MULTI-COMMODITY SUPPLY NETWORK DESIGN IN NONPROFIT REVERSE LOGISTICS

BY

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Dedicated to

My dear father

Waleed

My dear mother

Mona

My lovely wife

Maha

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All praise is to ALLAH and peace and blessings be upon our prophet Muhammad and upon his family and companions. I thank almighty ALLAH for assistance in achieving this work.

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LIST OF ABBREVIATIONS

FLA	**:**	Facility location – allocation
SP	**:**	Selection process
MILP	**:**	Mixed integer linear programming
MINLP	**:**	Mixed integer nonlinear programming
LMOP	**:**	Linear multi-objective programming
NLMOP	**:**	Nonlinear multi-objective programming
GCCP	**:**	Grey chance-constrained programming
GMCDM	**:**	Multiple-criteria decision-making
S	**:**	Stochastic
D	**:**	Deterministic
L	**:**	Limited
U	**:**	Unlimited
MCRS	**:**	Multi-Commodity Collection and Redistribution System
FECRS	**:**	Food Excess Collection and Redistribution System
CRC	**:**	Collection and Redistribution Center

S	**:**	Single-type CRC
M	**:**	Multi-type CRC
F	**:**	Food
C	**:**	Cloth
P	**:**	Pharmaceuticals

ABSTRACT

Full Name : Adel Waleed Fadhel

Thesis Title : Multi-Commodity Supply Network Design in Nonprofit Reverse Logistics

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The awareness of the necessity of introducing reverse logistics network design into the strategic supply chain management is increasing among researchers and practitioners of reverse logistics systems. The literature review of this field reveals that two main approaches are adopted to develop and implement reverse logistics network design which are the integrated or the closed loop supply chain and the separated reverse logistics design. The selection between these two approaches depends on the assumptions of the system to be modeled. Unlike commercial logistics, humanitarian logistics is at the first stages of development. The research in this regard has grown rapidly in recent years but the challenges appearing in theory and practice require expediting the research more and more to satisfy market demand. In this thesis, we study the problem of designing a model of a collection and redistribution system network that reduces the cost in a nonprofit supply network and increases benefits to beneficiaries. By adopting the reverse production system framework in the nonprofit reverse logistics environment, we developed two collection and redistribution system models for the Saudi Food Bank (Eta'am). The first model is concerned with the excess food collection and redistribution system and the second model is developed for a multi-commodity collection and redistribution system as an extension of the first one. By solving the two models for different budget constraints, we identified a point between centralization and decentralization of the collection and redistribution centers at which the responsiveness of the system is increased. Finally, we provided suggestions to increase the efficiency of collection and redistribution processes for Eta'am and discussed areas of future research of the study.

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ABSTRACT ARABIC

ملخص الرسالة

الاسم الكامل	:	عادل وليد فضل
عنوان الرسالة	:	تصميم شبكة إمداد متعددة السلع في الدعم اللوجستي العكسي غير الربحي
التخصص	:	هندسة النظم
تاريخ الدرجة العلمية	:	مايو ٢٠١٤ م

الوعي بضرورة تقديم مفهوم تصميم شبكات اللوجستية العكسية في إدارة سلاسل الإمداد الإستراتيجية يزداد بين الباحثين والممارسين لمجال أنظمة اللوجستية العكسية. المراجعة الأدبية لهذا الحقل تكشف وجود منهجيتين رئيسيتين لتطوير وتطبيق تصميم شبكة اللوجستية العكسية، وهما منهج سلاسل الإمداد المتكاملة أو مغلقة الحلقة ومنهج اللوجستية العكسية المنفصلة. الإختيار بين هذين المنهجيتين يعتمد على فرضيات النظام المراد نمذجته. بخلاف اللوجستية التجارية، فإن اللوجستية الإنسانية تعتبر في بداية مراحل تطورها. البحث في هذا الصدد ينمو ويزداد سريعا في السنوات الأخيرة ولكن التحديات التي تظهر باستمرار في النظرية والتطبيق تتطلب تكثيف جهود البحث أكثر وأكثر لاستيفاء سوق الطلب. في هذه الأطروحة ، ندرس مشكلة تصميم نموذج شبكة نظام الجمع وإعادة التوزيع بحيث يراعي تقليل التكلفة في شبكات الإمداد الغير ربحية ويزيد من المنافع للمستفيدين. من خلال تعديل إطار نظام الإنتاجية العكسية ليتوائم مع البيئة الغير ربحية، قمنا تطوير نموذجين لنظام التجميع وإعادة التوزيع لبنك الطعام السعودي (إطعام). يعنى النموذج الأول بتطوير نظام إطعام لجمع الطعام الزائد وإعادة توزيعه للمستفيدين. أما النموذج الثاني فهو إمتداد للنموذج الأول بحيث يشمل النظام جمع وإعادة توزيع منتجين أو أكثر ولا يقتصر على الطعام الزائد فقط. بإتمام حل النموذجين لميزانيات مختلفة، حددنا درجة بين المركزية واللامركزية لمراكز الجمع وإعادة التوزيع بحيث تزداد إستجابة النظام لجمع المنتجات الزائدة. ختامًا ، قمنا بتقديم إقتراحات لزيادة فاعلية عملية الجمع وإعادة التوزيع لإطعام وناقشنا مجالات البحث المستقبلية للدراسة.

درجة ماجستير في العلوم

جامعة الملك فهد للبترول والمعادن

مايو ٢٠١٤ م

CHAPTER 1

INTRODUCTION

In the past, the decision making process was based on decoupled components and functions of an organization [1]. However, with market globalization and increasing component dependencies, firms have moved toward supply chain management which can be defined as the management of logistics systems that start at the supply of raw-materials and end with the sales and distribution of goods to final consumers [2]. The supply chain usually consists of three different stages; procurement, production and distribution. The operational coordination can be categorized into Buyer-Vendor coordination (see e.g. [3]), Production-Distribution coordination (see e.g. [4]) and Inventory-Distribution coordination (see e.g. [5]) [2].

As an expected consequence of increasing consumption of different types of products and as a result of the high rate of purchasing process of new products, particularly in the electronics products sector, a need for better treatment of used products arises in the supply chain management planning. This need becomes essential since the environmental awareness increases and countries' environmental regulations become more strict [6]. As a result, the term "Reverse logistics" appears in the literature as a part of the supply chain management process. Reverse logistics can be defined as the activities related to product recovery and the process of deciding the best disposal option of different products [7].

Reverse logistics is related to many research areas such as after sales services, facility location, demand forecasting, product quality and reliability, and others. Therefore, to understand the supply chain process in a way that we can integrate strategic planning decisions with tactical and operational applications, we need to investigate the critical problems of reverse logistics. As a first step to study reverse logistics, one can review studies conducted in forward logistics where the research is more active. However, the models of forward logistics can't be used directly in reverse logistics without any modification, since there are many differences between the two terms. Reverse logistics has more probabilistic parameters such as the decision about which disposal option to choose, rate of disposal, existence of collection and rework centers and others. So, we notice that dealing with reverse logistics networks is much more complicated than forward logistics and there are many differences that have not been tackled in the literature yet [7].

1.1 Nonprofit Supply Chain

Much of the current research in operations management and economics has focused on cost effectiveness of recycling, on political and economic strategies to encourage recycling by influencing both supply and demand, and on methods to create effective, efficient, and optimal logistical paths for product return [8]. The social and ethical dimensions of sustainability, however, particularly as they apply to Reverse Logistics (RL), remain inchoate topics [9]. Nonprofit supply chain is the term that is usually applied to such topics.

The success of a nonprofit supply chain is measured in terms of the achievement of its specific nonprofit goal. This differs from commercial supply chains, which define their success based on supply chain profitability. The nonprofit supply chain can be composed of multiple stakeholders: nonprofit organizations (NPOs), public entities, and private companies. This situation naturally leads to decentralized control, in which much of the supply often comes from the private sector, while demand comes from the public or nonprofit sector. The most important nonprofit supply chain challenges are listed below:

- Lack of single performance measure
- Limited/uncertain funds, supply, and resources
- Allocation when demand exceeds supply
- Weak demand forecasts
- High value of loss and stock-out costs
- Lack of intra- and inter-collaboration

In recent researches, some papers prefer to use the term nonprofit supply network instead of nonprofit supply chain to emphasize the ad hoc and changing nature of the means by which aid is delivered to beneficiaries. It is claimed that the use of the term supply networks is more appropriate as it helps to underline the complication that is inherent in such an endeavor.

The significance of such networks in the humanitarian field cannot be overlooked and, as has generally been suggested, some 60-80 per cent of the expenditure of a nongovernmental organization (NGO) is consumed in support of this aspect of their work. Additionally, in this era of rolling 24 hour news, the public opinion of the effectiveness of the response to a disaster is, at least in part, based on the reported presence (or absence) of key commodities such as shelter, food, water and medical supplies [10].

1.2 Humanitarian Logistics

Some supply chains in the nonprofit context have already been studied in the literature, and they can be considered as specific examples of nonprofit supply chains [11]. The field of humanitarian logistics and supply chain management has recently gained much attention in research. Of particular interest to humanitarian logisticians is the rising number of beneficiaries every year, that is to say, people affected by a disaster, to whom humanitarian logisticians need to deliver aid. Apart from the frequency and impact of disasters, humanitarian organizations are under an increased pressure to improve their logistics performance. Not surprisingly, such trends triggered an interest also in humanitarian logistics research. Thus since 2005, a vast number of special issues of scientific journals have been dedicated to humanitarian logistics, encouraging even more research in this field [12]. However, the literature often states that humanitarian logistics is decades behind the commercial sector in the areas of recognition, utilization, and resources [13]. Figure 1 on page 5 shows the trend of research in humanitarian logistics since 1993 [14].

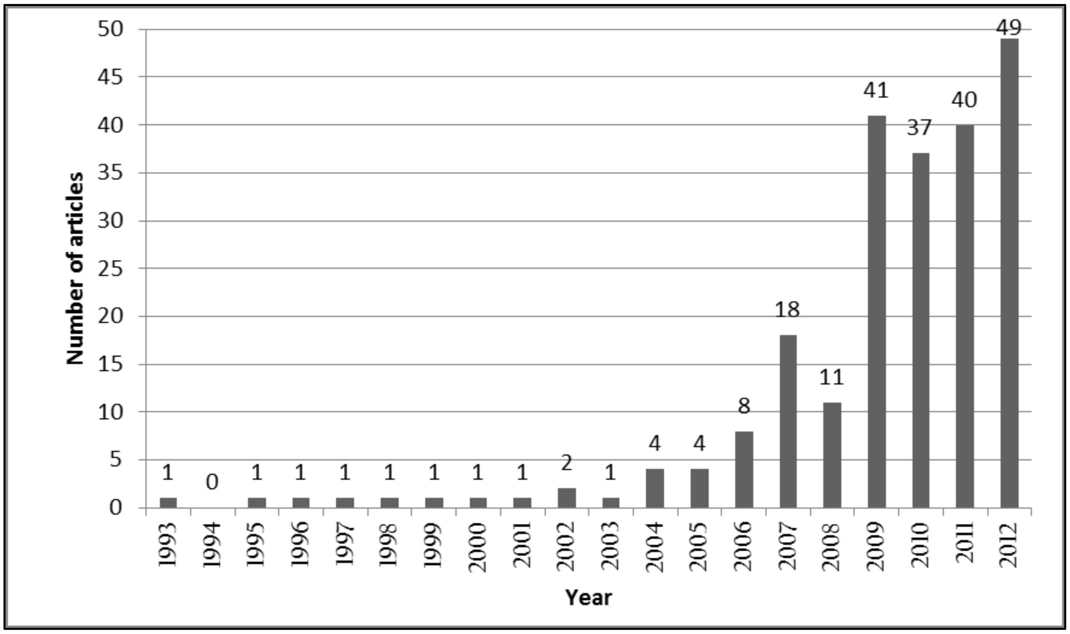

Figure 1 Humanitarian logistics literature trend

Humanitarian logistics can be defined as "the process of planning, implementing and controlling the efficient, cost-effective flow and storage of goods and materials, as well as related information, from point of origin to point of consumption for the purpose of meeting the end beneficiary's requirements". Except for its focus on the end beneficiary, this definition is largely comparable to any definition of business logistics. Summarized, the crucial characteristics of humanitarian logistics (as different from business logistics) comprise the:

- Unpredictability of demand, in terms of timing, location, type, and size;
- Suddenness of the occurrence of demand in large amounts but with short lead times for a wide variety of supplies;
- High stakes associated with the timeliness of deliveries; and

- Lack of resources in terms of supply, people, technology, transportation capacity and money. [15]

Complexities of humanitarian logistics are due to many factors such as unknowns, time uncertainty, paucity of trained logisticians, variability of the media and funding, modest equipment and information technology, and disturbance of interference [13]. Table 1 shows some differences between humanitarian logistics and commercial logistics.

Table 1 Comparison between humanitarian and commercial logistics

	Humanitarian Logistics	**Commercial Logistics**
Objective	Social	Economic
Demand	Always uncertain	Occasionally uncertain
Resource	scarce	abundant
Supply	Variable	stable
Performance Measure	Many factors	One or two factors
Information technology	Modest	Advanced
funding	Unsecured	Secured
Interference	High	Low

In this thesis we will investigate the problem of designing returned products collection and redistribution system network in the context of nonprofit organizations. Our aim is to design a model of collection and redistribution system network that reduces the cost in a nonprofit supply and increases benefits to beneficiaries. Two mixed integer linear programming (MILP) models are formulated for single and multi-commodity products. The delivered models are utilized to analyze the existing network of the Saudi Food Bank Association (Eta'am) which will be introduced next.

1.3 About Eta'am

1.3.1 Introduction

Eta'am is a nonprofit organization started on the initiative of a group of businessmen in the Eastern Province of Saudi Arabia. Its primary objective is to reduce food wastage by adopting this initiative from the worldwide idea of food banks to be applied in Saudi Arabia in a professional manner with the best quality and safety standards that are commensurate with the specifics of the community. Its main activities are creating awareness and spreading the culture of the proper disposal of excess food in our society through the establishment of educational exhibitions, seminars and lectures to educate the community about the importance of food waste reduction. In addition, Eta'am initiates many agreements with hotels and wedding halls to mobilize and distribute excess food with the best quality and safety standards.

Figure 2 Eta'am logo

1.3.2 Mission

Support the partnership between spectrums of society by proper redistribution of excess food and attract philanthropic resources to provide adequate food to the beneficiaries and to achieve the concept of social solidarity.

1.3.3 Vision

Be a world leader in the provision of adequate food to the beneficiaries through a professional method of operation.

1.3.4 Goals

1. Creating community awareness of the importance of the proper disposal and redistribution of excess food.

2. Distribution of the surplus food to beneficiaries with the best international quality and safety standards.

3. Creating new jobs for those ambitious generations, including the initiative of training and qualifying beneficiaries' dependents to become self-sufficient in the future.

4. Stimulate all community segments to take part in volunteering activities.

5. Work to the further development of philanthropic activities to reach professionalism.

1.3.5 Achievements

1. An agreement with Princess Jawaher Center to train and recruit employees.

2. An agreement with the Egyptian Food Bank as a kind of mutual cooperation.

3. Employment of more than 80 young men and women so far.

4. Packaging and distribution of more than 342,000 meals up to the end of December 2013.

Figure 3 Meals ready for distribution

5. Distribution of more than 40,000 Iftar meals to the beneficiaries in the holy month of Ramadan for the year 1433 AH.

Figure 4 Iftar meal

6. Campaign "Don't waste God's bounty... Responsibility of all of us " in Ramadan 1433 AH.

7. Provide lectures for companies to promote a culture of reducing food waste.

8. The opening of the first branch of Eta'am in Al-Ahsa.

9. First place as the best positive project in the Arabian Gulf in 2012.

10. Of the top three projects in the Middle East in Kambdn competition for best charitable project, held in Abu Dhabi in December 2012.

11. Attain first place in the "I'm positive" at the level of the Gulf region.

12. Launch of schools campaigns "We aim to perpetuate God's bounty".

Figure 5 Campaign in a school by Eta'am

13. Applying Smart Phone Applications to promote Eta'am.

1.4 Terms and Terminology

1. **Nonprofit organization:** An incorporated organization which exists for educational or charitable reasons, and from which its shareholders or trustees do not benefit financially. Any money earned by a nonprofit organization must be retained by the organization and used for its own expenses, operations, and programs. Many nonprofit organizations also seek tax exempt status and may also be exempt from local taxes including sales taxes or property taxes. Well-known non-profit organizations include Habitat for Humanity, American Red Cross, and United Way.

2. **Beneficiary:** any person who or entity (i.e. a charity) which is to receive assets or profits from an estate, a trust, an insurance policy or any instrument in which there is distribution of goods.

3. **Food Bank:** is a nonprofit, charitable organization that distributes food to those who have difficulty purchasing enough food to avoid hunger.

1.5 Thesis Objectives

The objective of this thesis is, in light of the limited resources, to integrate the collection and redistribution system in reverse logistics of humanitarian aid through determining the number and location of the centers in the returned products collection and redistribution network. Designing a collection and redistribution system network that reduces the cost in a nonprofit supply chain and increases benefits to society is essential to achieve the goal of returned products collection and redistribution effectively and efficiently. In the next sections we will present a case study of designing Eta'am food excess collection and redistribution system model and multi-commodity collection and redistribution system model.

The delivered models are utilized to analyze the existing network of Eta'am for the following purposes:

1. Design collection and redistribution system network that meets Eta'am expansion goals in order to cover the determined areas with least cost and the best utilization of resources.

