p: maximum number of primary facilities to be located,

q: maximum number of secondary facilities to be located,

r: maximum number of tertiary facilities to be located, where $p \geq q \geq r$.,

z: number of multiple visits to a primary unit where pregnant woman's progress is monitored,

a_i : proportion of pregnant women (high risky category) at demand point $i \epsilon I$ attending primary unit that will directly go to a tertiary unit to give birth and for neonatal care ($0 \leq a_i \leq 1$),

c : proportion of mothers (and their babies) at secondary units referred to a tertiary unit ($0 \leq c \leq 1$),

b : proportion of referred mothers from a secondary unit to a tertiary unit that will go back to the secondary unit from which they came, after their intensive care are completed ($0 \leq b \leq 1$),

t: relative unit cost of referred travel ($0 \leq t \leq 1$) (since travel of patients (mothers and their babies) referred from secondary units to tertiary units is done by ambulance). "*t*" is a policy variable. If the Health Authority is concerned about the usage of ambulances, then "*t*" can be set to be high, whereas if the convenience of mothers is the determining factor, then "*t*" can be very small or even zero (Boffey et al., 2003).

M: a large number.

Decision Variables

X_{ijkl} = fraction of demand at point i, requiring l type service given by a type k facility at site j ($0 \leq X_{ijkl} \leq 1$),

R_{jh} = total number of referred patients (sum of forward- and back-referrals) between a secondary unit at site j and a tertiary unit at site h ($R_{jh} \geq 0$),

$$Y_{jk} = \begin{cases} 1, & \text{if a type k facility is located at site j ,} \\ 0, & \text{otherwise.} \end{cases}$$

The flows between demand points and facilities are shown in Figure 3.1, where X_{ij11}, X_{ij21}, X_{ij31} represent, respectively, the flow of demand requiring level-1 service being supplied by primary, secondary or tertiary units; X_{ij22} and X_{ij32} represent, respectively, the flow of demand requiring level-2 service being supplied by secondary or tertiary units; X_{ij33} represents the flow of demand requiring level-3 service being supplied by tertiary units and R_{jh} represents the flow of mothers (and their babies) referred from a secondary unit at $j \epsilon J$ to a tertiary unit $h \epsilon J$. As the hierarchy has a successively inclusive property, each facility is represented as a set of pseudo-units where each one performs a single level of service.

Given the above definitions, we formulate the 3-level hierarchical model, called as 3-HLM , for perinatal facilities location problem as follows:

MIN

$$\left\{\sum_{i\in I}\sum_{j\in J} W_i d_{ij}\left(z\,(X_{ij11}+X_{ij21}+X_{ij31})+(1-a_i)(X_{ij22}+X_{ij32})+a_iX_{ij33}\right)+\sum_{j\in J}\sum_{h\in J} R_{jh}\,t\,d_{jh}\right\}$$

SUBJECT TO:

$$\sum_{j\in J}(X_{ij11}+X_{ij21}+X_{ij31})=1 \qquad \forall i \tag{1}$$

$$\sum_{j\in J}\left(X_{ij22}+X_{ij32}\right)=1 \qquad \forall i \tag{2}$$

$$\sum_{j\in J} X_{ij33}=1 \qquad \forall i \tag{3}$$

$$\sum_{h\in J} R_{jh}=\sum_{i\in I} W_i c\ (1-a_i)(1+b)X_{ij22} \qquad \forall j \tag{4}$$

$$X_{ij11} \le Y_{j1} \qquad \forall\ i, j \tag{5.1}$$

$$X_{ij21} \le Y_{j2} \qquad \forall\ i, j \tag{5.2}$$

$$X_{ij31} \le Y_{j3} \qquad \forall\ i, j \tag{5.3}$$

$$X_{ij22} \le Y_{j2} \qquad \forall\ i, j \tag{5.4}$$

$$X_{ij32} \le Y_{j3} \qquad \forall\ i, j \tag{5.5}$$

$$X_{ij33} \le Y_{j3} \qquad \forall\ i, j \tag{5.6}$$

$$R_{jh} \le MY_{h3} \qquad \forall\ j,h \tag{6.1}$$

$$R_{jh} \le MY_{j2} \qquad \forall\ j,h \tag{6.2}$$

$$\sum_{j\in J} Y_{j1} \le p \tag{7}$$

$$\sum_{j\in J} Y_{j2} \le q \tag{8}$$

$$\sum_{j\in J} Y_{j3} \le r \tag{9}$$

$$0 \le X_{ijkl} \le 1 \qquad \forall\ i, j, k,l \tag{10}$$

$$R_{jh} \ge 0 \qquad \forall j,h \tag{11}$$

$$Y_{jl} \in \{0,1\} \qquad \forall j, l. \tag{12}$$

Objective Function: Before explaining our model's objective function structure, it is useful to clarify the difference between the location of public facilities such as emergency services, fire stations, police centers, etc. and private facilities. It can be said that the main difference is the objective(s) considered by decision-makers. Marianov and Serra (2002) state that public and private sector applications are different, due to the optimization criteria used. That is to say, profit maximization and capture of larger market shares from competitors are the main criteria in private applications, while minimization of cost to society, efficiency and equity are the goals in the public sector. They also note that since these objectives are difficult to measure, they are frequently surrogated by the minimization of the locational and operational costs needed for full coverage by the service, or the search for maximal coverage given the levels of available resources.

The problem considered here is a part of the public health system. "In this respect, rather than minimizing the cost charged to the owner of the system, the cost charged to beneficiaries is considered by minimizing the total demand-weighted distance. This consideration, in other words, maximizes the average accessibility of services by the public and furthermore increases the service level" (Şahin, 2002). This accessibility also means proximity of demand points to facilities. So, the objective is to minimize the total demand-weighted travel distance between each demand point and its the nearest facility.

Furthermore, in many developed countries the adjustment of the supply of regional hospital's healthcare to demand corresponds to a desire to associate economy and healthcare. Thus this objective has two aspects and each of them corresponds to one sub-objective (Pelletier and Weil, 2003). The details of these objectives can be found in Pelletier and Weil (2003). Now we will turn our attention to the main sub-objective, defined as "to reduce healthcare inequalities", which reflects our model's objective.

“A simple way to improve public healthcare accessibility is to bring the components of the healthcare system closer to the potential patients. This tendency falls within a new decentralization trend in public services and basically aims to *decrease the distance* between the patients and the hospital, clinic, physician, etc. The distance is a subjective concept here and concerns the measurement of travel cost (budget, time, comfort) of a patient going to a healthcare facility (Lucas and Tonnelier, 1997)” (Pelletier and Weil, 2003).

We can say that our problem aims to reduce healthcare inequalities and maximize healthcare access via minimizing the geographical distance and to reduce the overall system cost, as shown in the objective hierarchy (Figure 3.2) with the boxes in broken lines.

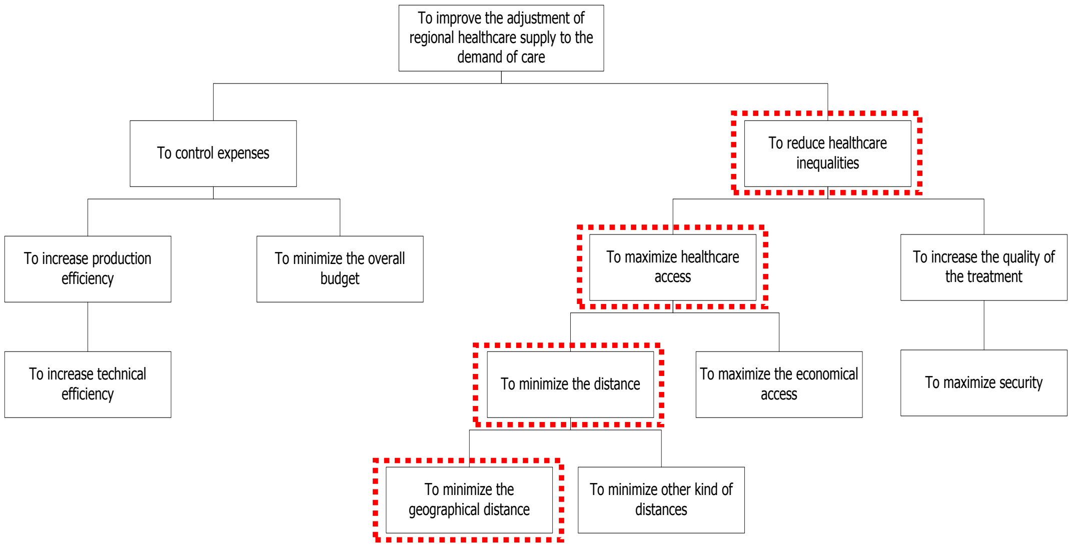

Figure 3.2. The objective hierarchy (Pelletier and Weil, 2003)

In the mathematical formulation above, the objective function is comprised of two parts. The first part includes: cost of travel to a primary, secondary or tertiary unit for level-1 service (assuming that there will be “z” many visits); cost of travel to a secondary or tertiary unit for level-2 service with a factor of (1-a_i) to account for patients at a primary unit who need to attend a secondary unit to give a birth; cost of travel to a tertiary unit for level-3 service. The second part corresponds to referred flow (for forward and back referrals) and it includes cost of travels (weighted by the constant "t") between secondary and tertiary units.

Assignment Constraints: Constraints (1)-(3) state that each district is allocated to precisely one facility for each type of service. Constraints (1), (2) and (3), respectively, ensure that mothers-to-be requiring level-1 service at a district *i* can take this service from a primary, secondary or a tertiary unit; mothers-to-be requiring level-2 service at a district *i* can take this service from a secondary or a tertiary unit; and mothers-to-be requiring level-3 service at a district *i* can take this service from a tertiary unit. In this formulation we separate the demand types (by index *l*) and facility types (by index *k*). One distinguishing property of our model from others in the literature is that our allocation decision variables, X_{ijkl}, have four indices, as opposed to theirs which had only three. This situation increases the number of variables in the model, but we have a chance to assign various in-facility costs for services taken from different types of facilities in the hierarchy. For example, in real life, the costs of level-1 service offered by level-1 facility, level-2 facility or level-3 facility may be different, so we need separately to weigh the allocation decision variables (X_{ij11}, X_{ij21}, X_{ij31}) in the objective function by their related in-facility costs. For example, with regard to a general health system, it may be cheaper to go to a health center for a minor ailment than a major hospital right next door for treatment. Here, it is possible to define new parameters, s_{kl} and c_{ijkl}. When we define s_{kl} as in-facility cost of servicing a type *l* demand at type *k* facility, c_{ijkl} becomes the total cost of servicing a type *l* demand at location *i* by a type *k* facility at site *j,* as defined in Mirchandani (1987); that is

$$c_{ijkl} = d_{ij} + s_{kl}.$$

Furthermore, if we allow for allocating different types of facilities at the same site because of capacity constraints, then we need the allocation variables with four indices in order to discriminate the demand assigned to different types of facilities for the same service.

In our model, for the sake of simplicity in the solution methods developed in the next sections, we assume that in-facility costs are the same for all services taken from different types of facilities (e.g. for level-1 service, s_{11}, s_{21}, s_{31}, are the same).

Constraint (4) is used for forward-referrals and back-referrals between secondary and tertiary units. It provides a proportion of total demand assigned to a secondary unit for level-2 service being equal to R_{jh} and each secondary unit being allocated to precisely one tertiary unit for referrals.

Budget Constraints: These constraints as specified by limits on the numbers allowed for each type of facility are given by (7), (8) and (9). If there is no restriction on the amount of resources, then it will be optimal to locate a tertiary unit in every district (since a tertiary unit offers all types of services). This is not realistic and budget constraints of the form that requires that there be

no more than *p* primary units: $\sum_{j \in J} Y_{j1} \leq p$,

no more than *q* secondary units: $\sum_{j \in J} Y_{j2} \leq q$,

no more than *r* tertiary units: $\sum_{j \in J} Y_{j3} \leq r$

will be assumed to be operative and/or perhaps an overall budget constraint as well (Boffey, 2003).

These constraints also reflect the type of our location model. It is a 3-level *p-median* problem belonging to a class of formulations called minisum location models. If only one type of facility is located, it would be a traditional *p-median* problem, which is commonly used in location literature. The problem can be stated as (Marianov and Serra, 2002):

Find the location of a fixed number of 'p' facilities so as to minimize the weighted average distance of the system.

While three types of facilities are located in our model, we call this problem as 3-HLM. Here *p*, *q* and *r* stand for, respectively, number of facilities located at the lowest level, medium level and the highest level of hierarchy. Now this problem can be stated as:

Find the location of a fixed number of 'p' level-1 facilities,
'q' level-2 facilities and 'r' level-3 facilities so as to minimize
the total weighted average distance of the system.

Constraints (5.1.) - (5.6) state that demand districts can only be allocated (for level-1, -2 and -3 services) to a facility at site *j* if there is a facility there capable of providing the required services and ***constraints (6.1)*** ensures that allocation of secondary units at site *j* to site *h* for the level-3 service is only permitted if a tertiary unit is located there and ***(6.2)*** ensures that only open secondary units at site *j* will be assigned to a tertiary unit at site *h*. ***Constraint (10)***, ***(11)*** and ***(12)*** are nonnegativity and integrality constraints.

3.4 THEORETICAL PROPERTIES OF THE MODEL

Some theoretical properties of 3-HLM is as follows:

1- 3-HLM is a mixed integer programming (MIP) problem with 3n zero-one integer variables, $7n^2$ continuous variables and $8n^2+4n+3$ constraints.

2- 3-HLM is NP-hard, since it contains a *p*-median problem as a specialization. To see this let c=b=0, $a_i=1$ and p=q=0. Then $Y_{j1}=Y_{j2}=0$, for all j, $X_{ij11}=X_{ij21}=X_{ij22}= X_{ij32}=0$ for all i and j, $X_{ij31}=X_{ij33}$ for all i and j and $R_{jh}=0$ for all j and h; the new problem reduces to a r-median problem (Galvão et al., 2002; Boffey et al., 2003).

3- X_{ijkl} decision variables are defined as continuous variables between 0 and 1 in the formulation, but it should be noted that they will always be 0 or 1 in the solution. Since the facilities are uncapacitated, when any demand point is assigned to either a level-1, level-2 or level-3 facility, all demand at that point is completely served by a single facility, in this respect, there is no fractional value for X_{ijkl} in the solution (Şahin, 2002).

4- Since the model is uncapacitated and has a successively inclusive property, different types of facilities are not located at the same site.

5- Since the model is a minimization problem and location of different types of facilities in the same site (may be assumed that $p+q+r \leq n$) is prohibited, the inequality constraints (7), (8) and (9) are satisfied as equality at the optimal solution and can be reformulated and strengthened as

$$\sum_{j\in J} Y_{j1} = p,\ \sum_{j\in J} Y_{j2} = q,\ \sum_{j\in J} Y_{j3} = r \qquad (12)$$

6- Another property for our model is related to the "coherent" structure. In a coherent structure, all demand areas assigned to a facility at one level must be assigned to one and the same facility belonging to the next level of the hierarchy (Serra and Revelle, 1994). The resulting assignments in the solution satisfy coherency, for the referrals between the secondary and the tertiary facilities in our system, because of uncapacitated facilities.

7- According to the classification scheme presented in Chapter 2, our model can be defined as follows:

- Level of service provided: hierarchical;
- Types of objective function: single objective function and p-median type;
- Aim of the study: finding a set of optimal sites;
- Nesting property: successively inclusive;
- Flow type: integrated;
- Referral Pattern: forward- and back-referrals between level-2 and level-3 facilities;
- Discrete location model;
- Capacity constraints: uncapacitated;
- Solution strategies: top-down and integrated.

