MULTI-ECHELON TRANSPORTATION LOCATION AND ROUTING PROBLEM FOR DESIGNING SCHOOL LUNCH DISTRIBUTION NETWORK

ECE UYAR

FEBRUARY 2023

ÇANKAYA UNIVERSITY

GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

DEPARTMENT OF INDUSTRIAL ENGINEERING

M.Sc. Thesis in

INDUSTRIAL ENGINEERING

MULTI-ECHELON TRANSPORTATION LOCATION AND ROUTING PROBLEM FOR DESIGNING SCHOOL LUNCH DISTRIBUTION NETWORK

ECE UYAR

FEBRUARY 2023

ABSTRACT

MULTI-ECHELON TRANSPORTATION LOCATION AND ROUTING PROBLEM FOR DESIGNING SCHOOL LUNCH DISTRIBUTION NETWORK

UYAR, Ece
M.Sc. in Industrial Engineering

Supervisor: Assist. Prof. Dr. Ayyüce AYDEMİR KARADAĞ
February 2023, 97 pages

The National School Lunch Program (NSLP) provides school children nutritious lunches. NSLP benefits health, obesity, and school attendance rates. Developing a distribution network for the program requires solving the multi-echelon transportation location and routing problem to design a distribution network. The first two echelons comprise the distribution of agricultural products from farmers to food processing centers (FPCs) through distribution centers (DC). The third echelon involves determining the locations of food processing centers and routes between schools as part of a multi-depot location routing problem. Since the consider problem is NP-Hard, we propose a two-stage solution approach. We aim to minimize the total transportation cost in all echelons and the fixed costs of distribution and food processing centers. A Simulated Annealing Algorithm (SA) is used in the first stage of the process to handle the routing decisions of the third echelon. As part of the second stage, a mixed-integer linear mathematical model is presented that determines the locations of the distribution centers and provides a solution to the transportation problem at the first echelon. Several hypothetical problems are used to test the performance of the proposed method. According to the computational results, SA can be considered an effective and efficient solution algorithm that reduces the computational cost and enhances the quality of the solution.

Keywords: School Lunch Program, Multi-Echelon Transportation Location and Routing Problem, Simulated Annealing Algorithm

ÖZ

OKUL ÖĞLE YEMEĞİ DAĞITIM AĞI TASARIMI İÇİN ÇOK AŞAMALI ULAŞTIRMA YER SEÇİMİ VE ROTALAMA PROBLEMİ

UYAR, Ece
Endüstri Mühendisliği Yüksek Lisans

Danışman: Dr. Öğr. Üyesi Ayyüce AYDEMİR KARADAĞ
Şubat 2023, 97 sayfa

Ulusal Okul Öğle Yemeği Programı (NSLP) aracılığıyla öğrencilere besleyici öğle yemekleri sağlanır. NSLP sağlık, obezite ve okula devam oranlarına fayda sağlar. Program için bir dağıtım ağı tasarlamak ve geliştirmek için çok kademeli ulaşım yeri ve rotalama problemi çözmeyi gerektirir. İlk iki kademe, tarımsal ürünlerin çiftçilerden dağıtım merkezleri (DC) aracılığıyla gıda işleme merkezlerine (FPC) dağıtımını içermektedir. Üçüncü aşama, çok depolu yer seçimi ve rotalama probleminin bir parçası olarak gıda işleme merkezlerinin konumlarının ve okullar arasındaki yolların belirlenmesini içerir. Bu problem NP Hard olduğundan bu problemi çözmek için iki aşamalı bir çözüm yaklaşımı öneriyoruz. Amacımız, tüm kademelerdeki toplam nakliye maliyeti ile dağıtım ve gıda işleme merkezlerinin sabit maliyetlerini en aza indirmektir. Üçüncü kademenin yönlendirme kararlarını işlemek için sürecin ilk aşamasında bir Tavlama Benzetimi (SA) Algoritması kullanılır. İkinci aşamada, dağıtım merkezlerinin yerlerini belirleyen ve birinci kademedeki ulaşım problemine çözüm sağlayan bir karma tamsayılı doğrusal matematiksel model sunulmuştur. Önerilen yöntemin performansını test etmek için çeşitli varsayımsal problemler kullanılmıştır. Hesaplama sonuçlarına göre SA, hesaplama maliyetini azaltan ve çözüm kalitesini artıran etkili ve verimli bir çözüm algoritması olarak kabul edilebilir.

Anahtar Kelimeler: Okul Öğle Yemeği Programı, Çok Aşamalı Ulaştırma Yer Seçimi ve Rotalama Problemi, Tavlama Benzetimi Algoritması

ACKNOWLEDGEMENT

I would like to express my sincere gratitude to my supervisor Ayyüce AYDEMİR KARADAĞ for the excellent guidance and suggestions for providing me with an excellent atmosphere to conduct this research.

Finally, it is my pleasure to express my special thanks to my mother Nesrin UYAR, my father Yüksel UYAR and my big brother Arda UYAR for their valuable support.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

DC	: Distribution Center
FLP	: Facility Location Problem
FPC	: Food Preparation Center
GA	: Genetic Algorithm
HGA	: Hybrid Genetic Algorithm
HHS	: Hybrid Harmony Search
LRP	: Location Routing Problem
MDVRP	: Multi Depot Vehicle Routing Problem
MILP	: Mixed Integer Linear Problem
MIP	: Mixed Integer Problem
M-NSGA-II	: Modified Non-Dominated Sequence Genetic Algorithm-II
MOGWO	: Multi-Objective Grey Wolf Optimizer
MOHCGA	: Hybrid Cultural and Genetic Algorithm
MOLAHC	: Multi-Objective Late Acceptance Hill-Climbing Algorithm
MOPSO	: Multi-Objective Particle Swarm Optimization
MOWCA	: Multi-Objective Water Cycle Algorithm
NNSA	: Nearest Neighbor Search Algorithm
NSGA-II	: Non-Dominated Sorting Genetic Algorithm
NSLP	: National School Lunch Program
PROMETHEE	: Preference Ranking Organization Method for Enrichment Evaluation
PSO	: Particle Swarm Optimization
TLRP	: Transportation Location Routing Problem
VRP	: Vehicle Routing Problem

CHAPTER I

INTRODUCTION

The National School Lunch Program (NSLP) is a program that provides free or low-price meals to students in public primary schools. NSLP offers healthy nutrition for students and aims to prevent unhealthy eating habits that poor students are exposed to more. It is important to avoid the development of health problems due to malnutrition that students may have in the future and to protect students from obesity which has become a big problem in recent years. Healthy-fed children play an active role especially in school activities. This also contributes to the success of children in lessons.

While in already developed countries, the school meal is a source of nutritious meals, in developing countries, it is an incentive to send children to school and continue their education. In developing countries, school meals provide food security during crises and help children to become healthy and productive adults, thus helping to break the cycle of poverty and hunger. According to the calculations, about 16 percent of a child's total food consumption can be met through the school lunch program (Bundy et al. 2009). Also, this corresponds to approximately 10 percent of the expenditure on children of a low-income family (Candaş et al. 2011).

The National School Lunch Program Act was first promulgated in the United States in 1946. The law's purpose is to protect children's health and encourage local consumption of agricultural products (Gunderson 2003). The procurement of domestic producers contributed to the consumption of healthy foods and farmers economically. After the NSLP was a success, in 1966, the Child Nutrition Act was enacted. The goal of this program was to improve NSLP to satisfy the nutritional needs of kids. With this program, school meal services were combined under a single institution. Contributed to ensuring uniform nutritional standards and program continuity. In 1970, some changes were made to the National School Lunch Program Act. Based on families' economic level, national standards were established to determine who was eligible for free and reduced school lunches (Murugaswamy 2011).

NSLP is being implemented in more than a hundred countries around the world with different levels of development, as it increases children's development and success and is beneficial in many other aspects (Candaş et al. 2011). There are some applications in the world are given in Table 1.

Table 1: Some Applications of the School Lunch Program Around the World

Since	Country	Since	Country
1890	Norway	1980	Norway
1900	Japan	1984	Japan
1914	Ireland	1987	Ecuador
1920	Chile & India	1994	Pakistan
1937	Sweden	2005	Haiti
1939	United States	2007	Malawai
1955	Brazil	1955	Afganistan

The benefits of school meals vary from country to country. America, Mexico, Chile, and India are some countries that apply for this program in different ways. For example, in Mexico, children are selected based on their income levels, so only those selected are eligible to benefit from this program. Since this causes selected children of primary school age to feel excluded, discriminated, and humiliated, it is more appropriate to apply this program to children in a region or school rather than selecting students individually (Murugaswamy 2011). In Chile, this program is implemented in most schools in poor districts and neighborhoods in densely populated areas (Candaş et al., 2011). This program will be more successful if it is supported by the state, together with the incorporation of the Ministry of Education and the Ministry of Health (Murugaswamy 2011).

- *Motivation of the Study*

The milk distribution program was implemented in Turkey during the 2016-2017 academic year. Although the school lunch distribution program wasn't implemented, we know that a school lunch distribution program is planned. The Minister of National Education previously announced that it would start to be implemented in the 2020-2021 academic year, but it could not be implemented due to the pandemic. What motivates us in this study is the benefits of NSLP mentioned above and the planning of its implementation in Turkey. Many decisions must be made in designing the school lunch distribution network system. There should be a late due to the covid pandemic. However, it is still necessary to conduct how the school lunch distribution system is designed.

- *Scope of the Study*

The School Lunch Program involves supplier selection, network distribution, location of facilities, logistics, etc., and decisions to develop a food supply chain (Murugaswamy 2011). This problem can be defined as a multi-echelon transportation location and routing problem. It includes the distribution of products from farmers to food processing centers (FPC) via distribution centers (DC), the location of FPCs, and determining routes between schools.

In this thesis, we focused on three echelon transportation location and routing problems. The first and second echelons involve the distribution of products from farmers to DCs and from DCs to FPCs. The locations of DCs are determined. There is a multi-depot location routing problem in the third echelon. The third echelon determines the locations of FPCs, from which FPCs schools receive service, and the route of the vehicles from the opened FPCs to the schools.

- *Originality of the Study*

We propose a two-stage solution approach to solve this problem. We offer a Simulated Annealing Algorithm (SA) to solve the problems in the third echelon. We used four different operators and tried to improve our solutions. Our proposed SA algorithm generates feasible solutions. Since the location decisions are given by the proposed SA, the problem considered in the first and second echelons can be regarded as a transportation location problem. We present a mixed integer programming formulation to solve the transportation location and routing problem. To the best of the authors, there are no studies in the literature that focus on the National School Lunch Distribution Problem in this respect and propose solution algorithms.

The remainder of the thesis is organized as follows. Chapter II provides an overview of location routing problems. Chapter III presents the relevant transportation, location and routing literature. We then give the problem definition and mathematical formulations in Section IV. The solution methodology is summarized in Section V. We provide computational results in Section VI. Finally, the conclusion and future works have been given in Chapter VII.

CHAPTER II

OVERVIEW OF LOCATION ROUTING PROBLEMS

Location routing problems (LRP) are one type of network design problem. The LRP deals with the combination of the facility location problem (FLP) and the vehicle routing problem (VRP) (Nasrollahi et al. 2018). Since both problems are NP-hard, the location routing problem is classified as an NP-hard problem.

2.1. FACILITY LOCATION PROBLEMS

Facility location problems focus on the size, equipment, and number of facilities to be established. It includes decisions about closing and relocation of existing facilities, as well as decisions about their size.

2.1.1. Classification of Facility Location Problems

Facility location problems for distribution designing can be classified as follows;

- *Capacitated & Un-capaticated*

Capacitated refers to a facility that has no demand constraints. There may be limitations on the number of products in depots. It is an un-capacitated facility location if a facility has an infinite capacity.

- *Continuous & Discrete*

A location problem that explores every possible location along a space continuum or plane is called a continuous location problem. A locating problem that chooses from a finite number of potential candidate facilities is called a discrete location problem.

- *Single Commodity & Multi Commodity*

In single-product models, capacity, demand, and cost for several products can be aggregated into a homogeneous product. If the products are not homogeneous, the demand and capacity must be considered separately for each product in the model.

- *Single-Stage & Multi-Stage*

Single-stage location problems involve distributing products from only one stage of the supply chain to customers. In the multi-stage location problem, the distribution activities of the products involve more than one stage. For example, the distribution of products from the manufacturer to the customer through the distributor is a multi-stage problem.

- *Deterministic & Stochastic*

If the inputs and outputs of the model are known, they are called deterministic models. If the model inputs and outputs are uncertain, they are called stochastic models.

- *Static & Dynamic*

Static location models are resolved for a specific time in the planning horizon. However, dynamic models are time dependent. Dynamic location models include cost, demand, capacities, etc., which change over time within a given planning horizon.

2.2. VEHICLE ROUTING PROBLEMS

A Vehicle Routing Problem (VRP) is a type of problem in which the product or service is delivered to customers from a particular center. It is a combinatorial optimization problem in which the routes that enable the vehicles to return to the center are determined.

VRP was first introduced to the literature by Dantzig and Ramser in 1959. In this study, they focused on the problem of distributing gasoline to gasoline stations where transportation costs are minimized. They established the first linear mathematical model to solve the problem. Later, different scenarios were added to this problem, and various solution methods were developed by diversifying the problem (Garic 2008).

In addition, VRP is similar to the Traveling Salesman Problem (TSP). TSPP is the most basic and most studied version of VRP. The difference between them is that in TSP the traveling salesman has no capacity, so that a single seller can serve all customers (Ho et Al. 2008; Magnanti 1981).

In VRP, it is studied to determine the best routes to be followed by a vehicle fleet serving a particular customer group. The solution to classical VRP problems is a set of routes, where each route starts from the warehouse and ends with the warehouse.

While determining the routes to be created between the warehouse and the customers, the VRP should meet the following conditions (Cordeau et al. 2002).

i) Each route starts and ends at the warehouse.

ii) Each customer is visited once by a vehicle.

iii) The total demand of each route cannot exceed the vehicle capacity.

iv) The total routing cost is minimized. (The factors that create the cost are the distance traveled, the duration of use of the vehicle and other elements, transportation costs, etc.)

In addition, some side constraints may need to be provided depending on the type of problem. The most common side constraints are; capacity constraint, maximum possible demand point constraint on a route, total time constraint of the vehicle on a route, time window constraint at which service to demand points can be started, priority constraint where a demand point must be visited before another demand point (Laporte 1992).

In vehicle routing problems, if the values of the parameters are known beforehand, it is defined as a deterministic vehicle routing problem. It is defined as a stochastic vehicle routing problem if these parameters are unknown. In stochastic VRP, time, demand, and customers can get stochastic values. Vehicle routing problems take different names according to the added constraints.

- *Capacity-constrained VRP*

Capacity-constrained VRP is the most basic form. It is the most used deterministic VRP type, and customer demands are deterministic. The demands of all customers are met from a single warehouse, and the vehicles have the same capacity. The total order of customers assigned to a route cannot exceed the vehicle capacity. The objective is to determine vehicle routes that minimize the total cost so that all customers are served (Toth 2001).

- *Distance-restricted VRP*

Distance-restricted VRP is the distance vehicles in a depot can travel on a limited route. In other words, it does not allow a tour to exceed the predetermined maximum route length.

- *Time Window VRP*

In VRP, with a time window, there is a time interval for each customer that the vehicle can visit the customer. It is necessary to start the service within this time interval. When serving customers, the earliest and latest service times are defined. A vehicle cannot be sent to the customer after the latest service time; if it arrives before the earliest service time, it will be held until that time. Thus, for each customer, there is a certain service time for distribution or product collection (Desrochers et al. 1992).

- *Partial Distributed VRP*

In partially distributed VRP, it is allowed to meet the demand of the same customer from more than one vehicle to reduce the cost. Customer demand may be greater than the vehicle capacity. However, the total demand of each route cannot exceed the vehicle capacity. In this case, the orders of the customers are divided into vehicles (Jin et al. 2008).

- *Periodic VRP*

In the periodic VRP, the visiting plan for a certain period is made. The number of services to be made to customers varies according to the demand amounts of the customers and their stock areas. By determining the customers to be visited for each day, vehicle routes are generated to ensure cost minimization. If the demand amount of a customer is very high, it will be visited more than the customer with a small amount of demand, or if the stocking area is small, it will be visited more than the customer with a large amount (Hemmelmayr et al. 2007).