2. Design collection and redistribution system network that meets Eta'am goals to include other commodities besides excess food such as used clothes, electronic devices and remnants of pharmaceuticals at least cost and the best utilization of resources.

1.6 Thesis Organization

This remainder of this thesis is organized as follows: the literature related to supply network design in nonprofit and humanitarian logistics is reviewed and classified in the next chapter and the problem and scope are defined. Chapter 3 describes the Eta'am food excess collection and redistribution system and presents the model assumptions and formulation. Chapter 4 describes the Eta'am multi-commodity collection and redistribution system and presents the model assumptions and formulation. Finally, we conclude in Chapter 5 and present future research areas.

CHAPTER 2

LITERATURE REVIEW AND PROBLEM DEFINITION

2.1 Introduction

In literature, the recent studies of supply chain are extended to consider aspects related to the environment and society [16]. As a result, the design and planning of reverse logistics activities that lead to closed loop supply chain has been investigated in many recent researches. However, most of the studies considered the reverse network independently of the forward chains (see e.g. [17]) although this structure of reverse logistics results in increasing transportation costs and reducing total profit [18]. So, the study of forward and reverse logistics simultaneously is necessary to improve the design and planning of the network. Few studies have considered this problem (see e.g. [19]) and further research in this area is still required [20].

However, in the literature, there are some other comments on the advantages and disadvantages of separate/integrated reverse logistics design (see [21], [22]). The main advantage of the integrated or the closed loop approach is the synergy coming from common uses of resources, especially for the transportation. However, a separate study is preferred when return quality, hazardous nature of the products and several other factors of return do not yield any benefit and only complicate the problem. Mixing the return flow due to its varied location and its quality is not desirable. Additionally, as [21] mentioned, if speed is an important factor for reverse logistics, the integration decision may not be rational [23]. One important question which arises in this case is whether to integrate collection and recovery with the original forward distribution network or rather to separate both channels. To this end, it is important to know how much product recovery is restricted by the constraints that are implied by existing logistics infrastructure [24].

Many attempts have been conducted in the literature to classify reverse logistics problems and models. As an overview of reverse logistics modeling opportunities, the problem of number and location of centralized return centers (CRCs) and the issue of whether or not to outsource reverse logistics are discussed widely in the literature [7]. A different view of classifying the literature of reverse logistics is based on reverse logistics system categories which contain inputs, processes and structure, and outputs [25]. Another classification is based on quantity models which are mixed integer linear programming, mixed integer nonlinear programming, mixed integer goal programming and linear multi-objective programming [26]. Alternatively, a general classification of reverse logistics network models is based on four categories which are closed-loop, generic model, stochastic model and third-party-logistics (3PLs) [26]. Another classification could be delivered according to network structure. That is to divide the literature into two categories, closed loop and recovery problem [27]. The recovery problem in more detail and a model formulation are introduced in [6]. The reverse logistics network could be classified into four kinds: the directly reusable network (DRN), the remanufacturing network (RMN), the repair service network (RSN), and the recycling network (RN) [28]. However, there are many areas of reverse logistics that need more investigation. Research in the literature has not differentiated between forward and reverse logistics in terms of modeling methodologies although there are many differences and variations [27].

In this thesis, we will classify the literature of research in reverse logistics network design into two main categories, namely the closed loop supply chain network design, and the reverse logistics network design. The researches in both categories will be characterized according to whether case studies are provided or not. Each section involves tables that show the characteristics of each article in terms of the scope of the model, solution methods, quantity models, uncertainty and the capacity of facility. Further, we will investigate the literature of nonprofit supply chain and humanitarian logistics. Before that, a brief literature review about the facility location problem is presented.

2.2 Literature Review

2.2.1 The Facility Location Problem

A general facility location problem usually consists of a set of demands nodes and facilities to serve these demands (see e.g. [29]). The solution of the facility location problem provides information about the number of facilities which should be opened and the allocation of demands on these facilities [27]. The Facility locations problem has been considered as an active research within the context of Operations Research (OR) [27]. References to papers and books discussing this issue can be found in [30]. In recent years, researchers have realized that facility location problems should be treated as a strategic decision in the supply chains management [31].

The basic settings to model the facility location problems are represented by the p-median problem in which p facilities are to be selected to minimize the distance of covering demands nodes (see e.g. [30]). One important extension of the last model is the uncapacitated facility location problem (UFLP) in which the setup cost is varies from one candidate location to another. Examples of the UFLP can be found in [32]. One important extension of the UFLP is the capacitated facility location problem (CFLP) in which each potential site can serve a maximum predetermined demand (see e.g. [33]). Including the stochastic components is another important extension in facility location models. Parameters such as customer demands are usually uncertain in practical problems. Examples of this type of modeling can be found in [34].

2.2.2 Closed Loop Network Design

The integration of forward and reverse logistics networks has been put forward by many researchers. A closed loop supply chain (CLSC) consists of both the forward supply chain, and the reverse supply chain. Correspondingly, the closed loop logistic network consists of both the forward logistic network and the reverse logistic network [26]. The research in closed loop supply chain design can be classified into two main categories. The first category is the researches that apply the derived model formulation on a case study to obtain and discuss the results practically. The second category is the researches that verify and validate the formulated models using numerical examples and discuss the results theoretically.

2.2.2.1 Case study

Despite the increasing number of environmental legislation and international operational standards that assist the implementing of environmental management, companies are not so motivated to regain value from return because of the lack of awareness of the closed loop supply chain, and the difficulty to implement the closed loop supply chain for some categories of products [35]. However, besides the environmental benefits from implementing the closed loop supply chain, companies can generate more profit and gain business benefits such as improving customer satisfaction, increasing spare parts availability and improving product quality through re-engineering [36]. One approach to improve the implementation of the closed loop supply chain is to establish a strategic alliance with an eco-nonprofit organization in the collection process which creates a green image, generates more profit and allows the company to focus on its core business [35].

There are many researches in the literature that fall into the first category. In [20] a mixed integer linear programming (MILP) formulation is developed for the design and planning of supply chains with reverse flows while simultaneously considering production, distribution and reverse logistics activities. Product demand uncertainty is also considered using a scenario tree approach. The model is applied to a representative European supply chain case study and its applicability is demonstrated. In [37] the peculiarities of establishing a closed-loop supply chain (CLSC) are presented, based on an example considering the end-of-life vehicle (ELV) treatment in Germany. Different design options for a CLSC are offered, concentrating on how reverse material flows can be handled with regard to reintegrating them into their genuine supply chains. In [38] a multi-echelon, multi-period, multi-product closed loop supply chain network model is developed for product returns and the decisions are made regarding material procurement, production, distribution, recycling and disposal. The proposed heuristics based genetic algorithm (GA) is applied as a solution methodology to solve the mixed integer linear programming model (MILP). The model is applied to a case of a battery manufacturing industry located in the southern part of India. The model in [39] seeks to describe several features of establishing a closed-loop supply chain for the collection of end-of-life vehicles (ELV) in Mexico where the problem is handled through Reverse Logistics and is modeled through an uncapacitated facility location problem. This work also presents a brief description of the current Mexican ELV management system and the future trends in ELV generation in Mexico. The objective function is solved through the facility location software SITATION which implements the Lagrangian Relaxation to find the optimal number of facilities for the end-of-life vehicles collection network. In [6] an analytical approach towards production planning and control for closed-loop supply chains with product recovery and reuse is presented. This approach consists of a mathematical programming model, RAPP (Remanufacturing Aggregate Production Planning), for aggregate production planning and control. The model is designed to aid operational decision-makers in an intermediate to long-range planning environment and also may serve as a focal point for developing formal systems for production planning, inventory control, and other tactical decision-making. Data from a company that remanufactures mobile telephones is used to validate the model. In [40], an MILP formulation is proposed for the design of a reverse logistics network based on a warehouse location–allocation model, which optimizes, simultaneously, the forward and reverse networks. A single product model with unlimited capacity is first defined. Subsequently, the model is extended to a multi-product capacitated recovery network model, where capacity limitations and a multi-product system can be considered. Two case studies are analyzed in this paper, one considers copier remanufacturers and the other considers a document office company that operates in the Iberian market. [41] develop a hybrid approach to establishing a closed-loop supply chain that combines an optimization model for planning a reverse-supply network and a flow-sheeting process model that enables a simulation tailored to potential recycling options for spent batteries in the steel making industry.

The following legends are used for tables 2, 3, 4 and 5 on pages 23, 28, 35 and 41 respectively.

FLA	: Facility location – allocation
SP	: Selection process
MILP	: Mixed integer linear programming
MINLP	: Mixed integer nonlinear programming
LMOP	: Linear multi-objective programming
NLMOP	: Nonlinear multi-objective programming
GCCP	: Grey chance-constrained programming

GMCDM	: Multiple-criteria decision-making
S	: Stochastic
D	: Deterministic
L	: Limited
U	: Unlimited

Table 2 on page 23 shows some papers in the first category and the properties of each research in terms of the scope of the model, solution methods, quantity models, uncertainty, the capacity of facility and the case study.

Table 2 Applications of closed loop supply chain design

Paper	**Model scope**	**Quantity Model**	**Solution Method**	**Demand**	**Capacity**	**Case Study**
S.R. Cardoso et al. [20]	Supply chain	MILP	Scenario tree approach	S	L	A representative European supply chain
F. Schultmann et al. [37]	Vehicle rooting	MINLP	Tabu search	D	L	End-of-life vehicle (ELV) treatment in Germany
G. Kannan et al. [38]	Recycling	MILP	Genetic algorithm	D	U	Battery manufacturing industry in India
Cruz-Rivera et al. [39]	FLA	MILP	Lagrangian Relaxation	D	U	Mexican end-of-life vehicle (ELV) management system
Jayaraman	Production planning	MILP	GAMS software	D	L	Mobile telephones

MI Salema et al. [40]	FLA	MILP	GAMS software	D	L	Copier remanufacturers and Document office company
Schultmann et al.	Recycling	MILP	Flow-sheeting simulation	D	L	Spent batteries in Germany

2.2.2.2 Quantity model

On the other hand, many researches have been developed for the closed-loop network design and the results analyzed through numerical examples. In [42], the main issues to be addressed by this study are to choose the location and determine the number of hybrid distribution collection, production/recovery and disposal centers that represent the degree of centralization of the network, and to determine the quantity of flow between network facilities. Design of this closed-loop integrated logistics network may involve a trade-off relationship between the total fixed costs and the total variable costs. [43] present a mixed integer nonlinear programming model for the design of a dynamic integrated distribution network to account for the integrated aspect of optimizing the forward and return network simultaneously. A genetic algorithm-based heuristic with associated numerical results is presented and tested in a set of problems by an exact algorithm. [44] propose a multi objective mixed-integer linear programming model to determine which suppliers and refurbishing sites should be selected (strategic decisions), and find out the optimal number of parts and products in CLSC network (tactical decisions). The objective functions maximize profit and weights of suppliers, and one of them minimizes defect rates. The model presented in [45] has been formulated with the intent of examining issues surrounding the recent European Union directive regarding waste of electric and electronic equipment (WEEE). In the general network investigated, there are two tiers, the first consisting of manufacturers and the second of consumer markets. Competition occurs horizontally along tiers, but cooperation can occur vertically between tiers. The algorithm selected to solve the variation inequality is the extra-gradient method with constant step length proposed by Korpelevich (1976). In [46] a composite multi-objective optimization model is formulated to seek optimal solutions along with the goal of maximizing the systematic net profit across the proposed nuclear-power green supply chain. An uncapacitated mixed integer programming facility location model for a remanufacturing network system where forward and reverse flows are simultaneously considered and strongly correlated as the remanufactured products are assumed to be as good as new is proposed in [28]. For solving the model, an algorithm based on Lagrangian heuristics is developed and the model is tested on data adapted from classical test problems. [47] presents a generic stochastic model for the design of networks comprising both supply and return channels, organized in a closed loop system. This model is described by a decomposition approach based on the branch-and-cut procedure known as the integer L-shaped method. The integrated forward/reverse logistics network is investigated in [48], and a capacitated multi-stage logistics network design is proposed by formulating a generalized logistics network problem into a bi-objective mixed-integer programming model (MIP). Branch and Bound algorithm is applied to find a global optimum for this model which provides the decisions related to the facility location problem, optimum quantity of shipped product and facility capacity. [49] propose dynamic location and allocation models to cope with reverse logistics configurations. A two-stage stochastic programming model is further developed by which a deterministic model for multi-period reverse logistics network design can be extended to account for the uncertainties. A solution approach integrating a recently proposed sampling method with a heuristic algorithm is also proposed in this research. [50] consider a multi-product closed-loop logistics network design problem with hybrid manufacturing/ remanufacturing facilities and finite-capacity hybrid distribution/collection centers to serve a set of retail locations. Second, a solution method based on Benders' decomposition with strengthened Benders' cuts for improved computational efficiencies is devised.

Table 3 on page 28 shows some papers in the second category and the properties of each research in terms of the scope of the model, solution methods, quantity models, uncertainty and the capacity of facility.

Table 3 Closed loop supply chain design with numerical examples

Paper	Model scope	Quantity Model	Solution Method	Demand	Capacity
M.S. Pishvaee et al. [42]	FLA	MILP	Scenario-based stochastic approach	S	L
H.J. Ko	FLA	MINLP	Genetic algorithm	S	L
S.H. Amin et al. [44]	FLA	MILP	Fuzzy Analytic Hierarchy Process (FAHP) and the compromise Programming method	S	L
D. Hammond [45]	Material flow	MINLP	The extra-gradient method	S	-
J.B. Sheu	Supply chain	LMOP	Simulated annealing	D	L
Zhiqiang Lu et al. [28]	FLA	MILP	Lagrangian Relaxation	D	U
Ovidiu Listes [47]	FLA	MINLP	Integer L-shaped	S	L

Lida Khajavi et al.	FLA	MILP	Branch and Bound algorithm	D	L
D.H. Lee et al.	FLA	MINLP	Sample Average Approximation (SAA) with a Simulated annealing	S	L
Easwaran et al. [50]	FLA	MILP	Benders' decomposition with strengthened Benders' cuts	D	L

2.2.3 Reverse Logistics Network Design

Due to the complexity of optimizing the integration of the forward and reverse logistics network simultaneously, many researches have studied the reverse logistics network design separately from the original forward channel. The network design in reverse logistics has been researched extensively in the last few years, (see e.g. [51]). Those types of problems involve the treatment of basic questions such as the location and size of the main facilities in the reverse logistics network [28]. Because of the presence of the recovery activities in reverse logistics systems, the resulting network imposes many characteristics such as the involvement of intermediate return centers that are used mainly to recover used products from different customers [28]. As we survey the literature for the network design in reverse logistics systems, we see that there are many different approaches that consider either new ideas for modeling the reverse location problem or different applications for existing models. As a result, the research in reverse logistics network design can be classified into two main categories. The first category is the researches that apply the derived model formulation on a case study to obtain and discuss the results practically. The second category is the researches that verify and validate the formulated models using numerical examples and discuss the results theoretically.

2.2.3.1 Case study

In the application area, general location models in reverse logistics have been applied to specific types of products such as end-of-life products like end-of-life vehicles (ELV), waste of electric and electronic equipment (WEEE) and municipal solid waste (MSW) [52]. In [23] a multi-objective model for the reverse logistics network design (RLND) problem and a novel methodology are proposed. The proposed methodology comprises two stages: the centralized return center (CRC) evaluation stage and the reverse logistics network design (RLND) stage. In the first stage an integrated Analytic Network Process (ANP) and fuzzy Technique for Order Preferences by Similarities (TOPSIS) methodology is utilized. In the second stage, using the CRC weights obtained in the first stage, the RLND model is solved via genetic algorithms (GAs). The proposed methodology is applied to a case from the Turkish white goods industry. [53] propose a mixed-integer linear programming formulation with the objective of a profit maximization framework for reverse logistics network design problems that is flexible to incorporate most of the reverse network structures plausible in practice. The proposed general framework is justified by a case study in the context of reverse logistics network design for washing machines and tumble dryers in Germany. [54] present a decision support tool for policymakers and regulators to optimize electronic products' reverse logistics network. To that effect, a Mixed Integer Linear Programming mathematical model is formulated taking into account existing infrastructure of collection points and recycling facilities. The applicability of the developed model is demonstrated employing a real-world case study for the Region of Central Macedonia, Greece. [55] propose a single-objective, nonlinear, mixed-integer programming model to maximize the potential cost savings accrued from the multi-echelon reverse logistics channel. The proposed model is designed to find the optimal location, number and size of both initial collection points and centralized return centers in the reverse logistics network under capacity limits and service requirements. The proposed model and algorithm was validated by its application to an illustrative example dealing with products returned from online sales. The work in [17] focuses on the recovery network run by Amb3e. With the support of this organization, producers developed economies of scale allowing for a more efficient WEEE management and a reduction in the usual uncertainty associated with the quantity and quality of end-of-life equipment. A generic mixed integer linear programming model is proposed to represent this network, and is applied to its design and planning, where the best locations for collection and sorting centers are chosen simultaneously with the definition of tactical network planning. The objective of the model in [56] is to find out which facilities should be built and how the sand should be classified, stored and cleaned so that the total costs of the system are minimized given the potential locations of regional depots and treatment facilities, the cost structures - transporting, processing and fixed costs - and the location of the sources of sieved sand. The results obtained for the sand recycling network in the Netherlands are summarized. Another application considers the facility location allocation model for the collection, preprocessing and redistribution and reusing of carpet materials where no restrictions with respect to the locations of the regional preprocessing centers exist and the expenses for building and buying facilities are explicitly taken into account via linear depreciations [57]. For solving the model, an algorithm is suggested that is based on examining all different combinations of preprocessing centers and selecting the one that has the lowest value for the objective function. Two applications of the model, one in Europe and one in the United States of America, are described. [52] present a modeling approach that could be used to establish one important part of reverse logistics networks for end-of-life vehicles (ELVs) by defining optimum locations for collection points. To minimize aggregation errors, this research proposes an approach where service zones are partitioned into subzones, i.e., subsets of demand locations. Sub zones are covered by one or more collection facilities and the demand of each sub zone is proportional to the zone area covered. All of these modifications are incorporated into the novel formulation of maximal covering location problem. The proposed modeling approach is illustrated on Belgrade city area and obtained results confirmed that it can be used very efficiently to position ELV's collection facilities. [58] present a stochastic programming based approach by which a deterministic location model for product recovery network design may be extended to explicitly account for the uncertainties. The stochastic model is applied to a representative real case study on recycling sand from demolition waste in the Netherlands. A model to tackle a recycling network of electrical appliances and computers in Taiwan is proposed in [59]. A mixed integer programming model is utilized to optimize the infrastructure design and the reverse network flow for end-of-life computers and home appliances. [24] present a generic facility location model and discuss differences with traditional logistics settings. The model is used to analyze the impact of product return flows on logistics networks and shows that the influence of product recovery is very much context dependent. The model is illustrated by means of two examples concerning copier remanufacturing and paper recycling, respectively. [60] address a used parts selection problem for product configuration in reverse logistics. The proposed framework minimizes product pricing, while meeting reliability and functionality requirements of customer orders. An integer programming model is formulated to determine an optimal selection plan of new and used parts for order fulfillment. A fuzzy rule based system is designed to determine the price of used parts according to their physical and external conditions. A case study was used to illustrate the applicability of the fuzzy optimization model in high-end server reverse logistics. A two-stage stochastic programming model is proposed in [61] to determine a long term strategy including optimal facility locations and optimal flow amounts for large scale reverse supply chain network design problems under uncertainty. A paper recycling network problem is proposed to verify the model. [62] propose a multiple criteria decision-making (MCDM) model based on fuzzy-set theory. The proposed model can help in designing effective and efficient flexible return policy depending on the various criteria. In [63] a generalized model is proposed that contemplates the design of a generic reverse logistics network where capacity limits, multi-product management and uncertainty about product demands and returns are considered. A mixed integer formulation is developed which is solved using standard branch-and-bound techniques. To test the model, a case of an office document company that operates in the Iberian market is solved.