CHAPTER 4

HEURISTIC METHODS FOR THREE-HLM PROBLEM

4.1 INTRODUCTION

After formulating the model, we now turn our attention to the solution approaches for 3-level p-median problem. It is possible to find a variety of solution approaches in literature for hierarchical facility location problems. Most common approaches use a stepwise strategy, i.e. top-down or bottom-up strategy. While the procedure involved in top-down is to locate each level independently of the other in a successive manner starting from the top of the hierarchy and proceeding down to the bottom, the bottom-up approach starts from the bottom of the hierarchy and proceeds up to the top (Serra and ReVelle, 1994). Applications of these solution approaches could be found in the studies conducted by Banerji and Fisher (1977), Fisher and Rushton (1979), Dökmeci (1977), Oppong & Hodgson (1994) and Galvão et al*.* (2002).

In addition to the top-down and the bottom-up approaches, Fisher and Rushton (1979) and Rushton (1984) construct a hierarchical procedure where the first step is to locate a middle-level of the hierarchy optimally, and then proceed as the bottom-up heuristic for upper levels, and as the top-down heuristic for lower levels (Marianov and Serra, 2002).

Serra and ReVelle (1994) reflect the disadvantages of these stepwise approaches as follows: traditional top-down approaches optimize the top level location, but the enforced use of such locations as low-level centers produces systems in which the lower level solution is generally inferior to the lower level solution obtained if the location were done without considering the siting of top-level facilities. Similarly, traditional bottom-up approaches generate the best low-order locations because of their unconstrained goal of optimization at that level, but tend to produce very bad results in the location of higher-level facilities. That’s why; it is necessary to solve any hierarchical location problem using some kind of heuristics which provide a compromise between the top-down and the bottom-up heuristics.

Narula and Ogbu (1979) formulate a capacitated successively inclusive hierarchical location-allocation problem as a mixed integer programming model. They proposed five heuristic procedures: forward p-median, backward p-median, add heuristic, drop heuristic and a greedy interchange heuristic to solve this problem. Forward p-median is the same as the bottom-up approach and backward p-median is the same as the top-down approach. They state that the most robust of these approaches is the greedy interchange heuristic.

Narula and Ogbu (1985) develop a Lagrangean relaxation and decomposition method for an uncapacitated 2-level hierarchical location-allocation problem. They relax two assignment constraints and get a Lagrangean dual problem. Using this relaxation, the Lagrangean dual problem is decomposed into subproblems and a master problem. After solving the Lagrangean dual problem, a lower bound is found and maximized by the subgradient optimization technique.

Serra and Revelle (1994) propose several heuristics based on integrated solution strategy for the *pq-median* problem formulated as multi-objective model. This pq-median formulation locates two types of facilities by combining two p-median formulations. Each hierarchical level has the objective of minimizing the average distance or travel time from the demand areas to the nearest facility whilst ensuring coherence. Then, in order to find a solution, a compromise (trade-off) between the objectives at both levels is found. Heuristics described in this study are based on the Teitz and Bart algorithm and the top-down and bottom-up methods for the coherent hierarchical model with two levels.

Okabe et al. (1997) propose a computational method for optimizing a system of successively inclusive hierarchical facilities with budget constraints (total construction cost) on a continuous plane. The optimization procedure has two steps. The first step optimizes a system of exclusive hierarchical facilities by an analytical method. Using this optimal solution, the second step optimizes a system of successively inclusive hierarchical facilities by a computational heuristic search method (a combination of the grid search method and the descent method). In their study, they show a method that optimizes not only a spatial configuration, but also a spatial hierarchical structure.

As explained in Chapter 2, two basic heuristics are developed by Galvão et al. (2002) in order to solve the 3-HLM: a Lagrangean Heuristic (LH) and a heuristic based on the solution of 3 successive p-median problems using the bottom-up approach. LH is then modified to include an initial upper bound calculated by the 3 p-median heuristic; new strategies are also tested to update the step size, resulting in a Modified Lagrangean Heuristic. Then, Boffey et al. (2003) propose an alternative approach towards the location of the 3-level hierarchical system in Galvão et al. (2002). The objective function of their formulation includes a non-linear term and the authors develop a genetic algorithm to solve this problem. The results obtained with the genetic algorithm are of very similar quality to those obtained by Galvão et al. (2002) with their Lagrangean heuristics.

In this chapter, we propose three heuristics to solve the 3-HLM . Although the problem can be solved by any of the MIP codes, it is not advisable when the problem size is large even for moderate value of *n*, since the solution time increases non-polynomial, as shown in Table 4.1 for some test problems. On the other hand, the hierarchical *pq-median* problem, which is more common in literature, is very intensive computationally to be solved using linear programming relaxation and branch and bound or dual heuristics, since it has a very large number of variables and constraints (Serra and ReVelle, 1994). This situation is also valid for the three-level hierarchical p-median problem with larger number of variables and more constraints.

The solution times of the optimal MIP solutions are tested on a variety of problems available in the literature, ranging from 10 to 130 vertices, for different sets of p, q and r. The 81-vertex network is composed of cities in Turkey, using the real distance data supplied from the General Directorate of Highways of the Republic of Turkey and real population data of provinces. The 10-, 30- and 40-vertex networks correspond to "reduced" networks, created using distances from the 81-vertex network. The 130-vertex network is built by adding some counties of certain provinces into the 81-vertex network. The solution times of the MIP solutions are provided by GAMS/CPLEX 10.0. The optimal solutions are found for the problems 10-, 30-, 40- and 81-vertex networks (See Table 4.1). We could not find any optimal solution for the problem with 130-vertex in four days (345,600 seconds), therefore the solution process is terminated when the solution process is reached at this time limit.

Table 4.1. Solution time for selected test problems

n	10	10	10	30	30	30	40	40	40	81	81	81	130
p	2	3	4	3	7	10	3	5	9	5	10	20	33
q	1	2	3	2	4	5	2	3	3	2	5	12	23
r	1	1	1	1	3	4	1	2	2	1	3	4	8
CPU Time (seconds)	0.25	0.21	0.31	4.2	3.6	6.7	43.1	35.1	43.0	3,697	40,438	70,876	345,600

Here, we propose the following three heuristic approaches:

- Top-Down Heuristic (TDH)
- Modified Top-Down Heuristic (MTDH)
- Lagrangean Relaxation Based Heuristic (LRH)

The procedure involved in TDH and MTDH is first to locate the highest-level facility and then to move down the hierarchy. In TDH approach, three sub-problems, each being a p-median problem, are successively solved. MTDH relies on a problem size reduction idea where second (medium)-level and third-level (highest) facilities are solved simultaneously and determines the locations of first-level (lowest) facilities considering the site selection decisions obtained for level-2 and level-3 facilities. The LRH procedure uses the integrated solution strategy for 3-level hierarchical location models.

In the following three sections, these heuristics are presented. Computational results are discussed in Section 5.4 in order to test the performance (in terms of gap % and solution time) of heuristics.

4.2 HEURISTICS BASED ON P-MEDIAN PROBLEM

4.2.1. Top-Down Heuristic

The TDH has widely been used in literature for 2-level hierarchical location problems. It decomposes the problem into two parts such that each one is a p-median problem and finds the facility locations solving the two successive p-median problems. This solution strategy assigns a priority to the higher levels rather than to lower levels. For the pq-median problem (p is used for lower level and q is for higher level), firstly, a q-median problem is solved to locate level-2 facilities; and then a p-median problem for the points not in the q medians is solved to find the locations of level-1 facilities.

We adapt this procedure to our 3-level hierarchical model with p, q and r facilities. Here *p*, *q* and *r* stand for the lowest level, the medium level and the highest level of hierarchy, respectively. The TDH starts by solving the *r-median* problem to find the locations of level-3 facilities on the entire network and moves down the hierarchy to find the locations of lower level facilities.

The steps of the algorithm are as follows:

- Solve the *r-median* problem considering the demand for level-3 service and find the locations of level-3 facilities.
- Given the locations of level-3 facilities, solve the two level (*qr-median*) problem considering the demand for level-2 service and find the locations of level-2 facilities.
- Given the locations of level-2 and level-3 facilities, solve the original *pqr-median* problem considering the demand for level-1 service and find the locations of level-1 facilities.

These steps of the heuristic are explained in detail below. Let S_t be the set of potential facility sites for level *l* service (*l* =1, 2, 3*)* and v_j^k a new binary variable, defined as follows:

$$v_j^k = \begin{cases} 1, \text{if a type k facility is located at site j}, \\ 0, \text{otherwise.} \end{cases}$$

Step 1. *Location of level-3 facilities*

The total number of facilities that offer level-3 service is *r*. Make $S_1 = \{j \mid j = 1,2,,...,n\}$. The location-allocation problem at this step consists of selecting a maximum of *r* tertiary locations from set S_1 to site level-3 facilities ensuring to minimize the total of weighted distance traveled for receiving level-3 service.

The following *r-median* problem (RMP) is solved at this step:

$$\text{MIN} \left\{ \sum_{i \in I} \sum_{j \in J} W_i d_{ij} a_i X_{ij33} \right\}$$

S.T:

$$\sum_{j \in J} X_{ij33} = 1 \qquad \forall \ i$$

$$X_{ij33} \le v_j^3 \qquad \forall \ i, \text{ and } j \in S_1$$

$$\sum_{j \in J} v_j^3 = r$$

$$0 \le X_{ij33} \le 1 \qquad \forall \ i, \text{ and } j \in S_1$$

$$v_j^3 \in \{0,1\} \qquad \forall \ j \in S_1.$$

Note that this model is a traditional p-median problem. After this problem is solved, we define $S_2 = \{j \mid v_j^3 = 1\}$ and $S_3 = S_1 - S_2$, and enter the fixed locations of level-3 facilities into the next sub-problem.

Step 2. *Location of level-2 facilities*

The total number of facilities that offer level-2 service is r+q. We know the locations of r medians as the level-2 service providers. The location-allocation problem at this step is to select a maximum of *q* secondary locations from set S_3 to site level-2 facilities ensuring to minimize the total of weighted distance traveled for receiving level-2 service and level-3 service for referred patients.

The following q-*median* problem (QMP) is solved in this step:

$$\text{MIN}\ \left\{\sum_{i\in I}\sum_{j\in J} W_i d_{ij}(1-a_i)(X_{ij22}+X_{ij32})+\sum_{j\in J}\sum_{h\in J} R_{jh}\ t\ d_{jh}\right\}$$

S.T.

$$\sum_{j\in J}\left(X_{ij22}+X_{ij32}\right)=1 \qquad \forall\, i$$

$$\sum_{h\in J} R_{jh}=\sum_{i\in I}^{m} W_i c\,(1-a_i)(1+b)X_{ij22} \qquad \forall\, j \in S_3$$

$$X_{ij22} \le v_j^2 \qquad \forall\, i, \text{ and } j \in S_3$$

$$X_{ij32} \le v_j^3 \qquad \forall\, i, \text{ and } j \in S_2$$

$$R_{jh} \le M v_h^2 \qquad \forall\, j,h \in S_2$$

$$R_{jh} \le M v_j^2 \qquad \forall\, j \in S_3,\ h \in S_2$$

$$\sum_{j\in J} v_j^2 = q$$

$$0 \le X_{ij22} \le 1 \qquad \forall\, i, \text{ and } j \in S_3$$

$$0 \le X_{ij32} \le 1 \qquad \forall\, i, \text{ and } j \in S_3$$

$$v_j^2 \in \{0,1\} \qquad \forall\, j \in S_3.$$

As RMP, this is also a p-median problem. After this problem is solved, we define S$_4$=$\left\{ j \,\middle|\, v_j^2 = 1 \right\}$ and S$_5$=S$_3$-S$_4$, and enter the fixed locations of level-2 and level-3 facilities into the next sub-problem.

Step 3. *Location of level-1 facilities*

The total number of facilities that offer level-1 service is r+q+p. We know the locations of r and q medians as level-1 service providers. The location-allocation problem at this step is to select a maximum of *p* primary locations from set S$_5$ to site level-1 facilities ensuring to minimize the total of weighted distance traveled for receiving level-1 service.

The following *p-median* problem (PMP) is solved in this step:

$$\text{MIN } \left\{ \sum_{i \in I} \sum_{j \in J} W_i d_{ij} \, z \left(X_{ij11} + X_{ij21} + X_{ij31} \right) \right\}$$

S.T.

$$\sum_{j \in J}^{n} \left(X_{ij11} + X_{ij21} + X_{ij31} \right) = 1 \quad \forall i$$

$$X_{ij11} \leq v_j^1 \qquad \forall \ i, \text{ and } j \in S_5$$

$$X_{ij21} \leq v_j^2 \qquad \forall \ i, \text{ and } j \in S_4$$

$$X_{ij31} \leq v_j^3 \qquad \forall \ i, \text{ and } j \in S_2$$

$$\sum_{j \in J} v_j^1 = p$$

$$0 \leq X_{ij11} \leq 1 \qquad \forall \ i, \text{ and } j \in S_5$$

$$0 \leq X_{ij21} \leq 1 \qquad \forall \ i, \text{ and } j \in S_4$$

$$0 \leq X_{ij31} \leq 1 \qquad \forall \ i, \text{ and } j \in S_2$$

$$v_j^1 \in \{0,1\} \qquad \forall j \in S_5.$$

Similarly, RMP and QMP, PMP is also a p-median problem. After this problem is solved, we define $S_6 = \left\{ j \,\middle|\, v_j^1 = 1 \right\}$.

As a summary, we can state that sets S_6, S_4 and S_2 contain, respectively, the locations of *p* primary units, *q* secondary units and *r* tertiary units.

4.2.2. Modified Top-Down Heuristic

Modified top-down heuristic (MTDH) is based on top-down heuristic, defined in the previous section. As mentioned before, MTDH relies on a problem-size reduction idea where secondary (medium) and tertiary (highest) facilities are determined simultaneously and then the locations of primary (lowest) facilities are selected considering the site selection decisions obtained for secondary and tertiary facilities.

The steps of the algorithm are as follows:

- Solve the ***r-median*** problem considering the demand for **level-3 service** and find the set of sites, S_1, where "*r*" facilities are located.
- Solve the ***r-median*** problem considering the demand for **level-2 plus level-3 services** and find the set of sites, S_2, where "*r*" facilities are located.
- Solve the ***(q+r)-median*** problem considering the demand for **level-2 service** and find the set of sites, S_3, where "(*q* + *r*)" facilities are located.
- Define the new set of sites, S_4, which is the union of S_1, S_2 and S_3. S_4 has minimum q+r and maximum q+3r elements and is smaller than the total number of potential facility sites (*n*) in the original model. Therefore, the size of the 2-level hierarchical problem used at the

next step is reduced. Consequently, computational time may be reduced, while good solutions are obtained.

- Solve the ***qr-median*** (2-level) problem considering the demand for **level-2 and level-3 services, and referrals**. At this step, locations of secondary and tertiary facilities are obtained simultaneously, using the set S_4 for potential facility sites.
- Given the locations of secondary and tertiary facilities, solve the original 3-HLM *p-median* problem, using the set J-S_5 (S_5 contains the j's where "*q and r*" facilities are located), considering the demand for level-1 service and find the locations of primary facilities.

These steps of this heuristic are explained in detail as follows:

Steps 1, 2 and 3 below are performed in order to generate *the reduced set, S_4*. Each problem at the three steps is a traditional p-median problem and is solved using the procedure at Step 1 of the top-down heuristic.

Let us define:

$$v_j^s = \begin{cases} 1, \text{if a facility is located at site j at Step s } (s = 1,2,3) \text{ ,} \\ 0 \text{ otherwise.} \end{cases}$$

for the location variables, and

$$Z_{ij}^s = \begin{cases} 1, \text{if demand point i assigned to a facility located at site j at Step s,} \\ 0 \text{ otherwise.} \end{cases}$$

for the assignment variables used at Steps 1, 2 and 3.

Step 1. *Generating the set S_1*

The total number of facilities that offer level-3 service is *r*. The location-allocation problem at this step is the selection of a maximum of *r* locations ensuring to minimize the total of weighted distance traveled for receiving level-3 service.

The following *r-median* problem is solved at this step:

$$\text{MIN } \left\{ \sum_{i \in I} \sum_{j \in J} W_i d_{ij} a_i Z_{ij}^1 \right\}$$

S.T.

$$\sum_{j \in J} Z_{ij}^1 = 1 \qquad \forall\ i$$

$$Z_{ij}^1 \leq v_j^1 \qquad \forall\ i, j$$

$$\sum_{j \in J} v_j^1 = r$$

$$v_j^1,\ Z_{ij}^1 \in \{0,1\} \quad \forall\ i, j.$$

After this p-median problem is solved, we define $S_1 = \left\{ j \,\middle|\, v_j^1 = 1 \right\}$.