- *Pick-up and Delivery VRP*

In pick-up and delivery VRP, a product can be delivered to or received from a customer simultaneously. The orders to be delivered are assigned to customers from warehouses. The customers' orders that need to be delivered to the warehouse are picked up at the same time. Attention is paid to the capacity as collection and distribution are done simultaneously. Since vehicles can do distribution and collection together along their routes, it is difficult to maintain vehicle capacity at all times. The amount of product to be delivered to each customer or the amount to be collected is known in advance (Bianchessi 2007).

- *VRP with Customer Priority Rules*

In VRP with Customer Priority Rules, there are situations where customer priorities are different. This problem ensures that priority customers are served earlier.

- *Multi-depot VRP*

In Multi-depot VRP, the problem is expanded, and service is provided from more than one warehouse. Customers are assigned to each warehouse, and routes are determined for each warehouse. Every vehicle has to return to the depot from which it moved.

2.2.1. Vehicle Routing Problems According to Route Status

- *Open-ended VRP*

In Open-ended VRP, vehicles that leave the warehouse do not return to the warehouse after serving customers. That is, the routes terminate at the customer.

- *Closed-ended VRP*

In closed-end VRP, vehicles leaving the warehouse return to the warehouse after serving customers. That is, the starting and ending points of the routes are the same.

2.2.2. Vehicle Routing Problems According to The Environmental Situation

- *Static VRP*

In static VRP, all information is available at the beginning of the problem, and it is assumed that environmental conditions do not change over time. In such problems, all necessary information (such as constraints, demands, capacities, cost information, etc.) is known before to the problem's solution, and this information does not change during the solution phase of the problem, it is fixed (Larsen 2001).

- *Dynamic VRP*

In dynamic VRP, most of the information, such as vehicle travel and service time, customer demand, and customer geographic location cannot be predicted from road optimization. This information is dynamic, new information may occur, or existing information may change.

2.2.3. Vehicle Routing Problems According to The Road Situation

- *Symmetric VRP*

In symmetric VRP, the distances traveled by a vehicle between two points on the route are equal (Erol 2006).

- *Asymmetric VRP*

In asymmetric VRP, the distances traveled by a vehicle between two points on the route are different from each other (Erol 2006).

2.2.4. Vehicle Routing Problems According to Vehicle Fleet

- *Homogeneous VRP*

In homogeneous VRP, the vehicle fleet consists of vehicles with the same capacity.

- *Heterogeneous VRP*

In heterogeneous VRP, the vehicle fleet consists of heterogeneous vehicles with different capacities. Vehicles may also have other limitations, such as load capacity, fuel consumption, maximum distance, and loading and unloading.

CHAPTER III

LITERATURE REVIEW

In this study, we have focused on the multi-echelon transportation location and routing problem and its implementation in the school lunch distribution design. Our problem is divided into two. Initially, the first and second echelon involves transportation location problem. Secondly, the third echelon is a multi-depot location routing problem. Therefore, we have reviewed the relevant literature using the keywords including; multi-echelon, multi-depot location routing problems, fresh and perishable food distribution, and simulated annealing algorithm. We restricted our literature review to studies between 2010 and 2022 because there are numerous studies on location routing problems. The summary of the literature for important characteristics of the problem is given in Table 2.

Table 2: Summary Table of the Literature Review

Authors	Year	Objective		Product	Location	Routing	Inventory	Transportation	Time Windows	Service Time	Multi Depot	Solution Method
		Single	Bi/Multi									
Murugaswamy	2011	+		Perishable	+	+					+	K-Means Clustering Method
Govindan	2014		+	Perishable	+	+			+		+	MHPV
Martinez-Salazar	2014		+	Single	+	+		+		+	+	SSPMO & NSGA II
Ghezavati	2015	+		Perishable	+	+	+	+	+		+	Benders Decomposition Method
Vidovic	2016	+		Waste	+	+			+		+	MILP & Proposed Heuristics
Kouchaksaraei	2017	+	+	Blood	+	+	+		+	+	+	Robust Optimization & Goal Programming
Majd	2017	+		Perishable	+	+	+				+	Lagrangian Relaxation Algorithm
Hiassat	2017		+	Persihable	+	+	+					GA
Rabbani	2018		+	Multi	+	+		+	+	+	+	NSGAII & MOPSO
Pichka	2018	+		Single	+	+					+	MIP + Hybrid Metaheuristic

Table 2 continued

Authors	Year	Objective		Product	Location	Routing	Inventory	Transportation	Time Windows	Service Time	Multi Depot	Solution Method
		Single	Bi/Multi									
Wang	2018		+	Multi	+	+			+		+	GA
Vahdani	2018		+	Multi	+	+	+		+		+	NSGAII & MOPSO
Farrokhi	2018		+	Waste	+	+		+		+	+	MOHCG
Dai	2018	+		Perishable	+		+					HGA & HHS
Ghomi	2019		+	Perishable	+	+	+	+		+	+	Hybrid Metaheuristic
Saragih	2019	+		Single	+	+	+			+	+	SA
Dai	2019	+		Single	+	+					+	A Two-Phase Method based on Improved Clarke and Wright Savings Algorithm
Amini	2020		+	Single	+	+		+		+	+	NSGA-II & MOLAHC
Masoudipour	2020		+	Single	+	+		+			+	Augmented Epsilon Constraint Method

Table 2 continued

Authors	Year	Objective		Product	Location	Routing	Inventory	Transportation	Time Windows	Service Time	Multi Depot	Solution Method
		Single	Bi/Multi									
Safari	2020		+	Single	+	+		+			+	MOGWO & MOPSO & MOWCA &NSGA-II
Yu	2020		+	Waste	+	+		+			+	INSGA-DLS
Liu	2021		+	Waste				+			+	CW-ALNS
Guillen	2021	+		Single	+	+					+	Metaheuristic
Sherif	2021	+		Single	+	+	+	+			+	SA
This Study		+		Perishable	+	+		+		+	+	MIP & SA

Facility Location Problem (FLP) and Vehicle Routing Problem (VRP) should be combined to address decisions of location and routing, which results in Location Routing Problem (LRP). The problem has various applications in the real world, such as in the blood supply chain, food supply chain, waste collection, and humanitarian logistics. Our problem includes location, routing, and transportation decisions, simultaneously. It is called a Transportation Location Routing Problem. The problem was first proposed by Martinez Salazar et al. (2014). They presented a new bi-objective model for the LRP problem. They evaluated two objectives to minimize overall network costs and create balanced routes. Two metaheuristic methods were proposed to solve this problem, demonstrating that the algorithms presented worked efficiently when applied at large scales. However, unlike our problem, Martinez-Salazar et al. (2014) have a two-echelon network. The first echelon involves the distribution of products from the plants to established distribution centers. In the second echelon, location and routing decisions are given. In our problem, there are multi-echelons. Also, in our thesis, the time of arrival at school is important, since lunch has to be ready at a certain time. Therefore, we have considered the service time.

In this thesis, we review and present the most relevant literature addressing transportation location routing and multi-depot location routing problems. We first review the studies that focus on transportation location routing problems. Ghezavati et al. (2015) consider the freshness and maturity of products in the multi-stage distribution of the perishable product supply chain. They took into account the processes of freshness and maturity, transport and storage. The problem presents a mixed integer programming model. The objective is to optimize the profit of the distributor, which influences logistical decisions regarding the delivery of fresh produce in the agri-food supply chain. They used Benders' decomposition method to solve the problem. According to their numerical experiments, using the represented feasibility and optimality cuts results in a significant reduction in computational times.

Rabbani et al. (2018) study a Location Routing Problem (LRP) for distribution systems. They focus on the transportation step in the first stage. There is a transportation problem due to the truck capacity limitation. Then, a transportation location routing problem (TLRP) is solved as an extension of the two-stage LRP. In the second echelon, they consider the time intervals to serve customers. The objective is to minimize distribution operating costs, fuel consumption costs, and CO2 emission costs. NSGA-II and Multi-Objective Particle Swarm Optimization (MOPSO) are developed.

Ghomi et al. (2019) propose the first study combining transportation problems and inventory location routing decisions in perishable distribution systems. They studied a new model including three echelon supply chains entitled. They develop a new mathematical model limited to solving only small-sized problems with supply source nodes. Due to the NP-hardness of the problem, three metaheuristic algorithms are applied to deal with the complexity of the problem in large-scale problems.

Amini et al. (2020) study a transport-location-arc-routing problem and formulate a dual-objective mathematical model to minimize the total cost and makespan. An augmented ε-constraint algorithm is used to find the optimal and Pareto solutions. They merged the Multi-Objective Late Acceptance Hill-Climbing (MOLAHC) algorithm with the Non-Dominated Sorting Genetic Algorithm (NSGA-II) as a population-based approach.

Farrokhi et al. (2020) focus on the waste collection problem. In light of a new collection network, they provide a novel multi-objective mathematical model for this issue. The problem pertains to a multi-stage network's collection, treatment, recycling, and disposal of hazardous material. The problem includes three objective functions simultaneously. They are economic cost, transportation risk, and total population who live around undesirable facilities in the presented collection network. To solve the problem, five multi-objective metaheuristic algorithms were used, with one of them, the Hybrid Cultural and Genetic Algorithm (MOHCGA), being proposed. MOHCGA is first applied in location routing problems.

Masoudipour et al. (2020) study a closed-loop supply chain network design focusing on location routing decisions. The forward link of this supply chain includes manufacturers, warehouses, distributors, and customers. In the backward chain, the distributors collect the returns. Then, it separates into three batches to be sent to emerging markets, a decomposition center, or a secondary chain facility. The establishment, transportation, and routing costs in the forward and backward chains are taken into account in the first objective is to be minimized. The second objective to be minimizes the numbers of vehicles utilized for transportation by the manufacturers, the out of town depots respectively. They are solving the multi objective model using both the ε-constraint method and the multi-objective fuzzy algorithm. They are test the model under different scenarios. The results show that the ε-constraint method performs as well as or better than the fuzzy algorithm.

Safari et al. (2021) study Transportation-Location-Routing problem. They proposed a tri-objective mathematical model. Their model includes three echelon supply chain. The objective is minimize the total costs, maximize the minimum reliability of the routes traveled and create a balanced route set. They used four metaheuristics to solve the proposed model. These metaheruistics are Non-Dominated Sorting Genetic Algorithm- II (NSGA-II), Multi-Objective Grey Wolf Optimizer (MOGWO), Multi-Objective Water Cycle Algorithm (MOWCA) and Multi-objective Particle Swarm Optimization (MOPSO). They tested the algorithms on various problems. According to the results, NSGA-II and MOGWO algorithms perform better for each test problem.

Yu et al. (2020) study a two-stage multi-objective location routing problem. They consider different requirements from various realistic waste collection practices. The proposed model considers flow constraints and capacity constraints. A non-dominant sequencing genetic algorithm developed with a specially designed directed local search is offered.

Liu et al. (2021) focus on a two-echelon common waste collection vehicle routing problem. The two-echelon waste transportation network contains two-level facilities. They create an optimization model for the problem whose objective is to minimize total costs and carbon emissions. The K-means customer clustering method is used to reduce the computational complexity in solving this model. They develop a three-stage solution approach that includes a hybrid heuristic and an adaptive large neighborhood search algorithm to search for optimal vehicle routes based on the Clarke & Wright algorithm.

Sherif et al. (2021) focus on the two-echelon supply chain network of the battery manufacturing industry. The green transportation and inventory-related problems are resolved in the first echelon using an integrated optimization process. The problem of multi-depot heterogeneous green vehicle routing with simultaneous pick-up and delivery is researched in the second echelon. The objective is to minimize the inventory carrying cost, transportation cost, and carbon emission cost. They focuses on solving the problem by formulating a mixed integer nonlinear programming model and using the Simulated Annealing Algorithm.

Many studies focus on the multi-depot location routing problem.

Murugaswamy (2011) study a mixed-integer linear formulation to locate distribution centers for a food supply chain based on the school lunch program concept for Mexican Schools. The K-means clustering algorithm is used to classify food processing centers based on the distance between schools. The multi-echelon facility location model is then solved with the Benders Decomposition Algorithm.

Govindan et al. (2014) focus on the two-echelon location routing problem in a perishable food supply chain network. They investigated the total cost and the total environment-caused impact. They considered time windows to constrain delivery times to each customer and operation times and introduce a Hybrid Meta-Heuristic Algorithm.

Kretschmer et al. (2014) highlight the essential aspects that influence the performance and sustainability of the school lunch supply chain. The study is based on a framework for Laos, located in Southeast Asia. According to their research, local supply chain models that support local finance, local suppliers, and local control of the system are more beneficial.

The two-stage location orientation problem in the collection of recyclables that aren't hazardous is studied by Vidovic et al. (2016). They use their proposed model to simultaneously determine the locations of the collection points, the locations of the intermediate consolidation points, and the routes taken by the collection vehicles based on the relationship between the quantities of recyclable materials collected and the distance between end users and the collection points. They developed heuristic methods to solve the problem.

Hiassat et al. (2017) focus on the location inventory routing problem for perishable products. It presents a mixed-integer problem with homogeneous vehicles of a given capacity and minimizing inventory holding costs. A genetic algorithm has been developed to solve the problem.

Dai et al. (2018) focus on integrating the location inventory problem into the supply chain network. They develop an optimization model for perishable products with fuzzy capacity and carbon emission restrictions. They formulated as a mixed-integer nonlinear programming model. They optimized the warehouse inventory levels and the number of plants and warehouses. The objective is to minimize the total costs. A Hybrid Genetic Algorithm (HGA) and Hybrid Harmony Search (HHS) are used to solve this model. The proposed algorithms were also tested under different conditions.

According to the results of their numerical experiments, it was revealed that both algorithms were successful. Especially the quality of HHS's solution is higher than HGA's.

Pichka et al. (2018) focus on the two-echelon open location routing problem (2E-OLRP), where a vehicle does not need to return to its departing facility. They formulated three mixed-integer linear programming models. To address large-scale samples, a hybrid simulated annealing heuristic is developed.

Kouchaksaraei et al. (2018) study the design of a three-echelon blood supply chain network in the event of a disaster. The network consists of procurement, processing, and distribution. Unlike other studies, they focus on all levels of the supply chain, from blood supply to distribution. The objective is to maximize meeting demand while minimizing total cost. They use a goal programming method and real data to solve the problem.

Majd et al. (2018) study a three-echelon supply chain for perishable products with a constrained time horizon using an integrated Inventory Location Routing Problem. This supply chain consists of one supplier, several distribution centers, and several retailers. They assumed that the transport fleet is heterogeneous, and retailers' demand is taken as stochastic. Their study uses a timeline to not interfere with vehicles' operation. In addition, this timetable prevents a vehicle from being allocated to more than one distribution center in each period. They use a problem Lagrange Relaxation Algorithm to solve problem.

Wang et al. (2018) focus on two-echelon location routing problems with time windows. They develop a three-stage customer clustering-based approach to solve the problem. They formulate a bi-objective model that minimizes cost and maximizes customer satisfaction. They create a Modified Non-Dominated Sequence Genetic Algorithm-II (M-NSGA-II) technique to locate logistics facilities, allocate customers, and optimize the vehicle routing network. They apply the algorithm in a beverage distribution network to see the real-world relevance of the problem.

Vahdani et al. (2018) focus on a two-phase multi-product, multi-commodity, multi-purpose problem in the three-level aid supply chain. In the first stage, the problem of vehicle location routing and distribution from warehouses in warehouses and establish distribution centers are focused on. The same problem is study in the second stage by considering time windows. They use NSGAII and MOPSO meta-heuristic algorithms to solve the problem and numerical examples to evaluate the accuracy of the mathematical model and the effectiveness of the proposed procedures. They evaluated the results of the algorithms using different problems.

Dai et al. (2019) focus on the three-echelon and four-echelon location routing problem. They develop a two-phase method based on the Clarke and Wright savings algorithm for the location routing problems. The objective is to minimize the total cost. The total cost consists of transportation cost and fixed costs for vehicles and facilities. In their studies, they take the demand of the customers as deterministic rather than uncertain.

Saragih et al. (2019) consider the location-inventory-routing problem in a three-echelon supply chain network where inventory decisions are made at three relevant institutions. Their problem consists of a single supplier, multiple warehouses, and multiple retailers. They considered homogeneous fleets and single products. They proposed the heuristic method. The heuristic method consists of two stages, namely, the configuration stage and the improvement stage. Location, inventory, and routing problems are solved in the configuration phase. Simulated annealing is used in the improvement phase to improve the solution.