Table 4 on page 35 shows some papers in the first category and the properties of each research in terms of the scope of the model, solution methods, quantity models, uncertainty, the capacity of facility and the case study.

Table 4 Applications of reverse logistics network design

Paper	Model scope	Quantity Model	Solution Method	Demand	Capacity	Case Study
G. Tuzkaya et al. [23]	FLA	LMOP	ANP and fuzzy - TOPSIS and genetic algorithm	D	L	The Turkish white goods industry
S.A. Alumur et al. [53]	FLA	MILP	Genetic algorithm	D	L	Washing machines and tumble dryers in Germany
Ch. Achillas et al. [54]	FLA	MILP	The mathematical programming language AMPL	D	L	The reverse supply network for WEEE collection in the Region of Central Macedonia
H. Min et al. [55]	FLA	MINLP	Genetic algorithm	D	L	Online sales of Beta.com
M.I. Gomes et al. [17]	FLA	MILP	Genetic algorithm	D	L	Efficient WEEE management of the recovery network run by Amb3e
A.I. Barros et al. [56]	FLA	MILP	A linear heuristic is based on transforming the linear relaxation of the problem into a feasible solution.	D	L	Sand recycling network in the Netherlands

Louwers, Dirk, et al. [57]	FLA	MILP	Cyclic heuristic algorithm	D	L	Two applications of the carpet waste model, one in Europe and one in the United States of America, are described.
Vidovic, Milorad, et al. [52]	FLA	MILP	Open source solver	D	U	The model is illustrated on Belgrade city area to position ELV's collection facilities.
Ovidiu Listes et al. [58]	FLA	MILP	Scenario-based stochastic approach	S	L	Recycling sand from demolition waste in The Netherlands
Li-Hsing Shih [59]	FLA	MILP	Scenario approach	S	L	End-of-life electrical products disposition in northern Taiwan
Moritz Fleischmann et al. [24]	FLA	MILP	Linear relaxation approach	D	U	Copier manufacturing and Paper recycling
Jie Chen et al. [60]	Order price	MILP	Fuzzy rule based system	D	L	High-end server reverse logistics
S. Soner Kara [61]	FLA	MILP	Scenario stochastic approach	S	L	Paper recycling

S. Wadhwaet al et al. [62]	SP	GMCDM	Fuzzy Logic	D	-	Original equipment manufacturing (OEM) company manufacturing high-value and medium-volume products (brown goods)
Maria Salema et al. [63]	FLA	MILP	Standard B&B techniques	S	L	An office document company that operates in the Iberian market

2.2.3.2 Quantity model

On the other hand, many researches have been developed for the reverse logistics network design and the results analyzed through numerical examples. [64] propose a mixed integer linear programming model to minimize the transportation and fixed opening costs in a multistage reverse logistics network. Since such network design problems belong to the class of NP-hard problems, a simulated annealing (SA) algorithm with special neighborhood search mechanisms is applied to find the near optimal solution. [65] provides an integrated holistic conceptual framework that combines descriptive modeling with optimization techniques at the methodological level. Detailed solutions are provided for network configuration and design at the topological level, by carrying out experimentation with the conceptual model of product returns. A multi-product, multi-echelon, profit maximizing RL and value recovery network model is developed covering activities from collection to first stage of remanufacturing. [66] propose strong and weak mathematical programming formulations for a reverse distribution problem and new solution methods are developed for this problem. The solution methodology complements a heuristic concentration procedure, where sub-problems with reduced sets of decision variables are iteratively solved to optimality. Based on the solutions from the sub-problems, a final concentration set of potential facility sites is constructed, and this problem is solved to optimality. The potential facility sites are then expanded in a greedy fashion to obtain the final solution. [67] propose a multi-stage reverse logistics network problem (m-rLNP) which considers the minimizing of total shipping cost and fixed opening costs of the disassembly centers and the processing centers in reverse logistics. For solving this problem, a genetic algorithm

(GA) is proposed with priority-based encoding method consisting of 1st and 2nd stages combining a new crossover operator called weight mapping crossover (WMX). A heuristic approach is applied in the 3rd stage to transportation of parts from processing center to manufacturer. [68] propose a multi-product, multistage reverse logistics network problem for the return products to determine not only the subsets of disassembly centers and processing centers to be opened, but also the transportation strategy that will satisfy demand imposed by manufacturing centers and recycling centers with minimum fixed opening cost and total shipping cost. A priority based genetic algorithm to find reverse logistics network to satisfy the demand imposed by manufacturing centers and recycling centers with minimum total cost under uncertainty condition is proposed. To help a manufacturer of electronic products provide quality post-sale repair service for their consumer, [69] propose a multi-objective reverse logistics network optimization model that considers the objectives of the cost, the total tardiness of the cycle time, and the coverage of customer zones. The Non-dominated Sorting Genetic Algorithm II NSGA-II is employed for solving this multi-objective optimization model. To evaluate the performance of NSGA-II, a genetic algorithm based on the weighted sum approach and Multi-objective Simulated Annealing MOSA are also applied. [70] realize a multi-objective location-routing network optimization in reverse logistics using particle swarm optimization based on grey relational analysis with entropy weight. A mathematical model of the multi-objective location-routing problem (LRP) of reverse logistics has been constructed. A hybrid particle swarm optimization with grey relational analysis and entropy weight has been developed to resolve the model. [71] realize a location-routing network optimization in reverse logistics (RL) using grey systems theory for uncertain information. In the location-routing problem (LRP) of RL, grey recycling demands are taken into account. Then, a mathematical model with grey recycling demands has been constructed. The model is transformed into grey chance-constrained programming (GCCP) model; grey simulation and a proposed hybrid particle swarm optimization (PSO) are combined to resolve it. [11] studies a capacitated facility location model with bidirectional flows and marginal value of time for returned products. Furthermore, this research studies a particular nonprofit supply chain design problem in the context of a humanitarian organization distributing food in a less secure area. The model is a nonlinear mixed-integer program that optimizes distribution center (DC) location and allocation between retailers and DCs. Conic programming approach is the solution method of choice for the problems presented in this research.

Table 5 on page 41 shows some papers in the second category and the properties of each research in terms of the scope of the model, solution methods, quantity models, uncertainty and the capacity of facility.

Table 5 Reverse logistics network design with numerical examples

Paper	Model scope	Quantity Model	Solution Method	Demand	Capacity
Pishvaee et al. [64]	FLA	MILP	Simulated annealing	D	L
S.K. Srivastava [65]	FLA and capacity decision	MILP	A bi-level program with decomposition	D	L
Jayaraman et al. [66]	FLA	MILP	Heuristic expansion and greedy heuristic	D	L
Jeong-Eun Lee et al. [67]	FLA	MILP	A genetic algorithm (GA) with priority-based encoding method and weight mapping crossover (WMX) operator	D	L
Hosseinzadeh et al. [68]	FLA	MILP	A priority based genetic algorithm	S	L

Shuang Li et al. [69]	FLA	NLMOP	Non-dominated Sorting Genetic Algorithm II NSGA-II - genetic algorithm - Simulated Annealing	D	L
Hong Liu et al. [70]	Location-routing	NLMOP	Hybrid particle swarm optimization with grey relational analysis and Entropy weight	D	L
Hong Liu et al. [71]	Location-routing	GCCP	Grey simulation and a proposed hybrid Particle Swarm Optimization (PSO)	Grey recycling demand	L
Gemma Berenguer-Falguera [11]	FLA	MINLP	Conic programming approach	S	L

2.2.4 Nonprofit Supply Chain

Recent researches tentatively investigate some dimensions of nonprofit supply chain. [11] studies a capacitated facility location model with bidirectional flows and marginal value of time for returned products. Furthermore, this research studies a particular nonprofit supply chain design problem in the context of a humanitarian organization distributing food in a less secure area. The model is a nonlinear mixed-integer program that optimizes distribution center (DC) location and allocation between retailers and DCs. Conic programming approach is the solution method of choice for the problems presented in this research. [72] present a model based on risk pooling through preventive lateral transshipment as a method for improving the responsiveness of not-for-profit core business practice of redistributing donated products in order to increase revenues. The model considers a three-echelon structure consisting of three collection centers, one sorting and disposition center, and three retail stocking locations. [9] focus on addressing the social aspects of sustainability in reverse logistics by linking various sustainable indicators with various reverse logistics practices to develop a profile of reverse logistics for social sustainability. [73] focus on the operational planning issues in a non-profit supply chain that distributes food for the ‘‘food insecure’’ to improve the efficiency and effectiveness of its operations. A detailed simulation model of the warehouse operations where food is processed served as a framework for making changes that improved the efficiency of the operations in terms of handling extra volume without investing in additional warehouse space.

2.2.5 Humanitarian Logistics

Most of the humanitarian literature concentrated on the preparation or planning phase [13]. A categorization of humanitarian logistics research articles is presented in [13]. Borrowing from the theory of constraints and management information systems literature, the authors provide future researchers with a framework for conducting research in the unique field of humanitarian logistics. [12] present a brief overview of the field of humanitarian logistics and supply chain management and outline the scope of the new Journal of Humanitarian Logistics and Supply Chain Management (JHLSCM). It further aims to highlight the variety of humanitarian logistics research and summarizes the articles in the inaugural issue. [74] present current trends and developments in humanitarian logistics (HL) practice, research, and education, and analyze the gaps between these. The article serves as an update on previous literature reviews in HL. Data are compiled through keyword searches, publicly available bibliographies, and websites of educational institutions, as well as drawing on material from practitioner workshops, tutorials, conference presentations, and personal communication with practitioners and educators. [14] give an up-to-date and structured insight into the most recent literature on humanitarian logistics, and suggest trends for future research based on the gaps identified through structured content analysis. The authors analyze the broadest set of papers (174) ever covered in previous literature reviews on humanitarian logistics. A quantitative analysis of the papers was conducted in order to analyze the situational factors which have mostly been studied so far in literature. Literature is scant in [75] on both gender issues in logistics and on humanitarian logistics. The paper contributes to both areas, while evaluating the impact of gender on logistics performance. In [76] an assessment of the agility capabilities of the supply chain has been deduced using a symbolic modeling approach. [15] identify the challenges of humanitarian logisticians with respect to different types of disasters, phases of disaster relief and the type of humanitarian organization. Based on a study of humanitarian organizations in Ghana, a conceptual model is constructed that serves as a basis to identify such challenges. [77] present an OR model for planning water distribution in disaster relief situations. The paper proposes a method that could support decision makers in finding appropriate compromise solutions where conflicting objectives exist and, in doing so, develops a model which can rapidly devise solutions for the physical location of water tanks and the selection of roads to use for the transport of drinking water in the aftermath of a disaster.

Researchers suggest that more attention be paid to the logistics of continuous aid operations, and more focus be put on slow onset man-made disasters and that the case study and survey methodologies be increasingly used to collect empirical knowledge [14]. Future research areas and potential topics within these areas are suggested in table 6 on page 46 [12].

Table 6 Future research in humanitarian logistics

Future research areas	**Potential topics**
Product/service development for humanitarian purposes	• Product, package, service, and technology development • Product and process standardization and modularization – improving the interoperability of humanitarian operations • The role of humanitarian organizations as service providers
Relationship management in the humanitarian supply chain	• Managing dormant supplier relationships • Relationship portfolios with suppliers, logistics services, and donors
The combination of inter-agency collaboration with supply chain collaboration	• Purchasing consortia in humanitarian supply chains • Sharing resources and capacities, e.g. in transportation, warehousing
Financial flows in humanitarian supply chains	• Managing and soliciting in-kind donations • Matching needs and donations • Microfinance and cash components in aid

The sustainability of aid	• Bridging the gap between disaster relief and long-term development and managing the transitions between these • Supply chain design for preparedness, and with an exit strategy • Community-based supply chain design • Greening humanitarian supply chains • Local, regional vs. global sourcing and capacity building
Responding to new challenges	• Urbanization • Climate change adaptation • Security

2.3 Problem Definition

In this report we will investigate the problem of designing a returned products collection and redistribution system network in the context of nonprofit organizations. Key success factors in managing humanitarian supply chains fall into two broad categories, namely, (a) preparedness and readiness and (b) unity of direction and cohesive control of responding agencies [73]. Our aim is to design a model of a collection and redistribution system network that reduces the cost in a nonprofit supply and increases benefits to beneficiaries. In the next section, we will present the framework that is followed to deliver our model.

2.3.1 Nonprofit Multi-Commodity Collection and Redistribution System

In the commercial reverse logistics, reverse production systems (RPSs) include collection, sorting, remanufacturing, and refurbished processes networked by reverse logistics operations to recover discarded products [78]. On the other hand, in the nonprofit reverse logistics environment, multi-commodity collection and redistribution systems (MCRSs) include collection, sorting, recycling, and redistribution processes networked by reverse logistics operations to recover different returned products for the benefit of society. MCRS model can be represented by a multi-tier network, where retuned products, such as leftovers, end-of-life electronic devices or remnants of pharmaceuticals, flow between these tiers from an upstream boundary tier to a downstream one through intermediate tiers. Centers in the upstream tier that could be seen as nonprofit organizations collect returned products from supply sources, such as residential households, businesses, schools, hotels, pharmacies or the government. The quantity of the collected items can be different from one source to another depending on the collection response time, the size of the source and the willingness to donate. The Intermediate tiers may contain several levels of centers which receive these returned products and perform value-added processes such as sorting, disassembling or recycling operations. Centers in the downstream tier collect returned products from intermediate centers and conduct refurbishment processes before the distribution to beneficiaries who are scattered in different locations. Figure 6 on page 50 shows a nonprofit multi-tier MCRS network structure, which consists of M_1 supply sources, M_2 centers in the upstream boundary tier, $\mathrm{M}_3, \ldots, \mathrm{M}_{\mathrm{N}-2}$ centers in intermediate tiers 3, N-2 , respectively , $\mathrm{M}_{\mathrm{N}-1}$ centers in downstream tier and M_{N} locations in the demand tier.