Step 2. *Generating the set* S_2

The total number of facilities opened is *r*. The location-allocation problem at this step is the selection of a maximum of *r* locations ensuring to minimize the total of demand-weighted distance. The demand of point *i* is now the sum of level-2 service and level-3 service demand in the original problem, i.e. $W_i(1-a_i) + W_i a_i = W_i$.

The following *r-median* problem is solved at this step:

$$\text{MIN}\left\{\sum_{i\in I}\sum_{j\in J} W_i d_{ij} Z_{ij}^2\right\}$$

S.T.

$$\sum_{j\in J} Z_{ij}^2 = 1 \qquad \forall\ i$$

$$Z_{ij}^2 \le v_j^2 \qquad \forall\ i, j$$

$$\sum_{j\in J} v_j^2 = r$$

$$v_j^2,\ Z_{ij}^2 \in \{0,1\} \quad \forall\ i, j.$$

After this p-median problem is solved, we define $S_2 = \left\{ j \mid v_j^2 = 1 \right\}$.

Step 3. *Generating the set S_3*

The total number of facilities opened at this step is ($q+r$). The location-allocation problem at this step is the selection of a maximum of ($q+r$) locations ensuring to minimize the total of demand-weighted distance. The demand of point *i is* the demand for level-2 service in the original problem, i.e. $W_i(1-a_i)$.

The following $(q+r)$*-median* problem is solved at this step:

$$\text{MIN}\left\{\sum_{i\in I}\sum_{j\in J} W_i d_{ij}(1-a_i) Z_{ij}^3\right\}$$

S.T.

$$\sum_{j\in J} Z_{ij}^3 = 1 \qquad \forall\ i$$

$$Z_{ij}^3 \le v_j^3 \qquad \forall\ i, j$$

$$\sum_{j\in J} v_j^3 = (q+r)$$

$$v_j^3,\ Z_{ij}^3 \in \{0,1\} \quad \forall\ i, j.$$

After this p-median problem is solved, we define $S_3 = \left\{ j \,\middle|\, v_j^3 = 1 \right\}$.

Now, we can define the set S_4 as the union of sets S_1, S_2 and S_3:

$S_4 = S_1 \cup S_2 \cup S_3$.

Step 4. *Location of level-2 and level-3 facilities*

Here, we solve a 2-level hierarchical *p-median* problem. In this way, it is possible to find the locations of level-2 and level-3 facilities simultaneously, using a smaller set of potential facility sites.

The following qr*-median* problem is solved at this step:

$$\text{MIN} \quad \left\{ \sum_{i \in I} \sum_{j \in S_4} W_i d_{ij} \left((1 - a_i)(X_{ij22} + X_{ij32}) + a_i X_{ij33} \right) + \sum_{j \in S_4} \sum_{h \in S_4} R_{jh} t \, d_{jh} \right\}$$

S.T.

$$\sum_j \left(X_{ij22} + X_{ij32} \right) = 1 \qquad \forall i$$

$$\sum_j X_{ij33} = 1 \qquad \forall i$$

$$\sum_h R_{jh} = \sum_{i \in I} W_i c \, (1 - a_i)(1 + b) X_{ij22} \qquad \forall j \in S_4$$

$$X_{ij22} \le Y_{j2} \qquad \forall i, \text{ and } j \in S_4$$

$$X_{ij32} \le Y_{j3} \qquad \forall i, \text{ and } j \in S_4$$

$$X_{ij33} \le Y_{j3} \qquad \forall i, \text{ and } j \in S_4$$

$$R_{jh} \le MY_{h3} \qquad \forall j \in S_4, h \in S_4$$

$$R_{jh} \le MY_{j2} \qquad \forall j \in S_4, h \in S_4$$

$$\sum_{j \in S4} Y_{j2} = q$$

$$\sum_{j \in S4} Y_{j3} = r$$

$$0 \le X_{ij22} \le 1 \qquad \forall i, \text{ and } j \in S_4$$

$$0 \le X_{ij32} \le 1 \qquad \forall i, \text{ and } j \in S_4$$

$$0 \le X_{ij33} \le 1 \qquad \forall i, \text{ and } j \in S_4$$

$$R_{jh} \ge 0, \; Y_{j1}, Y_{j2} \in \{0,1\}, \qquad \forall j \in S_4, h \in S_4.$$

After this problem is solved, we define $S_5 = \left\{ j \mid Y_{j2} = 1 \text{ and } Y_{j3} = 1 \right\}$ and $S_6 = J - S_5$.

Step 5. *Location of level-1 facilities*

While starting this step, we know the locations of *q* many level-2 and *r many* level-3 facilities as level-1 service providers. So, the location-allocation problem at this step is to select a maximum of *p* primary locations from set the S_6 to site level-1 facilities ensuring to minimize the total of weighted distance traveled for receiving level-1 service.

The following *p-median* problem is solved at this step:

$$\text{MIN} \left\{ \sum_{i \in I} \sum_{j \in J} W_i d_{ij} z (X_{ij11} + X_{ij21} + X_{ij31}) \right\}$$

S.T.

$$\sum_{j \in J} (X_{ij11} + X_{ij21} + X_{ij31}) = 1 \quad \forall i$$

$$X_{ij11} \leq Y_{j1} \qquad \forall\ i, \text{ and } j \in S_6$$

$$X_{ij21} \leq Y_{j2} \qquad \forall\ i, \text{ and } j \in S_6$$

$$X_{ij31} \leq Y_{j3} \qquad \forall\ i, \text{ and } j \in S_6$$

$$\sum_{j \in J} Y_{j1} = p$$

$$0 \leq X_{ij11} \leq 1 \qquad \forall\ i, \text{ and } j \in S_6$$

$$0 \leq X_{ij21} \leq 1 \qquad \forall\ i, \text{ and } j \in S_6$$

$$0 \leq X_{ij31} \leq 1 \qquad \forall\ i, \text{ and } j \in S_6$$

$$Y_{j1} \in \{0,1\} \qquad \forall j \in S_6.$$

After this problem is solved, we define $S_7 = \left\{ j \mid Y_{j1} = 1 \right\}$.

As a summary, we can state that sets S_7 and S_5 contain, respectively, the locations of *p* primary, *q* secondary and *r* tertiary units.

4.2.3. Solution Methodology for the p-Median Type Sub-Problems of the TDH and MTDH

While p-median problem can be solved in polynomial time on a tree network for fixed values of *p*, the problem is NP-hard for variable values of *p* (Daskin, 1995). Hence, a number of heuristic algorithms for the solution of the p-median problem are proposed. Myopic algorithm, exchange heuristic, neighborhood search algorithm, Lagrangean relaxation and metaheuristics like Tabu search are examples of these heuristics. Among them, we select the Lagrangean Relaxation algorithm which often gives results that are either provably optimal or very close to the optimal. All sub-problems of the p-median type in both TDH and MTDH (except *pq-median* problem in MTDH) are solved using this algorithm. We now give the main steps of this algorithm below.

The *p-median* problem can be summarized as follows:

Parameters

h_i : demand at site i, i∈I

d_{ij} : distance between demand site *i* and candidate facility j, i∈I, j∈J

p : number of facilities to locate

Decision Variables

$$Y_j = \begin{cases} 1, & \text{if a facility is located at site j}, \\ 0, & \text{otherwise.} \end{cases}$$

$$X_{ij} = \begin{cases} 1, & \text{if a demand site i is served by facility located at site j}, \\ 0, & \text{otherwise.} \end{cases}$$

Mathematical Formulation

$$\text{MIN} \left\{ \sum_{i \in I} \sum_{j \in J} h_i d_{ij} X_{ij} \right\}$$

Subject to:

$$\sum_j X_{ij} = 1 \qquad \forall\, i \qquad (1)$$

$$\sum_j Y_j = p \qquad (2)$$

$$X_{ij} - Y_j \leq 0 \qquad \forall\, i, j \qquad (3)$$

$$Y_j \in \{0,1\} \qquad \forall\, j, \qquad (4)$$

$$X_{ij} \in \{0,1\} \qquad \forall\, i,j \qquad (5)$$

Suppose that we relax the constraint set (1). When these constraints are relaxed and included in the objective function by the Lagrange multipliers, we obtain the following Lagrangean relaxation problem:

OFV(LRP) [OFV: Objective Function Value] =

$$\max_{\lambda} \min_{X,Y} L = \sum_i \sum_j h_i d_{ij} X_{ij} + \sum_i \lambda_i (1 - \sum_j X_{ij})$$

$$= \sum_i \sum_j (h_i d_{ij} - \lambda_i) X_{ij} + \sum_i \lambda_i$$

subject to: (2)-(5).

For fixed values of the Lagrange multipliers, λ_i, the objective function, L, is minimized by computing the value of setting each of the location variables, Y_j, to 1. This value is given by:

$U_j = \sum_i \min(0, h_i d_{ij} - \lambda_i)$ for each candidate location j. The *p* smallest values of U_j are then determined and the corresponding location variables, X_{ij}, are set to 1 and all other X_{ij} values to 0. We then set

$$X_{ij} = \begin{cases} 1, & \text{if } X_{ij} = 1 \text{ and } h_i d_{ij} - \lambda_i < 0, \\ 0, & \text{otherwise.} \end{cases}$$

Then using this solution, we obtain a lower bound, L*,* on the objective function value of the original problem. This Lagrangean solution may not be feasible for the original p-median problem, since the constraints (1) we relax may be violated (i.e. demand sites *i* may be assigned to several or no facility). So, we need to convert these infeasible solutions to feasible ones. In this way, we can get good solutions to the original problem. This solution value represents an upper bound on the optimal solution. The best (lowest) such value found over all iterations of the Lagrangean relaxation procedure is used as the upper bound. We can obtain an upper bound by easily allocating the demand sites to the nearest open facility found in the Lagrangean problem.

The final step is to update the Lagrangean multipliers based on the solutions found. Firstly, we need to compute a stepsize, t^n, at the n^{th} iteration of the Lagrangean algorithm as follows:

$$t^n = \frac{\alpha^n (UB - \ell^n)}{\sum_i \left(\sum_j X_{ij}^n - 1 \right)^2}$$

where

t^n =stepsize at the n^{th} iteration of the Lagrangean procedure

α^n =constant at the n^{th} iteration ($\alpha \in (0, 2]$ and α^0 generally set to 2),

UB =the best (smallest) upper bound on the p-median objective function

ℓ^n =the value of the objective function using the solution obtained from the relaxed problem at the nth iteration

X_{ij}^n =the optimal value of the allocation variable, X_{ij}, at the n^{th} iteration

After any iteration *n,* the Lagrange multipliers are updated using the following equations:

$$\lambda_i^{n+1} = \max \{ 0,\ \lambda_i^n - t^n \left(\sum_j X_{ij}^n - 1 \right) \} \quad \forall\, i$$

We start with an initial α value of 0.6 and if there is no improvement in the value of ℓ (lower bound) after 12 iterations, then α is replaced with $\alpha / 2$; this method of updating α is the same as in Sridharan (1991).

The solution of the original problem is always given by the value of the upper bound at the end of Lagrangean relaxation procedure. The stopping conditions of the algorithm are:

- If the best lower bound (OFV(LRP)) = the best upper bound, an optimal solution for the problem has been found.
- Stop if gap (%) = [(best upper bound – best lower bound) / best lower bound]*100 is smaller than 0.1.
- Stop if the number of iterations > 200.

If none of the above stopping conditions is satisfied, the algorithm re-iterates.

The pseudo-code of this solution procedure is given in Figure 4.1:

```
Begin
Set   LB = - ∞ {initial value of the lower bound};
      UB = + ∞ {initial value of the upper bound};
      $\lambda_i$ = 0 {the initial values of the Lagrangean multipliers used for relaxed constraints (1)};
      $\alpha$ = 0.6 {constant used for calculating the stepsize};
      noimprovement = 0 {the number of iterations without change in the lower bound};
      max_ number_of_iter = 200 {maximum number of iterations Lagrangean relaxation
                                 algorithm is executed};
      continue = 1 {if stopping conditions are not met };
while (continue=1) do
      solve Lagrangean problem (L), obtain ( $Y_j'$ and $X_{ij}'$ ) and OFV(LRP),
      find a feasible solution ( $Y_j''$ and $X_{ij}''$ ) using $Y_j'$ ;
      make the objective function value of this feasible solution = F_OFV(LRP);
      if (LB ≥ OFV(LRP)) {check if lower bound has been improved};
            then noimprovement = noimprovement + 1;
            else noimprovement = 0;
                  if noimprovement =12;
                  then make $\alpha$ = $\alpha / 2$;
                  endif.
      End if.
      LB = max [LB, OFV(LRP)] {find the best (biggest) lower bound };
      UB = min [UB, F_OFV(LRP)] {find the best (smallest) upper bound };
      Calculate the subgradients,
      Update stepsize and Lagrangean multipliers;
      Compute the gap between LB and UB;
      If gap ≤ 0.1 or max_ number_of_iter > 200 {check for whether stopping conditions are
      met}
      then stop;
End while.
Write results.
End.
```

Figure 4.1. The pseudo-code of the Lagrangean relaxation algorithm for p-median problem

The *pq-median* problem defined in Step 4 of the Modified Top-Down Heuristic is also solved using the Lagrangean Relaxation algorithm, developed for 3-HLM *p-median* problem in the next section.

4.3 LAGRANGEAN RELAXATION BASED HEURISTIC FOR 3-HLM

When using any heuristic, we try to have a trade-off between the solution time and the solution quality. While we can find good solutions quickly using TDH and MTDH given above, it is difficult to assess the solution quality, because we have no information about how far solutions from optimality (if not known) are. One advantage of the technique known as Lagrangean relaxation is that it provides both upper and lower bounds on the value of the objective function (Fisher, 1981; as cited in Current et al., 2002). That is, we know that the optimal objective function value lies between the value of the best feasible solution found (upper bound) and a value that it can be no better than (lower bound). The difference between the bounds is known as the "gap" (Fisher, 1985).

Lagrangean relaxation is a method that is increasingly being used for solving large-scale mathematical programming problems. Fisher (1985) explains this method in summary as follows: Lagrangean relaxation is based upon the observation that many difficult integer programming problems can be modeled as a relatively easy problem complicated by a set of side constraints. To exploit this observation, a Lagrangean relaxation problem, in which the complicating constraints (e.g. assignment equality constraints in p-median location problem) are replaced with a penalty term in the objective function involving the amount of violation of the constraints and their dual variables, is created. The Lagrangean problem is easy to solve and provides an upper bound (for a maximization problem) on the optimal value of the original problem.

Generally speaking, there are three major steps in designing a Lagrangean-relaxation-based procedure:

- Decide on the constraint(s) to be relaxed (selected relaxed constraints should make the problem significantly easier) and develop a procedure to solve the relaxed problem.
- Compute good multipliers, v, *if one constraint is relaxed* (or vector of nonnegative multipliers, V=[v_1, v_2, v_3,…], *if more than one constraint is relaxed*), and for this purpose use a method (e.g. a general purpose procedure called subgradient method).
- Develop an algorithm (which tends to be problem specific) for good feasible solutions to the original problem.
- Check for the stopping conditions and continue until these conditions are met.

For our problem, firstly, a Lagrangean problem is solved for a known V (vector of Lagrangean multipliers) at the each iteration of the algorithm. Secondly, a feasible solution, producing an upper bound value, is found using the solution values of the Lagrangean problem. Finally, the subgradients are calculated; stopping conditions are checked after the stepsize and the Lagrangean multipliers are updated. The main steps of our solution approach are explained in detail below:

Step 1. *Setting Up*

The idea at this step is to create a Lagrangean problem, associated with the original problem, whose optimal solution provides a lower bound (since our problem is a minimization problem) on the objective function of the original problem. This is done by relaxing the equality constraints, (1)-(3), of the original model and adding these constraints, multiplied by an associated Lagrange multiplier, to the objective function.