Buiki et al. (2020) study the sustainability issue, integrated decision-making at the location, routing, and inventory control planning. A two-stage approach is proposed in their study. In the first stage, the Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE) method is used to identify the sustainable-oriented suppliers. In the second stage, its mathematical formulation is developed and solved by multi-objective MIP. Since this problem is NP-hard, they use two hybrid meta-heuristics, parallel and serial combinations of Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) to solve the problem.

The multi-depot open location routing problem with a heterogeneous fixed fleet was introduced by Gullien et al. (2021). They are motivated by the collection problem of a company collecting raw materials from different suppliers. The objective is to minimize the total cost by choosing the contracted carriers, the vehicles used by each contracted carrier, and the collection routes. They proposed an intelligent meta-heuristic method that incorporates problem-specific information. The results demonstrate that the solution method is efficient and provides high-quality solutions.

As can be seen, few studies in the literature focus on food distribution for the school lunch program. The transportation location and routing problems (TLRP) are primarily applied to real-life problems. Our problem involves transportation, vehicle routing, and location decisions simultaneously. Vehicle capacities sent from farmers to distribution centers are larger, they are truck type. But the vehicles that deliver to schools do distribution within the city, so smaller transportation vehicles are used. For this reason, heterogeneous vehicles are used in our problem. Also, unlike the literature, we have imposed a service time restriction when delivering to schools so that the school lunch can arrive on time. For example, we defined 10 minutes of service time for each school. However, when we limit the total service time constraint in our problem, we may not be able to obtain a feasible solution. For this reason, we allowed the total time limit to be exceeded but added a penalty function to it. TLRP is classified as Np-Hard problem~~s~~ in the literature (Martinez et al., 2014). Our problem is more difficult because of these real aspects that we consider. Consequently, we offer a two-stage solution approach to solve this problem. We propose a SA algorithm to solve the problems in third echelon. In the third echelon, we determine the locations of FPCs, which FPCs serve to which schools, and the routes between the schools. After selecting the location of FPCs, we solve the transportation location problem for DCs in the second echelon. By modifying the presented mathematical model, we solve the problems in the first echelon.

CHAPTER IV

PROBLEM DEFINITION AND MATHEMATICAL FORMULATIONS

4.1. PROBLEM DEFINITION

We have farmers, DCS, FPCs, and schools as supply chain partners. The first two echelons involve the distribution of products from farmers to food processing centers (FPC) through distribution centers (DC). The second echelon includes the locations of distribution centers and routes between food processing centers. The third echelon forms a multi-depot location routing problem where the locations of food processing centers and routes between schools are determined. The school lunch distribution network is presented in Figure 1.

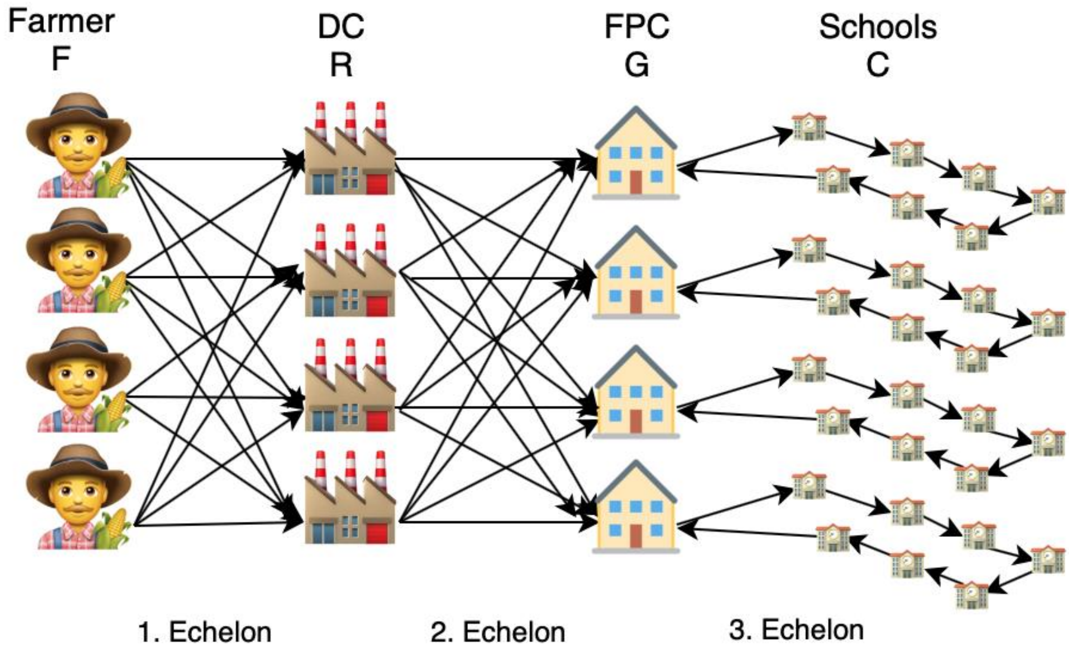

Figure 1: School Lunch Distribution Network

Farmers are our suppliers. Farmers produce fresh and organic products to meet the demand of DCs. While providing healthy nutrition to students, local farmers also are supported. DCs are vital for distributing products from local farmers to FPCs. In our problem, we assumed that a single type of product could be supplied to DCs from all farmers. We also supposed that the product is always available for all farmers. DCs act as intermediaries between farmers and FPCs. DCs transfer foods to food preparation centers (FPC). FPCs are involved in the processes of cleaning, cutting, cooking, packaging, and preparing ready services for the products supplied by the DCs. So, FPCs are the centers with kitchens where meals are prepared and packaged to be sent to schools. DCs and FPCs have limited capacities. The amount sent from farmer to DC cannot exceed the capacity of DC, and the amount sent from DC to FPC cannot exceed the capacity of FPC. At the same time, the quantity sent from the farmer to the DC must meet the demand of the DC, and the amount sent from the DC to the FPC must meet the demand of the FPC. FPCs are the depots that the vehicles must return to after serving schools. Schools are the last link of the distribution network. Every school has a certain demand. This demand is satisfied by FPCs. Only one FPC serves each school.

Arrival time to school is essential as lunch has to be ready at a certain time. Therefore, we have taken into account the service time. We have the risk of producing an infeasible solution due to the limited-service time. For this reason, we permit exceeding the service time. However, we added a penalty function for cases that exceed the total service time. As the total service time is exceeded, the cost increases. We used heterogeneous vehicles in our problem. Truck-type vehicles with larger capacities are used to transport products from farmers to DCs. Since the vehicles delivering from FPCs to schools distribute within the city, smaller transport vehicles are used. Vehicles have a limited capacity, and these capacities cannot be exceeded. We aim to minimize the total transportation cost in all three echelons and the fixed costs of vehicles and DCs, and FPCs.

4.2 MATHEMATICAL MODEL

The objective mathematical model has been developed, taking into account the following assumptions:

- DCs are capacitated, and the capacity of each is the same
- The single commodity distribution model is assumed
- The demands of the schools are known with certainty
- Vehicles are heterogeneous
- DCs and FPCs have limited capacities
- The total FPC capacities cannot be less than the sum of the demands of the schools
- The total DC capacities cannot be less than the sum of the demands of the FPCs
- The number of vehicles that leave an FPC must be equal to the number of vehicles returning to that FPC

The objective is to minimize the total transportation cost in all three echelons and the fixed cost of vehicles, DCs and FPCs. The mixed integer nonlinear programming formulation of the problem is given below.

Sets and Indexes

F(f)	Set of farmers
R(r)	Set of Distribution Centers (DC)
G(g)	Set of Food Processing Centers (FPC)
C(c)	Set of Schools
V(v)	A fleet of vehicles in the third echelon
T(t)	A fleet of vehicles used between farmers and DCs
K(k)	A fleet of vehicles used between DCs and FPCs
i	Origin/destination, $i \in I = \{G, C\}$
j	Origin/destination, $j \in J = \{ G, C\}$

Parameters

c_{ij}	Transportation cost from node i to node $j, i, j \in G \cup C$
c_{rg}^{k}	Transportation cost of vehicle k from DC r to FPC g, $r \in R$, $g \in G, k \in K$
c_{fr}^{t}	Transportation cost of vehicle t from farmer f to DC r, $f \in F, r \in R, t \in T$
CF_f	Capacity of farmer f, $f \in F$
CR_r	Capacity of DC r, r $\in R$
CG_g	Capacity of FPC g, g $\in G$
CV	Vehicles capacity in the third echelon
CV_t	Capacity of vehicle t used between farmers and DCs, $t \in T$
CV_k	Capacity of vehicle k used between DCs and FPCs, $k \in K$
d_c	Demand for each school c, $c \in C$
l_{rg}	Distance from DC r to FPC $g, r \in R, g \in G$
l_{ij}	Distance between node i and j, $i \in G \cup C, j \in G \cup C$
l_{fr}	Distance from farmer f to DC r, $f \in F, r \in R$
F_r	Fixed cost of establishing DC $r, r \in R$
F_g	Fixed cost of establishing FPC $g, g \in G$
F_t	Fixed cost of using vehicle t in the first echelon, $t \in T$
F_k	Fixed cost of using vehicle k in the second echelon, $k \in K$
F	Fixed cost of vehicle in the third echelon
M	Big Number
s_c	Service time at school c, $c \in C$
T	Total service time
PN	Penalty cost for exceeding service time at school c, $c \in C$
SV	Speed of vehicle

Decision variables

y_{gc} $\begin{cases} 1, \text{if school } c \text{ is assigned to FPC } g, c \in C, g \in G \\ 0, \text{otherwise} \end{cases}$

w_{rg} $\begin{cases} 1, \text{if FPC } g \text{ is assigned to DC } r, g \in G, r \in R \\ 0, \text{otherwise} \end{cases}$

z_g $\begin{cases} 1, \text{if FPC } g \text{ is established}, g \in G \\ 0, \text{otherwise} \end{cases}$

z'_r $\begin{cases} 1, \text{if DC } r \text{ is established}, r \in R \\ 0, \text{otherwise} \end{cases}$

x^t_{fr} Quantity sent from farmer f to DC r by vehicle type $t, r \in R, f \in F, t \in T$

x'^k_{rg} Quantity sent from DC r to FCP g by vehicle type $k, r \in R, g \in G, k \in K$

p_{ij} $\begin{cases} 1, \text{if there is a connection from node } i \text{ to } j,\ i, j \in G \cup C \\ 0, \text{otherwise} \end{cases}$

p^t_{fr} $\begin{cases} 1, \text{if vehicle } t \in T \text{ travels from farmer } f \text{ to } DC\ r,\ f \in F, r \in R, t \in T \\ 0, \text{otherwise} \end{cases}$

p^k_{rg} $\begin{cases} 1, \text{if vehicle } k \in K \text{ travels from DC } r \text{ to FPC } g;\ r \in R, g \in G, \text{k} \in K \\ 0, \text{otherwise} \end{cases}$

d'_g Demand for FPC $g \in G$.

u_i Load of the vehicle after visiting school i, $i \in G \cup C$

$$min \sum_{r\in R} F_r z'_r + \sum_{g\in G} F_g z_g + \sum_{t\in T}\sum_{f\in F}\sum_{r\in R} F_t p^t_{fr} + \sum_{k\in K}\sum_{g\in G}\sum_{r\in R} F_k p^k_{rg} + \sum_{i\in G\cup C}\sum_{j\in G\cup C} l_{ij} c_{ij} p_{ij} + \sum_{f\in F}\sum_{r\in R}\sum_{t\in T} x^t_{fr} c^t_{fr} + \sum_{r\in R}\sum_{g\in G}\sum_{k\in K} x'^k_{rg} c^k_{rg} + \sum_{c\in C} PN\left(\sum_{i\in G\cup C}\sum_{j\in G\cup C} p_{ij} l_{ij} / SV + \sum_{i\in G\cup C}\sum_{j\in G\cup C} s_j p_{ij}\right) - T$$

(1)

The objective is to minimize the total transportation cost in all three echelons and the fixed cost of vehicles and DCs and FPCs. The first two terms represent the fixed costs of establishing DCs and FPCs, respectively. The third and fourth terms represent the fixed cost of using vehicles in the first and second echelons. The fifth, sixth, and seventh terms show total transportation cost in each echelon. The last term assigns a penalty cost to the objective function for each tour unit time the vehicle exceeds the service time, thus aiming to produce tours that delay the arrival time at a school the least.

The first and second echelons

$$\sum_{r\in R} w_{rg} = z_g \qquad \forall\, g \in G \qquad (2)$$

Single-sourcing restrictions require only one FPC to provide services to a school.

$$z'_r \geq w_{rg} \qquad \forall\, g \in G,\ r \in R \qquad (3)$$

A DC *r* can serve an FPC *g* if it is established.

$$d'_g = \sum_{c\in C} d_c y_{gc} \qquad \forall\, g \in G \qquad (4)$$

The demand of FPC *g* equals the total demand of customers assigned to it.

$$\sum_{r\in R} \sum_{t\in T} x^t_{fr} \leq CF_f \qquad \forall\, f \in F \qquad (5)$$

The capacity of a farmer *f* cannot be exceeded.

$$\sum_{r\in R} \sum_{k\in K} x'^k_{rg} = d'_g \qquad \forall\, g \in G \qquad (6)$$

Quantity sent from DC *r* to FPC *g* must satisfy the demand of FPC.

$$\sum_{f\in F} \sum_{t\in T} x^t_{fr} = \sum_{g\in G} d'_g w_{rg} \qquad \forall\, r \in R \qquad (7)$$

Quantity sent from farmer *f* to DC *r* must satisfy the demand of DC.

$$\sum_{f\in F} \sum_{t\in T} x^t_{fr} \leq CR_r \qquad \forall\, r \in R \qquad (8)$$

The capacity of a DC *r* cannot be exceeded.

$$\sum_{f\in F} \sum_{t\in T} x^t_{fr} = \sum_{g\in G} \sum_{k\in K} x^k_{rg} \qquad \forall\, r \in R \qquad (9)$$

Flow balance at each DC *r*.

$$\sum_{f\in F} \sum_{t\in T} x^t_{fr} \leq CR_r z'_r \qquad \forall\, r \in R \qquad (10)$$

The amount sent from farmer *f* to DC *r* cannot exceed the DC’s capacity.

$$d'_g \leq CG_g z_g \qquad \forall\, g \in G \tag{11}$$

The capacity of an FPC g cannot be exceeded.

$$\sum_{r \in R} x^t_{fr} p^t_{fr} \leq CV_t \qquad \forall\, t \in T, f \in \mathrm{F} \tag{12}$$

The vehicle capacity sent from the farmer f to DC r cannot be exceeded.

$$\sum_{g \in \mathrm{G}} x'^k_{rg} p^k_{rg} \leq CV_k \qquad \forall\, k \in \mathrm{K}, r \in \mathrm{R} \tag{13}$$

The vehicle capacity sent from a DC r to an FPC g cannot be exceeded.