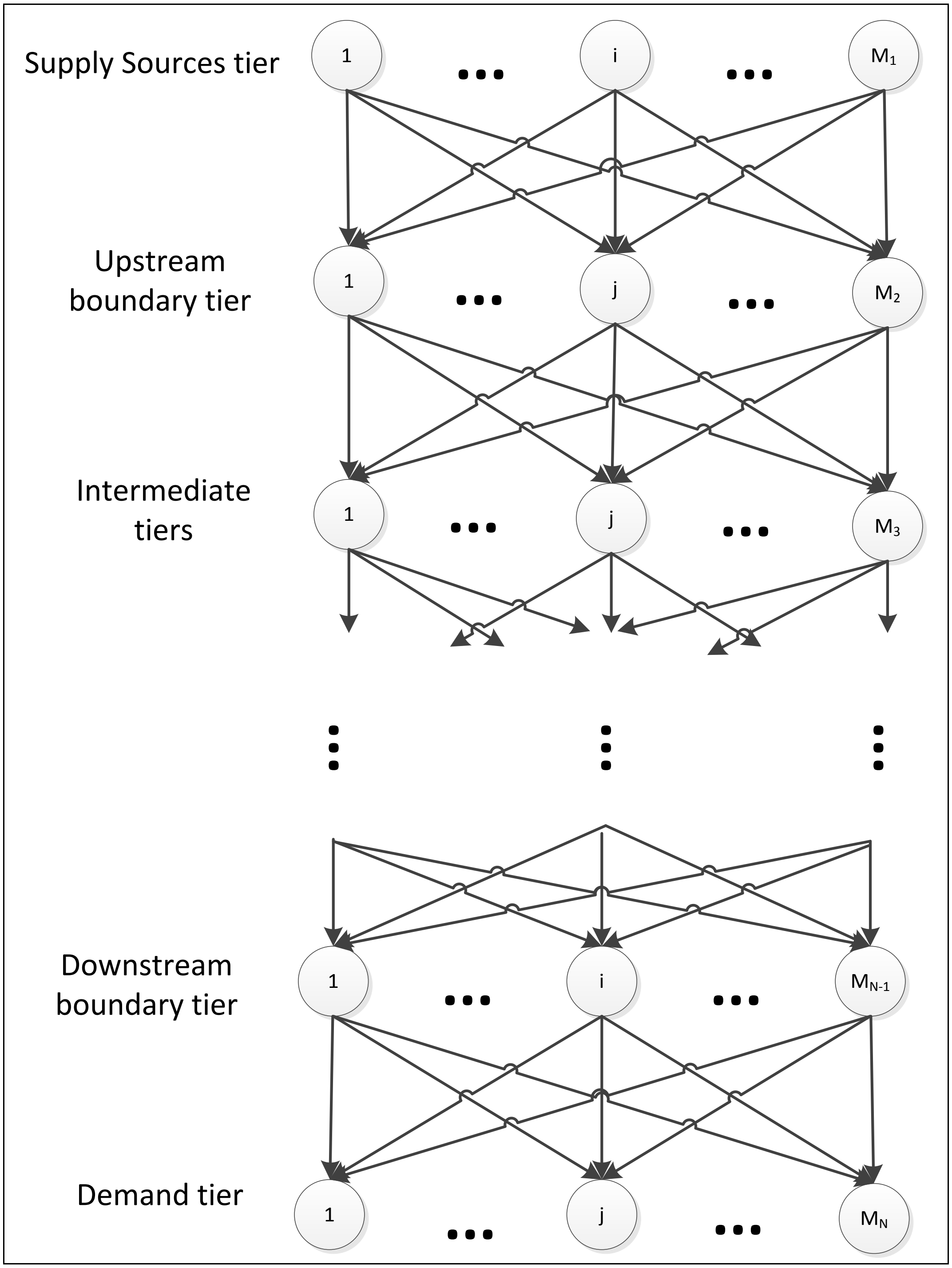

Figure 6 Nonprofit multitier MCRS network structure

To model the location of the centers, allocation of different resources and the material flows in MCRS, two scenarios are possible: centralized or decentralized models.

In the first scenario, we have one centralized center in each tier that receives returned products provided from different supply sources to be distributed to different demand locations. In this scenario, we notice that the cost of allocated resources is reduced as we have only one centralized center. However, the cost of transportation from supply sources to the centralized center and from that center to demand locations is increased.

In the decentralized scenario, we allocate one or more centers in the upstream, intermediate and downstream tiers for each supply source exclusively. In this scenario, despite the decrease in transportation cost to supply sources, we observe that the cost of resources allocated is increased as more centers are located.

In order to increase the amount of returned products collected and redistributed to satisfy the demand at the lowest cost and highest quality, we will consider a third scenario that determines the point of centralization or decentralization in modeling the MCRS. In this scenario, centers in different tiers should be located in areas that combine proximity of supply sources and zones with the most demand density. In addition, the optimal allocation of resources for these centers should be determined.

To integrate the MCRS in reverse logistics of humanitarian aid, we must determine the number and location of the centers in the returned products collection and redistribution network and the amount of inventory in these centers in light of the limited resources. Designing a MCRS network that reduces the cost in a nonprofit supply chain and increases benefits to society is essential to achieve the goal of returned products collection and redistribution effectively and efficiently. In the next chapters we will present a case study of designing an Eta'am food excess collection and redistribution system model and an Eta'am MCRS model. The following is Eta'am's existing process description.

2.3.2 Eta'am Process Description

Food insecurity is defined as the limited or uncertain availability of nutritionally adequate, safe foods, or a person's inability to acquire personally acceptable foods in socially acceptable ways. The recession of 2008–2009 has exacerbated the food insecurity problem. For example, in the United States of America close to 49 million people were found to be ''food insecure'' up from 36 million in 1997. A shortage of supply is not the problem as a surplus of food exists, even in countries poorer than the United States. However, the challenge is to distribute the available food to the beneficiaries. [73]

A typical nonprofit food bank in the United States is provided food through donations by individuals, grocers and other organizations. The food must be inspected for usability following strict standards to eliminate food packages that are damaged or having expired use-by dates. The food is then assembled in bulk lots by the food bank and distributed to other organizations that prepare the food through free meals or provide it in packaged form to the food insecure families. [73]

In Saudi Arabia, the amount of leftovers is increasing due to the population increase and other habits and customs related to the local culture. Eta'am operations are aiming to mobilize food from hotels, big social and professional function halls and companies that are signing a partnership agreement with Eta'am according to the "food conservation program" which has already recorded nineteen agreements in the cities of Khobar and Dammam.

Figure 7 Surplus food is wasted in huge amounts

Figure 8 Improper dispose of leftovers

The ultimate goal of all operational processes is to provide the best meal in terms of the arrangement, appearance, cleanliness and quality. The process consists of three main stages:

1. The planning Stage

2. The Packaging Stage

3. The Distribution Stage

First: The Planning Stage

- Construct a weekly schedule of all events held in hotels, halls and companies that cooperate with Eta'am.

- Allocate scheduled events to the teams and assign a supervisor to each team.
- Each team arrives at the appropriate place at the agreed time.
- Upon arrival, the supervisor assigns tasks to each team member.

Second: The Packaging Stage

- The entire team begins by sterilizing hands, putting on gloves, masks and headwear and taking into account all health and safety measures.
- The supervisor and team begin to test the excess food in terms of color, smell and taste. Nonconforming food will be appropriately disposed of.
- The temperature of the conforming food is measured to establish that it satisfies certain health criteria. Nonconforming food will be appropriately disposed of.

Figure 9 Filling food into boxes

- The conforming food is placed in special boxes that contain balanced, integrated and healthy meals in terms of carbohydrates, proteins and sugars.

Figure 10 Meals contains healthy nutritious

- After boxes are filled with meals, they are packaged and information is written on each box that shows the name of the hotel of provenance, the date and time. The packaged boxes are collected in baskets and placed in cars equipped for food storage.

Figure 11 Packaging meals

Third: The Distribution Stage

- If the packaging stage finishes during the working shift of charities, then the food baskets are delivered to two central charities, one in Dammam and the other in Khobar. From there they are distributed immediately to beneficiaries. In the Dammam charity, the boxes are home delivered but in the Khobar charity, the beneficiaries come and collect the boxes themselves.

- If the packaging stage finishes after the working shift of charities in the functions, which end late at night or early morning, the boxes are stored in chillers at $5^{o}C$, a temperature in which bacteria cannot grow. They are distributed the same day through the two charities in the same way.

Figure 12 Equipped cars used to distribute excess food

Figure 13 on page 60 shows the general process map of Eta'am. Basically, the excess food is provided by well-known hotels, wedding halls and restaurants. Additional food is obtained from large events held by some families. In seasons such as Ramadan, "Iftar" campaigns and mosques are additional sources of excess food. Nonperishable food is collected, packaged, and stored temporarily. The food is then redistributed to beneficiaries directly or through societies. Figure 14 on page 61 illustrates this food supply chain.

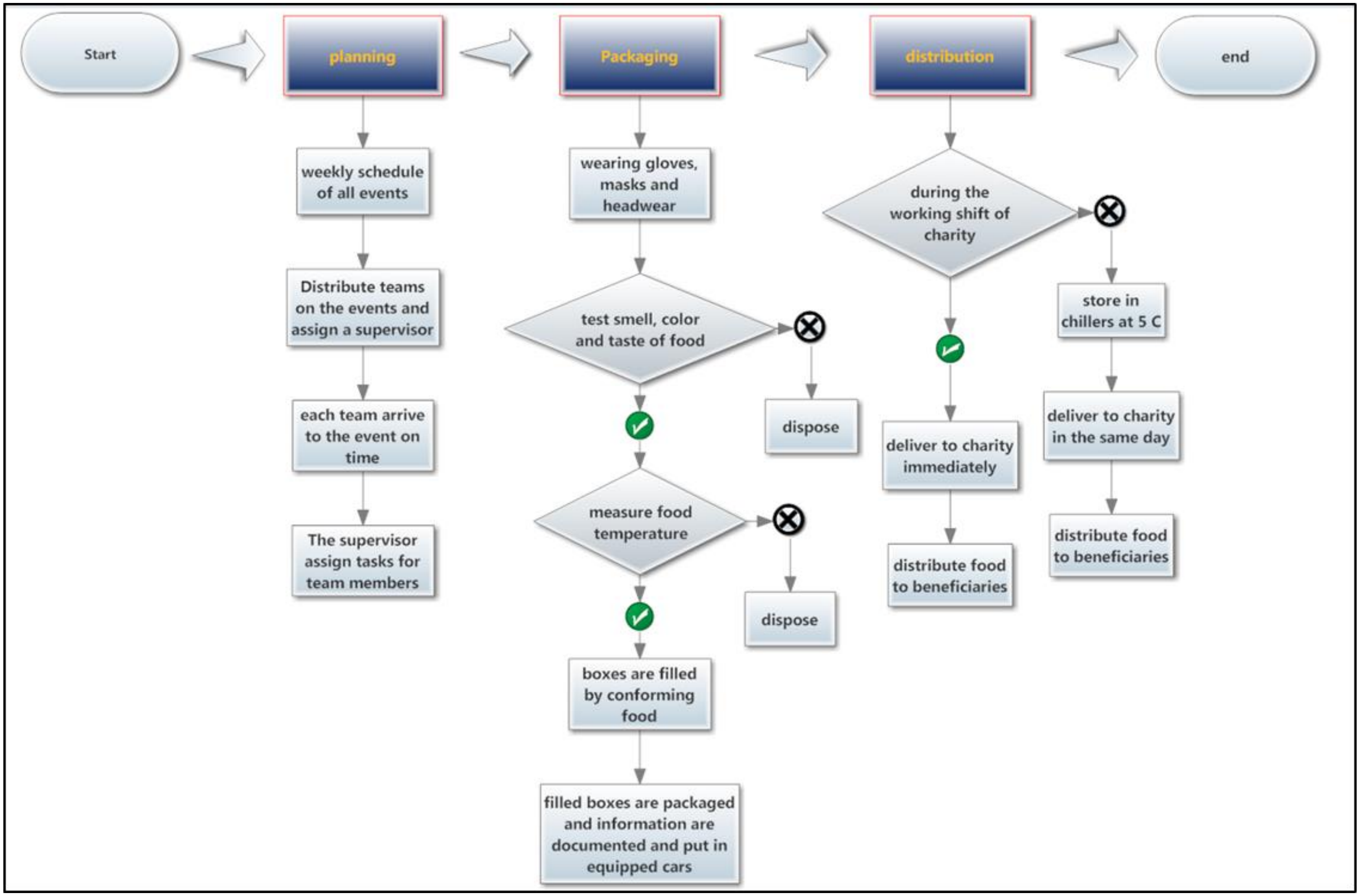

Figure 13 Eta'am process map

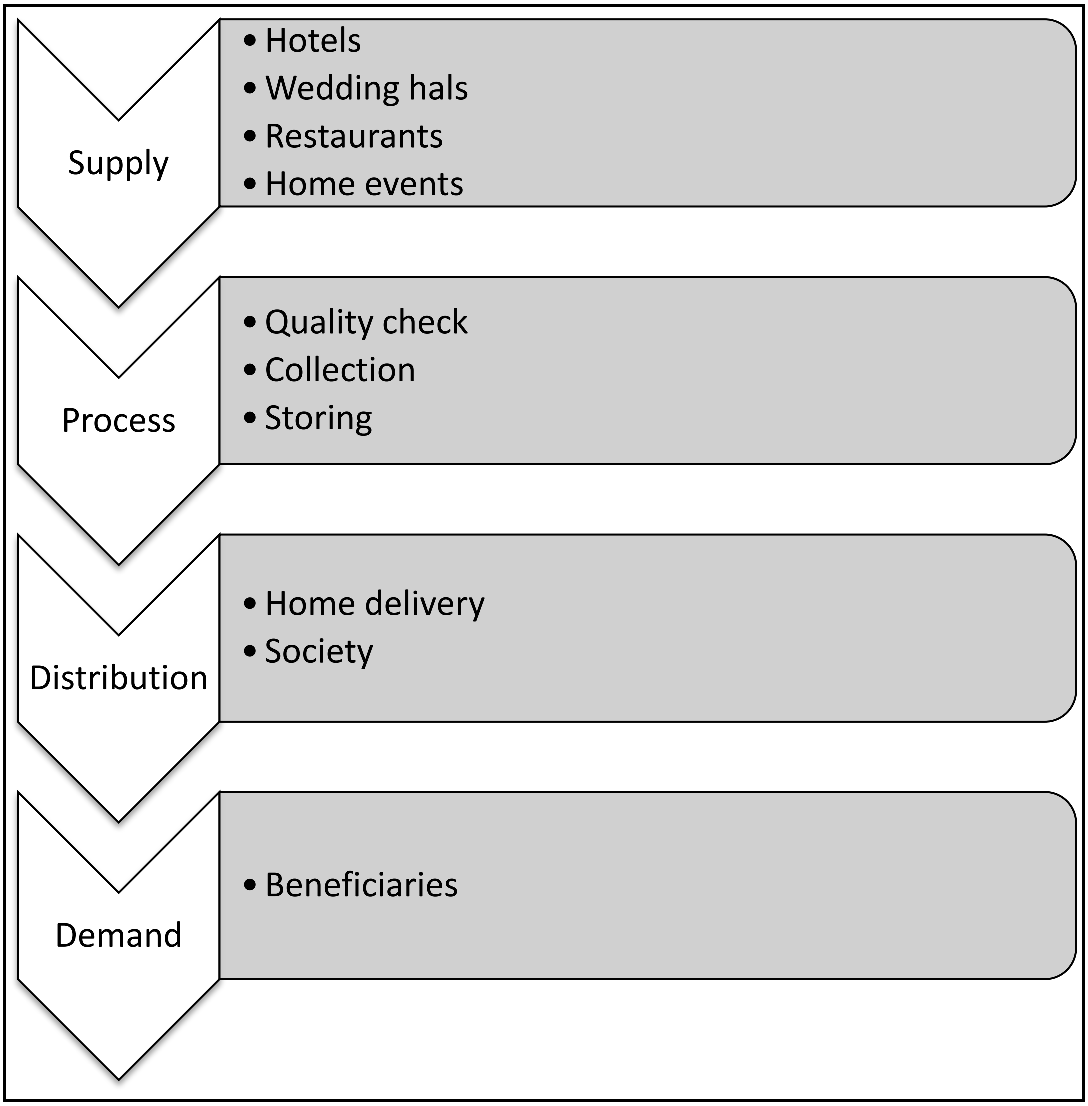

Figure 14 Food supply chain for Eta'am

2.4 Summary

In this chapter, we have reviewed the literature for the supply network design in nonprofit reverse logistics and classified the results into two main types: the closed loop and the reverse logistics network design. Then, we presented the framework that is followed to achieve the thesis objectives before concluding the chapter by presenting the existing operations process of Eta'am.

CHAPTER 3

ETA'AM FOOD EXCESS COLLECTION AND REDISTRIBUTION SYSTEM

3.1 System Description

After the great success of Eta'am in its first experience of having contributed significantly to the increased awareness of the importance of redistribution of leftovers in the cities of Khobar and Dammam, senior management decided to expand its scope to include central and eastern regions of the Kingdom of Saudi Arabia. The choice fell on four additional cities for opening administrative offices of Eta'am in those regions, namely Al-Ahsa, Hofuf, and Jubail in the eastern region and Riyadh in the central region. The goal of Eta'am is a clone of its experience in Khobar and Dammam to include these areas in order to:

1. create community awareness of the importance of proper redistribution of excess food in the expanded areas;
2. distribute excess food to beneficiaries in the expanded areas with the best quality and safety standards;

3. create new jobs for those ambitious generations in the expanded areas, including the training of a number of children of beneficiary families so that they can become self-reliant in the future;

4. motivate all segments of society in the expanded areas towards volunteer work;

5. professionally promote and present philanthropic work in the expanded areas.

All of the above objectives are of great importance to reach the ultimate goal of Eta'am which is preventing food wastage. Each of these goals requires a careful study, strategic planning and execution programs to ensure the achievement of the processes on the ground in the most expedient way. The scope of this study is focused on the second goal of Eta'am through the design of a food excess collection and redistribution system (FECRS) that connects the targeted areas and their surroundings. The first step to take is to describe the problem to find out how to formulate it as a mathematical model that can be solved by different algorithms. After the description of the operations of Eta'am within the cities of Khobar and Dammam, our aim is to describe how FECRS can be modeled after the expansion to the new range. Eta'am will be contracted with many hotels and function halls which will represent supply sources of excess food. This excess food is the leftovers after events and occasions which are held in these hotels at different times of the day, often for lunch or dinner. However, those events may not occur at all during the day in some supply sources or several occasions may occur for more than one supply source simultaneously. A large amount of returned food usually results but it differs from one occasion to another depending on their size. Supply sources are scattered in different places in the expanded areas. Eta'am is required to collect excess food in all of the events held in those supply sources at all times in order to distribute it to the beneficiaries who are distributed in different areas in the expanded areas. Data and information of their whereabouts can be accessed from the Ministry of Social Affairs or charities that work in this field. Beneficiaries usually receive all the quantities of excess food offered to them.