Let us define $V=[v_{1(i)}, v_{2(i)}, v_{3(i)}] \geq 0$, as a set of non-negative Lagrange multipliers (a vector of variables) where $v_{1(i)}=[v_{1(1)}, v_{1(2)}, v_{1(3)}, \ldots, v_{1(n)}]$, $v_{2(i)}=[v_{2(1)}, v_{2(2)}, v_{2(3)}, \ldots, v_{2(n)}]$ and $v_{3(i)}=[v_{3(1)}, v_{3(2)}, v_{3(3)}, \ldots, v_{3(n)}]$ are vectors associated with constraint sets (1), (2) and (3), respectively. Note that despite the fact that we are relaxing constraints (and would therefore generally expect that the Lagrange multipliers could be unrestricted in sign), we can restrict the Lagrange multipliers to nonnegative values as long as all demands, W_i, and all distances, d_{ij}, are nonnegative; doing so will improve the values of the lower bounds that we obtain from the Lagrangean objective function (Daskin, 1995). When we remove the (1)-(3) constraint sets and add them to the objective function of 3-HLM *p-median* model by multiplying with the associated Lagrange multipliers, we obtain the following Lagrangean problem (LRP):

$$\max_{V} \min_{X,Y} \text{OFV(LRP)} =$$

$$\left\{ \begin{array}{l} \sum_{i \in I} \sum_{j \in J} W_i d_{ij} \big(z\,(X_{ij11} + X_{ij21} + X_{ij31}) + (1 - a_i)(X_{ij22} + X_{ij32}) + a_i X_{ij33} \big) \\ + \sum_{j \in J} \sum_{h \in J} R_{jh} t\, d_{jh} + \sum_{i \in I} v_1(i) \left[1 - \sum_{j \in J} (X_{ij11} + X_{ij21} + X_{ij31}) \right] \\ + \sum_{i \in I} v_2(i) \left[1 - \sum_{j \in J} (X_{ij22} + X_{ij32}) \right] + \sum_{i \in I} v_3(i) \left[1 - \sum_{j \in J} X_{ij33} \right] \end{array} \right\}$$

subject to (4)-(11).

After a little algebra, the LRP can be rewritten as follows:

$$\max_{V} \min_{X,Y} \mathrm{OFV(LRP)}$$

$$\left\{\begin{array}{l} \sum_{i\in I}\sum_{j\in J}\left(W_i d_{ij} z - v_1(i)\right)X_{ij11} + \sum_{i\in I}\sum_{j\in J}\left(W_i d_{ij} z - v_1(i)\right)X_{ij21} + \sum_{i\in I}\sum_{j\in J}\left(W_i d_{ij} z - v_1(i)\right)X_{ij31} + \\ + \sum_{i\in I}\sum_{j\in J}\left(W_i(1-a_i)d_{ij} - v_2(i)\right)X_{ij22} + \sum_{i\in I}\sum_{j\in J}\left(W_i(1-a_i)d_{ij} - v_2(i)\right)X_{ij32} + \\ \sum_{i\in I}\sum_{j\in J}\left(W_i a_i d_{ij} - v_3(i)\right)X_{ij33} + \sum_{i\in I} v_1(i) + \sum_{i\in I} v_2(i) + \sum_{i\in I} v_3(i) + \sum_{j\in J}\sum_{h\in J} R_{jh} t\, d_{jh} \end{array}\right\}$$

subject to (4)-(11).

Note that the objective function of LRP is minimized with respect to the original (location and assignment) variables (X_{ijkl} and Y_{jl}, respectively) and is maximized with respect to the Lagrangean multipliers, ($V=[v_{1(i)}, v_{2(i)}, v_{3(i)}]$). The largest value of LRP over all iterations of the procedure represents a lower bound on the objective function for the original 3-HLM *p-median* model.

We solve the LRP omitting the referrals, i.e. removing the constraint set (4) and $\sum_{j\in J}\sum_{h\in J} R_{jh} t\, d_{jh}$ part from the objective function.

Step 2. *Solving the Lagrangean Problem*

For fixed values of the Lagrange multipliers, $V=[v_{1(i)}, v_{2(i)}, v_{3(i)}]$, the objective function in the previous step is minimized by computing the costs of setting each of the location variables of level-1, -2 and -3 facilities (Y_{j1}, Y_{j2}, Y_{j3}) to 1.

These costs are given by:

$U_j^1 = \sum_{i\in I} \min\left(0, W_i d_{ij} z - v_1(i)\right)$: cost of offering level-1 service from a level-1 facility located at site $j \in J$,

$U_j^2 = \sum_{i \in I} \min\left(0, W_i d_{ij} z - v_1(i)\right)$: cost of offering level-1 service from a level-2 facility located at site $j \in J$,

$U_j^3 = \sum_{i \in I} \min\left(0, W_i (1 - a_i) d_{ij} - v_2(i)\right)$: cost of offering level-2 service from a level-2 facility located at site $j \in J$,

$U_j^4 = \sum_{i \in I} \min\left(0, W_i d_{ij} z - v_1(i)\right)$: cost of offering level-1 service from a level-3 facility located at site $j \in J$,

$U_j^5 = \sum_{i \in I} \min\left(0, W_i (1 - a_i) d_{ij} - v_2(i)\right)$: cost of offering level-2 service from a level-3 facility located at site $j \in J$,

$U_j^6 = \sum_{i \in I} \min\left(0, W_i a_i d_{ij} - v_3(i)\right)$: cost of offering level-3 service from a level-3 facility located at site $j \in J$,

We use these costs in order to define the locations of level-1, level-2 and level-3 facilities. Since all these costs (coefficients) are non-positive (i.e. U_j^1, U_j^2, U_j^3, U_j^4, $U_j^5 \leq 0$) and it is a minimization problem, we must consider the cost of offering level-1 service at this site, when locating a level-1 facility at any site; we must consider the cost of offering level-1 plus level-2 services (since the system is successively inclusive) at this site, when locating a level-2 facility at any site; we must consider the cost of offering level-1 plus level-2 plus level-3 services at this site, when locating a level-3 facility at any site.

Now, using these facility location costs, we seek to locate facilities of level-1, level-2 and level-3 such that the total installation costs are minimized. This minimization sub-problem (SP) is formulated as follows:

SP:

$$\text{OFV (SP)} = \min \sum_{j \in J} \left(U_j^1 Y_{j1} + (U_j^2 + U_j^3) Y_{j2} + (U_j^4 + U_j^5 + U_j^6) Y_{j3} \right)$$

subject to:

$$\sum_{j \in J} Y_{j1} = p$$

$$\sum_{j \in J} Y_{j2} = q$$

$$\sum_{j \in J} Y_{j3} = r$$

$$Y_{j1} + Y_{j2} + Y_{j3} \le 1, \quad \text{for all } j \in J,$$

$$Y_{j1}, Y_{j2}, Y_{j3} \in \{0,\ 1\}, \quad \text{for all } j \in J,$$

In this formulation, we add a new constraint ($Y_{j1} + Y_{j2} + Y_{j3} \le 1, \text{for all } j \in J$) in order to avoid the location of different types of facility at the same site.

Note that this sub-problem (SP) is a traditional transportation problem with three sources and $|J|$ destinations. The available amounts of resources are "p", "q" and "r", respectively, in the sources of level-1, level-2 and level-3 facilities and all demands in the destinations are equal to "1". At the each iteration of the Lagrangean relaxation algorithm, this transportation problem is solved as an MIP problem using GAMS/CPLEX 10.0. After solving this problem, we determine the locations of level-1, level-2 and level-3 facilities and define S_1, S_2 and S_3 as the set of j's where a level-1 facility is located, the set of j's where a level-2 facility is located and the set of j's where a level-3 facility is located, respectively.

The allocation variables (X_{ijkl}) are then set to:

$$X_{ij11} = \begin{cases} 1, & \text{if } Y_{j1} = 1 \quad \text{and} \quad W_i d_{ij} z - v_1(i) < 0 \\ 0, & \text{if not} \end{cases}$$

$$X_{ij21} = \begin{cases} 1, & \text{if } Y_{j2} = 1 \quad \text{and} \quad W_i d_{ij} z - v_1(i) < 0 \\ 0, & \text{if not} \end{cases}$$

$$X_{ij31} = \begin{cases} 1, & \text{if } Y_{j3} = 1 \quad \text{and} \quad W_i d_{ij} z - v_1(i) < 0 \\ 0, & \text{if not} \end{cases}$$

$$X_{ij22} = \begin{cases} 1, & \text{if } Y_{j2} = 1 \quad \text{and} \quad W_i\,(1 - a_i)\,d_{ij} - v_2(i) < 0 \\ 0, & \text{if not} \end{cases}$$

$$X_{ij32} = \begin{cases} 1, & \text{if } Y_{j3} = 1 \quad \text{and} \quad W_i\,(1 - a_i)\,d_{ij} - v_2(i) < 0 \\ 0, & \text{if not} \end{cases}$$

$$X_{ij33} = \begin{cases} 1, & \text{if } Y_{j3} = 1 \quad \text{and} \quad W_i\,a_i\,d_{ij} - v_3(i) < 0 \\ 0, & \text{if not} \end{cases}$$

We may finally write

$$\text{OFV(LRP)} = \text{OFV (SP)} + \sum_i (v_1(i) + v_2(i) + v_3(i)).$$

This value is a lower bound, LB, (an optimistic estimate of the best case scenario) on the objective function of the original problem.

Step 3. *Obtaining a Feasible Solution (Finding an Upper Bound Value)*

The solution of LRP found at Step 2 may not be feasible for the original 3-HLM, since the constraints we relax, (1)-(3), may be violated, that is, a demand node *i* may be assigned to several facilities or no facility at any level). So, we need to convert these infeasible solutions to feasible ones. In this way, we can get good solutions to the original model. The solution thus obtained represents an upper bound (estimate of the worst case scenario) on the optimal solution. The best (lowest) such value found over all iterations of the Lagrangean relaxation procedure is used as the upper bound. In order to obtain an upper bound we use the procedure defined as follows: Firstly, the location decisions obtained from the solution of the LRP are chosen as the location decisions for the facilities in the upper bound algorithm. The feasible values of the allocation variables (X_{ijkl}'s) are then obtained using the following procedure:

- Assign the demand requiring level-1 service at demand point *i* to a level-1, -2 or -3 facility that is nearest to them and make $X_{ij11} = 1,$ if the nearest facility is a level-1 facility; $X_{ij21} = 1,$ if the nearest facility is a level-2 facility and $X_{ij31} = 1,$ if the nearest facility is a level-3 facility.
- Assign a proportion, a_i, of the demand at point *i* to a level-3 facility that is nearest to them and make $X_{ij33} = 1.$
- Assign a proportion, $(1-a_i)$, of the demand at point *i*, requiring level-2 service, to a level-2 or a level-3 facility according to the following rule:

  If ({distance between location of demand point *i* and nearest level-3 facility} > {distance between location of demand point *i* and nearest level-2 facility} + c(1+b)t{distance between level-2 facility and nearest level-3 facility}),

  then assign all the demand requiring level-2 service at demand point *i* to the nearest level-2 facility and make $X_{ij22} = 1.$

  If not assign all the demand requiring level-2 service at demand point *i* to the nearest level-3 facility and make $X''_{ij32} = 1.$
- Refer a proportion, c(1+b), of the demand at point *i* assigned to a level-2 facility to the nearest level-3 facility. Let us define R_j as the

total number of mothers-to-be that refer to site *j* where a level-2 facility is located and make $R_j = \sum_{i \in I} W_i c\,(1 - a_i)(1 + b) X_{ij22}$.

We can then evaluate the 3-HLM objective function, an upper bound on the solution, as follows:

F_OFV(LRP) =

$$\left\{ \begin{array}{l} \sum_{i \in I} z\,W_i \min_{j \in S_1} \{d_{ij}\} X_{ij11} + \sum_{i \in I} z\,W_i \min_{j \in S_2} \{d_{ij}\} X_{ij21} + \sum_{i \in I} z\,W_i \min_{j \in S_3} \{d_{ij}\} X_{ij31} \\ + \sum_{i \in I} W_i\,(1 - a_i) \min_{j \in S_2} \{d_{ij}\} X_{ij22} + \sum_{i \in I} W_i\,(1 - a_i) \min_{j \in S_3} \{d_{ij}\} X_{ij32} + \\ \sum_{i \in I} W_i\,a_i \min_{j \in S_3} \{d_{ij}\} X_{ij33} + \sum_{j \in S_2} R_j \min_{h \in S_3} \{d_{jh}\} \end{array} \right\}$$

Thus, for each set of multipliers $V = [v_1(i), v_2(i), v_3(i)]$ the procedure computes both a lower bound and an upper bound. If these bounds coincide, an optimal solution has been found. Otherwise, in order to determine the multipliers corresponding to the maximum possible (or at least a satisfactory bound), the standard subgradient optimization algorithm, explained in the next section, is used.

Step 4. *Updating the Lagrangean Multipliers*

The Lagrangean multipliers should be updated using a procedure which drives the iterations to an optimal solution that satisfies the original problem's constraints. Based on the subgradient optimization, we firstly compute the subgradients for LRP. Let us define:

$s(v_1(i))$, $s(v_2(i))$ and $s(v_3(i))$ as the amount of violation of the constraints (1), (2) and (3), respectively.

$$s(v_1(i)) = 1 - \sum_{j \in J} (X_{ij11} + X_{ij21} + X_{ij31}) \text{ for } \forall i,$$

$$s(v_2(i)) = 1 - \sum_{j \in J} (X_{ij22} + X_{ij32}) \text{ for } \forall i,$$

$$s(v_3(i)) = 1 - \sum_{j \in J} X_{ij33} \text{ for } \forall i,$$

$$\text{Norm} = s(v_1, v_2, v_3] = \sum_{i \in I} [s(v_1(i))]^2 + \sum_{i \in I} [s(v_2(i))]^2 + \sum_{i \in I} [s(v_3(i))]^2$$

Now, we need to compute a stepsize, t^n, at the n^{th} iteration of the Lagrangean procedure as follows:

$$t^n = \frac{\alpha^n (BUB - \ell^n)}{norm}$$

where

t^n = the stepsize at the n^{th} iteration of the Lagrangean procedure

BUB = the best (smallest) upper bound on the 3-HLM objective function

ℓ^n = the value of the objective function using the solution obtained from the relaxed problem at the n^{th} iteration (i.e. ℓ^n =OFV(LRP)^n)

Norm = total amount of violation (squared deviation from the right hand side values of the constraints (1), (2) and (3)

α^n = a constant at the n^{th} iteration ($\alpha^n \in (0, 2]$ and $\alpha^0 = 2$; in case of no improvement in ℓ^n (lower bound) after 15 iterations, set $\alpha^{n+1} = \alpha^n/2$)

After any iteration *n,* the Lagrange multipliers are updated using the following equations:

$$v_1(i)^{n+1} = \max \{ 0, v_1(i)^n + t^n s(v_1(i))^n \}$$

$$v_2(i)^{n+1} = \max \{ 0, v_2(i)^n + t^n s(v_2(i)^n) \}$$

$v_3(i)^{n+1} = \max \{ 0,\ v_3(i)^n + t^n s(v_3(i)^n) \}$

Step 5. *Evaluating the Results*

The solution of the original problem is given by the value of the upper bound at the end of Lagrangean relaxation procedure. The stopping conditions of the algorithm are:

- Let "curr" be the current iteration counter;

  If $\max_{n=0,\ldots,curr} \ell^n = \mathrm{BUB}$ (the best upper bound), an optimal solution for the problem is found.
- Stop if gap (%) = $((\mathrm{BUB} - \max_{n=0,\ldots,curr} \ell^n) / \max_{n=0,\ldots,curr} \ell^n)\ 100 \leq 0.01$.
- Stop, if the number of iterations > 750.
- Stop, if step size (t^n) < 0.0001