The third echelon

$$\sum_{g \in G} y_{gc} = 1 \qquad \forall\, c \in C \tag{14}$$

Each school is served by only one FPC.

$$y_{gc} \leq z_g \qquad \forall\, c \in C,\ g \in G \tag{15}$$

A school can be served by only one FPC if it is established.

$$\sum_{j \in G \cup C} p_{ij} = \sum_{j \in G \cup C} p_{ji} \qquad \forall\, i \in G \cup C \tag{16}$$

The number of vehicles that leave an FPC g must equal the number of vehicles returning to that FPC.

$$\sum_{c \in C, j \neq c} p_{cj} = y_{gj} \qquad \forall\, j \in G \cup C, g \in G \tag{17}$$

$$\sum_{j \in G \cup C, g \neq j} p_{cj} = y_{gc} \qquad \forall\, g \in G,\ c \in C \tag{18}$$

Constraint sets (17) and (18) impose, first, that each school must be visited immediately after exactly one FPC or after another school, and that exactly one school or FPC must be visited immediately after, respectively. Second, these constraints enable the construction of routes only between schools assigned to the same FPC.

$$u_c - u_i + CV \sum_{j \in G \cup C} p_{cj} \leq CV - d_c \qquad \forall\, i \in G \cup C,\ c \in C, i \neq c \tag{19}$$

$$d_c \leq u_c \leq CV \qquad \forall\, c \in C \tag{20}$$

Constraint sets (19) and (20) prevent exceeding vehicle capacities and avoid the generation of sub-tours.

$$\sum_{i\in G\cup C}\sum_{j\in G\cup C} p_{ij}l_{ij}/SV + \sum_{i\in G\cup C}\sum_{j\in G\cup C} s_j p_{ij} \leq \mathrm{T} \quad (21)$$

Prevents exceeding the maximum total service time T.

$$u_i \geq 0 \qquad \forall\, i \in G \cup C \quad (22)$$

$$x_{fr}^{t} \geq 0 \qquad \forall\, f \in F;\ \forall\, r \in R;\ \forall\, t \in T \quad (23)$$

$$x_{rg}^{\prime k} \geq 0 \qquad \forall\, r \in R;\ \forall\, g \in G;\ \forall\, k \in K \quad (24)$$

$$d_g' \geq 0 \qquad \forall\, g \in G \quad (25)$$

$$y_{gc} \in \{0,1\} \qquad \forall\, g \in G;\ \forall\, c \in C \quad (26)$$

$$w_{rg} \in \{0,1\} \qquad \forall\, r \in R;\ \forall\, g \in G \quad (27)$$

$$z_g \in \{0,1\} \qquad \forall\, g \in G \quad (28)$$

$$z_r' \in \{0,1\} \qquad \forall\, r \in R \quad (29)$$

$$p_{ij} \in \{0,1\} \qquad \forall\, i \in I;\ \forall\, j \in J \quad (30)$$

$$p_{fr}^{t} \in \{0,1\} \qquad \forall\, f \in F;\ \forall\, r \in R;\ \forall\, t \in T \quad (31)$$

$$p_{rg}^{k} \in \{0,1\} \qquad \forall\, r \in R;\ \forall\, g \in G;\ \forall\, k \in K \quad (32)$$

Sign and type restrictions

CHAPTER V

SOLUTION METHODOLOGY

Since our problem is NP-hard, different solution approaches are required. SA is a local search algorithm that is capable of escaping from local optima by accepting bad solutions during its iterations. There are many studies in the literature using the simulated annealing algorithm because it is widely and simply applicable. SA has been successfully applied to real-world examples, location-routing problems, and complicated combinatorial optimization problems (Yu et al. 2010; Sherif et al. 2021).

We propose a two-stage solution approach to solve this problem. The first stage provides a Simulated Annealing Algorithm that handles the routing decisions of the third echelon. These decisions include locations of FPCs, routes between schools, and which FPC will serve which school. After these decisions are determined, the problem turns into a transportation location problem. The second stage presents a mixed-integer linear mathematical model that determines the locations of distribution centers and solves the transportation location problem in the first echelon. This is a reduced version of the MILP model proposed for the transportation location problem above. The outputs of SA (d'_g and z_g) become the inputs of the reduced model. Thus, we know the demands and location of FPCs (d'_g and z_g), routes between schools, and which FPC will be serving to which school. In other words, d'_g and z_g turned into parameters, which are used as parameters in the reduced model. When the reduced model is solved, the transportation location routing problem is completely solved. The proposed solution is represented in Figure 2.

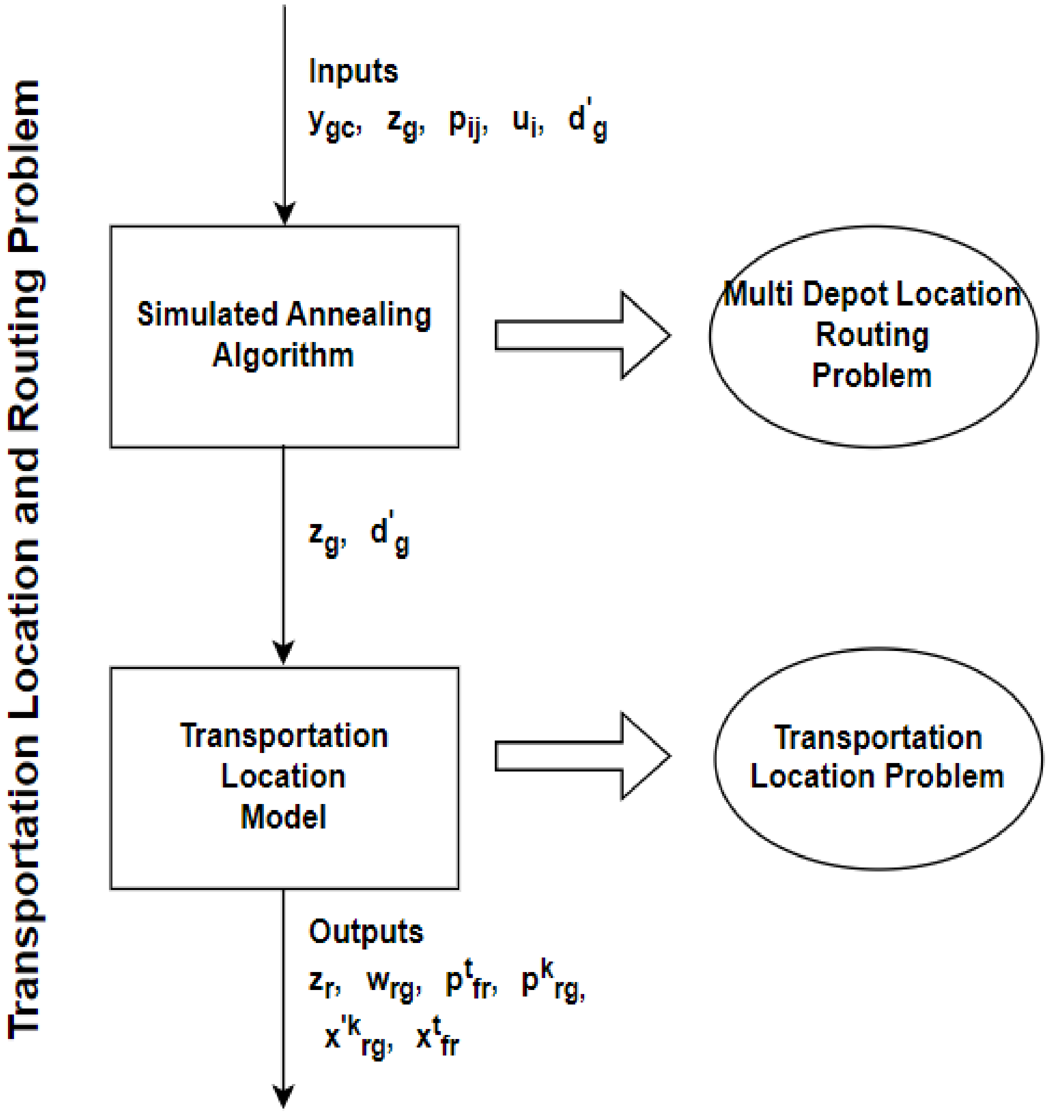

Figure 2: Solution Approach Diagram

5.1. FIRST STAGE OF THE SOLUTION APPROACH

5.1.1 Simulated Annealing Algorithm

Simulated annealing is a metaheuristic that uses a hill-climbing search method (Bayram 2013). A metal is heated to allow the molecular structure to change during the simulation of annealing. After that, the temperature is continuously lowered, which lowers atoms' energy and prevents them from reorganizing until the metal structure is finally adjusted. This process minimizes the number of defects in the structure of the material. Similarly, simulated annealing gradually restricts the freedom of the solution search until it only approves moves in the direction of superior tours (Shi-hua Zhan 2016).

In a combinatorial optimization problem, a solution corresponds to the state of the physical system and the cost of the solution for the system's energy. One of the primary parameters in the simulated annealing algorithm is temperature. The temperature is gradually reduced while the algorithm is running. A certain number of iterations are performed at each temperature level. A neighbor solution is generated at each step. The current solution is randomly selected from a set of neighboring solutions in each iteration. If the new solution is better than the current one, it is automatically accepted and becomes the new solution. Otherwise, the new solution is obtained according to the following acceptance probability function;

$$p = e^{\frac{-\Delta E}{T}}$$

$p = probability\ of\ acceptance$

$T = current\ temperature$

$\Delta = difference\ between\ the\ objective\ values\ obtained\ from\ the\ current$
$and\ the\ neighbor\ solutions$

The probability of acceptance is related to the size of the cost increase and the temperature parameter. A move is more likely to be accepted if the temperature is high and the cost increase is low. It is considered to improve movements only when the temperature is sufficiently lower. The algorithm stops at a local optimum (Diabat et al. 2017).

Simulated annealing permits bad moves to states with a lower value hence letting us escape conditions that lead to a local optimum. Gradually decreases the frequency of such moves and their size. Simulated annealing is a variant of local (neighborhood) search. Traditional local search (e.g., steepest descent for minimization) always moves toward improvement. Simulated annealing allows non-improving moves to avoid getting stuck at a local optimum. Simulated annealing allows probabilistic acceptance of non-improving moves.

5.1.2. Initial Solution Generation

The nearest neighbor algorithm (NNSA) is used in the production of the initial solution. We preferred the nearest neighbor algorithm because it is simple and easy to implement. The NNSA is frequently used to produce the initial solution in location routing and vehicle routing problems. It is highly preferred because it gives simple and effective results (Marinakis 2001; Sherif et al. 2021). In this thesis, this algorithm was used to obtain effective results. The NNSA proceeds with selecting the nearest neighbors as the starting node. All nodes are visited, and the tours are completed.

In the NNSA algorithm, it chooses the school closest to the FPC from the schools assigned to the FPC as the school to be visited first. The algorithm continues to select the school closest to the last assigned school in order until the FPC capacity is exceeded. At the same time, vehicle capacities are also checked. When the FPC capacity is exceeded, it moves to the next randomly opened FPC, and when the vehicle capacity is exceeded, it moves to the next vehicle and continues in the same way until the capacities are full. The steps of the nearest neighbor search algorithm and initial solution are given in Figure 3.

```
Set Parameters:
    Vehicle Capacity, Schools Length, Schools Demand, FPC Capacity
    Generate an initial solution from using a nearest neighboor prosedure
    based on allocating schools to the closest FPCs
    Choose a randomly opened FPC and open
    For all FPCs open randomly
        Assign the closest school to the FPC.
        Capacity (FPC)= Demand of School
        While (Total demand of assigned schools <= FPC capacity)
         Choose the school closest to the last assigned school.
         Capacity (FPC)= Capacity (FPC)+Demand of School
        Do While
   End for
   For all FPC's
         k=0 (Number of vehicles)
         j=1
         CAP (vehicle)=0
   While (until all schools on the route have been inspected.)
                CAP (vehicle)=CAP (vehicle) + Demand of school (j)
                   If (CAP (vehicle) > Max vehicle capacity)
                      Return vehicle to FPC. (j-1. Returns from school)
                      Add new roue for FPC. k=k+1
               j= the school to be visited first in the next round. (j=j-1)
                      CAP (vehicle)=0
                 End If
               j=j+1
    Do While
End for
Calculate the objective for each generated route.
```

Figure 3: Pseudo Code for a Detailed NNSA to Genereate Initial Solution

5.1.3. Solution Representation

A solution representation is given in Table 2. Consider the situation when the FPC maximum capacity is 60 and the vehicle maximum capacity is 40. The solution matrix below illustrates the first FPC is opened at random and subsequently assigned to the nearby school (school 8). The next step is to choose the school (6) that is closest to the school assigned to the FPC. The FPC and vehicle capacities are checked concurrently. If the FPC capacity or vehicle capacity is not exceeded, the FPC is assigned to school. Afterward, the capacities are checked, and a new assignment is made to the closest school (school 3). When the assignment to the closest school is desired, a second vehicle is needed as the vehicle capacity is exceeded. Each school is visited once. For this reason, the school closest to FPC is selected among the schools that have not been visited before. The second vehicle from FPC 1 is assigned to the school (school 2) closest to FPC 1. Then the capacities are checked, and the assignments continue in the same way. When the FPC's maximum capacity is reached, a new FPC is opened at random and so on until all of the schools have been assigned.

As indicated in Table 3, the randomly opened first FPC visited the eighth, sixth and third schools with the first vehicle, respectively. When the vehicle capacity is exceeded, vehicle two visits schools two and four, respectively. When the FPC capacity is exceeded, schools continue to be served in the same way from the other FPCs opened. FPCs and vehicles have specified capacities, and these capacities cannot be exceeded. The sum of FPC capacities must be greater than or equal to the aggregate demand of schools.

Table 3: Representation Route Matrix

		Schools		
FPC	Vehicles	1	2	3
1	1	8	6	3
1	2	2	4	
4	3	7	5	
2	4	1	10	
2	5	9		

5.1.4. Detailed Simulated Annealing Algorithm

The proposed SA heuristic requires four parameters: $ITER$, T_i, T_{max}, and α. $ITER$ represents the total number of iterations that the neighborhood search should repeat at a particular temperature; T_i denotes the initial temperature, T_{max} is the final temperature, and α is the coefficient of the cooling schedule. In this thesis, a geometric cooling schedule was used. In the geometric schedule, the temperature is updated using this formula $T = \alpha * T$. α (α ∈ |0,1|) should be between 0.5 and 0.99. Each iteration at a particular temperature generates a neighborhood solution S' from the current solution S by using a neighborhood search mechanism. The proposed SA heuristic uses four move mechanisms: swap move, insertion move, swap center move, and close center move. A neighborhood solution is generated by either one of these four mechanisms. The probability of choosing each type of move is equal.

Let Δ be the objective function difference between the new neighborhood solution and the current solution. If $\Delta <= 0$, then the new neighborhood solution is better than the current solution and S' replaces S as the current solution; otherwise, the new neighborhood solution is accepted with a probability exp $(-\frac{\Delta}{T})$.

The current temperature decreases to $\alpha * T$, after running $ITER$ iterations at the current temperature T_i. The algorithm terminates at two conditions: the current temperature is below or equal to the final temperature T_{min} and the number of maximum iterations is achieved. The best solution (S') and its objective function value $(f(S'))$ are updated whenever a new best solution is found. The Simulated Annealing algorithm accepts bad solutions with a certain probability value. Thus, we have always ensured to produce feasible solutions. The pseudo-code of the proposed heuristic is given in Figure 4.

The proposed simulated annealing algorithm evaluates the solutions by using the same objective function given in the MILP formulation. If the route exceeds the service time, the penalty function $(f(Z))$ is calculated as given below.

$X = total\ distance$

$S = service\ time$

$N = number\ of\ school$

$T = total\ service\ time$

$V = speed\ of\ vehicle$

$P = penalty\ cost$

$f(Z) = \left(\left((X/V) + (S * N)\right) - T\right) * P$

Start

Input: T_i, T_{max}, i ←0, α

Generate the initial solution $S \leftarrow S_0$, $iter \leftarrow 1$

While ($T_i \geq T_{max}$)

While ($iter \leq ITER$)

Generate r=random (1,4)

If (r=1) **then**

S' ←generate a new solution by applying swap move

If (r=2) **then**

S' ←generate a new solution by applying insertion move

If (r=3) **then**

S' ←generate a new solution by applying swap center move

If (r=4) **then**

S' ←generate a new solution by applying close center move

$\Delta = f(S') - f(S)$

If ($\Delta \leq 0$) **then**

$S \leftarrow S'$ **else** $S \leftarrow S'$ with probability of $exp^{-\frac{\Delta}{T_i}}$

$iter = iter + 1$

End While

$T_{i+1} = \alpha * T_i$, $i = i + 1$

End While

Figure 4: Pseudo Code of the Proposed Heuristic

5.1.4.1. Swap Move

We implement the swap move by randomly choosing the two schools from different routes and then exchanging the numbers in these two positions. In other words, swap move provides making changes between routes. The swap move representation on the route matrix is given in Table 4.

Table 4: Swap Move Representation on the Route Matrix

FPC	Schools		
1	8	6	3
1	2	4	
4	7	5	
2	1	10	
2	9		

Swap Move

FPC	Schools		
1	8	6	3
1	2	**1**	
4	7	5	
2	**4**	10	
2	9		

5.1.4.2. Insertion Move

We implement the insertion move by randomly choosing the two schools from different routes and then inserting one next to the other. Insertion move provides making changes between routes. The insertion move representation on the route matrix is given in Table 5.