During any event, Eta'am has to allocate resources for the collection process that include a team furnished with the necessary equipment to collect excess food and cars prepared for transfering it to storage places. Eta'am's task is to collect and distribute this food to beneficiaries at the right time, at the lowest cost and highest quality. By the right time we mean the time that allows the provision of resources to any supply source immediately after the end of the event. This is because arriving at the supply source a long time before the end of the event will cause resources to lie idle. At the same time, arriving at the supply source a long time after the event will cause problems for the supply source and may result in food spoilage. Further, by the lowest cost we mean that we need to determine the appropriate amount of resources that match the quantity of excess food. The lowest cost also includes reducing the cost of transportation between centers while collecting excess food from supply sources on the one hand and between these centers and among the beneficiaries to redistribute excess food on the other.

Eta'am is applying the following scenario for designing FECRS network. Each supply source is considered as a center for storing food in addition to being a redistribution point to the beneficiaries. Each source is provided with the necessary equipment for food preservation and storage. Excess food is collected from these sources and redistributed to beneficiaries who are located in different places over a wide area. In this scenario, despite the fact that the transportation cost to supply sources is decreased, we notice that the cost of resources allocated to supply sources is increased. Also, the cost of storing excess food is increased because of the decentralization of storage points. Figure 15 shows nonprofit decentralized FECRS network structure, which consists of M_1 supply sources, M_2 decentralized centers where the upstream, intermediate and downstream tiers are combined in one tier and M_3 locations in the demand tier.

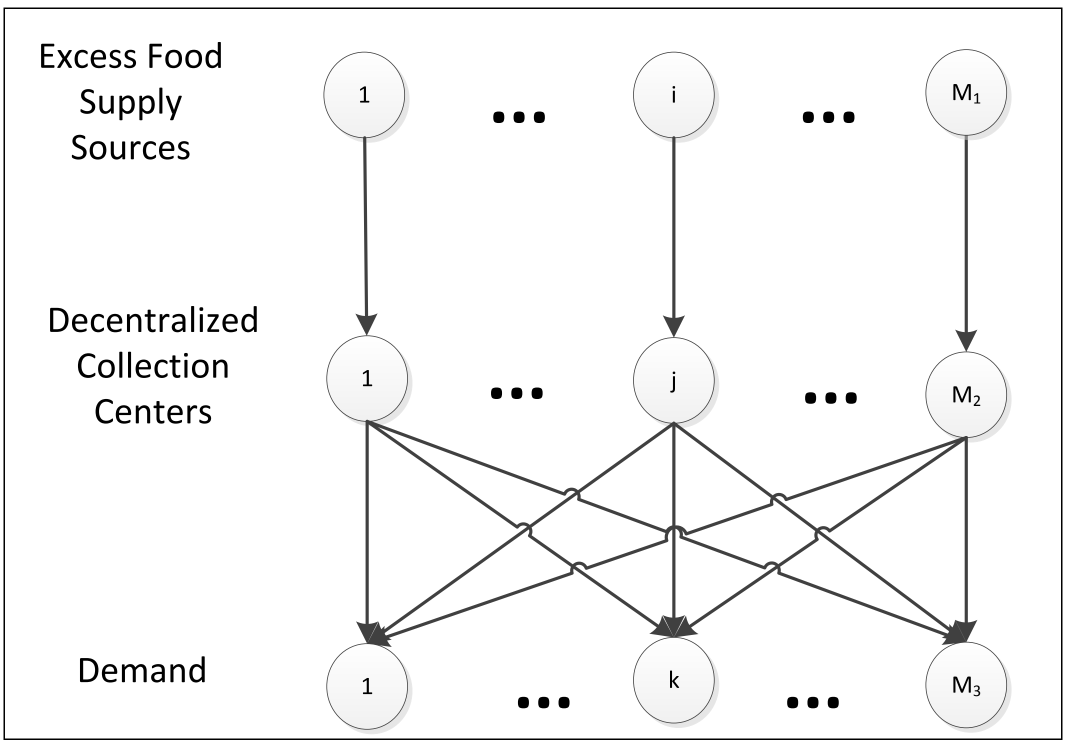

Figure 15 Nonprofit decentralized FECRS network structure

In contrast, other charities collect excess food in a centralized center for all supply sources. After that, the excess food is redistributed to beneficiaries from this centralized center. In this scenario, we notice that the cost of allocated resources is reduced as we have only one centralized center. However, the cost of transportation from supply sources to the centralized center and from that to demand locations is increased. Figure 16 shows nonprofit centralized FECRS network structure, which consists of M_1 supply sources, one centralized collection and redistribution center where the upstream, intermediate and downstream tiers are combined in one tier and M_3 locations in the demand tier.

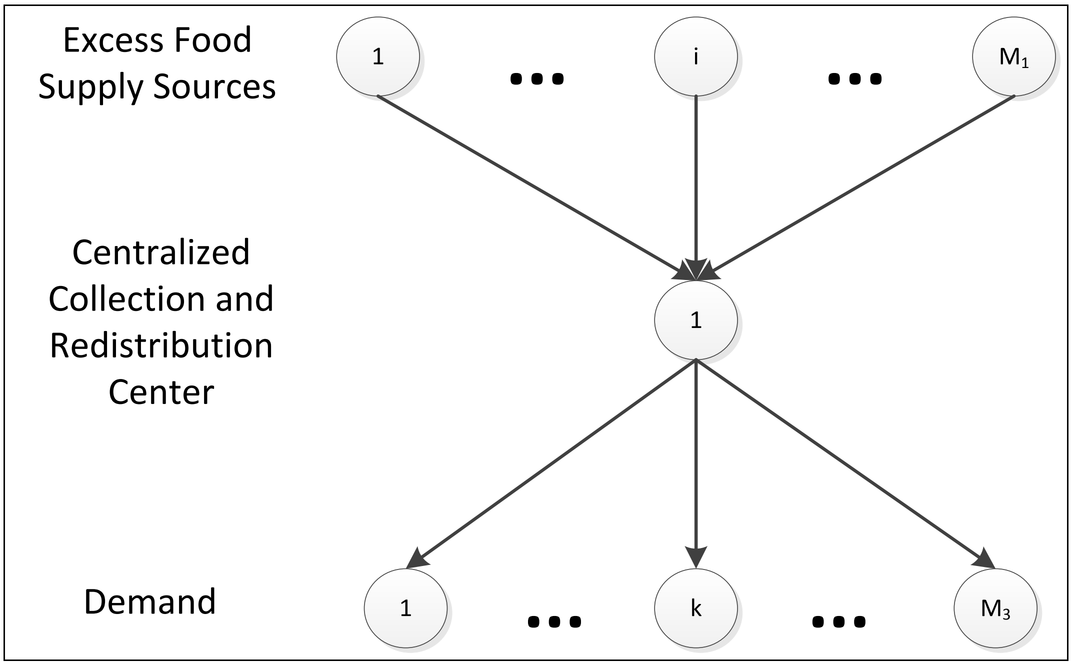

Figure 16 Nonprofit FECRS network structure

In order to ensure the achievement of the goal of Eta'am in terms of increasing the amount of returned food collected and redistributed to the beneficiaries at the lowest cost and highest quality, we will consider a third scenario that determines the degree of centralization or decentralization of the collection and redistribution processes and balances between collecting the largest amount of excess food and the cost of collection, storage and redistribution to beneficiaries in modeling the FECRS network. In this scenario, collection and redistribution centers should be located in areas that combine proximity of supply sources and areas with the most demand density. When events are held in supply sources, the necessary resources must be provided to them at the right time. After that, excess food is collected and transferred to the collection and redistribution centers for storage before transporting to the beneficiaries. Figure 17 shows nonprofit FECRS network structure, which consists of M_1 supply sources, candidate collection and redistribution centers where the upstream, intermediate and downstream tiers are combined in one tier and M_3 locations in the demand tier. The dashed arrows in the figure indicate that we need to determine the optimal solution among these potential assignments.

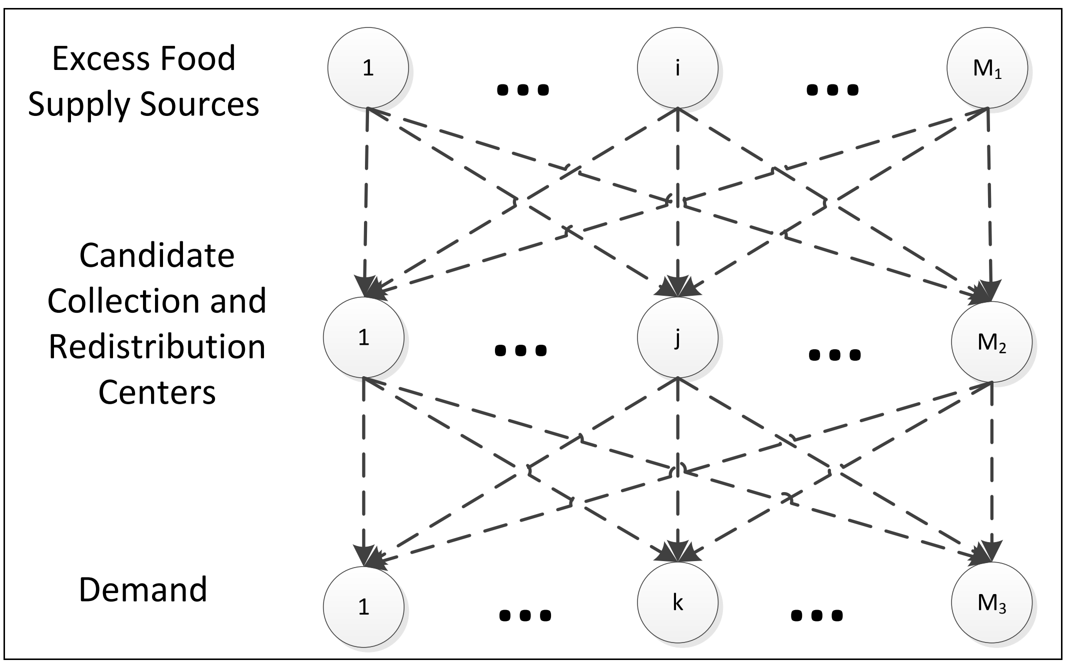

Figure 17 Nonprofit FECRS network structure

To integrate Eta'am FECRS in reverse logistics of humanitarian aid, we must determine the number and location of the centers in the excess food collection and redistribution network and the amount of inventory in these centers in light of limited resources.

Designing FECRS network that reduces the cost in a nonprofit supply chain and increases benefits to beneficiaries is essential to achieve the goal of excess food collection and redistribution effectively and efficiently. In the next section we will present FECRS model formulation.

3.2 Model Assumptions

1. The collection of the excess food can be achieved at different coverage levels, where each coverage level, l is characterized by an upper and lower response time limit UR_l and LR_l , respectively.

2. The coverage efficiency, α_l decreases as coverage level increases, and is represented by a decreasing step function. That is, for coverage levels $1 \leq 2 \leq \cdots \leq l \leq \cdots \leq L$, the associated efficiencies are $\alpha_1 = 1 > \alpha_2 > \cdots > \alpha_l > \cdots > \alpha_L \geq 0$.

3. $N_s(l)$ represents the set of collection and redistribution center (CRC) candidates that can provide coverage level l for excess food provided by supply source i.

4. We assume excess food characteristics (criticality, response time limits) are identical for different supply sources.

5. Collection of excess food can only be achieved from CRCs that can cover the corresponding supply source location.

6. The cost of establishing CRCs is constrained by a setup budget

7. The transportation costs associated with collecting and delivering excess food supplies from supply sources to CRCs and from CRCs to demand locations for any event scenario are assumed to be limited by a redistribution budget.

8. Multiple supplies will not occur simultaneously.

9. Capacity restrictions on each CRC in the network are imposed.

The following figure on page 71 illustrates different coverage levels for excess food provided by a single supply source which is an event in the Novotel Hotel. In this example, there are three candidate CRCs and two coverage levels, where the inner polygon represents the first coverage level. CRC candidates at $j = 1$ and $j = 2$ are within the first and second coverage levels, respectively, whereas the CRC candidate at $j = 3$ is outside of both coverage levels and can therefore not collect excess food from the event location.

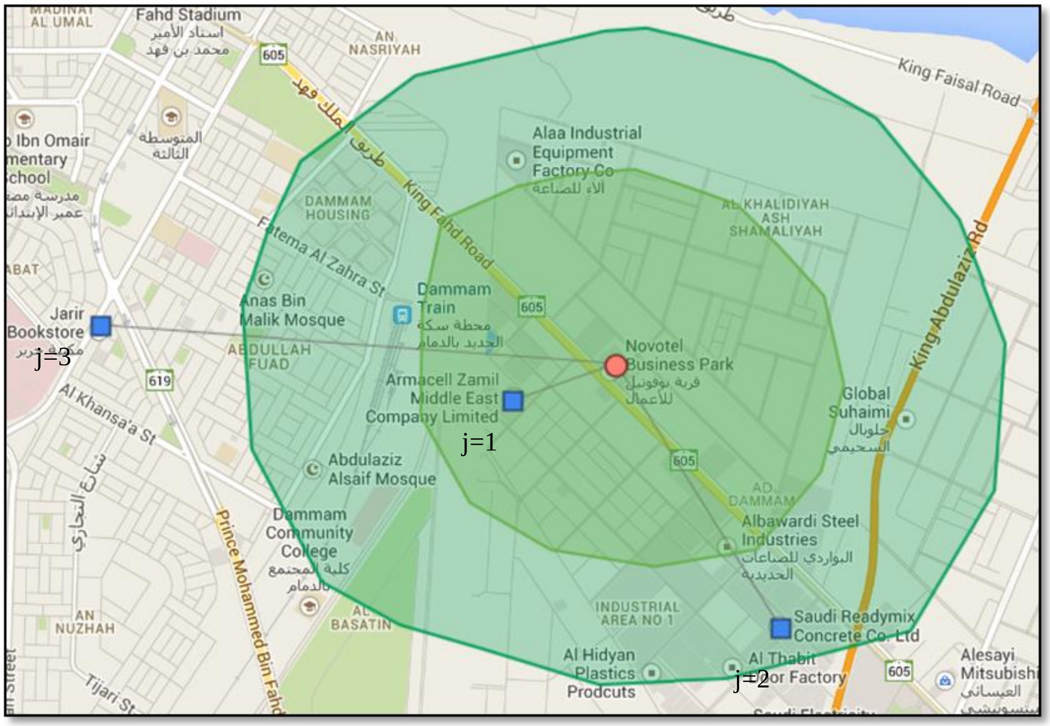

Figure 18 Different coverage levels for excess food provided by a single scenario

So, our objective is to choose the set of CRCs in the network that maximize the coverage efficiency of events and beneficiaries. This depends not only on the quality of events coverage, but also on the capability of satisfying the expected demand within a short timeframe.

3.3 Model Formulation

The following notation is used to formulate the facility location model for CRCs:

Sets

S set of supply sources; $i \in S$

M set of demand locations; $k \in M$

N set of candidate CRCs; $j \in N$

Parameters

p_i probability of occurrence of supply source i

U_i expected amount of excess food in supply source i (units)

D_k expected demand of excess food in demand location k (units)

Cap_j capacity of CRC j (volume)

γ unit volume of excess food

B_0 budget allocated for establishing CRCs (SR)

B_1 budget allocated for redistribution process (SR)

F_j fixed cost of establishing CRC j (SR)

g_{ij} unit cost of transporting excess food of supply source i to CRC j (SR/unit)

c_{jk} unit cost of shipping excess food from CRC j to demand location k (SR/unit)

t_{ij} time to transport excess food from supply source i to CRC j (minutes)

l coverage level for excess food

α_l coverage level weight $\alpha_1 = 1 > \alpha_2 > \cdots > \alpha_l > \cdots > \alpha_L \geq 0$

$N_i(l)$ candidate CRC locations that can provide l coverage level for excess food for supply source i; $N_i(l) = \{j | LR_l < t_{ij} \leq UR_l\}$

where

LR_l lower response time limit defining coverage level l, and

UR_l upper response time limit defining coverage level l

Decision variables

f_{ij} proportion of excess food acquired by CRC j in supply source i

d_{jk} proportion of excess food demand k satisfied by CRC j

$$X_j = \begin{cases} 1, & \text{if CRC j is located} \\ 0, & \text{otherwise} \end{cases}$$

The formulation for the problem is as follows:

$$\max \sum_{i} \sum_{j \in N_i(l)} \sum_{l} p_i \alpha_l U_i f_{ij} \tag{3.1}$$

Subject to

$$\sum_{i \in S} \gamma U_i f_{ij} \leq Cap_j X_j \qquad \forall j \in N \tag{3.2}$$

$$\sum_{j \in N} (F_j X_j) \leq B_0 \tag{3.3}$$

$$\sum_{j \in N} \left(\sum_{k \in M} D_k d_{jk} c_{jk} + \sum_{i \in S} U_i f_{ij} g_{ij} \right) \leq B_1 \tag{3.4}$$

$$\sum_{k \in M} D_k d_{jk} - \sum_{i \in S} U_i f_{ij} = 0 \qquad \forall j \in N \qquad (3.5)$$

$$\sum_{j \in N} f_{ij} \leq 1 \qquad \forall i \in S \qquad (3.6)$$

$$\sum_{j \in N} d_{jk} \leq 1 \qquad \forall k \in M \qquad (3.7)$$

$$f_{ij}, d_{jk} \geq 0 \qquad \forall i \in S, \forall k \in M, \forall j \in N \qquad (3.8)$$

$$X_j \in \{0,1\} \qquad \forall j \in N \qquad (3.9)$$

The objective function (3.1) maximizes the total expected supply of excess food covered by the established CRCs. Constraint set (3.2) guarantees that the supply is held only at established CRCs, and the amount of supply kept at any of these centers does not exceed its capacity. Constraint (3.3) requires that the expenditures related to establishing a CRC do not exceed the determined budget, and constraint set (3.4) guarantees that the transportation costs incurred between supply sources, CRCs and demand locations are less than the expected redistribution process budget. Constraint set (3.5) guarantees that the amount of supply collected from supply sources is redistributed totally to demand locations. Constraint set (3.6) ensures the amount of collected excess food of a supply source does not exceed the actual excess food. Constraint set (3.7) ensures the amount of excess food sent to satisfy the demand does not exceed the actual demand. Finally, constraint set (3.8) is the non-negativity constraint on the proportion of excess food collected and proportion of demand satisfied and constraint set (3.9) defines the binary location variable.