If none of the above stopping conditions is met, the algorithm re-iterates starting at Step 2. The pseudo-code of the solution approach is given in Figure 4.2.

```
Start
Set    $\ell^0$ = - ∞ {initial value of the lower bound};
       BUB = + ∞ {initial value of the upper bound};
       $v_1(i)$ = 0 {the initial values of the Lagrangean multipliers used for relaxed constraint set (1)};
       $v_2(i)$ = 0 {the initial values of the Lagrangean multipliers used for relaxed constraint set (2)};
       $v_3(i)$ = 0 {the initial values of the Lagrangean multipliers used for relaxed constraint set (3)};
       $\alpha^0$ = 2 {constant used for calculating the stepsize};
       noimprovement = 0 { number of iterations with no change in the lower bound}
       max_number_of_iter =750 {maximum number of iterations}
       continue = 1 {if none of the stopping conditions is not met };
while (continue=1) do
       solve the Lagrangean problem (LRP) and obtain $Y_{j1}^n$, $Y_{j2}^n$, $Y_{j3}^n$, $X_{ijkl}^n$ and $\ell^n$;
       find a feasible solution for $X_{ijkl}^n$ using $Y_{j1}^n$, $Y_{j2}^n$ and $Y_{j3}^n$;
       make the objective function value of this feasible solution = F_OFV(LRP)$^n$;
       if ( $\max_{n=0,\dots,curr} \ell^n \geq \ell^n$ ) {check if lower bound has been improved};
       then noimprovement = noimprovement + 1;
       else noimprovement = 0;
              if noimprovement =15;
              then make $\alpha^{n+1} = \alpha^n/2$;
              endif.
       End if.
       $\max_{n=0,\dots,curr} \ell^n = \max[\max_{n=0,\dots,curr-1} \ell^n, \ell^n]$ {find the best (largest) lower bound};
       BUB$^n$ = min [BUB$^{n-1}$, F_OFV(LRP)$^n$]     {find the best (smallest) upper bound };
       Calculate the subgradients, s[$v_1(i)$], s[$v_2(i)$] and s[$v_3(i)$], of LRP using $X_{ijkl}$ (found solving the LRP);
       Update the stepsize and the Lagrangean multipliers;
       Compute the gap between LB and UB;
       If gap ≤ 0.01 or max_number_of_iter > 750 or stepsize < 0.0001 {check for whether any of stopping condition is satisfied}
       then stop;
End while.
Write results.
End.
```

Figure 4.2. The pseudo-code of the Lagrangean relaxation based heuristic

4.4 COMPUTATIONAL RESULTS

In order to test the performances of the three heuristic approaches, a variety of problems in the literature (that we call literature problems), ranging from 57 to 737 vertices, are solved for different sets of p, q and r. In addition to these problems, the problems with 10-, 30-, 40-, 81- and 130-vertex networks (that we call Turkey specific problems), are generated using the 81-vertex network provinces in Turkey, using the real distance data supplied from the General Directorate of Highways of the Republic of Turkey and real population data of the provinces. The 10-, 30- and 40-vertex networks correspond to the "reduced" networks, generated using 81-vertex network. The 130-vertex network is built by adding counties of some provinces into the 81-vertex network. The proportion of demand requiring level-3 service, a_i, and the proportion of referrals *c* and *b* are generated from a uniform distribution, defined in the range of (0, 0.15], (0, 0.30] and (0, 0.30], respectively.

The literature problems with 57-, 100-, 150-, 263-, 316- and 737-vertex networks, developed for the p-median problems, are generated using different networks defined in literature. The 57- and 100-vertex networks are defined by Nelio Pizzolato; 150-, 263- and 737-vertex networks are defined by Mark Daskin; and 316-vertex network (Alberta problem set) is defined by Alp et al. (2003). Since all problems are defined within a network structure, a demand point (*i*) is also a potential facility site (*j*) for any level of the hierarchy. All these problems are available at http://www.business.ualberta.ca/eerkut/testproblems/. The population data for these networks are generated from a uniform distribution defined in the range of [20, 30]. The proportion of demand requiring level-3 service, a_i, and the proportion of referrals *c* and *b* are also generated from a uniform distribution, defined in the range of (0, 0.15], (0, 0.10] and (0, 0.10], respectively.

All sub-problems defined in the TDH and MTD heuristics are solved using the Lagrangean relaxation procedure, coded in GAMS 22.2 and solved by CPLEX 10.0. The LRH is also coded in GAMS 22.2 and solved using CPLEX 10.0. We solve the test problems on a 3.20 GHz Pentium 4 computer with 2.5 GB of RAM memory, under Windows XP. In order to compare the solutions produced by the heuristics; we attempt to solve the problems for their optimal solutions using GAMS 22.2/CPLEX 10.0 (for this purpose, we define a time limit as 3 days). But optimal solutions can only be found for 10-, 30-, 40-, 57- and 81-vertex problems.

The results of the test problems are shown in Tables 4.2-4.4. Before elaborating on the results, some explanations are require with regard to the result tables:

- In the first column of the Table 4.2 and 4.3 we see the identification of the problems (number of vertices (*n*), number of level-1, 2, and 3 facilities that will be opened (p, q and r)).
- For the Lagrangean relaxation heuristic, *lower bound* (best available), *solution value* (best available upper bound), *gap* (%)*, best_iteration* counter (iteration at which the best solution is obtained) and *CPU Time (solution time in seconds)* are defined.
- For the Top-Down and Modified Top-Down heuristics, *solution value (the objective function value), gap (%) and CPU Time (solution time in seconds)* are defined. The gaps are computed as follows:
    - **If** an optimal solution is available, *Gap(%) = ((solution value-optimal solution)/optimal solution)*100;*

    - **Else** replace the “optimal solution” value by “best available upper bound” obtained from the Lagrangean relaxation based heuristic.

In Tables 4.2 and 4.3, we show the results for the Turkey specific problems and the literature problems, respectively. A summary of the observed gaps in terms of mean and standard deviation is shown in Table 4.4.

Table 4.2. Computational results, Turkey specific problems

COMPUTATIONAL RESULTS																
Problem				**Optimal Solution GAMS/CPLEX 10.0**		**Lagrangean Relaxation Based Heuristic (LRH)**					**Modified Top-Down Approach (MTD)**			**Top-Down Approach (TDH)**		
n	**P1**	**P2**	**P3**	**Solution Value**	**CPU Time**	**Lower Bound**	**Upper Bound**	**Gap (%)**	**Best Iteration Counter**	**CPU Time**	**Solution Value**	**Gap (%)**	**CPU Time**	**Solution Value**	**Gap (%)**	**CPU Time**
10	2	1	1	9.001104E+09	0.25	8.844550E+09	9.001104E+09*	1.770	101	21.8	9.001104E+09*	0.000	11.4	9.001104E+09*	0.000	5.4
10	3	2	1	4.817541E+09	0.21	4.574841E+09	4.817541E+09*	5.305	71	11.1	4.817541E+09*	0.000	9.1	4.817541E+09*	0.000	5.1
10	4	3	1	2.524743E+09	0.31	2.269540E+09	2.524743E+09*	11.245	122	22.1	2.524743E+09*	0.000	10.9	2.524743E+09*	0.000	5.2
30	3	2	1	1.670450E+10	4.20	1.614120E+10	1.670450E+10*	3.489	109	33.5	1.755460E+10	5.089	14.1	1.670450E+10*	0.000	5.6
30	7	4	3	6.469829E+09	3.60	6.190555E+09	6.469829E+09*	4.512	183	37.4	6.511863E+09	0.650	17.6	7.105594E+09	9.827	5.3
30	10	5	4	3.930952E+09	6.70	3.734922E+09	3.942178E+09	5.549	199	31.5	3.930952E+09*	0.000	16.5	4.287112E+09	9.060	6.4
40	3	2	1	3.064380E+10	43.1	2.943080E+10	3.064380E+10*	4.122	196	44.8	3.178470E+10	3.723	11.4	3.148460E+10	2.744	8.6
40	5	3	2	1.790170E+10	35.1	1.693670E+10	1.790170E+10*	5.698	178	47.8	1.790170E+10*	0.000	14.1	1.790170E+10*	0.000	7.9
40	9	3	2	1.444480E+10	43.0	1.347980E+10	1.444480E+10*	7.159	199	42.4	1.444480E+10*	0.000	19.9	1.444480E+10*	0.000	8.0
81	5	2	1	5.293910E+10	3,697.0	5.121470E+10	5.293910E+10*	3.367	290	138.0	5.293910E+10*	0.000	20.2	5.293910E+10*	0.000	8.9
81	10	5	3	2.605470E+10	40,438.0	2.499190E+10	2.605470E+10*	4.252	293	149.0	2.663680E+10	2.234	20.1	2.670770E+10	2.506	10.3
81	20	12	4	1.227930E+10	70,876.0	1.128940E+10	1.227930E+10*	8.769	380	137.0	1.228770E+10	0.068	30.5	1.251410E+10	1.912	11.4
130	13	7	4	-----	-----	4.371730E+10	4.610600E+10	5.464	199	295.0	4.686590E+10	1.648	149.0	4.667360E+10	1.231	46.5
130	33	23	8	-----	-----	1.239960E+10	1.383800E+10	11.600	393	297.0	1.408090E+10	1.755	159.8	1.422800E+10	2.818	46.9
130	50	20	10	-----	-----	9.531967E+9	1.064690E+10	11.697	397	293.0	1.078050E+10	2.255	145.3	1.096460E+10	2.984	51.5

*Optimal solution

Table 4.3. Computational results, literature problems

COMPUTATIONAL RESULTS																
Problem				Optimal Solution GAMS/CPLEX 10.0		Lagrangean Relaxation Based Heuristic (LRH)					Modified Top-Down Approach (MTDH)			Top-Down Approach (TDH)		
n	P1	P2	P3	Solution Value	CPU Time	Lower Bound	Upper Bound	Gap (%)	Best Iteration Counter	CPU Time	Solution Value	Gap (%)	CPU Time	Solution Value	Gap (%)	CPU Time
57	4	3	2	1.563185E+06	34.70	1.548669E+06	1.563185E+06*	0.937	195	42.6	1.568146E+06	0.317	12.3	1.605321E+06	2.696	9.7
57	6	3	2	1.400430E+06	34.50	1.386671E+06	1.400430E+06*	0.992	169	37.7	1.405391E+06	0.354	16.6	1.436051E+06	2.544	9.7
57	10	6	4	8.315386E+05	217.00	8.224282E+05	8.315386E+05*	1.108	159	62.9	8.427646E+05	1.350	20.3	8.670025E+05	4.265	9.8
100	6	3	2	-----	-----	4.010622E+06	4.049805E+06	0.977	498	220.0	4.084751E+06	0.863	56.2	4.263143E+06	5.268	20.1
100	15	8	3	-----	-----	1.998306E+06	2.032229E+06	1.698	427	308.1	2.065536E+06	1.639	75.1	2.132441E+06	4.931	19.8
100	30	12	7	-----	-----	1.038923E+06	1.059023E+06	1.935	455	307.2	1.081015E+06	2.077	100.4	1.116481E+06	5.425	19.8
150	8	4	2	-----	-----	2.152720E+06	2.171643E+06	0.879	259	124.0	2.186309E+06	0.675	215.9	2.208244E+06	1.685	65.5
150	20	10	5	-----	-----	1.231108E+06	1.243880E+06	1.037	383	336.0	1.248709E+06	0.388	271.0	1.263955E+06	1.614	68.9
150	30	20	10	-----	-----	7.063708E+05	7.202570E+05	1.966	491	340.1	7.273075E+05	0.979	281.6	7.348529E+05	2.026	78.6
263	10	5	3	-----	-----	3.037737E+06	3.066254E+06	0.939	263	543.2	3.094333E+06	0.916	560.4	3.271550E+06	6.695	185.7
263	40	20	8	-----	-----	1.117234E+06	1.135467E+06	1.632	500	1017.6	1.148370E+06	1.136	751.1	1.157428E+06	1.934	295.9
263	90	50	20	-----	-----	3.065993E+05	3.193521E+05	4.159	492	1137.6	3.232513E+05	1.221	941.4	3.230026E+05	1.143	339.8
316	30	15	5	-----	-----	1.421812E+06	1.463870E+06	2.958	493	2040.3	1.466014E+06	0.147	1051.0	1.470018E+06	0.420	543.1
316	60	35	7	-----	-----	7.815016E+05	8.179516E+05	4.664	491	1920.8	8.483969E+05	3.722	1175.4	8.169346E+05	-0.124	598.6
316	100	60	15	-----	-----	3.962251E+05	4.096503E+05	3.388	496	2102.0	4.135914E+05	0.962	1096.3	4.180965E+05	2.062	697.8
737	100	60	15	-----	-----	9.409264E+05	9.695766E+05	3.045	497	8142.5	9.825503E+05	1.338	6594.2	1.017374E+06	4.930	4620.3
737	200	100	50	-----	-----	4.631705E+05	4.756925E+05	2.704	492	8141.6	4.810411E+05	1.124	6654.2	4.859018E+05	2.146	4396.1
737	300	150	50	-----	-----	2.733080E+05	2.846550E+05	4.152	498	8261.4	2.862014E+05	0.543	6721.2	2.884740E+05	1.342	4952.8

*Optimal solution

Table 4.4. Mean and standard deviations of the gap (%)

	Turkey specific problems			Literature problems		
	LRH	TDH	MTDH	LRH	TDH	MTDH
Mean	6.267	3.179	1.571	2.252	2.833	1.097
Standard Deviation	3.165	2.206	1.095	1.275	1.933	0.821

Conclusions and Remarks on the Solutions

- As shown in Tables 4.2 and 4.3, the best solution values, when compared to the optimal solutions, are generally obtained through the LRH. When the average gap values (solution quality) over all test problems obtained by the LRH are analyzed from Table 4.4, it is observed that solution quality on the literature problems is better than that of the Turkey specific problems in which the referral rate is higher. In this context, we can say that when referral rate is high, the gap values are expected to increase. Furthermore, the MTDH produces better solutions than the TDH in terms of gap (%) values.

- Although the TDH produces worse gap values than both the MTDH and the LRH, it always obtains the solution in a less computational time. The most time-consuming heuristic is the LRH. It is obvious noted that there is a reverse relationship between the solution time and the solution quality (in terms of gap %).

- For the LRH heuristic, although there is a gap between the best lower bounds and the best upper bounds in the problems (whose optimal solution values are known), upper bounds are equal to the optimal solution values for those Turkey specific problems: all 57-vertex problems, 30-vertex with p =3, q=2 and r=1, 30-vertex with p =7, q=4 and r=3, all 40-vertex problems and all 81-vertex problems.

- It can be easily observed that for the 10-vertex Turkey specific problems with different p, q and r values, we obtain the optimal solutions with the TDH and the MTDH.

- The TDH provides the same results with the LRH and the MTDH, or even better results than the other two heuristics in a few of test problems, all 10-vertex problems 30 (p=3, q=2, r=1), 40 (p=5, q=3, r=2), 40 (p=9, q=3, r=2), 81(p=5, q=2, r=1) and 316 (p=60, q=35, r=7). We may say that if a solution found by the TDH is better than both the MTDH and the LRH, it is highly likely that it is the optimal solution.

- We also observe that, in most of the problems, the MTDH outperforms the TDH in terms of solution quality. However, LRH outperforms the MTDH in terms of solution time, but not in terms of solution quality. Therefore, if we want to get a solution trading-off between the solution quality and the solution time, it would be better to use the MTDH.

- When we fix the size (number of vertices) of any problem and increase the number of facilities that will be opened, the solution time generally increases for the three heuristics for the literature problems, while there is not a significant variation in solution time for the three heuristics for the Turkey specific problems.

CHAPTER 5

AN APPLICATION: THE EAST REGION OF TURKEY

5.1 INTRODUCTION

In this chapter, the proposed approaches are tested in a case study designed to solve the location-allocation problem of the perinatal facilities in the East Region of Turkey, using the real data of this region. While the model we proposed in the previous chapters is a 3-level one, we solved the Turkey case as a 2-level problem. The justifications of solving the problem in this way are given in the next sections.