Table 5: Insertion Move Representation on the Route Matrix

FPC	Schools		
1	8	6	3
1	2	4	
4	7	5	
2	1	10	
2	9		

Insertion Move

FPC	Schools		
1	8	6	3
1	2	4	
4	7	5	
2	1	**6**	**10**
2	9		

5.1.4.3. Swap Center Move

The swap center move is executed by randomly selecting the two FPCs and then exchanging the numbers in these two positions. Swap center move provides making changes between FPCs. The swap center move representation on the route matrix is given in Table 6.

Table 6: Swap Center Move Representation on the Route Matrix

FPC	Schools		
1	8	6	3
1	2	4	
4	7	5	
2	1	10	
2	9		

Swap Center Move →

FPC	Schools		
1	8	6	3
2	2	4	
4	7	5	
1	1	10	
2	9		

5.1.4.4. Close Center Move

Closing an opened FPC and opening a closed one: An opened FPC is randomly selected. A closed FPC is also randomly selected, and all of the schools in the closed FPCs are moved to the newly opened FPCs. This neighborhood structure investigates different combinations of opened FPCs. The close center move representation on the route matrix is given in Table 7.

Table 7: Close Center Move Representation on the Route Matrix

FPC	Schools		
1	8	6	3
1	2	4	
4	7	5	
2	1	10	
2	9		

Close Center Move →

FPC	Schools		
1	8	6	3
1	2	4	
4	7	5	
3	1	10	
3	9		

5.2. SECOND STAGE OF THE SOLUTION APPROACH

In this section, we present a mixed integer mathematical model formulation for the problems in the first and second echelons. A similar formulation presented in Section 4.2 is given here. However, we obtained the locations of FPCs, allocations of schools to FPCs, and the routes for schools as outputs of SA. Thus, decision variables related to FPC turned into parameters. In other words, z_g and d'_g are not decision variables anymore. So, constraints (5) and (7) are linear constraints. Some of the constraints are eliminated from the original model and the mathematical model of the transportation location model given below.

Constraints 3, 5, 6, 7, 8, 9, 10, 11 and 12 are used as they are in Section 4.2.

$$z'_r \geq w_{rg} \qquad \forall\, g \in G,\ r \in R \qquad (3)$$

$$\sum_{r \in R} \sum_{t \in T} x_{fr}^{t} \leq CF_f \qquad \forall\, f \in F \qquad (5)$$

$$\sum_{r \in R} \sum_{k \in K} x'^{k}_{rg} = d'_g \qquad \forall\, g \in G \qquad (6)$$

$$\sum_{f \in F} \sum_{t \in T} x_{fr}^{t} = \sum_{g \in G} d'_g w_{rg} \qquad \forall\, r \in R \qquad (7)$$

$$\sum_{f \in F} \sum_{t \in T} x_{fr}^{t} \leq CR_r \qquad \forall\, r \in R \qquad (8)$$

$$\sum_{f \in F} \sum_{t \in T} x_{fr}^{t} = \sum_{g \in G} \sum_{k \in K} x_{rg}^{k} \qquad \forall\, r \in R \qquad (9)$$

$$\sum_{f \in F} \sum_{t \in T} x_{fr}^{t} \leq CR_r z'_r \qquad \forall\, r \in R \qquad (10)$$

$$\sum_{r \in R} x_{fr}^{t} p_{fr}^{t} \leq CV_t \qquad \forall\, t \in T, f \in \mathrm{F} \qquad (12)$$

$$\sum_{g \in \mathrm{G}} x'^{k}_{rg} p_{rg}^{k} \leq CV_k \qquad \forall\, k \in \mathrm{K}, r \in \mathrm{R} \qquad (13)$$

Constraints (12) and (13) are still nonlinear. To linearize Constraints (12) and (13), we replace them with (33)-(36). Constraints (33) impose that the total transported amount from a farmer to DCs cannot exceed the capacity of vehicle *t*. Constraints (34) ensure that if vehicle *t* travels between farmer *f* and DC *r*, then x_{fr}^{t} takes a value of 1, where M is a very big number. Similar constraints between DCs and FPCs are represented by Constraints (35) and (36).

$$\sum_{r \in R} x_{fr}^{t} \leq CV_t \qquad \forall\, t \in T, f \in \mathrm{F} \qquad (33)$$

$$x_{fr}^{t} \leq M p_{fr}^{t} \qquad \forall\, t \in T, f \in \mathrm{F}, r \in \mathrm{R} \qquad (34)$$

$$\sum_{g \in \mathrm{G}} x'^{k}_{rg} \leq CV_k \qquad \forall\, k \in \mathrm{K}, r \in \mathrm{R} \qquad (35)$$

$$x'^{k}_{rg} \leq M p_{rg}^{k} \qquad \forall\, k \in \mathrm{K}, r \in \mathrm{R}, \mathrm{g} \in \mathrm{G} \qquad (36)$$

We solved the model using GAMS 24.1. We found the locations of DCs, which farmers assigned to which DCs, and which DCs assigned to which FPCs. Results are included in Appendix 1-5.

For example, we examine the solution to the P01 problem. The route, FPC demand, the vehicles used, and their capacities obtained in the P01 problem solving with the SA algorithm are given in Table 8-9-10. Objective function value is 842 ₺. In the solution matrix, the first, the second and the fourth FPCs are opened.

Table 8: P01 Problem Solution Routing Matrix

FPC	Schools					
1	4	17	15	44	42	19
1	41	13	25			
1	47	46	12	37		
1	14	6	18			
2	27	1	22	28	31	8
2	32	2	16	11		
2	48	26	23	7	43	24
2	38	9	49	5		
4	21	34	50	29		
4	10	45	33	39	30	
4	20	3	36	35		

Table 9: FPC Demands in P01 Problem

FPC	Demand
1	290
2	299
4	188

Table 10: Vehicle Capacities in P01 Problem

Vehicle Number	Capacity
1	67
1	78
1	68
1	77
2	78
2	76
2	80
2	65
4	50
4	71
4	67

As a result of solving the problem with the SA algorithm which FPCs to open and FPC demands obtained. So, decision variables related to FPC turned into parameters. The mathematical model is solved by using these parameters in the GAMS. According to the GAMS model outputs, 2 of the 3 farmers are served for distribution centers. The second farmer also serves the first DC and the third DC. The third farmer serves the second DC. There is a total of 777 kg of food transported from farmers. Also, we found the quantity sent from which farmer to DC by vehicle type. 3 vehicle type t vehicles are used for food transported from farmers to DCs. 3 distribution centers are opened and all of them are served for FPCs. The first DC is assigned to the fourth FPC, the second DC to the second FPC, and the third DC to the first FPC. Likewise, we found the quantity sent from which DC to which FPC by vehicle type. 777 kg of food is transported from distribution centers to FPCs. During this transportation, 3 vehicle type k vehicles are used. The objective function value of the P01 problem is 23.158 ₺. P01 GAMS result is included in Appendix 1. In the P01 problem, the total objective function value of all echelons is calculated as;

842 + 23158 = 24.000 ₺

CHAPTER VI

COMPUTATIONAL RESULTS

6.1. THE BENCHMARK PROBLEM SETS

In the literature, test problems generated by Cordeau et al. (1997) are frequently used to solve Multi Depot Vehicle Routing Problems (MDVRP). We used five of the MDVRP test problem set to evaluate the effectiveness of our solution method.

Our problem was tested on 5 problems selected according to the variety of the number of customers in data set. These problems are P01, P07, P013, P016 and P019. The characteristics of the test problems are given in Table 11. The number of customers in the data set represents the number of schools in our problem, and the number of depots represents the number of FPCs. We used this data to utilize the effectiveness of the algorithm. We could not compare with the results of Cordeau et al. (1997) because we consider service time that include both the total traveling time of the route and the service time add schools. Cordeau et al. (1997) considers only the total traveling time of the tour and they do not allow exceeding the total route time for each route. However as explained in Section 4.2, we allow to exceed the total time and punish each unit of time that exceeds the service time. The fixed cost of establishing DCs and FPCs are 80 ₺ and 50 ₺, respectively, the punishment cost is 2 ₺, and the service time takes 10 minutes, treated the same in all our problems.

Table 11: Data Sets

Problem Set	Number of School	Vehicle Capacity	FPC Capacity
P01	50	80	320
P07	100	100	400
P13	80	60	300
P16	160	60	300
P19	175	60	300

6.2. PARAMETER TUNNING FOR SA

To determine the best combinations of the parameters used in the SA (alfa (α), T_i, T_{min}, $iteration\ number$), we carried out preliminary experiments by varying the parameters as given in Table 12. We tried three different values for the maximum number of iterations: n, $5n$, and $10n$, where n denotes the number of schools, alfa (α), T_i, and T_{min}. For each combination, the program was run 3 times. It results in 81 combinations. The combinations created according to the parameters are given in Appendix 6.

The best results are obtained for combinations 6, 9, 12, 15, 27, 33 and 42. The best combination of the parameters are reported in the Table 13. However, as the solution quality of the best combinations are very close to each other, the algorithm is run 3 more times only for the best combinations. The results are given in Appendix 7. The best combination is obtained in run 27. According to the results of the experiments, the best parameter set is defined as: $\alpha = 0.99$, $T_i = 7$, $T_{min} = 0.001$ and $iteration\ number = 10n$.

Table 12: Parameters

α	T_i	T_{min}	Iteration Number
0.99	3	0.1	n
0.95	5	0.01	5* n
0.85	7	0.001	10* n

Table 13: Parameter of Best Combinations

n =Number of School				
Number of Combination	α	T_i	T_{min}	$Iteration\ Number$
6	0.99	3	0.01	$10n$
9	0.99	3	0.001	$10n$
12	0.99	5	0.1	$10n$
15	0.99	5	0.01	$10n$
27	0.99	7	0.001	$10n$
33	0.95	3	0.001	$10n$
42	0.95	5	0.01	$10n$

6.3. COMPUTATIONAL RESULTS

The SA was coded with C programming language in the Visual Studio 2019 and solved with the help of a computer with 8 GB RAM, 1.80 GHz and Intel CORE I7 processor. All the solutions were carried out on the same computer. Table 14 represents the results for three runs of five test problems with the best parameter set. All results are included in Appendix 8-12. P01_27 represents the problem number and the combination number respectively.

Table 14: Results for Three Runs with Best Parameter Set

Problem No	Initial Solution	Run 1			Run 2			Run 3		
		Obj	CPU (sec.)	Imp (%)	Obj	CPU (sec.)	Imp (%)	Obj	CPU (sec.)	Imp (%)
P01_27	1288	842	3,326	34,62	878	47,525	31,83	866	6,375	32,76
P07_27	3357	2511	16,654	25,20	2518	13,752	24,99	2398	240	28,57
P013_27	2643	1886	4,925	28,64	1878	8,885	28,94	1842	29,566	30,31
P016_27	5369	4078	87	24,04	4089	55,547	23,84	4134	12,545	23,01
P019_27	6414	5054	160	21,21	5054	258	21,20	5067	24,642	21,00

The best improvement in the objective function value is observed for the P01 problem. (34,62%) Compared to the first solution, a better solution was obtained with 446 less costs. Then, the best improvement over the first solution is the problem P013 with 30,31% less costs, P07 with 28,57% less costs, P016 with 24,04% less costs, and P019 with 21,21% less costs. The comparison of the first solution and the best results is given in Figure 5.

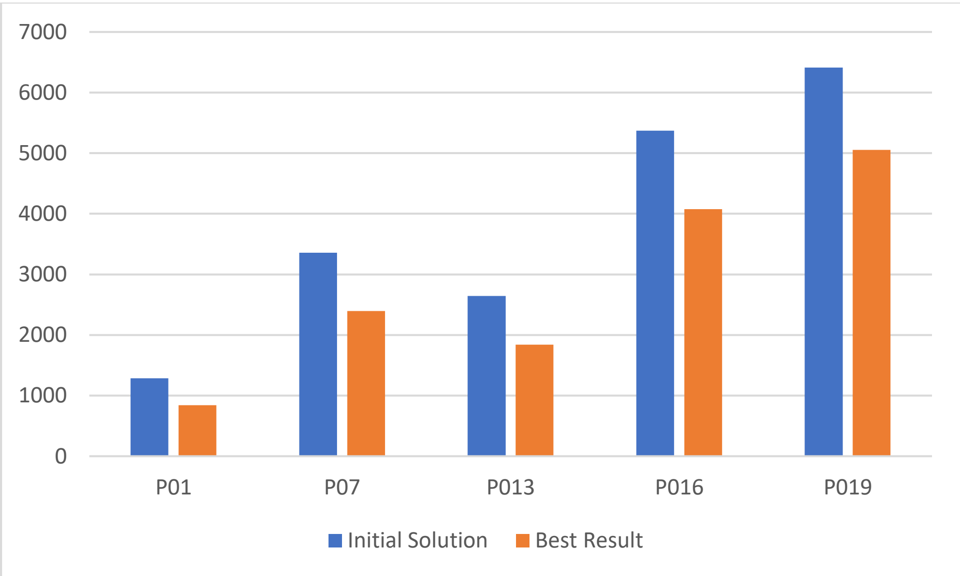

Figure 5: Comparison of Initial Solution and Best Solution

We run the same algorithm with the best combinations by neglecting the service time. The results are given in Appendix 19-23. Table 15 represents the results for three runs of five test problems. The service time constraint complicates the problem more difficult. Therefore, the results of the problem solved by ignoring the service time are better.

Our algorithm yielded the best results for the P01 problem. The P019 problem is the one in which the proposed algorithm gives the farthest result. The number of schools directly affects the size of the problem and is very effective on the distances obtained in the solution.

Table 15: Results for Three Runs with Best Parameter Set by Neglecting the Service Time

		Run 1			Run 2			Run 3		
Problem No	Initial Solution	Obj	CPU (sec.)	Imp (%)	Obj	CPU (sec.)	Imp (%)	Obj	CPU (sec.)	Imp (%)
P01_27	1092	650	30,39	40,48	673	7,72	38,37	658	26,32	39,74
P07_27	3140	2148	8,22	31,59	2173	8,83	30,79	2097	30,31	33,22
P013_27	2522	1637	11,69	35,09	1655	7,27	34,38	1641	19,87	34,93
P016_27	5232	3613	13,99	30,94	3671	12,41	29,84	3690	14,29	29,47
P019_27	6238	4569	273	26,75	4632	29,97	25,75	4434	97	28,92

The best improvement in the objective function value is observed for the P01 problem. (40,48%) Compared to the first solution, a better solution was obtained with 442 less costs. Then, the best improvement over the first solution is the problem P013 with 35,09% less costs, P07 with 33,22% less costs, P016 with 30,94% less costs, and P019 with 29,97% less costs. The comparison of the first solution and the best results is given in Figure 6.

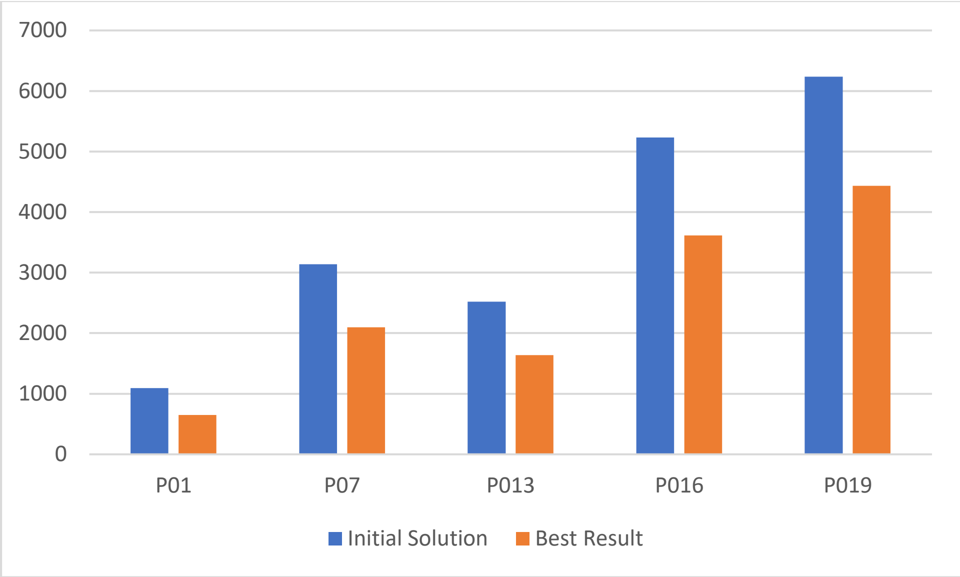

Figure 6: Comparison of Initial Solution and Best Solution by Neglecting Service Time

CHAPTER VII

CONCLUSION AND FUTURE WORKS

The National School Lunch Program is a program that provides free or low-price meals to students in public primary schools. The school lunch program provides healthy nutrition to students. At the same time, the program aims to prevent unhealthy eating habits that poor students are exposed to more. What motivates us in this study is the benefits of NSLP and the planning of its implementation in Turkey.