3.4 Numerical Analysis

In this section, we introduce the implementation of the proposed FECRS network design model and present computational results.

3.4.1 The Data Set

The parameters that are required to analyze the model are developed by analyzing the data obtained from the Eta'am database that contains data collected between 2012 and 2013 for the cities of Dhahran, Khobar, Dammam and Alhasa. From this database, we identified the locations of the source suppliers, the number of visits for each supplier and the amount of supply at each visit.

The total number of supply sources which have a contract with Eta'am is 50, 20 of which are hotels, 19 wedding halls, 8 restaurants, 2 universities and one company. We grouped supply sources based on their supply level. We consider three types of supply sources which were chosen based on the amount of food provided per visit as shown in table 7 on page 76.

Table 7 Source supply level

Supply Level	Amount of food (meals/visit)	Number of events	Number of supply sources
1	≤ 100	768	25
2	≤ 200	474	18
3	> 200	295	7

For our computational experiments, we estimated the probability of occurrence associated with each supply source based on past data for number of visits. Supply source occurrence likelihood was assumed to be equal to the fraction of visits for the same supply level. The probability of occurrence associated with each supply source and the amount of supply at each visit is provided in table 8 on page 77.

Table 8 Food supply sources parameters

Supply Source	Probability of occurrence	Amount supplied (food box)
1	0.023	95
2	0.305	205
3	0.133	134
4	0.044	174
5	0.163	244
6	0.035	93
7	0.495	220
8	0.127	184
9	0.226	168
10	0.547	35
11	0.019	153
12	0.057	154
13	0.087	46
14	0.006	116
15	0.010	277
16	0.006	147
17	0.070	189
18	0.004	103
19	0.004	65
20	0.001	70
21	0.006	132
22	0.001	80
23	0.023	80
24	0.003	83

25	0.001	56
26	0.001	19
27	0.001	100
28	0.035	22
29	0.035	22
30	0.035	22
31	0.035	25
32	0.009	46
33	0.035	74
34	0.035	74
35	0.036	106
36	0.034	164
37	0.078	144
38	0.086	168
39	0.003	77
40	0.003	65
41	0.027	168
42	0.035	74
43	0.001	33
44	0.008	179
45	0.007	85
46	0.032	189
47	0.020	412
48	0.003	227
49	0.003	700

We assumed two coverage levels for excess food. The lower and upper response time limits are set to one and two hours, respectively. The first and second coverage benefit levels are set to 1 and 0.7, respectively.

For the location of the demand points, we consider it to be the location of charities through which Eta'am is delivering excess food to beneficiaries. We neglect the process of distributing excess food from charities to beneficiaries. As a result we have 9 demand locations. According to the collected statistics, the demand always exceeds the supply.

For the location of candidate centers, we constructed grid cells with dimensions of one kilometer between each one inside the city and two kilometers outside the city and located a candidate center at the corner of each grid cell. The resulting candidate center locations number 600.

The unit volume of the meal box is 0.0015 m^3. There are two types of centers, one with a capacity of 1,800 meals and 400,000 SR as a setup cost and the other has a capacity of 5,400 meals and a setup cost of 1.8 million SR. The cost of collecting a meal is the sum of transportation vehicle expenses (1.585 SR/km) and labor cost (3.00 SR/km) as a rate of traveled kilometers where we have three workers on average for this process. The cost of distributing a meal is the sum of transportation vehicle expenses (1.585 SR/km) and worker cost (2.00 SR/km) as a rate of traveled kilometers where we have two workers on average for this process. The parameters required by the model are summarized in table 9 on page 80.

Table 9 FECRS model parameters

Candidate center capacity	Type 1: 1800 meals Type 2: 5400 meals
Fixed cost of locating a candidate center	Type 1: 400,000 SR Type 2: 1,800,000 SR
Unit cost of collecting a meal	$4.585\ (SR/\text{Km}) \times \text{distance between points (Km)}$
Delivery time between candidate center and supply source or demand	$\text{distance between points (Km)} \,/ 60\,\frac{Km}{Hr}$
Unit cost of distributing a meal to demand points	$3.585\ (SR/\text{Km}) \times \text{distance between points (Km)}$

3.4.2 Computational Results

In this section, we present and discuss the results obtained by solving the proposed model for the above parameters using LINGO 13.0. The solver status shows that the model consists of 3600 variables and 1262 constraints. The generator memory used is 28991 K and the average elapsed runtime is 21 second. The computer used to run the solver has Windows 7 Professional operating system, Intel(R) Core(TM) i5-2500 CPU @ 3.30GHz processor and 4.00 GB installed memory (RAM).

We ran the model for the current existing operations by Eta'am at budget constraints specified by the management. The results are provided in table 10 on page 81. By solving the model at different combinations of budgets, we obtain a better alternative solution that reduces the required budget by 13.3 %. The details of this solution are shown in table 11. Figure 19 on page 82 shows the current and alternative solutions and connections between the opened CRCs, supply sources and demand points for Khobar. Figure 20 on page 83 shows the solutions for Al-Ahasa.

Table 10 Results of current FECRS model

B0 (SR million)	B1 (SR million)	Number of CRC to open	Excess food acquired (%)	Average Response time (hrs.)	Suppliers Served at 1^{st} Coverage Level (%)
2.2	0.8	2	96	0.15	90

Table 11 Results of alternative FECRS model

B0 (SR million)	B1 (SR million)	Number of CRC to open	Excess food acquired (%)	Average Response time (hrs.)	Suppliers Served at 1^{st} Coverage Level (%)
2.4	0.2	6	100	0.09	100

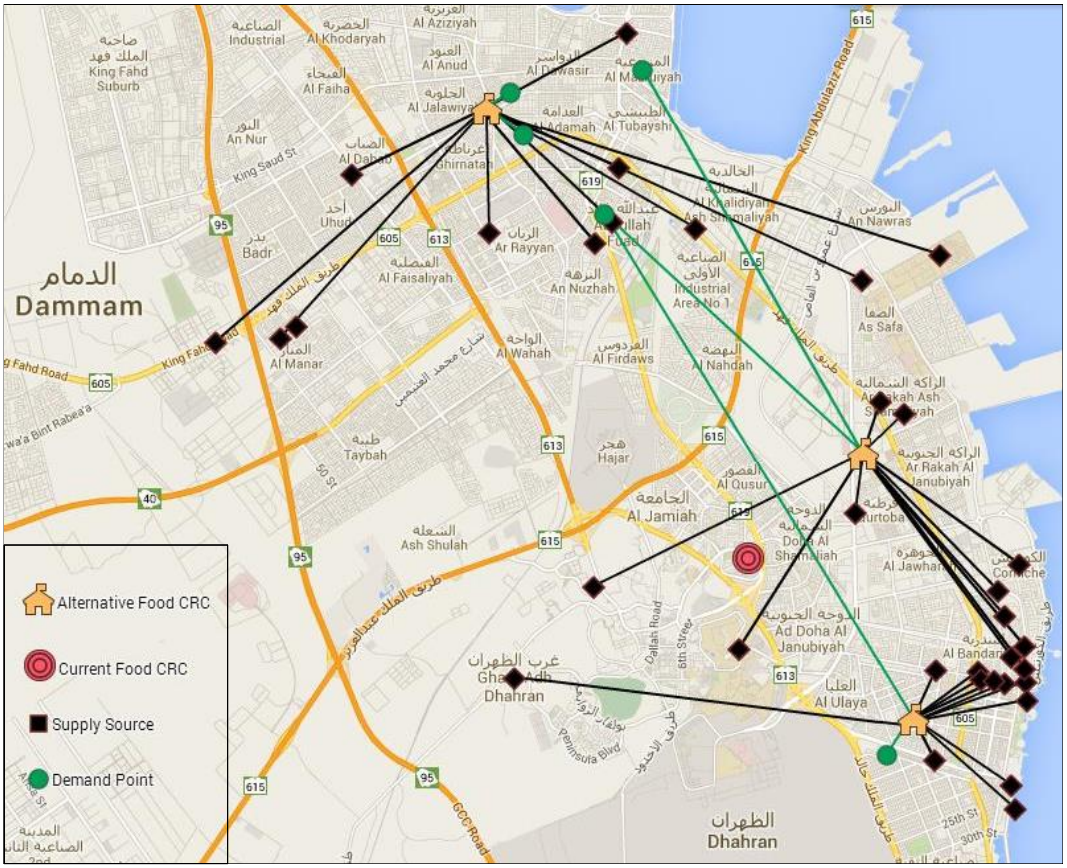

Figure 19 Current and alternative FECRS model for Khobar

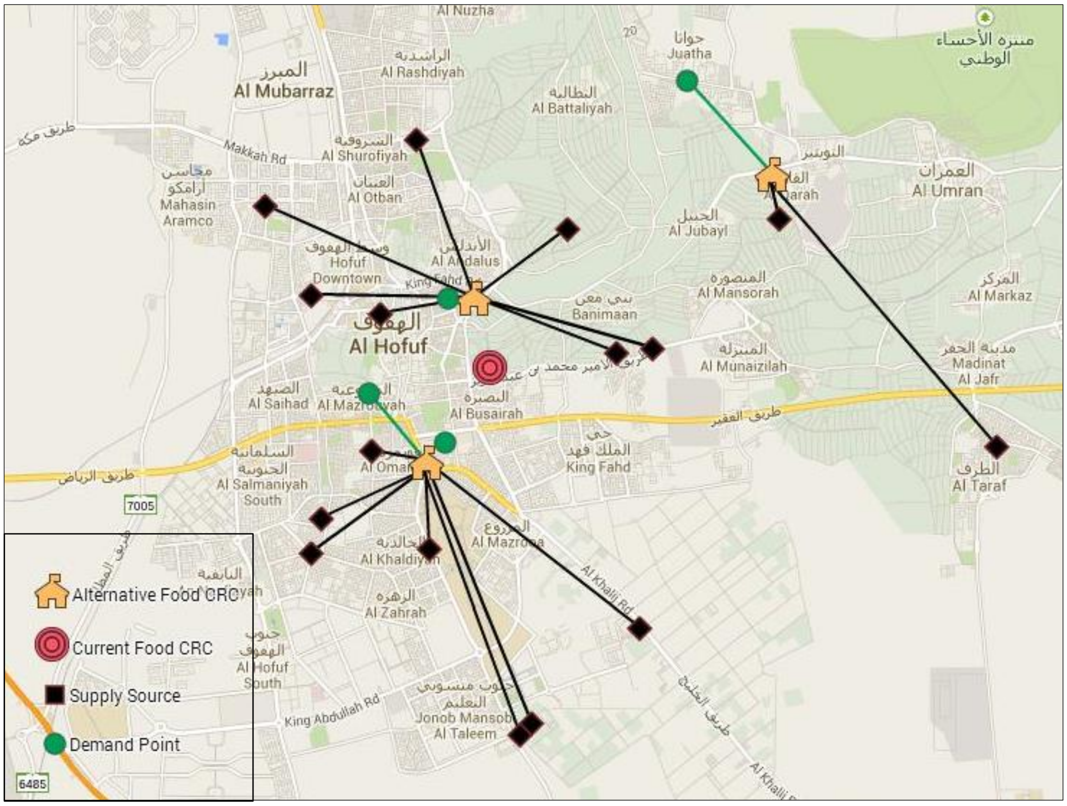

Figure 20 Current and alternative FECRS model for Al-Ahsa

We ran the model for different combinations of budget constraints whose results are provided in tables 12, 13 and 14 on pages 85, 86 and 87, respectively. These tables show the solutions obtained in terms of the number of CRCs opened, the percentage of food acquired, and the average response time to collect a supply of food. The last column of these tables show the percentage of supply sources in which collected food were satisfied at coverage level 1; that is, this column reflect quality of coverage for collected food.

The results in table 12 are obtained by increasing the setup budget while keeping the redistribution process budget constant. When the setup budget was set to its minimum for our example (SR 1,600, 000), the model opened four CRCs. From the results, the average response time is decreased compared with subsequent scenarios, due to the increase of opened CRCs. This is the case also for amount of food acquired.

As we increased the amount of setup budget to 3.2 million SR, the model opened eight CRCs. As shown in table 12, this change reduced average response time slightly.

As the setup budget was further increased, the model responded by locating more CRCs with the quality of coverage for clothes tending to improve as more CRCs were established. It was also observed that the average response time improved generally.

The results obtained for increased setup budget amounts while fixing the redistribution process budget indicated the advantages and disadvantages of establishing a decentralized FECRS.

As the setup budget increased, the distances between facilities and supply sources locations decreased, and hence the system's responsiveness improved. The practical disadvantages of excessive localization in the relief system may include the difficulties in managing many facilities and low throughput at the CRC which may lead to obsolescence.

Table 12 Results of FECRS model Set 1

B0 (SR million)	B1 (SR million)	Number of CRC to open	Excess food acquired (%)	Average Response time (hrs.)	Suppliers Served at 1st Coverage Level (%)
1.6	0.2	4	84	0.07	100
2.4	0.2	6	100	0.09	100
3.2	0.2	8	100	0.08	100

Table 13 shows the results from varying redistribution process budgets while keeping the setup budget constant. When the redistribution process budget is set at a minimal value, the model opened four CRCs. A 100% coverage level is achieved but the percentage of the collected supply is low. As redistribution process funding increased, the number of CRCs remained constant. Moreover, the percentage of collected amount increased.

In summary, as more redistribution process funds became available, the FECRS tended to become centralized on average. Larger supply amounts could be collected by fewer facilities, but at the expense of increased transportation costs and response times.

Table 13 Results of FECRS model Set 2

B0 (SR million)	B1 (SR million)	Number of CRC to open	Excess food acquired (%)	Average Response time (hrs.)	Suppliers Served at 1st Coverage Level (%)
1.6	0.2	4	84	0.07	100
1.6	1.0	4	100	0.32	100
1.6	1.8	4	100	0.15	100

Finally, table 14 shows the results obtained by simultaneously changing the setup and redistribution process budgets. According to the results, as both types of budgets increased, the number of CRCs gradually increased and the amount of collected items increased.

We observed greater improvements in model solutions when both budgets were increased. Those improvements were observed in terms of all response times, as compared to some cases in which only the redistribution budgets increased, while the setup budget was fixed. For example, suppose that both budgets were equal to SR 1.8 million and an additional SR 800,000 were invested for setup and/or distribution logistics. We observed improvements in all performance measures when both budgets were increased equally. The improvement in terms of each measure was slightly higher than what could be obtained when additional money was used exclusively for redistribution investment. However, the model here require more investment in the setup to increase the number of opened CRCs which results in lower redistribution expenses.

Table 14 Results of FECRS model Set 3

B0 (SR million)	**B1 (SR million)**	**Number of CRC to open**	**Excess food acquired (%)**	**Average Response time (hrs.)**	**Suppliers Served at 1st Coverage Level (%)**
1.6	0.2	4	84	0.07	100
2.0	0.6	5	100	0.25	100
2.4	1.0	6	100	0.17	100

CHAPTER 4

ETA'AM MULTI-COMMODITY COLLECTION AND REDISTRIBUTION SYSTEM

4.1 System Description

Another opportunity for Eta'am to develop philanthropy in addition to the spatial expansion is to include other commodities besides excess food such as used clothes, electronic devices and remnants of pharmaceuticals in the MCRS. An excess of these items has increased dramatically in the Kingdom of Saudi Arabia because of the increased consumption and the increased rate of population growth in recent years [79]. However, there is no organization, whether private or government, that collects these items to be recycled and redistributed in a professional manner. Eta'am could take this initiative and design a MCRS network.

The objective is to design a MCRS network that connects the whole expanded areas and aggregates all resources for different commodities to be utilized efficiently and effectively. The first step to take is to describe the problem and find out how to formulate it as a mathematical model that can be solved by different algorithms. After the description of the modus operandi of Eta'am within the expanded regions, we aim to describe how MCRS can be modeled after considering more than one returned item.

Eta'am will be contracted with many businesses, schools, hotels, pharmacies and social and professional function halls which will represent supply sources of returned products. Supply sources provide returned products at different times in different quantities depending on the collection response time, the size of the source and the willingness to donor. Supply sources are distributed in different places in the expanded areas. Eta'am is required to collect returned products from all those supply sources at all times to distribute it to beneficiaries. Those beneficiaries are scattered in different areas in the expanded regions. Data and information of their whereabouts could be accessed from the Ministry of Social Affairs or charities that work in this field.