This chapter is organized as follows. In Section 5.1 we give brief information about the East Region of Turkey and its perinatal health indicators. Section 5.2 presents the justifications of solving the problem as a pq-median model. Data required and properties of the model are also given in this section. The various scenarios considered in the case study and the results obtained for these scenarios are reported in Section 5.3. Finally, the conclusions follow in Section 5.4.

5.2 PERINATAL HEALTH CARE INDICATORS IN THE EAST REGION OF TURKEY

"The diverse geographical, climatic, cultural, social, and economic characteristics of different parts of the country are the basis for the conventional regional breakdown within Turkey. Five regions (West, South, Central, North, and East) are distinguished, reflecting, to some extent, the differences in socioeconomic development levels and demographic conditions within the country. Because this regional breakdown has been popularized as a powerful variable for understanding the demographic, social, cultural, and economic differences among different parts of the country, it is frequently used for sampling and analysis purposes in social surveys" (TDHS, 2003).

We also consider this regional division, as shown in Figure 5.1, for our case study.

PROVINCES IN EAST REGION

Adıyaman
Ağrı
Ardahan
Batman
Bayburt
Bingöl
Bitlis
Diyarbakır
Elazığ
Erzincan
Erzurum
Gaziantep
Hakkâri
Iğdır
Kars
Kilis
Malatya
Mardin
Muş
Siirt
Şanlıurfa
Şırnak
Tunceli
Van

Figure 5.1. Turkey-5 Regions

The East region is considered as the least developed part of the country in terms of economical indicators. When we analyze this region with respect to perinatal health care indicators, it has the worst values in perinatal and maternal mortality rate, fertility, family planning, maternal (antenatal care) and child health, nutritional status of women and children, and reproductive health. In order to make a good analysis, we benefit from the 2003 Turkish Demographic and Health Survey (TDHS–2003) which is the latest in a series of national-level population and health surveys that have been conducted by the Hacettepe University Institute of Population Studies (HUIPS), in the last four decades.

Perinatal Mortality Rate (per 1000)

Figure 5.2 shows the perinatal mortality rates, according to demographic and socioeconomic characteristics. The perinatal mortality rate is estimated as 24 per thousand during the five years preceding the TDHS-2003. As seen from the Figure, the rate is higher in the South and East region than the national average.

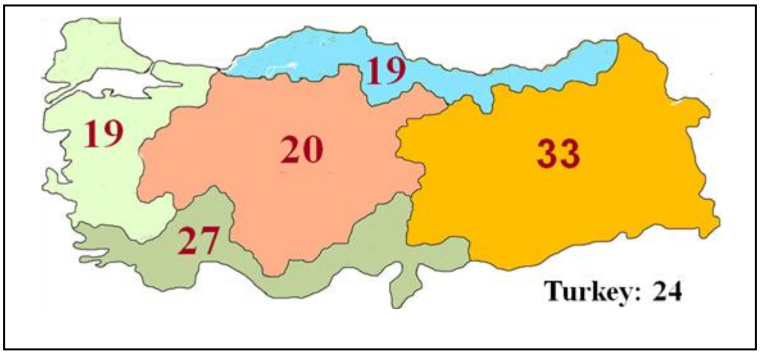

Figure 5.2. Perinatal mortality rates in the 5 regions (per 1000)
(TDHS, 2003)

Antenatal Care

Figure 5.3 shows the percent distribution of women, who had a live birth in the five years preceding the survey (TDHS, 2003), taking antenatal care from any provider during pregnancy for the most recent birth.

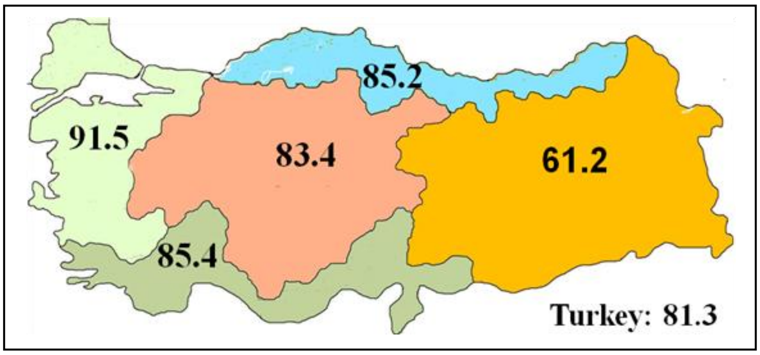

Figure 5.3. Distribution of women taking antenatal care in the 5 regions (%)
(TDHS, 2003)

As seen from Figure 5.3, 81 % of the mothers had at least one antenatal care from trained health personnel during the pregnancy of their most recent birth in the five years preceding the survey. Furthermore, three-quarters of the mothers received care from the doctor. On the other hand, nearly one-fifth of the mothers did not receive any antenatal care (TDHS, 2003).

Antenatal care coverage exceeds 80 percent in all regions except the East, where it is received by 61 percent of the mothers only at their most recent births in the five years prior to the survey.

We selected this region for the case study due to the following reasons: (1) the fertility rate of this region is the highest in Turkey (TDHS, 2003), (2) perinatal mortality rate is high and the rate of women benefiting from antenatal care, which is not in desirable levels, is the highest in the East Region among the five regions of Turkey. In the next section, we will give the details of the case study in which the purpose is to try to optimize the distribution of perinatal facilities in accordance with the regional requirements.

5.3 DESCRIPTION OF THE PROBLEM ENVIRONMENT AND ITS CHARACTERISTICS

"At the provincial level in Turkey, the health-care system[1] is the responsibility of the Health Directorates, under the supervision of the Ministry of Health. The provincial Health Director is responsible for delivering all primary health-care services as well as curative services. The present network of Health Centers and Health Houses is formed on the basis of "Legislation for the Socialization of Health Services" so that services and facilities are extended down to the village level. A substantial proportion of villages have health centers or health houses, and these are located so as to provide easy access to other villages" (TDHS, 2003).

The simplest element of the health services is the Health House, which serves a population of 2,500-3,000 and is staffed by a midwife. The Health Center serves a population of 5,000-10,000 and is staffed by a team consisting of a physician(s), a nurse(s), a health officer, midwives, an environmental health technician, medical secretary and a driver (TDHS, 2003). A Health House or a Health Center has the ability to give the level-1 service and when we turn our attention to Turkey, we can say that these Health Houses and Health Centers are widely dispersed, even in villages.

In the health care system of Turkey; Health Houses, Health Centers, and Mother and Child Health and Family Planning Centers can be considered the level-1 service providers (i.e. primary facilities) in our regionalized perinatal care system. Maternity homes and maternity clinics in county and provincial general hospitals, which can offer routine (in normal circumstances) delivery

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[1] In Turkish: Health House: Sağlık Evi, Health Center: Sağlık Ocağı, Mother and Child Health and Family Planning Centers: Ana Çocuk Sağlığı ve Aile Planlaması Merkezi, Province (County) General Hospital: İl (İlçe) Devlet Hastanesi.

services and neonatal assistance to low risk mothers and to low and medium risk babies, are considered the secondary facilities. Neonatal intensive care units in university hospitals, education and research hospitals, and some Ministry of Health hospitals can be considered the tertiary facilities in the regionalized perinatal care system; these units offer non-routine delivery (in high-risky circumstances) services and neonatal assistance for high-risk mothers and high-risk newborns.

While the secondary and tertiary facilities can be located in counties, primary facilities can be located in villages, towns or counties if it has a greater population than the limit defined by the Ministry of Health. So, we can consider that in every potential facility site (i.e. all counties of each province) we have at least one of primary facilities (Health House and/or Health Center). Thus, the location decision of primary facilities becomes independent from the location decisions of secondary and tertiary facilities. In addition, the demand data available is only on county level and it allows us to locate only secondary and tertiary facilities for this case study.

Mathematically, it means that the 3-level hierarchical model reduces to a 2-level hierarchical model when we consider the perinatal regionalization problem for Turkey. The 3-level hierarchical model includes primary facilities providing prenatal (antenatal) care, secondary facilities providing routine (in normal circumstances) delivery services and neonatal assistance for low and moderate-risk mothers and for low and medium risk babies, and tertiary facilities providing non-routine (in high-risky circumstances) delivery services and neonatal assistance for high risk mothers and high-risk newborns as described in Chapter 4.

We modify the mathematical formulation of the 3-level hierarchical model, cancelling all parameters and variables related to level-1 service and primary facilities. Now the problem can be redefined as follows:

Find the location of a fixed number of 'q' level-2 facilities
and 'r' level-3 facilities so as to minimize
the total weighted average distance of the system.

For solving this problem we define five types of parameters: demand (W_i), percentage of high-risk fertility (a_i), distances between potential facility sites and demand points (d_{ij}), percentage of referrals (c and b) and the number of facilities (q and r) that will be located. We consider the East Region as being divided into 204 sites *(total number of counties of the 24 provinces)*. The list of these sites is given in Table 5.1. The population (demand) of a county is represented by the number of babies born there in year 2006. This demand data is supplied from the Health Directorates of the 24 provinces. All population within a county is concentrated at the county "centroid" and county centroids provide the potential facility sites for both levels considered in the model. The network considered by the model developed for the East Region thus comprises 204 vertices, linked by the main roads connecting them. These main roads are available in the SONYMAP Route Planner Europe software (Windows version) developed by AND Technology Ltd. We calculate the distances for each of the 20,604 links. The distances used are therefore real distances.

Table 5.1. List of potential facility sites/demand points

1	ADIYAMAN	35	SOLHAN	69	KOVANCILAR	103	NİZİP	137	DOĞANYOL	171	CEYLANPINAR
2	BESNİ	36	YAYLADERE	70	MADEN	104	İSLÂHİYE	138	HEKİMHAN	172	HALFETİ
3	ÇELİKHAN	37	YEDİSU	71	PALU	105	OĞUZELİ	139	KALE	173	HARRAN
4	GERGER	38	BİTLİS	72	SİVRİCE	106	NURDAĞI	140	KULUNCAK	174	HİLVAN
5	GÖLBAŞI	39	ADİLCEVAZ	73	ERZİNCAN	107	ARABAN	141	PÜTÜRGE	175	SİVEREK
6	KÂHTA	40	AHLAT	74	ÇAYIRLI	108	YAVUZELİ	142	YAZIHAN	176	SURUÇ
7	SAMSAT	41	GÜROYMAK	75	İLİÇ	109	KARKAMIŞ	143	YEŞİLYURT	177	VİRANŞEHİR
8	SİNCİK	42	HİZAN	76	KEMAH	110	HAKKÂRİ	144	MARDİN	178	ŞIRNAK
9	TUT	43	MUTKİ	77	KEMALİYE	111	ÇUKURCA	145	DARGEÇİT	179	BEYTÜŞŞEBAP
10	AĞRI	44	TATVAN	78	OTLUKBELİ	112	ŞEMDİNLİ	146	DERİK	180	CİZRE
11	DİYADİN	45	BAYBURT	79	REFAHİYE	113	YÜKSEKOVA	147	KIZILTEPE	181	GÜÇLÜKONAK
12	DOĞUBEYAZIT	46	AYDINTEPE	80	TERCAN	114	IĞDIR	148	MAZIDAĞI	182	İDİL
13	ELEŞKİRT	47	DEMİRÖZÜ	81	ÜZÜMLÜ	115	ARALIK	149	MİDYAT	183	SİLOPİ
14	HAMUR	48	DİYARBAKIR	82	ERZURUM	116	KARAKOYUNLU	150	NUSAYBİN	184	ULUDERE
15	PATNOS	49	BİSMİL	83	AŞKALE	117	TUZLUCA	151	ÖMERLİ	185	TUNCELİ
16	TAŞLIÇAY	50	ÇERMİK	84	ÇAT	118	KARS	152	SAVUR	186	ÇEMİZGEZEK
17	TUTAK	51	ÇINAR	85	HINIS	119	AKYAKA	153	YEŞİLLİ	187	HOZAT
18	ARDAHAN	52	ÇÜNGÜŞ	86	HORASAN	120	ARPAÇAY	154	MUŞ	188	MAZGİRT
19	ÇILDIR	53	DİCLE	87	ILICA	121	DİGOR	155	BULANIK	189	NAZİMİYE
20	DAMAL	54	EĞİL	88	İSPİR	122	KAĞIZMAN	156	HASKÖY	190	OVACIK
21	GÖLE	55	ERGANİ	89	KARAÇOBAN	123	SARIKAMIŞ	157	KORKUT	191	PERTEK
22	HANAK	56	HANİ	90	KARAYAZI	124	SELİM	158	MALAZGİRT	192	PÜLÜMÜR
23	POSOF	57	HAZRO	91	KÖPRÜKÖY	125	SUSUZ	159	VARTO	193	VAN
24	BATMAN	58	KOCAKÖY	92	NARMAN	126	KİLİS	160	SİİRT	194	BAHÇESARAY
25	BEŞİRİ	59	KULP	93	OLTU	127	ELBEYLİ	161	AYDINLAR	195	BAŞKALE
26	GERCÜŞ	60	LİCE	94	OLUR	128	MUSABEYLİ	162	BAYKAN	196	ÇALDIRAN
27	HASANKEYF	61	SİLVAN	95	PASİNLER	129	POLATELİ	163	ERUH	197	ÇATAK
28	KOZLUK	62	ELAZIĞ	96	PAZARYOLU	130	MALATYA	164	KURTALAN	198	EDREMİT
29	SASON	63	AĞIN	97	ŞENKAYA	131	AKÇADAĞ	165	PERVARİ	199	ERCİŞ
30	BİNGÖL	64	ALACAKAYA	98	TEKMAN	132	ARAPGİR	166	ŞİRVAN	200	GEVAŞ
31	ADAKLI	65	ARICAK	99	TORTUM	133	ARGUVAN	167	ŞANLIURFA	201	GÜRPINAR
32	GENÇ	66	BASKİL	100	UZUNDERE	134	BATTALGAZİ	168	AKÇAKALE	202	MURADİYE
33	KARLIOVA	67	KARAKOÇAN	101	ŞEHİTKÂMİL	135	DARENDE	169	BİRECİK	203	ÖZALP
34	KİĞİ	68	KEBAN	102	ŞAHİNBEY	136	DOĞANŞEHİR	170	BOZOVA	204	SARAY

Another required data is the value of the percentage of high-risk fertility. This value is provided from the TDHS 2003. According to this study, 39 % of children born in the five years preceding the survey are at the elevated risk of dying at the time of their birth. This percentage, which is an average value for Turkey, is also used for the East Region in the case study. But we solve a number of problems with high risk fertility rates ranging from 0.12 to 0.60 in an attempt to obtain a robust solution. Since any data for referrals could not be found at any references, we use 0.10 for *c* (forward-referral rate) and 0.15 for *b* (back-referral rate). Therefore, we solve a number of problems with *c* ranging from 0.05 to 0.30 and with *b* ranging from 0.10 and 0.40 in an attempt to obtain a robust solution.

The values of *q* and *r* are computed using a method based on the coverage criteria. Firstly, a *q*-median problem and a *r-median* problem are solved as a maximum covering model with coverage distances of 60 and 110 km for level-2 and level-3 facilities, respectively. Coverage distance for referral between level-2 and level-3 facilities is also 110 km. We solved these problems using the SITATION software developed by Daskin (2006) and obtained the initial values as *q*=61 and *r*=21. Then using these values we created some problem instances changing the value of *r* between 20 and 28, and the value of *q* between 50 and 65. Thus we solved 145 problem instances using both Lagrangean relaxation based (LRH), top-down (TDH) and modified top-down (MTDH) heuristics. We know, from the computational results in Section 5.6, that the best solutions are generally provided by LRH, but for some problem instances we have observed that TDH gives better solutions than MTDH and LRH. The problem considered in this case study is also one of the problems in which TDH provides better solutions than MTDH and LRH. So, we have used TDH for solving the problem instances developed in scenario planning.