In this thesis, we addressed the multi-echelon transportation location and routing problem in designing a school lunch distribution network. The school lunch distribution network consists of three echelons. The first echelon includes farmers. Farmers produce fresh and organic products to meet the nutritional needs of students. While providing healthy nutrition to students, local farmers also are supported. In the second echelon are distribution centers. Distribution centers (DCs) have a certain capacity. DCs act as intermediaries between farmers and food preparation centers. DCs transfer food to food preparation centers (FPCs). In the third echelon are FPCs. The cleaning, cutting, cooking and packaging processes of the products are made in FPCs. Meals are made ready for distribution to schools. Arrival time to school is important, as lunch must be ready at a certain time. Therefore, we have considered the service time.

The problem is first formulated as a mixed integer nonlinear programming model. We create a two-stage process to solve the proposed problem. The first stage introduces a Simulated Annealing method that locates FPCs, assigns schools to FPCs, generates the routes of schools, and determines the demand of FPCs. To find the locations of DCs, and the quantities transferred between FPCs by heterogeneous vehicles, a mixed integer programming model is solved in the second stage. The objective is to minimize the total transportation cost in the network and the fixed cost of distribution and food processing centers. In addition, we aimed to produce tours that delay the arrival time at a school the least by assigning a penalty cost to the objective function for each tour unit time the vehicle exceeds its service time. The effectiveness of the suggested strategy is evaluated on hypothetical problems. In terms of cost and solution quality, computational findings indicate that SA can be regarded as an effective and efficient solution algorithm for tackling the problem.

The proposed solution approach is flexible that can be easily adapted to any networks that include transportation location and routing decisions such as blood supply chain, food supply chain, waste collection, and humanitarian logistics.

As a future study, a multi-objective, a multi-commodity distribution model could be developed. In addition, pick-up and delivery, inventory and time-windows restrictions can be taken into account. Since the model presented in this study is a general framework for designing a school lunch distribution network, applying this model in a real-world scenario and investigating results are recommended for future research.

REFERENCES

Aminia A., Tavakkoli-Moghaddam R. and Ebrahimnejad S. (2020), "A bi-objective transportation-location arc routing problem", *Transportation Letters the International Journal of Transportation Research*, Volume 12, Issue 9, pp. 623-637.

Bayram H. and Şahin R. (2013), "A New Simulated Annealing Approach For Traveling Salesman Problem", *Mathematical and Computational Applications*,Volume 18, pp. 313-322.

Bianchessi N. G. R. (2007), "Heuristic Algorithms for the Vehicle Routing Problem with Simultaneous Pick-up and Delivery", *Computers & Operations Research*, Volume 34, Issue 2, pp. 578-594.

Bundy D., Burbano C., Grosh M., Gelli A., Jukes M. and Drake L. (2009), *Rethinking School Feeding: Social Safety Nets, Child Development and the Education Sector*, The World Bank Washington, DC.

Candaş A., Akkan B. E. and Günseli S. (2011), *Devlet İlköğretim Okullarında Ücretsiz Öğle Yemeği Sağlamak Mümkün mü?: Farklı Ülke Modelleri Ve Türkiye'ye Yönelik Öneriler*, Açık Toplum Vakfı, İstanbul.

Cordeau J.-F., Gendreau M. and Laporte G. (1997), "A Tabu Search Heuristic for Periodic and Multi-Depot Vehicle Routing Problems", *Networks: An International Journal*, Volume 30, Issue 2, pp. 105-119.

Dantzig G. B. and Ramser J. H. (1959), "The Truck Dispatching Problem", *Management Science*, Volume 6, pp. 80-91.

Desrochers M., Desrosiers J. and Solomon M. (1992), "A New Optimization Algorithm for the Vehicle Routing Problem with Time Windows", *Operations Research*, Volume 40, Issue 2, pp. 342-354.

Diabat A., Dehghani E. and Jabbarzadeh A. (2017), “Incorporating Location and Inventory Decisions Into A Supply Chain Design Problem with Uncertain Demands and Lead Times”, *Journal of Manufacturing Systems*, Volume 43, pp. 139-149.

Erol V. (2006), *Araç Rotalama Problemleri İçin Popülasyon ve Komşuluk Tabanlı Metasezgisel Bir Algoritmanın Tasarımı ve Uygulaması* (Yüksek Lisans Tezi), Yıldız Teknik Üniversitesi, İstanbul.

Farrokhi-Asl H., Makui A., Jabbarzadeh A. and Barzinpour F. (2020), “Solving A Multi Objective Sustainable Waste Collection Problem Considering A New Collection Network”, *Operational Research*, Volume 20, Issue 4, pp. 1997-2015.

Garic T. and Gold H. (2008), *Vehicle Routing Problem*, In-Teh, Croatia.

Ghezavati V. R., Hooshyar S. and Tavakkoli-Moghaddam R. (2015), “A Benders' Decomposition Algorithm for Optimizing Distribution of Perishable Products Considering Postharvest Biological Behavior in Agri-Food Supply Chain: A Case Study of Tomato”, *Central European Journal of Operations Research*, Volume 25, pp. 29-54.

Ghomi S. F. and Asgarian B. (2019), “Development of Metaheuristics to Solve A Transportation Inventory Location Routing Problem Considering Lost Sale for Perishable Goods”, *Journal of Modelling in Management*, Volume 14, Issue 1, pp. 175-198.

Govindan K., Jafarian A., Khodaverdi R. and Devika K. (2014), “Two-Echelon Multiple-Vehicle Location–Routing Problem with Time Windows for Optimization of Sustainable Supply Chain Network of Perishable Food”, *Int. J. Production Economics*, Volume 152, Issue 2014, pp. 9-28.

Gunderson W. G. (2003), T*he National School Lunch Program: Background and Development*, Nova Science Publishers, New York.

Habibi-Kouchaksaraei M., Paydar M. and Asadi-Gangraj E. (2018), “Designing A Bi-Objective Multi-Echelon Robust Blood Supply Chain in A Disaster”, *Applied Mathematical Modelling*, Volume 55, Issue 2018, pp. 583-589.

Hemmelmayr V. C., Doerner K. F. and Hartl R. F. (2007), “A Variable Neighborhood Search Heuristic for Periodic Routing Problems”, *European Journal of Operational Research*, Volume 195, Issue 3, pp. 791-802.

Hiassat A., Diabat A. and Rahwan I. (2017), “A genetic algorithm approach for ocation-inventory-routing problem with perishable products”, *Journal of Manufacturing Systems*, Volume 42, pp. 93–103.

Ho W., Ho G. T., Ji P. and Lau H. C. (2008), “A hybrid genetic algorithm for the multi-depot vehicle routing problem”, *Engineering Applications of Artificial Intelligence*, Volume 21, Issue 4, pp. 548-557.

J-F. C., Gendreau M., Laporte G. J-Y P, and Semet F. (2002), “A Guide to Vehicle Routing Heuristics”, *Journal of the Operational Research Society*, Volume 53, pp. 512-522.

Jin M., Liu K. and Eksioglu B. (2008), “A column generation approach for the split delivery vehicle routing problem”, *Operations Research Letters*, Volume 36, Issue 2, pp. 265-270.

Kretschmer A., Spinler S. and Wassenhove L. N. (2014), “A School Feeding Supply Chain Framework: Critical Factors for Sustainable Program Design”, *Production and Operations Management*, Volume 23, pp. 990-1001.

Laporte G. (1992), “The vehicle routing problem: An overview of exact and approximate algorithms”, *European Journal of Operational Research*, Volume 59, Issue 3, pp. 345-358.

Larsen A. (2001), *The Dynamic Vehicle Routing Problem* (Doctoral Dissertation), Technical University of Denmark, Odense.

Liu L. and Liao W. (2021), “Optimization and profit distribution in a two-echelon collaborative waste collection routing problem from economic and environmental perspective”, *Waste Management*, Volume 120, Issue 2021, pp. 400-414.

Magnanti T. L. (1981), “Combinatorial Optimization and Vehicle Fleet Planning: Perspectives and Prospects”, *Networks and International Journal*, Volume11, Issue 2, pp. 179-213.

Marinakis Y. and Migdalas A. (2001), “Heuristic Solutions of Vehicle Routing Problems in Supply Chain Management”, *Combinatorial and Global Optimization*, Volume 14, pp. 205-236.

Martínez-Salazar I. A., Molina J., Ángel-Bello F., Gómez T. and Caballero R. (2014), "Solving a bi-objective Transportation Location Routing Problem by metaheuristic algorithms", *European Journal of Operational Research*, Volume 234, Issue 2014, pp. 25-36.

Masoudipour E., Jafari A., Amirian H. and Sahraeian R. (2020), "A novel transportation location routing network for the sustainable closed-loop supply chain considering the quality of returns", *Journal of Remanufacturing*, Volume 10, pp. 79-106.

Murugaswamy R. (2011), *A Multi-Echelon Facility Location Model For a Food Supply Chain Using Benders Decomposition* (Master's Thesis), Pennsylvania State University, Pennsylvania.

Nasrollahi M., Razmi J. and Ghodsi R. (2018), "A computational method for measuring transport related carbon emissions in a healthcare supply network under mixed uncertainty: An empirical study", *Promet-Traffic & Transportation*, Volume 30, Issue 6, pp. 693–708.

Nucamendi-Guillén S., Padilla A. G., Olivares-Benitez E. and Moreno-Vega J. M. (2021), "The multi-depot open location routing problem with a heterogeneous fixed fleet", *Expert Systems with Applications*, Volume 165, pp. 113846.

Olivares M., Weintraub G. Y., Epstein R. and Yung D. (2012), "Combinatorial Auctions for Procurement: An Empirical Study of the Chilean School Meals Auction", *Management Science*, Volume 58, pp. 1458-1481.

Pichka K., Bajgiran A. H., Petering M. E., Jang J. and Yue X. (2018), "The two echelon open location routing problem: Mathematical model and hybrid heuristic", *Computers & Industrial Engineering*, Volume 121, Issue 2018, pp. 97-112.

Rabbani M., Navazi F., Farrokhi-Asl H. and Balali M. H. (2018), "A sustainable transportation-location-routing problem with soft time windows for distribution systems", *Uncertain Supply Chain Management*, Volume 6, Issue 3, pp. 229-254.

Rafie-Majd Z., Pasandideh S. H. and Naderi B. (2018), "Modelling and solving the integrated inventory-location-routing problem in a multi-period and multi-perishable product supply chain with uncertainty: Lagrangian relaxation algorithm", *Computers and Chemical Engineering*, Volume 109, Issue 4, pp. 9-22.

Safari F. M., Etebari F. and Chobar A. P. (2020), "Modeling and Optimization of a Tri-objective Transportation-Location-Routing Problem considering route reliability: using MOGWO, MOPSO, MOWCA, and NSGA-II", *Journal of Optimization in Industrial Engineering*, Volume 14, Issue 2, pp. 99-114.

Saragih N. I., Bahagia S. N., Suprayogi and Syabri I. (2019), "A heuristic method for location-inventory-routing problem in a three-echelon supply chain system", *Computers & Industrial Engineering*, Volume 127, pp. 875-886.

Sherif S. U., Asokan P., Sasikumar P., Mathiyazhagan K. and Jerald J. (2021), "Integrated optimization of transportation, inventory and vehicle routing with simultaneous pickup and delivery in two-echelon green supply chain network", *Journal of Cleaner Production*, Volume 287, Issue 2021, pp. 125434.

Toth P. and Vigo D. (2001), "An overview of vehicle routing problems in the vehicle routing problem", *Society for Industrial and Applied Mathematics*, pp. 1-11.

Vahdani B., Veysmoradi D., Noori F. and Mansour F. (2018), "Two-stage multi-objective location-routing-inventory model for humanitarian logistics network design under uncertainty", *International Journal of Disaster Risk Reduction*, Volume 27, pp. 290-306.

Vidović M., Ratković B., Bjelić N. and Popović D. (2016), "A two-echelon location-routing model for designing recycling logistics networks with profit: MILP and heuristic approach", *Expert Systems With Applications*, Volume 51, pp. 34-48.

Wang Y., Assogba K., Liu Y., Ma X., Xu M. and Wang Y. (2018), "Two-echelon location-routing optimization with time windows based on customer clustering", *Expert Systems With Applications*, Volume 104, Issue 2014, pp. 244-260.

Yu V. F., Lin S.-W., Lee W. and Ting C.-J. (2010), "A simulated annealing heuristic for the capacitated location routing problem", *Computers & Industrial Engineering*, Volume 58, pp. 288-299.

Yu X., Zhou Y. and Liu X.-F. (2020), "The two-echelon multi-objective location routing problem inspired by realistic waste collection applications: The composable model and a metaheuristic algorithm", *Applied Soft Computing Journal*, Volume 94, pp. 106477.

Zhan S.-h., Lin J., Zhang Z.-j. and Zhong Y.-w. (2016), “List-Based Simulated Annealing Algorithm for Traveling Salesman Problem”, *Computational Intelligence and Neuroscience*, Volume 5, pp. 1-12.

Zhuo Dai and Aqlan F. (2018), “A Location-Inventory Supply Chain Network Model Using Two Heuristic Algorithms for Perishable Products with Fuzzy Constraints”, *Computers & Industrial Engineering*, Volume 119, pp. 338-352.

Zhuo Dai and Aqlan F. (2019), “A Two-Phase Method for Multi-Echelon Location-Routing Problems in Supply Chains”, *Expert Systems with Applications*, Volume 115, Issue 2019, pp. 618-634.