Eta'am has to allocate different resources for each supply source according to the type of items provided. There are common resources that are needed for all supply sources regardless of the item type, such as cars prepared for transporting items to storage places. Eta'am's task is to collect and redistribute these returned products to beneficiaries at the right time, lowest cost and highest quality. By the right time we mean the time that is required to provide resources to any supply source that is willing to provide returned products. This is because the arrival of the resources a long time before they are needed will cause resources to lie idle. Equally, arrival at the supply source a long time after they are needed will cause problems to the supply source and may result in returned products getting damaged. Also, to achieve the objective at the lowest cost means that we need to determine the appropriate amount of aggregated resources that match the quantity of returned products. The lowest cost also includes reducing the cost of transportation between sources while collecting returned products from supply sources on the one hand

and between these sources and among the beneficiaries after collecting returned products on the other.

Eta'am could apply the following scenario for designing a MCRS network. Each supply source is considered as a decentralized point for storing returned products in addition to a redistribution point to the beneficiaries. Each one of these centers is provided with the necessary equipment that is compatible with the item type returned for collection and storage. In this scenario, despite the fact that the transportation cost to supply sources is decreased, we notice that the cost of disaggregated resources allocated to supply sources is increased. Also, the cost of storing returned products is increased because of the decentralization of storage points. Figure 21 on page 91 shows nonprofit decentralized MCRS network structure, which consists of M_{q1} supply sources of commodity type q, M_{q2} decentralized centers that serve supply sources of commodity type q where the upstream, intermediate and downstream tiers are combined in one tier and M_3 locations in the demand tier.

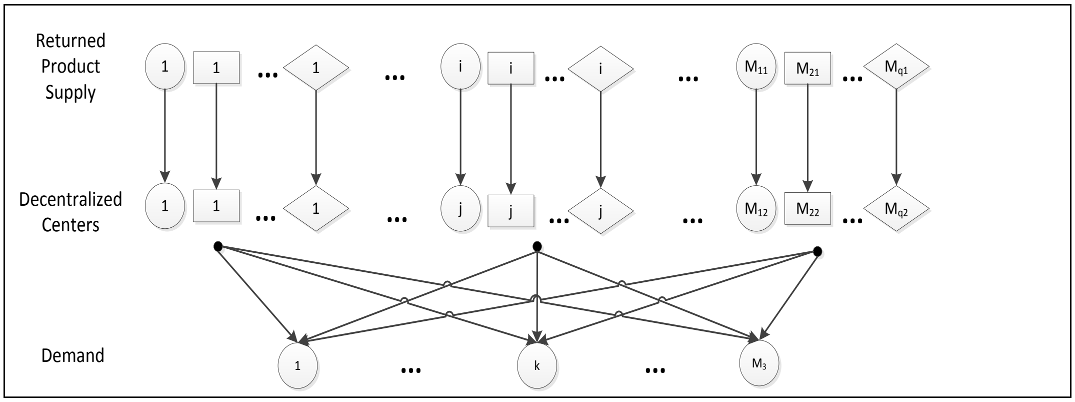

Figure 21 Nonprofit decentralized MCRS network structure

In contrast, the centralized scenario is described as follows. Returned products are collected from all supply sources before transporting to a centralized center for all regions and all item types. In this scenario, we observe that the cost of allocated resources is decreased as all resources are aggregated in one center, but the cost of transportation from supply sources to the centralized center and from that to demand locations is increased. Figure 22 on page 92 shows nonprofit centralized MCRS network structure, which consists of M_{q1} supply sources of commodity type q, a decentralized center that serves all supply sources and all commodity types where the upstream, intermediate and downstream tiers are combined in one tier and M_3 locations in the demand tier.

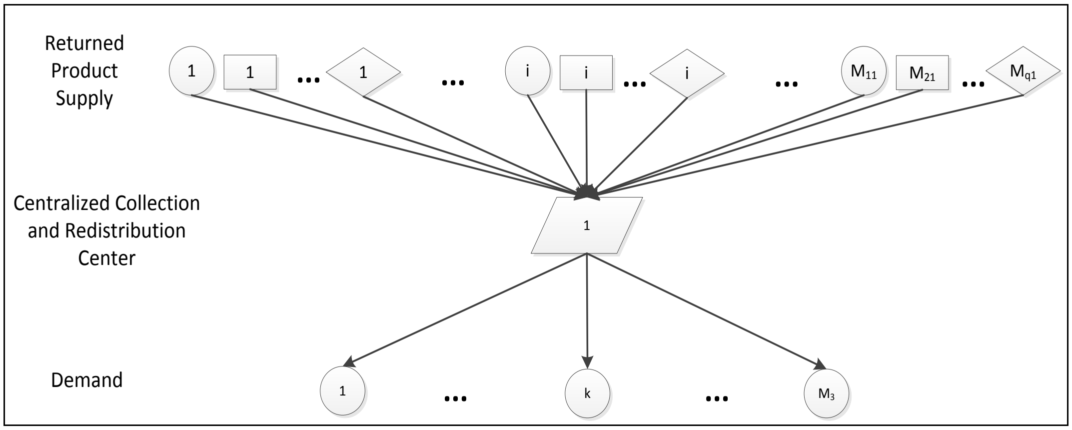

Figure 22 Nonprofit centralized MCRS network structure

To ensure the achievement of the goal of Eta'am in terms of increasing the amount of returned products collected and distributed to the beneficiaries at the lowest cost and highest quality, we consider a third scenario that determines the degree of centralization or decentralization in modeling a MCRS network. In this scenario, collection and redistribution centers should be located in areas that combine proximity of supply sources and areas with the greatest demand density. At the same time, we need to determine the types of these centers according to the commodity type they will receive. As a result, we will have two types of centers, either centers that receive a specific commodity type or centers that receive a mix of types. Given q commodity types, then the total number of different types of centers is $2^{\mathrm{q}} - 1$. When supply sources are willing to donor, the necessary resources must be provided to these sources at the right time. After that, returned products are collected and transported to the collection and redistribution centers for value-added operations such as sorting and refurbishing before transporting to the beneficiaries. Figure 23 on page 93 shows nonprofit MCRS network structure, which consists of M_{q1} supply sources of commodity type q, M_{v2} candidate centers of type v where $1 \leq v \leq 2^q - 1$. We have combined the upstream, intermediate and downstream tiers in one tier and specified M_3 locations in the demand tier. The dashed arrows in the figure indicate that we need to determine the optimal solution among these potential assignments.

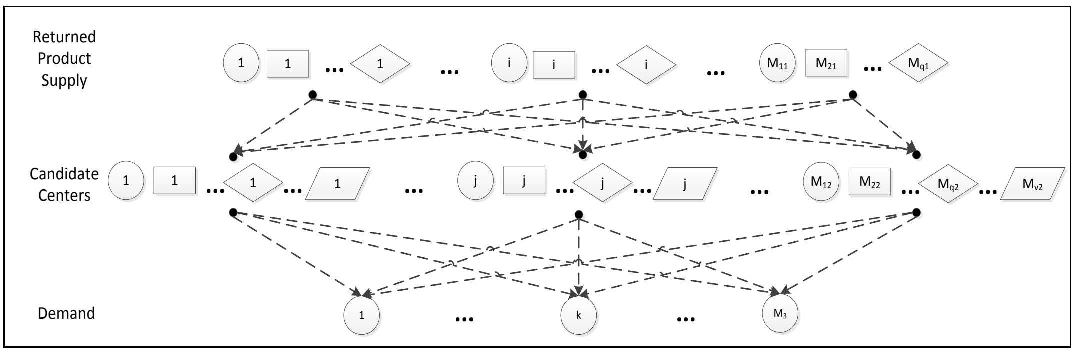

Figure 23 Nonprofit MCRS network structure

To integrate the MCRS in reverse logistics of humanitarian aid, we must determine the number and location of the centers in the returned products collection and redistribution network and the amount of inventory in these centers, in light of limited resources. Designing a MCRS network that reduces the cost in a nonprofit supply chain and increases benefits to beneficiaries is essential to achieve the goal of returned products collection and redistribution effectively and efficiently. In the next section we will present a MCRS formulation model.

4.2 Model Assumptions

1. A weight w_q is given to each commodity type q to represent relative need to response.

2. The collection of commodity type q can be achieved at different coverage levels, where each coverage level, l_q is characterized by an upper and lower response time limit $UR_q^{l_q}$ and $LR_q^{l_q}$, respectively.

3. The coverage efficiency, $\alpha_q^{l_q}$ decreases as coverage level increases, and is represented by a decreasing step function. That is, for coverage levels $1 \leq 2 \leq \cdots \leq l_q \leq \cdots \leq L_q$, the associated efficiencies are $\alpha_q^1 = 1 > \alpha_q^2 > \cdots > \alpha_q^{l_q} > \cdots > \alpha_q^{L_q} \geq 0$.

4. $N_i(l_q)$ represents the set of collection and redistribution center (CRC) candidates that can provide coverage level l_q for commodity type q provided by supply source i.

5. We assume particular returned product characteristics (criticality, response time limits) are identical for different supply sources.

6. Collection of returned products can only be achieved from CRCs that can cover the corresponding event location.

7. Collection of returned product of type q can only be achieved from CRCs of type v that can handle this type of products.

8. The cost of establishing CRCs is constrained by a setup budget.

9. The transportation costs associated with collecting and delivering returned product supplies from supply sources to CRCs and from CRCs to demand locations for any event scenario are assumed to be limited by a redistribution budget.

10. Multiple supplies will not occur simultaneously.

11. Capacity restrictions on each CRC in the network are imposed.

The following figure on page 96 illustrates different coverage levels for two different commodity types supplied by two sources (red and yellow circles). In this example, there are three candidate CRCs of type $v = 1$ and $v = 2$ for each scenario exclusively (red and yellow squares) and two candidate CRCs of type $v = 3$ that serve both scenarios (blue squares). CRC candidates at $j = 1$ and $j = 2$ are within the first and second coverage levels of commodity type 1, respectively, whereas the CRC candidate at $j = 3$ is outside of both coverage levels and therefore cannot collect returned products from the event location $i = 1$. CRC candidates at $j = 4$ and $j = 5$ are within the first and second coverage levels of commodity type 2, respectively, whereas the CRC candidate at $j = 6$ is outside of both coverage levels and therefore cannot collect returned products from the event location $i = 2$. CRC candidate at $j = 7$ is within the second coverage levels of both commodity types 1 and 2, whereas the CRC candidate at $j = 8$ is outside of $i = 1$ coverage levels and therefore cannot collect returned products from the event location $i = 1$. Although this CRC is inside the coverage level of $i = 2$, it cannot serve it as its type is the one that receives mixed types of products.

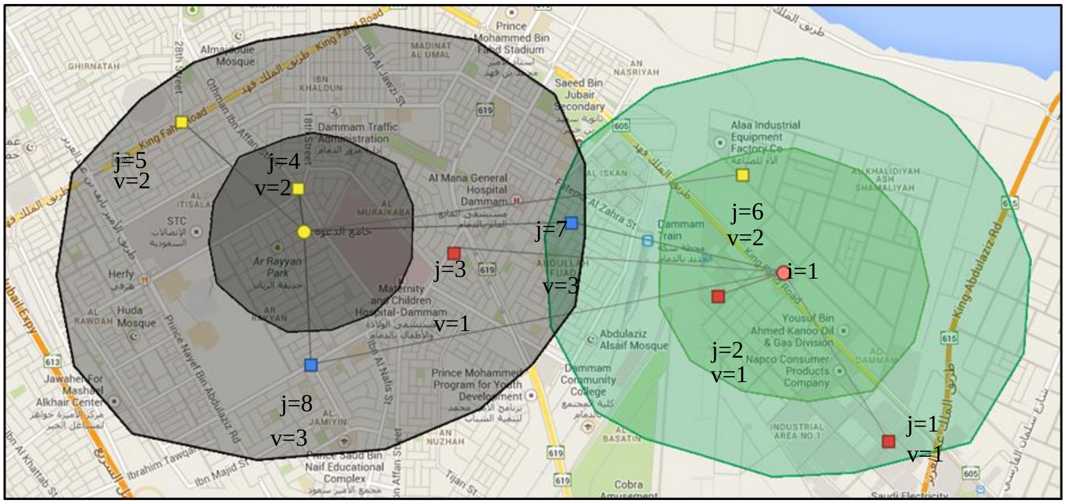

Figure 24 Coverage levels for two commodity types supplied by two scenarios

So, our objective is to choose the set of CRCs in the network that maximize the coverage efficiency of events and beneficiaries. This depends not only on the quality of events coverage, but also on the capability of satisfying the expected demand within a short timeframe.

4.3 Model Formulation

The following notation is used to formulate the facility location model for CRCs:

Sets

S set of supply sources; $i \in S$

M set of demand locations; $k \in M$

N set of candidate CRCs; $j \in N$

Q set of commodity types; $q \in Q$

Parameters

p_i probability of occurrence of supply source i

U_{iq} expected amount of commodity type q in supply source i (units)

D_{kq} expected demand for commodity type q in demand location k (units)

Cap_j capacity of CRC j (volume)

γ_q unit volume of commodity type q

B_0 budget allocated for establishing CRCs (SR)

B_1 budget allocated for redistribution process (SR)

F_j fixed cost of establishing CRC j (SR)

g_{ijq} unit cost of transporting commodity type q of supply source i to CRC j (SR/unit)

c_{jkq} unit cost of shipping commodity type q from CRC j to demand location k (SR/unit)

t_{ijq} time to transport commodity type q from supply source i to CRC j (minutes)

w_q need to response weight value for commodity type q ; $\sum_q w_q = 1$ and $w_q \geq 0$

l_q coverage level for commodity type q; $l_q = 1, \ldots, L_q$

$\alpha_q^{l_q}$ coverage level weight $\alpha_q^1 = 1 > \alpha_q^2 > \cdots > \alpha_q^{l_q} > \cdots > \alpha_q^{L_q} \geq 0$

$N_i(l_q)$ candidate CRC locations that can provide l_q coverage level for commodity type q for supply source i; $N_s(l_q) = \{j | LR_q^{l_q} < t_{sjq} \leq UR_q^{l_q}\}$

where

$LR_q^{l_q}$ lower response time limit defining coverage level l_q, and

$UR_q^{l_q}$ upper response time limit defining coverage level l_q

Decision variables

f_{ijq} proportion of commodity type q acquired by CRC j in supply source i

d_{jkq} proportion of commodity type q in demand location k satisfied by CRC j

$$X_j = \begin{cases} 1, & \text{if CRC j is located} \\ 0, & \text{otherwise} \end{cases}$$

The formulation for the problem is as follows:

$$\text{Max} \sum_{i} \sum_{j \in N_i(l_q)} \sum_{l_q} \sum_{q} p_i w_q \alpha_q^{l_q} U_{iq} f_{ijq} \tag{4.1}$$

Subject to

$$\sum_{i \in S} \sum_{q \in Q} \gamma_q U_{iq} f_{ijq} \leq Cap_j X_j \qquad \forall j \in N \tag{4.2}$$

$$\sum_{j \in N} (F_j X_j) \leq B_0 \tag{4.3}$$

$$\sum_{j \in N} \left(\sum_{k \in M} \sum_{q \in Q} D_{kq} d_{jkq} c_{jkq} + \sum_{i \in S} \sum_{q \in Q} U_{iq} f_{ijq} g_{ijq} \right) \leq B_1 \qquad (4.4)$$

$$\sum_{k \in M} D_{kq} d_{jkq} - \sum_{i \in S} U_{iq} f_{ijq} = 0 \qquad \forall j \in N, q \in Q \qquad (4.5)$$

$$\sum_{j \in N} f_{ijq} \leq 1 \qquad \forall i \in S, q \in Q \qquad (4.6)$$

$$\sum_{j \in N} d_{jkq} \leq 1 \qquad \forall k \in M, q \in Q \qquad (4.7)$$

$$f_{ijq}, d_{kjq} \geq 0 \qquad \forall i \in S, \forall k \in M, \forall j \in N, q \in Q \qquad (4.8)$$

$$X_j \in \{0,1\} \qquad \forall j \in N \qquad (4.9)$$

The objective function (4.1) maximizes the total expected returned products supply covered by the established CRCs. Constraint set (4.2) guarantees that the inventory is held only at established CRCs, and the amount of inventory kept at any of these centers does not exceed its capacity. Constraint (4.3) requires that the expenditures related to establishing a CRC do not exceed the determined budget, and constraint set (4.4) guarantees that the transportation costs incurred between supply sources, CRCs and demand locations are less than the expected redistribution process budget. Constraint set (4.5) guarantees that the amount of supply collected from supply sources is redistributed totally to demand locations. Constraint set (4.6) ensures the amount of collected returned products of a supply source does not exceed the actual returned products. Constraint set (4.7) ensures the amount of returned products sent to satisfy the demand does not exceed the actual demand. Finally, constraint set (4.8) is the non-negativity constraint on the proportion of returned products collected and proportion of demand satisfied, and constraint set (4.9) defines the binary location variable.

4.4 Numerical Analysis

In this section, we introduce the implementation of the proposed MCRS network design model and present computational results.

4.4.1 The Data Set

Some of the parameters that are required to analyze the model are set hypothetically as Eta'am has not yet begun the implementation of this project. We applied this model to cover the cities of Dhahran, Khobar, Dammam and Alhasa. We identified 10 different locations of the source suppliers which provide three commodities, where 5 suppliers provide used clothes and the others provide remnants of pharmaceuticals in addition to the 50 food supply sources contracted with Eta'am. As shown in table 8 for food sources, the probability of occurrence associated with each supply source and the amount of supply at each visit is provided in table 15 on page 101 for the cloth and pharmaceutical commodity types.