The objective function value of each problem instance, percent of covered demands requiring level-2 service and level-3 service, percent of covered demands referred, average weighted distance for referral between level-2 and level-3 facilities and average weighted distance for accessing to level-2 and level-3 facilities are taken into account for evaluating the problem instances defined by q-r pairs. Firstly, according to the objective function value of each problem instance, percent of covered demands requiring level-2 service and level-3 service and percent of covered demands referred, 142 instances are dominated by three of the instances. These three problem instances which are then non-dominated instances are shown in Table 5.2. Then according to average weighted distance for referral between level-2 and level-3 facilities and average weighted distance for accessing to level-2 and level-3 facilities, the non-dominated problem instance, i.e. *q*=59 and *r*=25, is found out. This result provides the final numbers of facilities that will be opened.

Table 5.2. Non-dominated problem instances

Criteria Used for Evaluating the Performance of Problem Instances	**Problem Instances**		
	q=59 p=25	**q=60 p=24**	**q=61 p=23**
Objective function value (obtained by TDH)	2,500,224.458	2,590,546.262	2,683,877.252
Percent of covered demands requiring level-2 service	93.818	93.616	93.356
Percent of covered demands requiring level-3 service	98.975	99.020	99.062
Percent of covered demands referred	100	100	100
Average weighted distance for accessing level-2 service	4.215	4.215	4.215
Average weighted distance for accessing level-3 service	20.495	21.436	22.418
Average weighted distance for referral between level-2 and level-3 facilities	52.885	54.083	54.939

5.4 RESULTS AND SENSITIVITY ANALYSIS

Once the computational experiments in order to find the number of facilities to locate are concluded, 128 scenarios are generated, representing all possible combinations of the parameters shown in Table 5.3. Thus, solution to the problem in the first stage is tested for its robustness to parameter changes.

Table 5.3. Parameters used to generate the scenarios

n	a_i	c	b	t
204	0.12, 0.25, 0.39, 0.60	0.05, 0.10, 0.20, 0.30	0.10, 0.20, 0.30, 0.40	0.5, 1.0

a_i: proportion of pregnant women in high risky category at demand point i,
c : proportion of mothers (and their babies) at secondary units referred to a tertiary unit,
b: proportion of referred mothers from a secondary unit to a tertiary unit,
t: relative cost of referred travel.

After solving the problem for all scenarios, we define the best locations of secondary and tertiary facilities that do well in most scenarios. All different scenarios are solved using TDH. The solution times (CPU time in seconds) obtained by TDH have a value with a mean of 16.25 and a standard deviation of 2.83. Here, we observe that TDH always gives the optimal solutions in less time. We can see the results of some selected problem instances in Table 5.4.

Table 5.4.Comparison of optimal and TDH solutions for the selected scenarios

Scenario	**Parameters**				**Objective Function Value**	**CPU Time (Seconds)**	
	a	**c**	**b**	**t**	**Optimal Solution (GAMS/CPLEX 10.0) / Top-Down Heuristic**	**Optimal**	**TDH**
1	0.12	0.05	0.10	0.5	1,473,732.553	459.7	17.6
2	0.12	0.05	0.40	1.0	1,625,651.678	8546.9	15.7
3	0.25	0.05	0.40	0.5	1,954,818.261	375.4	21.6
4	0.25	0.10	0.20	0.5	2,030,874.910	524.8	15.7
5	0.25	0.20	0.40	0.5	2,269,294.285	5580.5	14.5
6	0.39	0.05	0.10	1.0	2,493,217.095	414.3	16.3
7	0.39	0.05	0.20	0.5	2,424,883.474	308.1	17.4
8	0.60	0.10	0.20	1.0	3,313,314.080	326.7	15.7
9	0.60	0.05	0.10	0.5	3,164,667.524	257.8	14.8
10	0.60	0.30	0.40	0.5	3,453,029.168	7298.6	15.8

It should be noted that all the locations of tertiary facilities and 91.5 % of the locations of secondary facilities are the same in all scenarios. These level-2 facility locations are 2, 6, 12, 15, 18, 28, 33, 40, 42, 44, 45, 49, 50, 51, 53, 54, 56, 59, 61, 67, 69, 83, 88, 89, 91, 93, 103, 108, 110, 112, 115, 117, 123, 126, 135, 136, 146, 147, 149, 150, 160, 165, 169, 171, 175, 176, 180, 183, 184, 195, 196, 200, 202 and 203. In 48 of the scenarios, we observe that 11: Ağrı-Diyadin is replaced by 168: Şanlıurfa-Akçakale; in 76 of the scenarios, 4: Adıyaman-Gerger is replaced by 141: Malatya-Pütürge; in 78 of the scenarios 173: Şanlıurfa-Harran is replaced by 185: Tunceli and in 112 of the scenarios, the pair of (21: Ardahan-Göle, 162: Siirt-Baykan) is replaced by (121: Kars-Digor, 157: Muş-Korkut). According to these results, 11: Ağrı-Diyadin, 4: Adıyaman-Gerger, 21: Ardahan-Göle, 162: Siirt-Baykan and 185: Tunceli are expected to be in the robust solution. Thus, we can say that the location of the level-2 facilities (91.5 % of them) is robust to the parameter changes. A summary of these scenarios' results is given in Table 5.5, and the best locations are shown in Table 5.6 and Table 5.7 and Figure 5.4.

Table 5.5. A summary of the scenarios for the East Region of Turkey

Criteria used for evaluating the performance of the scenarios	**Mean**	**Standard Deviation**
Objective function value	2,520,784	635,876.45
Percent of covered demands requiring level-2 service	93.486	0.482
Percent of covered demands requiring level-3 service	98.975	0
Percent of covered demands referred	100	0
Average weighted distance for accessing level-2 service	4.272	0.09
Average weighted distance for accessing level-3 service	20.495	0
Average weighted distance for referral between level-2 and level-3 facilities	52.568	0.318

Table 5.6. Locations of 25 neonatal centers (level-3 facilities)

1	ADIYAMAN	113	YÜKSEKOVA (HAKKARİ)
10	AĞRI	114	IĞDIR
24	BATMAN	118	KARS
30	BİNGÖL	130	MALATYA
38	BİTLİS	144	MARDİN
48	DİYARBAKIR	154	MUŞ
55	ERGANİ (DİYARBAKIR)	155	BULANIK (MUŞ)
62	ELAZIĞ	167	ŞANLIURFA
73	ERZİNCAN	177	VİRANŞEHİR (ŞANLIURFA)
82	ERZURUM	178	ŞIRNAK
101	ŞEHİTKAMİL (GAZİANTEP)	193	VAN
102	ŞAHİNBEY (GAZİANTEP)	199	ERCİŞ (VAN)
104	İSLAHİYE (GAZİANTEP)		

Table 5.7. Locations of 59 maternity clinics (level-2 facilities)

2	BESNİ (ADIYAMAN)	108	YAVUZELİ (GAZİANTEP)
4	GERGER (ADIYAMAN)	110	HAKKARİ
6	KAHTA (ADIYAMAN)	112	ŞEMDİNLİ (HAKKARİ)
11	DİYADİN (AĞRI)	115	ARALIK (IĞDIR)
12	DOĞUBEYAZIT (AĞRI)	117	TUZLUCA (IĞDIR)
15	PATNOS (AĞRI)	123	SARIKAMIŞ (KARS)
18	ARDAHAN	126	KİLİS
21	GÖLE (ARDAHAN)	135	DARENDE (MALATYA)
28	KOZLUK (BATMAN)	136	DOĞANŞEHİR (MALATYA)
33	KARLIOVA (BİNGÖL)	146	DERİK (MARDİN)
40	AHLAT (BİTLİS)	147	KIZILTEPE (MARDİN)
42	HİZAN (BİTLİS)	149	MİDYAT (MARDİN)
44	TATVAN (BİTLİS)	150	NUSAYBİN (MARDİN)
45	BAYBURT	160	SİİRT
49	BİSMİL (DİYARBAKIR)	162	BAYKAN (SİİRT)
50	ÇERMİK (DİYARBAKIR)	165	PERVARİ (SİİRT)
51	ÇINAR (DİYARBAKIR)	169	BİRECİK (ŞANLIURFA)
53	DİCLE (DİYARBAKIR)	171	CEYLANPINAR (ŞANLIURFA)
54	EĞİL (DİYARBAKIR)	175	SİVEREK (ŞANLIURFA)
56	HANİ (DİYARBAKIR)	176	SURUÇ (ŞANLIURFA)
59	KULP (DİYARBAKIR)	180	CİZRE (ŞIRNAK)
61	SİLVAN (DİYARBAKIR)	183	SİLOPİ (ŞIRNAK)
67	KARAKOÇAN (ELAZIĞ)	184	ULUDERE (ŞIRNAK)
69	KOVANCILAR (ELAZIĞ)	185	TUNCELİ
83	AŞKALE (ERZURUM)	195	BAŞKALE (VAN)
88	İSPİR (ERZURUM)	196	ÇALDIRAN (VAN)
89	KARAÇOBAN (ERZURUM)	200	GEVAŞ (VAN)
91	KÖPRÜKÖY (ERZURUM)	202	MURADİYE (VAN)
93	OLTU (ERZURUM)	203	ÖZALP (VAN)
103	NİZİP (GAZİANTEP)		

Allocation decisions of demand points for level-2 and level-3 services, and assignment of secondary facilities to a tertiary facility for referral are shown in Table 5.8 and Table 5.9.

The percent distribution of total demand requiring level-2 and level-3 services to the level-2 and level-3 facilities is given in Table 5.10. It is observed that the 35 % of demand requiring level-2 service is assigned to level-2 facilities and the 65 % of them assigned to level-3 facilities. It should be noted in the table that level-3 service load is not uniformly distributed among the level-3 facilities which are highly resource intensive (range: [1.29% 12.19%]).

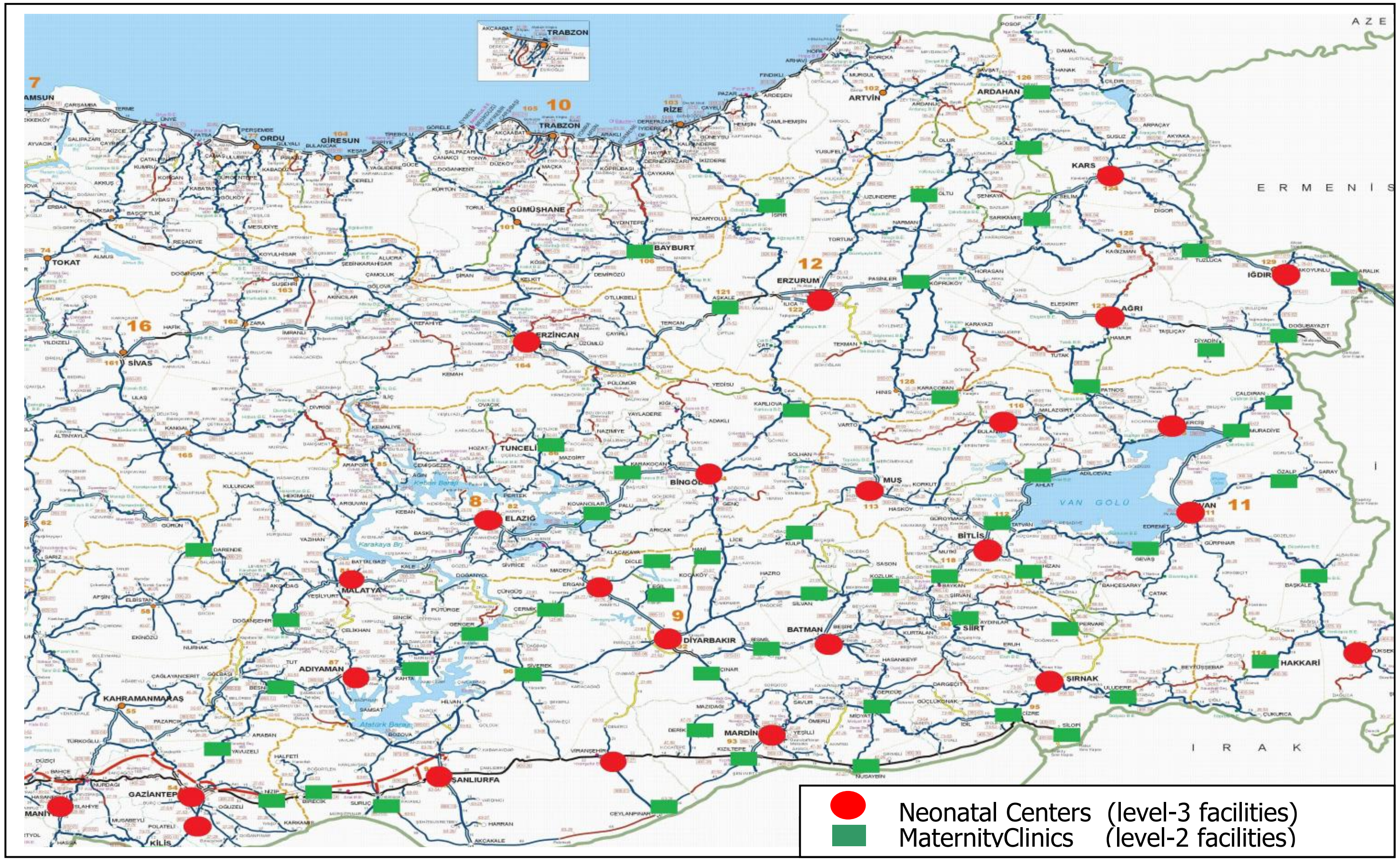

Figure 5.4. Spatial distribution of facilities

Table 5.8. Results of allocations to level-3 facilities

Level-3 Facility		**Assigned Demand Points for Level-3 Service**	**Assigned Demand Points for Level-2 Service**	**Assigned Level-2 Facilities for Referral**
1	ADIYAMAN	1, 2, 3, 5, 6, 7, 9	1	2, 6
10	AĞRI	10, 11, 13, 14, 16, 17	10, 13, 14, 16, 17	11
24	BATMAN	24, 25, 26, 27, 28, 49, 57, 61, 145, 164	24, 25, 27	28, 49, 61
30	BİNGÖL	30, 31, 32, 33, 34, 35, 36, 37, 60, 67, 69, 71, 189	30, 31, 32, 34, 35	33, 67, 69
38	BİTLİS	38, 41, 42, 43, 44, 160, 161, 162, 166	38, 41, 43	42, 44, 160, 162
48	DİYARBAKIR	48, 51, 59	48	51, 59
55	ERGANİ (DİYARBAKIR)	50, 52, 53, 54, 55, 56, 58, 64, 65, 70, 175	55, 64, 70	50, 53, 54, 56, 175
62	ELAZIĞ	62, 63, 66, 68, 72, 77, 132, 185, 186, 187, 188, 191	62, 63, 66, 68, 72, 77, 132, 186, 191	185
73	ERZİNCAN	45, 46, 47, 73, 74, 75, 76, 78, 79, 81, 190, 192	73, 74, 75, 76, 79, 81, 192	45
82	ERZURUM	80, 82, 83, 84, 86, 87, 88, 90, 91, 92, 93, 95, 96, 98, 99, 100	82, 84, 87, 98, 99	83, 88, 91, 93
101	ŞEHİTKAMİL (GAZİANTEP)	101, 107, 108, 172	101	108
102	ŞAHİNBEY (GAZİANTEP)	102, 103, 105, 109, 126, 127, 129, 169	102, 105	103, 126, 169
104	İSLAHİYE (GAZİANTEP)	104, 106, 128	104, 106	---
113	YÜKSEKOVA (HAKKARİ)	110, 112, 113, 195	113	110, 112, 195
114	IĞDIR	12, 114, 115, 116, 117	114, 116	12, 115, 117
118	KARS	18, 19, 20, 21, 22, 23, 94, 97, 118, 119, 120, 121, 122, 123, 124, 125	118, 119, 120, 121, 125	18, 21, 123
130	MALATYA	4, 8, 130, 131, 133, 134, 135, 136, 137, 138, 139, 140, 141, 142, 143	130, 131, 133, 134, 138, 139, 142, 143	4, 135, 136
144	MARDİN	144, 146, 147, 148, 149, 150, 151, 152, 153	144, 151, 152, 153	146, 147, 149, 150
154	MUŞ	29, 154, 156, 157, 159	154, 156, 157, 159	---
155	BULANIK (MUŞ)	40, 85, 89, 155, 158	155, 158	40, 89
167	ŞANLIURFA	167, 168, 170, 173, 174, 176	167, 168, 170, 173	176
177	VİRANŞEHİR (ŞANLIURFA)	171, 177	177	171
178	ŞIRNAK	111, 163, 165, 178, ,179, 180, 181, 182, 183, 184	163, 178	165, 180, 183, 184
193	VAN	193, 194, 197, 198, 200, 201, 203, 204	193, 198, 201	200, 203
199	ERCİŞ (VAN)	15, 39, 196, 199, 202	199	15, 196, 202