APPENDICES

Appendix 1: The GAMS Result of P01 Problem

---- 196 VARIABLE m.L = 23158.000 objective

---- 196 VARIABLE w.L if FPC g is assigned to DC r

	1	2	4
1			1.000
2		1.000	
3	1.000		

---- 196 VARIABLE x.L Quantity sent from farmer f to DC r by vehicle type t

	2	3	4
2.1		188.000	
2.3			290.000
3.2	299.000		

---- 196 VARIABLE xx.L Quantity sent from DC r to FCP g by vehicle type k

	2	4
1.4		188.000
2.2	299.000	
3.1		290.000

---- 196 VARIABLE p.L if vehicle t travels from farmer f to DC r

	2	3	4
2.1		1.000	
2.3			1.000
3.2	1.000		

---- 196 VARIABLE pp.L if vehicle k travels from DC r to FPC g

	2	4
1.4		1.000
2.2	1.000	
3.1		1.000

---- 196 VARIABLE z.L if DC r is opened

1 1.000, 2 1.000, 3 1.000

Appendix 2: The GAMS Result of P07 Problem

---- 197 VARIABLE m.L = 2860.000 objective

---- 197 VARIABLE w.L if FPC g is assigned to DC r

	1	2	3	4
2	1.000		1.000	
3		1.000		1.000

---- 197 VARIABLE x.L Quantity sent from farmer f to DC r by vehicle type t

	4	5
1.3		450.000
2.2	450.000	
2.3		265.000
3.2		293.000

---- 197 VARIABLE xx.L Quantity sent from DC r to FCP g by vehicle type k

	4	5	6
2.1	47.000		
2.3		350.000	
2.4			346.000
3.1			337.000

3.2	**350.000**	**19.000**	
3.3			**9.000**

---- 197 VARIABLE p.L if vehicle t travels from farmer f to DC r

	4	**5**
1.3		**1.000**
2.2	**1.000**	
2.3		**1.000**
3.2		**1.000**

---- 197 VARIABLE pp.L if vehicle k travels from DC r to FPC g

	4	**5**	**6**
2.1	**1.000**		
2.3		**1.000**	
2.4			**1.000**
3.1			**1.000**
3.2	**1.000**	**1.000**	
3.3			**1.000**

---- 197 VARIABLE z.L if DC r is opened

2 1.000, 3 1.000

Appendix 3: The GAMS Result of P013 Problem

---- 195 VARIABLE m.L = 38930.000 objective

---- 195 VARIABLE w.L if FPC g is assigned to DC r

	1	2
3		1.000
4	1.000	

---- 195 VARIABLE x.L Quantity sent from farmer f to DC r by vehicle type t

	2
1.4	273.000
2.3	159.000

---- 195 VARIABLE xx.L Quantity sent from DC r to FCP g by vehicle type k

	1	2
3.1		159.000
4.1		114.000
4.2	159.000	

```
----    195 VARIABLE p.L  if vehicle t travels from farmer f to DC r

                  2

1.4       1.000
2.3       1.000


----    195 VARIABLE pp.L  if vehicle k travels from  DC r to FPC g

               1          2

3.1                   1.000
4.1                   1.000
4.2       1.000


----    195 VARIABLE z.L  if DC r is opened

3 1.000,    4 1.000
```

Appendix 4: The GAMS Result of P016 Problem

----   242 VARIABLE m.L   =   39756.000 objective

----   242 VARIABLE w.L if FPC g is assigned to DC r

	1	2	3	4
1			1.000	
2		1.000		1.000
4	1.000			

---- 242 VARIABLE x.L Quantity sent from farmer f to DC r by vehicle type t

	1	5
2.1	270.000	
2.4		280.000
3.2		314.000

---- 242 VARIABLE xx.L Quantity sent from DC r to FCP g by vehicle type k

	1	2	5
1.3			270.000
2.2		284.000	
2.4	30.000		
4.1		280.000	

----   242 VARIABLE p.L if vehicle t travels from farmer f to DC r

	1	5
2.1	1.000	
2.4		1.000
3.2		1.000

----   242 VARIABLE pp.L if vehicle k travels from DC r to FPC g

	1	2	5
1.3			1.000
2.2		1.000	
2.4	1.000		
4.1		1.000	

----   242 VARIABLE z.L if DC r is opened

1 1.000,   2 1.000,   4 1.000

Appendix 5: The GAMS Result of P019 Problem

---- 212 VARIABLE m.L = 38528.000 objective

---- 212 VARIABLE w.L if FPC g is assigned to DC r

	1	2	3	4
1			1.000	
2				1.000
3	1.000			
4		1.000		

---- 212 VARIABLE x.L Quantity sent from farmer f to DC r by vehicle type t

	1	2	3
1.1			270.000
1.3	146.000		
4.2	182.000		
4.3		134.000	
4.4			284.000

---- 212 VARIABLE xx.L Quantity sent from DC r to FCP g by vehicle type k

	2	3	4	5
1.3	270.000			
2.1	182.000			
3.1			98.000	
3.4		182.000		
4.2				284.000

---- 212 VARIABLE p.L if vehicle t travels from farmer f to DC r

	1	2	3
1.1			1.000
1.3	1.000		
4.2	1.000		
4.3		1.000	
4.4			1.000

---- 212 VARIABLE pp.L if vehicle k travels from DC r to FPC g

	2	3	4	5
1.3	1.000			
2.1	1.000			
3.1			1.000	
3.4		1.000		
4.2				1.000

----   212 VARIABLE z.L if DC r is opened

1 1.000,   2 1.000,   3 1.000,   4 1.000

Appendix 6: Combinations of Parameters for SA

n=Number of School				
Number of Combination	α	T_i	T_{min}	**Iteration Number**
1	0.99	3	0.1	n
2	0.99	3	0.1	5n
3	0.99	3	0.1	10n
4	0.99	3	0.01	n
5	0.99	3	0.01	5n
6	0.99	3	0.01	10n
7	0.99	3	0.001	n
8	0.99	3	0.001	5n
9	0.99	3	0.001	10n
10	0.99	5	0.1	n
11	0.99	5	0.1	5n
12	0.99	5	0.1	10n
13	0.99	5	0.01	n
14	0.99	5	0.01	5n
15	0.99	5	0.01	10n
16	0.99	5	0.001	n
17	0.99	5	0.001	5n
18	0.99	5	0.001	10n
19	0.99	7	0.1	n
20	0.99	7	0.1	5n
21	0.99	7	0.1	10n
22	0.99	7	0.01	n
23	0.99	7	0.01	5n
24	0.99	7	0.01	10n
25	0.99	7	0.001	n
26	0.99	7	0.001	5n
27	0.99	7	0.001	10n
28	0.95	3	0.1	n
29	0.95	3	0.1	5n
30	0.95	3	0.1	10n
31	0.95	3	0.01	n
32	0.95	3	0.01	5n
33	0.95	3	0.01	10n
34	0.95	3	0.001	n
35	0.95	3	0.001	5n
36	0.95	3	0.001	10n
37	0.95	5	0.1	n
38	0.95	5	0.1	5n
39	0.95	5	0.1	10n
40	0.95	5	0.01	n

n=Number of School				
Number of Combination	α	T_i	T_{min}	Iteration Number
41	0.95	5	0.01	5n
42	0.95	5	0.01	10n
43	0.95	5	0.001	n
44	0.95	5	0.001	5n
45	0.95	5	0.001	10n
46	0.95	7	0.1	n
47	0.95	7	0.1	5n
48	0.95	7	0.1	10n
49	0.95	7	0.01	n
50	0.95	7	0.01	5n
51	0.95	7	0.01	10n
52	0.95	7	0.001	n
53	0.95	7	0.001	5n
54	0.95	7	0.001	10n
55	0.85	3	0.1	n
56	0.85	3	0.1	5n
57	0.85	3	0.1	10n
58	0.85	3	0.01	n
59	0.85	3	0.01	5n
60	0.85	3	0.01	10n
61	0.85	3	0.001	n
62	0.85	3	0.001	5n
63	0.85	3	0.001	10n
64	0.85	5	0.1	n
65	0.85	5	0.1	5n
66	0.85	5	0.1	10n
67	0.85	5	0.01	n
68	0.85	5	0.01	5n
69	0.85	5	0.01	10n
70	0.85	5	0.001	n
71	0.85	5	0.001	5n
72	0.85	5	0.001	10n
73	0.85	7	0.1	n
74	0.85	7	0.1	5n
75	0.85	7	0.1	10n
76	0.85	7	0.01	n
77	0.85	7	0.01	5n
78	0.85	7	0.01	10n
79	0.85	7	0.001	n
80	0.85	7	0.001	5n
81	0.85	7	0.001	10n

Appendix 7: Additional Runs to Determine the Best Combinations of Parameters

		Run 1		Run 2		Run 3	
Problem No_Combination No	Initial Solution	Obj	CPU (sec.)	Obj	CPU (sec.)	Obj	CPU (sec.)
P01_6	1288	868	8,42	891	18,822	842	35,364
P07_6	3357	2441	21,131	2387	97	2379	120
P013_6	2643	1852	5,625	1852	21,978	1874	21,712
P016_6	5369	4085	154	4162	50,297	4162	55,873
P019_6	6414	5110	28,229	5066	29,838	5056	114
P01_9	1288	857	7,531	844	69	854	46,428
P07_9	3357	2387	45,74	2370	358	2477	16,651
P013_9	2643	1852	21,925	1852	14,255	1848	169
P016_9	5369	4162	49,507	4120	126	4108	49,858
P019_9	6414	5139	27,11	5070	21,235	5063	77
P01_12	1288	915	5,349	895	3,648	871	7,36
P07_12	3357	2521	16,952	2521	29,59	2533	3,66
P013_12	2643	1869	105	1852	8,905	1872	5,407
P016_12	5369	4160	32,322	4171	17,533	4104	36,781
P019_12	6414	5124	16,358	5075	11,973	5106	68
P01_15	1288	924	2,522	923	3,28	879	10,534
P07_15	3357	2391	60	2451	16,617	2509	10,801
P013_15	2643	1854	13,271	1852	104	1852	68
P016_15	5369	4170	13,464	4120	45,139	4120	15,885
P019_15	6414	5118	14,832	5108	26,99	5054	134
P01_27	1288	842	3,326	878	47,525	866	6,375
P07_27	3357	2511	16,654	2518	13,752	2398	240
P013_27	2643	1886	4,925	1878	8,885	1842	29,566
P016_27	5369	4078	87	4089	55,547	4134	12,545
P019_27	6414	5054	160	5054	258	5067	24,642
P01_33	1288	904	7,138	862	4,061	895	5,558
P07_33	3357	2387	67	2415	49,791	2389	47,768
P013_33	2643	1869	34,696	1849	37,029	1852	24,146
P016_33	5369	4080	64	4146	51347	4121	18,674
P019_33	6414	5061	114	5097	60	5075	13,129
P01_42	1288	925	0,57	917	0,456	860	6,682
P07_42	3357	2524	3,909	2391	59,395	2520	3,507
P013_42	2643	1848	37,995	1871	5,838	1842	5,23
P016_42	5369	4096	64	4119	32,404	4147	33,746
P019_42	6414	5066	9,647	5099	19,365	5124	3,786

Appendix 8: P01 Problem Solutions for Different Combinations of Parameters

Initial Solution = 1288						
	Run 1		Run 2		Run 3	
Problem No	Obj	CPU (sec.)	Obj	CPU (sec.)	Obj	CPU (sec.)
P01_1	932	2,622	924	2,358	920	2,745
P01_2	911	2,235	922	9,998	887	9,344
P01_3	861	15,635	912	4,261	895	3,34
P01_4	932	5,136	932	4,32	932	4,045
P01_5	879	14,038	919	3,154	920	3,515
P01_6	868	9,636	871	12,874	905	3,165
P01_7	921	4,905	932	5,728	918	4,632
P01_8	922	2,593	876	21,845	901	19,073
P01_9	858	45,768	**844**	28,725	868	10,007
P01_10	907	3,34	920	3,22	932	3,524
P01_11	928	4,737	897	15,292	893	14,744
P01_12	876	20,075	846	13,251	906	2,278
P01_13	932	4,929	932	7,531	926	4,551
P01_14	920	7,461	928	3,247	926	2,832
P01_15	858	33,688	**844**	19,665	872	32,525
P01_16	925	8,294	925	6,678	908	5,007
P01_17	867	20,957	924	3,042	882	19,076
P01_18	929	3,262	856	40,341	858	47,176
P01_19	927	3,444	929	2,932	919	3,351
P01_20	923	3,1	882	3,603	880	10,983
P01_21	908	3,682	883	3,042	895	3,789
P01_22	910	3,575	925	6,353	908	5,418
P01_23	860	10,27	902	23,246	911	3,464
P01_24	882	24,009	917	4,454	921	3,942
P01_25	932	8,333	909	6,731	924	5,457
P01_26	901	2,38	898	24,037	904	3,868
P01_27	868	44,194	917	5,308	889	5,688
P01_28	932	0,35	932	0,1	916	0,45
P01_29	906	0,85	929	0,3	912	2,888
P01_30	867	3,903	915	2,8	906	3,853
P01_31	932	2,85	932	1,24	929	3,645
P01_32	896	3,461	889	3,717	911	2,844
P01_33	873	5,848	870	7,129	881	2,889
P01_34	914	0,38	925	0,25	932	0,67
P01_35	916	5,231	895	4,093	918	4,65
P01_36	853	8,181	887	7,002	900	8,268
P01_37	919	0,56	916	0,45	932	0,67
P01_38	918	0,78	932	0,39	905	2,583
P01_39	908	1,606	870	3,233	887	2,374
P01_40	932	0,689	932	0,68	932	0,92
P01_41	911	3,363	923	3,186	916	4,474
P01_42	880	4,312	880	6,074	869	6,457
P01_43	932	1,25	916	3,465	932	2,073
P01_44	931	2,57	932	2,892	923	4,276
P01_45	901	3,444	875	10,009	904	2,747
P01_46	921	2,689	932	3,388	932	2,223

P01_47	913	2,345	893	5,33	932	2,398
P01_48	882	5,025	913	3,507	868	3,754
P01_49	932	3,57	921	5,33	932	3,558
P01_50	932	2,484	894	3,795	908	4,27
P01_51	893	2,794	881	1,423	870	2,999
P01_52	932	2,349	931	2,449	929	1,274
P01_53	918	2,367	896	1,267	921	1,253
P01_54	898	1,959	896	2,146	925	3,833
P01_55	932	1,356	927	1,267	932	1,263
P01_56	917	1,234	912	2,127	928	1,267
P01_57	901	1,27	894	2,58	929	2,287
P01_58	923	2,288	925	1,289	914	1,299
P01_59	925	2,11	914	2,27	1098	2,67
P01_60	964	2,16	1045	1,278	868	2,208
P01_61	929	2,118	932	2,38	932	1,192
P01_62	909	1,278	916	1,907	932	2,217
P01_63	891	1,927	910	2,684	888	3,349
P01_64	932	1,278	932	1,48	927	1,268
P01_65	926	1,269	932	1,87	895	2,68
P01_66	922	1,58	900	1,768	903	1,289
P01_67	932	1,298	931	1,673	932	1,173
P01_68	901	1,137	927	1,22	932	1,123
P01_69	911	2,199	919	2,218	888	2,523
P01_70	932	1,223	932	1,112	924	1,45
P01_71	927	2,219	918	1,28	928	1,835
P01_72	909	3,617	909	1,28	900	3,483
P01_73	932	1,22	932	1,112	932	1,126
P01_74	931	0,94	913	1,2	911	0,83
P01_75	907	1,137	932	1,134	888	1,23
P01_76	932	1,12	932	1,45	932	1,32
P01_77	914	1,189	926	0,37	932	0,95
P01_78	925	0,56	929	0,67	932	0,45
P01_79	927	0,27	930	0,273	932	0,458
P01_80	930	0,83	913	1,44	930	2,111
P01_81	871	3,896	916	0,56	863	3,065

Appendix 9: P07 Problem Solutions for Different Combinations of Parameters

Initial = 3357						
	Run 1		Run 2		Run 3	
Problem No	Obj	CPU (sec.)	Obj	CPU (sec.)	Obj	CPU (sec.)
P07_1	2539	6,563	2509	19,78	2516	20,123
P07_2	2459	17,549	2523	3,055	2519	5,369
P07_3	2407	19,64	2525	7,291	2431	20,586
P07_4	2544	2,154	2540	4,156	2526	12,593
P07_5	2537	3,44	2470	7	2463	17,217
P07_6	**2359**	68	2524	9,016	2411	38,055
P07_7	2496	39,487	2537	3,596	2512	30,207
P07_8	2491	7,861	2367	63	2390	86
P07_9	2390	144	2383	77	2409	20,798
P07_10	2519	19,068	2550	3,721	2522	19,243
P07_11	2538	6,931	2491	13,999	2545	3,14
P07_12	2487	12,775	2457	7,014	2474	9,928
P07_13	2526	8,549	2517	27,988	2514	9,698
P07_14	2430	47,982	2480	13,897	2522	5,662
P07_15	2435	82	2537	8,831	2381	146
P07_16	2493	38,528	2546	2,886	2491	33,184
P07_17	2550	5,293	2514	5,353	2381	144
P07_18	2550	12,468	2382	88	2484	14,402
P07_19	2368	146	2535	11,054	2386	77
P07_20	2529	17,295	2549	3,151	2550	2,962
P07_21	2526	6,359	2521	4,627	2453	32,004
P07_22	2532	4,566	2527	5,542	2532	8,176
P07_23	2550	2,099	2483	31,773	2544	5,541
P07_24	2550	5,103	2521	5,58	2524	8,569
P07_25	2543	9,812	2550	25,642	2550	10,236
P07_26	2388	158	2507	7,827	2529	6,329
P07_27	2541	3,005	2527	3,113	2544	4,163
P07_28	2515	9,541	2491	9,296	2495	1,776
P07_29	2409	19,256	2409	22,53	2387	20,802
P07_30	2386	13,763	2411	23,157	2392	19,693
P07_31	2526	4,918	2532	4,45	2520	5,058
P07_32	2447	5,898	2445	27,609	2446	22,88
P07_33	2492	6,918	2487	3,22	2469	4,336
P07_34	2530	6,633	2536	9,069	2550	7,059
P07_35	2492	6,946	2525	2,668	2429	34,964
P07_36	2427	11,661	2460	5,563	2516	3,108
P07_37	2521	4,242	2532	4,533	2548	4,274
P07_38	2531	2,156	2463	15,328	2470	15,77
P07_39	2447	13,128	2445	3,201	2436	7,564
P07_40	2538	5,95	2545	5,273	2545	7,479
P07_41	2498	9,345	2407	23,621	2454	20,192
P07_42	2374	28,916	2378	29,272	2379	53,396
P07_43	2520	2,712	2529	8,08	2528	9,574