Table 15 MCRS supply sources parameters

Supply Source	Type of Commodity	Probability of occurrence	Amount supplied (unit)
1	Cloth	0.181	87
2	Cloth	0.120	100
3	Cloth	0.169	86
4	Cloth	0.241	105
5	Cloth	0.289	104
6	Pharmaceuticals	0.182	200
7	Pharmaceuticals	0.227	216
8	Pharmaceuticals	0.200	227
9	Pharmaceuticals	0.091	180
10	Pharmaceuticals	0.300	221

The criticality weights were set to 0.5, 0.3 and 0.2 for food, clothes and pharmaceuticals, respectively. We assumed two coverage levels for each item type. The lower and upper response time limits and first and second coverage benefit levels are shown in table 16.

Table 16 MCRS model parameters 1

Parameter	Coverage Level	Food items	Cloth items	pharmaceutical items
$\alpha_q^{l_q}$	1	1	1	1
	2	0.7	0.9	0.8
$LR_q^{l_q}$	1	0	0	0
	2	1	10	5
$UR_q^{l_q}$	1	1	10	5
	2	2	20	10

For the location of the demand points, we consider it to be the location of charities through which Eta'am is delivering excess food to beneficiaries. We neglect the process of distributing excess food from charities to beneficiaries. As a result we have 9 demand locations. We assume that the demand always exceeds the supply.

For the location of candidate centers, we constructed grid cells with dimensions of one kilometer between each one inside the city and two kilometers outside the city and located a candidate center at the corner of each grid cell. The resulting candidate center locations number 600. We assume that we have three types of candidate centers based on the item type to be served. As a result, type 1 candidate center is the one that serves cloth items, type 2 candidate center serves pharmaceutical items and type 3 candidate center is serving both items.

We assume that the unit volume is 0.075 m^3 and 0.00075 m^3 for cloth and pharmaceutical items, respectively. There are two types of centers, one with a capacity of 9,000 items and a 2 million SR setup cost and the other has a capacity of 7,000 items with a setup cost of 1.5 million SR. The cost of collecting an item is the sum of transportation vehicles expenses (1.585 SR/km) and labor costs (3.00 SR/km for food, 2.00 SR/km for cloth and pharmaceutical) as a rate of traveled kilometers. The cost of distributing an item is the sum of transportation vehicles expenses (1.585 SR/km) and labor costs (2.00 SR/km, 1.00 SR/km for cloth and pharmaceutical) as a rate of traveled kilometers. The parameters required by the model are summarized in table 17 on page 104.

Table 17 MCRS model parameters 2

Candidate center capacity	Type 1: 9,000 units Type 2: 7,000 units
Fixed cost of locating a candidate center	Type 1: 2,000,000 SR Type 2: 1,500,000 SR
Unit cost of collecting a food item	$4.585\ (\text{SR}/\text{Km}) \times \text{distance between points (Km)}$
Unit cost of collecting a cloth item	$3.585\ (\text{SR}/\text{Km}) \times \text{distance between points (Km)}$
Unit cost of collecting a pharmaceutical item	$3.585\ (\text{SR}/\text{Km}) \times \text{distance between points (Km)}$
Delivery time between candidate center and supply source or demand	$\text{distance between points (Km)}\ /60\,\frac{Km}{Hr}$
Unit cost of distributing a meal to demand points	$3.585\ (\text{SR}/\text{Km}) \times \text{distance between points (Km)}$
Unit cost of distributing a cloth item to demand points	$2.585\ (\text{SR}/\text{Km}) \times \text{distance between points (Km)}$
Unit cost of distributing a pharmaceutical item to demand points	$2.585\ (\text{SR}/\text{Km}) \times \text{distance between points (Km)}$

4.4.2 Computational Results

In this section, we present and discuss the results obtained by solving the proposed model for the above parameters using LINGO 13.0. The solver status shows that the model consists of 121212 variables and 2610 constraints. The generator memory used is 99512 K and the average elapsed runtime is 4.1 minutes. The computer used to run the solver has Windows 7 Professional operating system, Intel(R) Core(TM) i5-2500 CPU @ 3.30GHz processor and 4.00 GB installed memory (RAM).

We ran the model for the expected operations by Eta'am at estimated budget constraints specified by the management. The results are provided in table 18 on page 106. By solving the model at different combinations of budgets, we obtain a better alternative solution that reduces the required budget by 26.7%. The details of this solution are shown in table 19 on page 107. Figure 25 on page 108 shows the current and alternative solutions for Khobar. Figure 26 on page 109 shows the solutions for Al-hasa. The connections are not shown in these figures as we have one CRC only, which is connected to each supply and demand point.

The following legends are used for tables 18, 19, 20, 21 and 22 on pages 106, 107, 111, 113 and 115, respectively.

S : Single-type CRC

M : Multi-type CRC

F : Food

C : Cloth

P : Pharmaceuticals

Table 18 Results of MCRS current model

B0 (million SR)	**B1 (million SR)**	**Number of CRC**		**Excess food acquired (%)**			**Average Response time (hrs.)**			**Suppliers Served at 1st Coverage Level (%)**		
		S	M	F	C	P	F	C	P	F	C	P
4	2	0	2	100	100	100	0.13	2.02	2.03	100	0	0

Table 19 Results of MCRS alternative model

B0 (million SR)	B1 (million SR)	Number of CRC		Excess food acquired (%)			Average Response time (hrs.)			Suppliers Served at 1st Coverage Level (%)		
		S	M	F	C	P	F	C	P	F	C	P
4	0.4	0	2	100	100	100	0.17	0.12	0.14	100	100	100

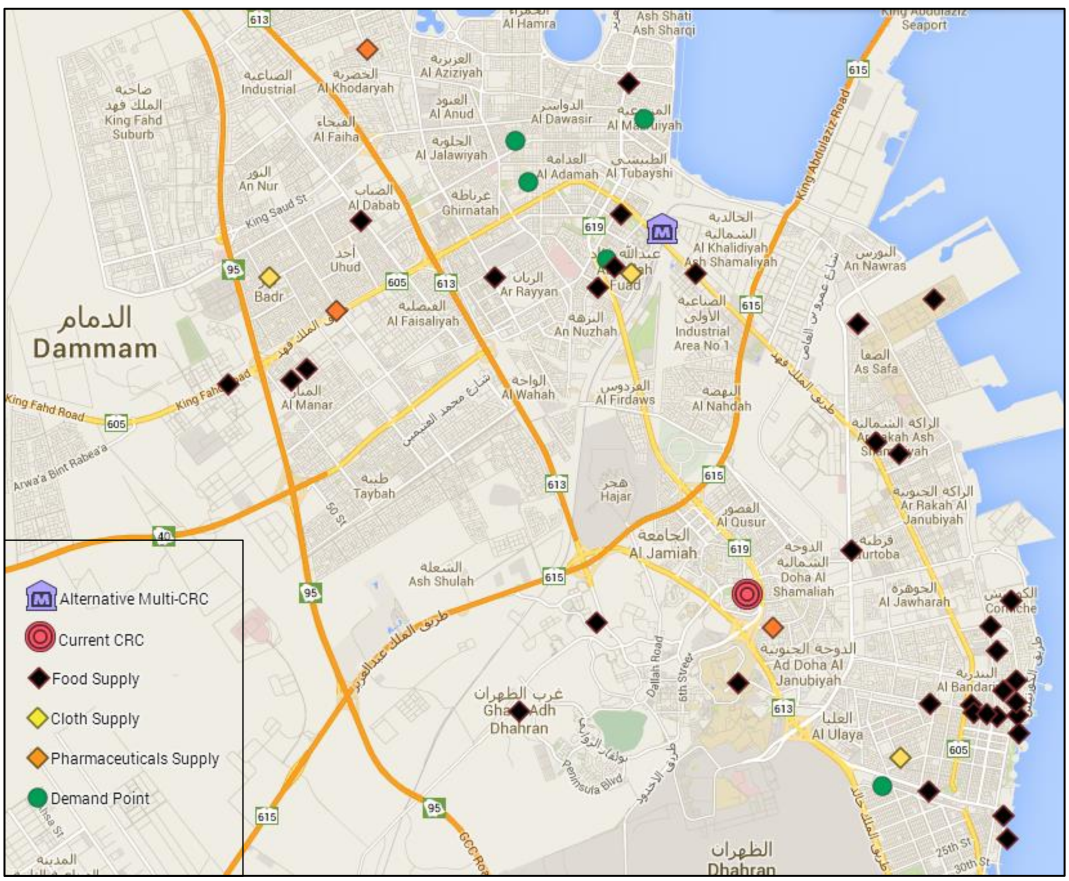

Figure 25 Results of MCRS current and alternative model for Khobar

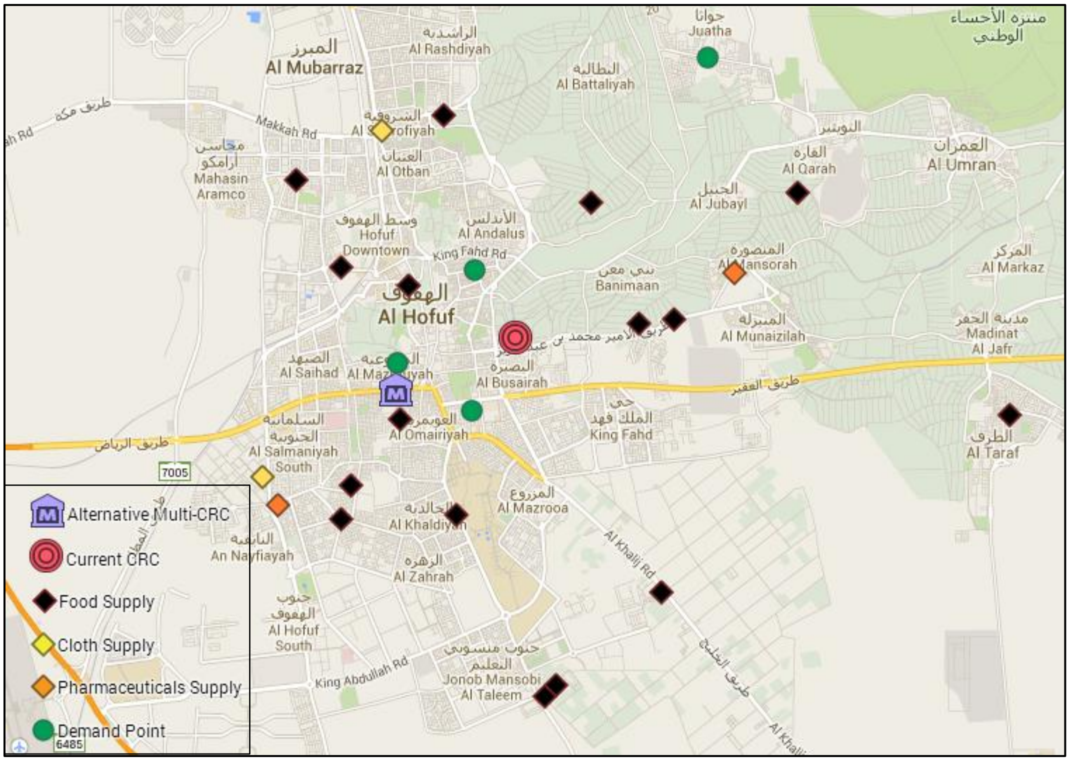

Figure 26 Results of MCRS current and alternative model for Al-Ahsa

We ran the model for different collection and distribution budget constraints, and the results are provided in tables 20, 21 and 22. These tables show the solutions obtained in terms of the number of CRCs of each type opened, the percentage of items acquired, and the average response time to collect a supply of all types of items. The last three columns of these tables show the percentage of supply sources in which collected items were satisfied at coverage level 1 for all item types; that is, these columns reflect quality of coverage for collected items.

The results in table 20 are obtained by increasing the setup budget while keeping the redistribution process budget constant. When the setup budget was set to its minimum for our example (SR 2,000, 000), the model opened a single CRC. The opened CRC stocked all types of items. From the results, the average response time for all items is decreased compared with subsequent scenarios, due to the increase of opened CRCs. This is the case also for amount of items acquired and coverage quality which are improved.

As we increased the amount of setup budget to 6.4 million SR, the model opened three CRCs. As shown in table 20, this change reduced average response time for cloth and pharmaceutical items.

As the setup budget was further increased, the model responded by locating more CRCs with the quality of coverage for clothes tending to improve as more CRCs were established. It was also observed that the average response time improved generally for all items.

The results obtained for increased setup budget amounts while fixing the redistribution process budget indicated the advantages and disadvantages of establishing a decentralized MCRS.

As the setup budget increased, the distances between facilities and supply sources locations decreased, and hence the system's responsiveness improved. The practical disadvantages of excessive localization in the relief system may include the difficulties in managing many facilities and low throughput at the CRC which may lead to obsolescence.

Table 20 Results of MCRS model Set 1

B0 (million SR)	**B1 (million SR)**	**Number of CRC**		**Excess food acquired (%)**			**Average Response time (hrs.)**			**Suppliers Served at 1st Coverage Level (%)**		
		S	M	F	C	P	F	C	P	F	C	P
2	0.4	0	1	46	100	80	0.19	0.93	0.66	100	60	80
4	0.4	0	2	100	100	100	0.17	0.12	0.14	100	100	100
6	0.4	0	3	100	100	100	0.17	0.1	0.13	100	100	100

Table 21 shows the results from varying redistribution process budgets while keeping the setup budget constant. When the redistribution process budget is set at a minimal value, the model opened one CRC. A good coverage level is achieved but the percentage of the collected supply is low. As redistribution process funding increased, the number of CRCs remained constant. Moreover, the percentage of supplies that could be covered at level 1 decreased for the food and pharmaceutical items. However, the percentage of collected amount increased for all items.

In summary, as more redistribution process funds became available, the MCRS tended to become centralized on average. Larger supply amounts could be collected by fewer facilities, but at the expense of increased transportation costs and response times.

Table 21 Results of MCRS model Set 2

B0 (million SR)	**B1 (million SR)**	**Number of CRC**		**Excess food acquired (%)**			**Average Response time (hrs.)**			**Suppliers Served at 1st Coverage Level (%)**		
		S	M	F	C	P	F	C	P	F	C	P
2	0.4	0	1	46	100	80	0.19	0.93	0.66	100	60	80
2	2.4	0	1	88	100	100	0.74	0.90	0.90	76	60	60
2	4.4	0	1	100	100	100	1.00	1.00	1.01	68	60	60

Finally, table 22 shows the results obtained by simultaneously changing the setup and redistribution process budgets. According to the results, as both types of budgets increased, the number of CRCs gradually increased and the amount of collected items increased.

We observed greater improvements in model solutions when both budgets were increased. Those improvements were observed in terms of all response times, as compared to some cases in which only the redistribution budgets increased, while the setup budget was fixed. For example, suppose that both budgets were equal to SR 2.4 million and an additional SR 4 million were invested for setup and/or distribution logistics. We observed improvements in all performance measures when both budgets were increased equally. The improvement in terms of each measure was slightly higher than what could be obtained when additional money was used exclusively for redistribution investment. However, the model here require more investment in the setup to increase the number of opened CRCs which results in lower redistribution expenses.

Table 22 Results of MCRS model Set 3

B0 (million SR)	**B1 (million SR)**	**Number of CRC**		**Excess food acquired (%)**			**Average Response time (hrs.)**			**Suppliers Served at 1st Coverage Level (%)**		
		S	M	F	C	P	F	C	P	F	C	P
2	0.4	0	1	46	100	80	0.19	0.93	0.66	100	60	80
3	1.4	0	1	68	100	100	0.55	0.88	0.89	86	60	60
4	2.4	0	2	100	100	100	0.31	0.93	0.97	100	60	60

CHAPTER 5

CONCLUSION AND FUTURE RESEARCH

The repercussion of humanitarian logistics on social, economic, environmental and other aspects is very apparent. Improvements in this field will lead to social consolidation, strengthening bonds between the different strata of society and solving any social problems before they turn into phenomena. At the same time, the advances in this area of study will motivate donators to support nonprofit organizations and increase funds that will benefit both sides in the end. However, it is not an easy task to overcome the challenges that face humanitarian logistics which needs to achieve "getting the right aid to the right people at the right time". The cornerstone of the resolution of these challenges is to model supply network design that leads to an efficient and effective collection and redistribution of goods to beneficiaries.

In this thesis, we discussed the supply network design of nonprofit reverse logistics and implemented the derived model on collection and redistribution of a multi-commodity system in general and excess food system in particular. The location of collection and redistribution centers was studied to identify the degree of centralization or decentralization which leads to an increase in the speed of response and reduces the wastage of food or used products. Ideas to improve the efficiency of Eta'am operations include but are not limited to:

1. Improving the human resources in general and the voluntary work in particular. Eta'am can attract voluntary teams from schools and universities to increase its labor force.
2. Develop the current operational practices. Eta'am could establish agreements with the supply sources so that they will collect the food at the site and then Eta'am will take it to a reclamation center for a quality check and redistribution to beneficiaries
3. Information technology is essential for improving the processes for Eta'am as it helps in the collection of data, quality control and planning for the future. Eta'am could contract with a large technology company that could establish a platform to monitor all operations.
4. Expanding supply sources coverage to include groceries and supermarkets. This will increase the supply and satisfy more demand with unsold products or those close to expiration date.
5. Establish an evaluation system that considers providing the right feedback from the right sources at a regular time interval. Third party evaluations are necessary as they provide credibility and independence which allows naming names and producing substantial analysis [80]. The evaluation should include beneficiaries as they are the cornerstone of the process.

At last, the derived model could be improved by considering the uncertainty of supply that will lead to develop a stochastic model that considers the randomness of the system parameters. In addition, the model could be studied after releasing the assumption of one scenario at a time and considering different scenarios simultaneously. Also, a simulation study could be conducted to improve the efficiency of the operation of the collection and redistribution system.

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