Table 5.9. Results of allocations to level-2 facilities

Level-2 Facility		**Assigned Demand Points for Level-2 Service**	**Level-2 Facility**		**Assigned Demand Points for Level-2 Service**
2	BESNİ (ADIYAMAN)	2, 5, 9	108	YAVUZELİ (GAZİANTEP)	107, 108
4	GERGER (ADIYAMAN)	4, 137, 141	110	HAKKARİ	110, 111
6	KAHTA (ADIYAMAN)	6, 7, 8	112	ŞEMDİNLİ (HAKKARİ)	112
11	DİYADİN (AĞRI)	11	115	ARALIK (IĞDIR)	115
12	DOĞUBEYAZIT (AĞRI)	12	117	TUZLUCA (IĞDIR)	117, 122
15	PATNOS (AĞRI)	15	123	SARIKAMIŞ (KARS)	123, 124
18	ARDAHAN	18, 19, 20, 22, 23	126	KİLİS	126, 127, 128, 129
21	GÖLE (ARDAHAN)	21, 94	135	DARENDE (MALATYA)	135, 140
28	KOZLUK (BATMAN)	28, 29	136	DOĞANŞEHİR (MALATYA)	3, 136
33	KARLIOVA (BİNGÖL)	33, 37	146	DERİK (MARDİN)	146, 148
40	AHLAT (BİTLİS)	39, 40	147	KIZILTEPE (MARDİN)	147
42	HİZAN (BİTLİS)	42	149	MİDYAT (MARDİN)	26, 145, 149
44	TATVAN (BİTLİS)	44	150	NUSAYBİN (MARDİN)	150
45	BAYBURT	45, 46, 47, 78	160	SİİRT	160, 161, 164, 166
49	BİSMİL (DİYARBAKIR)	49	162	BAYKAN (SİİRT)	162
50	ÇERMİK (DİYARBAKIR)	50, 52	165	PERVARİ (SİİRT)	165, 194
51	ÇINAR (DİYARBAKIR)	51	169	BİRECİK (ŞANLIURFA)	109, 169, 172
53	DİCLE (DİYARBAKIR)	53, 65	171	CEYLANPINAR (ŞANLIURFA)	171
54	EĞİL (DİYARBAKIR)	54	175	SİVEREK (ŞANLIURFA)	174, 175
56	HANİ (DİYARBAKIR)	56, 58, 60	176	SURUÇ (ŞANLIURFA)	176
59	KULP (DİYARBAKIR)	59	180	CİZRE (ŞIRNAK)	180, 181, 182
61	SİLVAN (DİYARBAKIR)	57, 61	183	SİLOPİ (ŞIRNAK)	183
67	KARAKOÇAN (ELAZIĞ)	36, 67	184	ULUDERE (ŞIRNAK)	179, 184
69	KOVANCILAR (ELAZIĞ)	69, 71	185	TUNCELİ	185, 187, 188, 189, 190
83	AŞKALE (ERZURUM)	80, 83	195	BAŞKALE (VAN)	195
88	İSPİR (ERZURUM)	88, 96	196	ÇALDIRAN (VAN)	196
89	KARAÇOBAN (ERZURUM)	85, 89	200	GEVAŞ (VAN)	197, 200
91	KÖPRÜKÖY (ERZURUM)	86, 90, 91,95	202	MURADİYE (VAN)	202
93	OLTU (ERZURUM)	92, 93, 97, 100	203	ÖZALP (VAN)	203, 204
103	NİZİP (GAZİANTEP)	103			

Table 5.10. Distribution of demand to facilities

Level-3 Facility	% of total demand assigned to a level-3 facility for level-3 service	% of total demand requiring level-2 service assigned to a level-3 facility
1	3.90	1.60
10	2.65	2.58
24	5.08	1.12
30	2.48	1.15
38	3.25	0.91
48	9.86	8.63
55	4.67	1.38
62	2.49	2.43
73	1.38	0.87
82	3.87	2.07
101	7.71	7.40
102	12.19	9.88
104	1.29	1.24
113	2.13	0.63
114	2.59	1.12
118	2.51	1.10
130	4.31	3.32
144	4.52	1.31
154	1.81	1.58
155	1.81	0.93
167	7.03	6.90
177	1.48	1.14
178	2.01	0.42
193	5.74	4.64
199	3.22	1.54
Parameters used		
a = 0.39 c = 0.10 b = 0.15		

Level-2 Facility	% of total demand requiring level-2 service assigned to a level-2 facility	Level-2 Facility	% of total demand requiring level-2 service assigned to a level-2 facility
2	1.01	**108**	0.51
4	0.29	**110**	0.55
6	1.15	**112**	0.28
11	0.42	**115**	0.26
12	0.96	**117**	0.41
15	0.34	**123**	0.41
18	0.44	**126**	0.87
21	0.19	**135**	0.36
28	0.34	**136**	0.37
33	0.60	**146**	0.42
40	0.70	**147**	1.19
42	0.29	**149**	0.74
44	0.51	**150**	0.77
45	0.48	**160**	1.26
49	1.54	**162**	0.29
50	0.83	**165**	0.28
51	1.13	**169**	0.79
53	0.64	**171**	0.36
54	0.29	**175**	0.86
56	0.91	**176**	0.24
59	0.38	**180**	0.56
61	1.45	**183**	0.30
67	0.22	**184**	0.30
69	0.38	**185**	0.20
83	0.27	**195**	0.61
88	0.14	**196**	0.42
89	0.40	**200**	0.47
91	0.87	**202**	0.54
93	0.53	**203**	0.68
103	1.10		

Total demand requiring level-2 service = 136, 747 mothers-to-be

Total demand requiring level-3 service = 92,335 mothers-to-be

Total demand referred from a level-2 facility to a level-3 facility = 5,288 mothers

5.5 CONCLUSIONS AND REMARKS

In this chapter we study on a real world case in order to make a more realistic assessment of the model developed for perinatal regionalization. According to results, it can be noted that the majority of tertiary units are located in high population provinces. It is also important to emphasize the robustness of solution. We observe that the location-allocation decisions in different scenarios are robust to parameter changes. Unfortunately, it has not been possible to compare the solution obtained with the existing perinatal care system in the East region.

Some possible improvements of the model can be suggested to make it more satisfactory for real life. Since we used only the demand data of the year 2006 in this study, it does not reflect the future conditions of the region. Regions such as Eastern and Southeastern Anatolian are not static and health care demand may change depending upon some social and economical factors. For instance, in Eastern and Southeastern Anatolia, a rapid changing population pattern can be observed in the last 20 years. "A substantial number of villages and adjacent arable lands have been abandoned because of terrorist movements. In addition to this, large-scale development projects in the frame of Southeast Anatolia Project, natural disasters, or improved settlement policies have also led to significant migration both within and outside of the region in the last two decades" (TDHS, 2003). However, with the "Southeast Anatolia Project", the economy in the Southeast has improved in the recent years and in addition to the economic benefits, the project is also expected to reverse the migration flow from the region to the rest of the country (TDHS, 2003). Because of this expected population changes, first of all, it is needed to make a good demand forecasting analysis that will reflect the effects of the economical developments and migration flow on the health care demand of the East region.

Another important point that should be considered in these studies is "*aggregation*" of demand points. When dealing with spatial problems of the type considered here there is always the question of aggregation to consider (Boffey et al., 2003). We used the administrative divisions of the Region as potential facility sites and demand points and for this reason; we have some very low population counties. Therefore, it would be better to aggregate these counties with one or more of their near counties. Similarly, large high population areas may be divided into smaller parts.

Number of facilities opened can be time-dependent in our system. It is stated that the neonatal specialist resources required in tertiary units are often in short supply in Turkey, since neonatology is a new discipline in Turkey and will be expected to improve within the following years. Because of this, it will not be possible to open all required tertiary facilities at the beginning of the planning horizon. Instead, some of them can be opened at the beginning and remaining facilities can be opened at later time periods, which require modeling the problem as a multi-period problem.

In the context of the policies of the health authority, the system can be designed in different structures. For instance, primary facilities can offer delivery service and neonatal services to babies in normal circumstances in addition to the antenatal care services. However, in the system that we proposed, these facilities offer only antenatal care for mothers-to-be in both normal and moderate risk categories. Now, while mothers-to-be in normal circumstances attending to a primary facility for antenatal care will also go to this facility to give a birth, mothers-to-be in moderate risk category will attend to a secondary facility for delivery. The remaining part of the system can be the same as the system that we developed.

Finally, in order to obtain a more satisfactory solution for all demand points we consider that travel distances should be weighted to represent the social composition and the geographical conditions of this region.

CHAPTER 6

CONCLUSIONS AND FURTHER RESEARCH ISSUES

6.1 CONCLUSIONS

In this study, we examine the three-level hierarchical p-median problem for the regional organization of perinatal care. The problem is stated as "finding the location of a fixed number of 'p' level-1 (primary) facilities, 'q' level-2 (secondary) facilities and 'r' level-3 (tertiary) facilities so as to minimize the total weighted average distance of the regional system".

We have developed a classification scheme for the location of the health care facilities including regionalization, location of specialized long-term care facilities, location of ambulatory neighborhood clinics and siting or removal of a single facility, and summarized the several studies with all their distinguishing characteristics on a table.

In our mathematical formulation and computational study, we focus on the three-level hierarchical p-median problem for the regionalization of perinatal care. We develop a mathematical formulation for this problem allowing for and taking account of receiving a certain service type from any level of facility which can offer that service. This provides a chance to assign various in-facility costs for the services received from different types of facilities in the hierarchy. Also, modeling the problem through discriminating facility types and service types allows us to incorporate the capacity limitations in the model very easily with very slight modifications only.

We develop three different heuristics to be able to solve real-sized problems in reasonable times. These heuristic approaches are: (1) top-down heuristic (TDH), (2) modified top-down heuristic (MTDH) and Lagrangean relaxation based heuristic (LRH). In order to evaluate the performance of the heuristics, we have performed a computational study using a set of test problems for different size networks. A significant result is that the Lagrangean relaxation based heuristic outperforms the other two heuristics in terms of solution quality. However, in terms of solution time, the performance of TDH is the best. Additionally, TDH provides better results than the other two heuristics in only a few test problems. We also observe that, in most of the problems, MTDH outperforms TDH in terms of solution quality. If we want to attain a solution making a trade-off between solution quality and time, it would be better to use MTDH. In our TDH, we solve the p-median problem at each level of the hierarchy by Lagrangean relaxation, which is observed to improve the solution quality of TDH. In MTDH, we improve the quality of TDH in general. The main idea of MTDH is reducing the problem size so as to increase the solution quality through a more integrated formulation for the higher levels of the hierarchy. Our LRH provides an integrated approach to the whole problem and provides very good results in reasonable computation times with an average gap of 2.25 % for literature problems and an average gap of 6.27 % for Turkey specific problems.

In the last chapter, using the developed mathematical model and the proposed methods to solve this model, we obtain a distribution of perinatal facilities at two levels of the hierarchy for the East region of Turkey. The significant results attained from this case study are given in the related chapter. Actually, this study has been the first one that addresses the regionalization problem of perinatal facilities in Turkey.

6.2 FURTHER RESEARCH ISSUES

It is obvious that the mathematical model we have developed neglects some of the situations which should be considered in real life applications. We now explain some possible enhancements for our model, based on experiences gained during this thesis:

Capacity constraints

We assume that the facilities have no capacity restrictions. But in real life, especially for the resource intensive facilities (neonatal centers), this assumption means that the capacity of each facility that will be established is sufficient to cope with any foreseeable demand (Boffey et al., 2003). So, a maximum ($\max Q_3$) capacity constraint can be defined for level-3 facilities.

Sometimes, in order to be efficient and to achieve a balanced demand assignment level, facilities need to have a minimum demand threshold level (Marianov and Serra, 2002). Hence, in the formulation of 3-HLM *p-median* problem, this can be achieved by imposing a minimum level of capacity for (resource intensive) level-3 and level-2 facilities.

Existing facility locations

The model which we are interested in aims to obtain an optimal facility distribution with no existing health facility system in a region. If some health facility systems exist, it is possible to regard the existing health care facilities as extra health service providers whose locations are already fixed. This can be incorporated into the present model by fixing some of the facilities' locations and thus we may have an easier problem in terms of less computational burden.

Stochastic nature of some parameters

We have assumed in our model that, all of the system parameters are deterministic. But in real life, demand and travel times are probabilistic. So, we may reformulate the hierarchical perinatal facility location-allocation problem by including probabilistic considerations.

Different attractiveness of facilities

Our model and most of the *p-median* problems assume that the patients always attend the nearest health care facility to their residence. It means that every health facility has the same attractiveness and the patients will patronize the facility closest to them under the capacity constraints (Mitropoulos et al., 2006). This assumption is unrealistic in practice and most of the time various usage patterns emerge (Cho, 1998; as cited at Mitropoulos et al., 2006). For instance, because of more quality service expectation from more equipped high level facilities, patients may be willing to travel more distances for being served by a tertiary unit instead of visiting the primary units. So, we can determine a patient preference parameter- the rate of preference- between primary, secondary and tertiary facilities; in other words we should incorporate the different attractiveness levels of facilities, which provide the same quality of services in different levels of hierarchy, into the present model. Geographic patterns, demographic and socio-economical situations (income, urbanization) of patients, decrease of attraction with distance, size of the health care facilities, etc. which are considered to be influential in consumer behavior can be used to estimate/determine the patient preference parameter for regionalized perinatal care. Mitropoulos et al. (2006) have developed a methodology for estimating a patient preference parameter through a public preference survey.

Multi-objective nature of the health care facility location problem

The main feature of the location problem of the health care facilities is their multi-criteria nature due to the need for an efficient system with good service quality and the endeavour to retain a balanced spatial distribution of services with people having access to the facilities, even in the most distant areas (i.e. equity) (Mitropoulos et al., 2006). While we use minimization of total demand-weighted distance as the single objective, in practice it will be more valid to take into consideration some other objectives such as avoiding overloading some facilities (especially resource-intensive units as neonatal centers), avoiding having remote facilities that serve too few customers compared to their capacity, maximization of the demand that is covered within a specified distance and minimization of the maximum distance that patients must travel to access health care treatment.

Dynamic nature of the system

Our model has a static nature, namely, we solve the problem for a specific point in time, usually the current time. It does not take into consideration the dynamic nature of the real world, where the model parameters change over time. So, we need to formulate the location problem as a multi-period problem where conditions change along. Such a model typically results in a schedule or plan for opening up new facilities at specific times and closing down some of the existing ones as well, and locations in response to changes in parameters over time, like changes in site populations.

On the other hand, there may be considerable uncertainty regarding the way in which relevant parameters (demand in terms of quantity and location, social values, facility and transportation costs, required capacities, etc.) in the location decision change over time (Current et al., 1997). In this context, we can evaluate various location strategies that reflect the changing attributes of data and parameters under dynamically changing scenarios. In this way, it is possible to select the best location decision which is robust with respect to uncertain future conditions, i.e. which produces well results in all (or most) scenarios (Daskin and Dean, 2004).

An Alternative for the Hierarchical Structure of the System

It is possible to design the system based on the different relationships among various levels of hierarchies, e.g. locally inclusive, instead of successively inclusive. Another formulation for a system with locally inclusive facilities can be developed and compared to the successively inclusive system, and the best system for perinatal care can be selected considering the coverage rates, cost and load balancing between the facilities.

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