P07_44	2492	11,421	2446	38,302	2501	3,291
P07_45	2397	46,635	2497	7,418	2391	55,515
P07_46	2519	4,457	2535	4,524	2541	4,599
P07_47	2497	9,511	2449	18,114	2457	18,011
P07_48	2459	13,016	2435	11,782	2513	4,348
P07_49	2538	6,504	2533	5,646	2538	6,284
P07_50	2494	4,232	2517	4,259	2530	1,978
P07_51	2508	4,889	2495	3,117	2477	6,967
P07_52	2511	8,252	2531	8,517	2533	7,664
P07_53	2516	3,031	2467	8,316	2516	5,505
P07_54	2390	38,739	2531	2,016	2536	4,851
P07_55	2549	1,35	2546	2,13	2538	1,24
P07_56	2537	1,24	2545	1,78	2457	3,946
P07_57	2466	8,036	2468	8,222	2427	10,93
P07_58	2546	1,26	2546	1,492	2538	1,706
P07_59	2483	10,965	2461	8,562	2480	9,637
P07_60	2449	16,835	2465	16,082	2403	24,078
P07_61	2548	2,566	2549	2,478	2536	2,966
P07_62	2474	9,678	2497	12,401	2464	9,811
P07_63	2436	20,182	2401	24,646	2391	25,861
P07_64	2540	1,32	2550	1,34	2546	1,56
P07_65	2524	1,25	2519	5,449	2535	1,21
P07_66	2525	1,367	2462	7,04	2432	10,913
P07_67	2550	1,353	2544	1,25	2533	1,265
P07_68	2487	8,47	2519	9,684	2480	10,796
P07_69	2413	18,567	2471	12,107	2414	21,782
P07_70	2531	3,218	2541	2,6	2550	2,752
P07_71	2514	2,831	2481	11,442	2449	12,293
P07_72	2394	26,749	2471	11,132	2425	13,439
P07_73	2538	1,23	2544	1,111	2543	1,18
P07_74	2503	4,814	2496	5,313	2543	1,56
P07_75	2453	9,71	2433	9,679	2450	9,481
P07_76	2536	1,695	2544	2,362	2545	2,117
P07_77	2515	3,236	2469	9,582	2527	1,322
P07_78	2526	1,12	2443	13,884	2482	6,75
P07_79	2530	2,765	2521	2,559	2545	3,035
P07_80	2454	12,078	2521	2,658	2485	10,633
P07_81	2449	7,733	2466	3,938	2404	20,669

Appendix 10: P013 Problem Solutions for Different Combinations of Parameters

Initial Solution = 2643						
	Run 1		Run 2		Run 3	
Problem No	Obj	CPU (sec.)	Obj	CPU (sec.)	Obj	CPU (sec.)
P013_1	1872	11,77	1869	8,87	1886	8,069
P013_2	1869	19,706	1872	38,128	1872	39,858
P013_3	1872	31,681	1849	35,107	1853	29,69
P013_4	1886	12,228	1872	11,168	1872	13,09
P013_5	1872	64	1852	44,119	1849	68
P013_6	1858	8,749	1872	39,442	1872	16,395
P013_7	1869	16,298	1872	16,516	1872	18,268
P013_8	1869	97	1851	47,22	1858	31,538
P013_9	1872	21,1	1869	134	1872	18,54
P013_10	1886	8,879	1869	10,934	1872	10,772
P013_11	1852	16,277	1884	10,899	1872	16,123
P013_12	1854	12,177	1854	11,773	1874	8,328
P013_13	1886	14,192	1872	17,156	1852	18,142
P013_14	1852	67	1872	55,875	1872	48,379
P013_15	1852	92	1869	102	1869	79
P013_16	1872	21,605	1886	20,953	1886	22,09
P013_17	1854	99	1869	67	1869	85
P013_18	1872	251	1872	25,549	1848	184
P013_19	1886	11,768	1872	11,199	1869	10,553
P013_20	1852	12,81	1874	13,822	1869	15,061
P013_21	1872	76	1846	25,221	1876	20,229
P013_22	1872	17,32	1872	20,937	1886	18,586
P013_23	1869	33,406	1852	47,888	1879	18,538
P013_24	1872	15,603	1886	6,566	1872	10,349
P013_25	1872	22,222	1869	19,762	1872	24,544
P013_26	1853	7,922	1872	81	1872	96
P013_27	1872	12,052	1852	32,259	1869	14,388
P013_28	1886	2,052	1886	2,346	1886	2,276
P013_29	1872	3,328	1872	10,006	1872	9,568
P013_30	1852	17,54	1852	19,802	1872	15,193
P013_31	1886	3,292	1869	3,553	1886	3,316
P013_32	1872	3,544	1869	15,876	1886	3,904
P013_33	1852	31,071	1869	5,479	1872	29,474
P013_34	1886	4,683	1869	4,472	1886	4,964
P013_35	1872	22,109	1869	21,714	1872	23,303
P013_36	1854	6,558	1858	24,145	1869	6,923
P013_37	1886	2,383	1886	2,674	1886	2,514
P013_38	1872	10,977	1853	9,902	1886	4,494
P013_39	1872	4,317	1872	18,53	1852	25,448
P013_40	1886	3,474	1886	3,701	1886	3,949
P013_41	1872	17,791	1872	10,32	1852	17,098
P013_42	1849	28,313	1867	3,461	**1842**	14,194

P013_43	1886	4,881	1886	4,813	1886	5,206
P013_44	1872	22,562	1872	17,469	1872	24,033
P013_45	1852	10,979	1872	37,015	1872	6,195
P013_46	1886	2,48	1886	2,935	1886	2,751
P013_47	1886	2,405	1874	11,129	1872	3,96
P013_48	1872	5,565	1872	18,938	1875	3,824
P013_49	1886	3,817	1886	3,963	1886	4,054
P013_50	1878	5,621	1872	12,779	1872	14,457
P013_51	1872	16,771	1871	6,612	1872	29,028
P013_52	1886	4,714	1886	5,052	1886	4,337
P013_53	1871	19,706	1886	3,877	1852	24,543
P013_54	1870	38,595	1874	8,428	1880	4,59
P013_55	1886	1	1886	1	1886	1
P013_56	1872	3,382	1886	4,356	1886	4,418
P013_57	1872	5,542	1872	2,355	1872	3,387
P013_58	1886	1	1886	1	1886	1
P013_59	1874	4,803	1872	5,535	1872	5,978
P013_60	1852	10,253	1872	10,652	1868	8,835
P013_61	1886	1	1886	1	1886	1
P013_62	1886	1	1869	7,699	1852	8,104
P013_63	1849	14,768	1849	16,083	1865	14,397
P013_64	1886	1	1886	1	1886	1
P013_65	1865	3,91	1886	4,047	1869	4,09
P013_66	1872	7,376	1872	7,719	1886	1
P013_67	1886	1	1886	1	1886	1
P013_68	1869	5,704	1865	5,503	1869	5,908
P013_69	1872	11,038	1872	11,956	1872	11,804
P013_70	1886	1	1869	1	1886	1
P013_71	1872	7,345	1872	8,1	1872	8,615
P013_72	1852	2,533	1853	17,399	1871	10,914
P013_73	1886	1	1886	1	1869	1
P013_74	1872	1	1872	4,19	1886	1
P013_75	1869	1	1871	1,867	1886	1,799
P013_76	1886	1	1886	1	1886	1
P013_77	1886	1	1886	1	1886	1
P013_78	1875	1	1872	10,896	1886	3,31
P013_79	1886	1	1886	1	1886	1
P013_80	1872	6,154	1872	6,404	1869	8,012
P013_81	1869	1,843	1872	11,27	1852	3,293

Appendix 11: P016 Problem Solutions for Different Combinations of Parameters

Initial Solution= 5369						
	Run 1		Run 2		Run 3	
Problem No	Obj	CPU (sec.)	Obj	CPU (sec.)	Obj	CPU (sec.)
P016_1	4176	23,785	4176	26	4162	26,993
P016_2	4120	16,112	4120	33,092	4146	33,274
P016_3	4123	73	4122	16,959	4111	19,502
P016_4	4160	46,012	4155	47,228	4176	48,384
P016_5	4078	176	4113	30,187	4134	10,482
P016_6	4112	40,682	4168	15,017	4113	65
P016_7	4120	66	4113	67	4134	68
P016_8	4162	12,95	4120	17,372	4108	216
P016_9	**4075**	279	4086	60	4162	27,048
P016_10	4176	4,636	4176	33,765	4162	31,756
P016_11	4146	8	4113	87	4176	8,084
P016_12	4162	8,134	4155	12,256	4178	9,154
P016_13	4162	59,448	4162	52,457	4162	79
P016_14	4178	7,555	4169	8,467	4120	19,923
P016_15	4118	71	4120	17,215	4162	27,434
P016_16	4162	83	4155	21,502	4162	110
P016_17	4090	70	4150	173	4162	15,675
P016_18	4081	91	4162	24,321	4176	19,424
P016_19	4362	2,556	4176	7,258	4176	15,063
P016_20	4162	12,263	4199	13,071	4176	7,933
P016_21	4085	102	4186	8,253	4176	21,704
P016_22	4176	61	4162	54,481	4169	53,566
P016_23	4176	12,101	4156	90	4172	9,608
P016_24	4170	19,275	4120	37,059	4078	245
P016_25	4176	20,617	4174	34,775	4120	75
P016_26	4125	130	4120	15,115	4113	43,568
P016_27	4116	41,404	4108	228	4176	17,243
P016_28	4162	7,955	4176	6,136	4182	6,514
P016_29	4113	28,384	4162	27,95	4155	4,186
P016_30	4162	4,524	4090	31,656	4078	57,157
P016_31	4176	9,454	4182	10,165	4176	9,376
P016_32	4113	31,569	4134	4,069	4162	6,125
P016_33	4155	13,707	4120	15,353	4162	3,089
P016_34	4176	14,588	4176	12,491	4162	13,98
P016_35	4120	82	4117	65	4088	68
P016_36	4164	8,704	4120	134	4162	13,352
P016_37	4176	6,441	4176	6,512	4176	7,013
P016_38	4176	6,902	4127	30,837	4162	13,055
P016_39	4168	5,297	4162	3,372	4162	2,644
P016_40	4176	8,981	4162	11,084	4176	10,444
P016_41	4176	5,781	4120	39,804	4162	9,994
P016_42	4108	93	4129	61	4142	7,806

P016_43	4176	14,599	4176	16,364	4176	15,044
P016_44	4153	68	4108	70	4120	48,435
P016_45	4170	6,764	4078	98	4176	5,26
P016_46	4200	7,583	4176	7,752	4176	7,589
P016_47	4162	3,216	4174	31,364	4134	8,943
P016_48	4138	3,544	4190	6,315	4212	2,904
P016_49	4176	11,227	4176	11,765	4176	11,677
P016_50	4161	3,503	4162	21,081	4176	3,59
P016_51	4176	3,742	4120	62	4176	3,195
P016_52	4176	11,385	4162	15,015	4162	15,281
P016_53	4176	4,957	4188	4,042	4113	21,757
P016_54	4164	5,473	4155	11,426	4079	87
P016_55	4306	1,968	4176	1,952	4176	1,876
P016_56	4176	8,851	4162	9,661	4120	6,199
P016_57	4162	5,31	4159	19,516	4119	17,035
P016_58	4176	3,04	4362	3,38	4176	3,709
P016_59	4113	16,015	4155	16,231	4160	16,185
P016_60	4144	30,575	4168	2,604	4155	30,319
P016_61	4176	4,767	4348	4,584	4362	20,707
P016_62	4120	21,278	4146	22,005	4162	11,303
P016_63	4129	41,05	4176	4,251	4176	2,177
P016_64	4301	2,22	4176	2,298	4176	2,459
P016_65	4162	10,093	4176	10,099	4162	10,076
P016_66	4176	3,172	4162	19,797	4180	2,136
P016_67	4362	3,164	4301	3,494	4176	3,636
P016_68	4162	16,011	4120	16,054	4176	16,069
P016_69	4162	13,04	4136	3,338	4170	3,067
P016_70	4176	4,832	4176	4,769	4176	4,969
P016_71	4162	19,927	4120	23,199	4120	23,562
P016_72	4170	2,415	4090	29,974	4132	27,121
P016_73	4176	2,551	4176	2,637	4176	2,192
P016_74	4175	3,221	4176	11,832	4176	4,084
P016_75	4170	3,152	4170	3,215	4174	7,772
P016_76	4176	4,241	4176	4,062	4176	4,391
P016_77	4162	17,93	4182	3,332	4120	18,476
P016_78	4155	32,423	4140	2,865	4184	13,025
P016_79	4176	5,608	4362	5,721	4176	5,277
P016_80	4176	2,753	4162	22,805	4176	20,343
P016_81	4120	40,497	4120	14,039	4160	48,482

Appendix 12: P019 Problem Solutions for Different Combinations of Parameters

Initial Solution= 6414						
	Run 1		Run 2		Run 3	
Problem No	Obj	CPU (sec.)	Obj	CPU (sec.)	Obj	CPU (sec.)
P019_1	5110	24,87	5110	42,22	5124	37,518
P019_2	5106	87	5105	72	5058	111
P019_3	5113	43,235	5124	10,688	5108	20,505
P019_4	5124	44,219	5122	8,687	5075	53,437
P019_5	5066	14,534	5108	67	5110	6,436
P019_6	**5054**	211	**5054**	95	5115	29,288
P019_7	5103	62	5110	63	5108	65
P019_8	5082	14,239	5103	29,143	5056	157
P019_9	5058	85	**5054**	237	5066	44
P019_10	5124	4,757	5110	35,926	5152	35,515
P019_11	5062	50,474	5139	4,342	5113	29,638
P019_12	5072	13,323	5066	26,099	**5054**	62
P019_13	5249	7,443	5068	47,271	5124	58,413
P019_14	5101	94	**5054**	175	5108	50,686
P019_15	**5054**	104	5099	54,391	5073	60
P019_16	5124	70	5110	73	5121	71
P019_17	5097	108	5107	58,568	5064	60
P019_18	**5054**	168	**5054**	353	5103	24,915
P019_19	5235	4,354	5310	1,779	5115	40,026
P019_20	5126	8,071	5110	9,015	5124	9,942
P019_21	5142	12,206	5138	16,868	5124	13,615
P019_22	5122	13,114	5124	65	5110	6,179
P019_23	5060	123	5110	13,307	5113	32,887
P019_24	5123	35,364	5097	131	5068	21,511
P019_25	5270	3,173	5066	86	5110	85
P019_26	5124	11,091	5101	150	**5054**	366
P019_27	**5054**	248	5068	32,299	**5054**	336
P019_28	5110	7,05	5110	7,785	5124	5,155
P019_29	5128	11,768	5103	6,724	5122	11,39
P019_30	5108	3,754	5061	13,832	5124	4,505
P019_31	5110	12,567	5113	12,142	5110	11,872
P019_32	5108	49,688	5067	11,44	5070	54,764
P019_33	5096	87	**5054**	108	5057	47,086
P019_34	5124	16,97	5082	15,616	5124	18,009
P019_35	5124	9,731	5066	76	5066	78
P019_36	5066	42,15	5110	13,103	5059	55,278
P019_37	5124	7,984	5110	7,286	5310	7,223
P019_38	5061	35,8	5066	37,061	5066	7,154
P019_39	5136	3,356	5143	6,452	5110	7,314
P019_40	5124	11,742	5124	11,588	5124	11,798
P019_41	5132	2,352	5124	2,334	5124	5,4

P019_42	5122	3,945	5059	18,895	**5054**	85
P019_43	5128	17,144	5075	17,904	5108	15,397
P019_44	5108	5,742	5066	51,067	5124	3,76
P019_45	5136	5,389	**5054**	144	5056	59,507
P019_46	5138	7,699	5110	8,87	5142	7,803
P019_47	5140	13,689	5118	4,598	5124	3,993
P019_48	5088	4,053	5148	3,234	5137	2,086
P019_49	5124	12,608	5124	11,446	5110	14,42
P019_50	5126	5,82	5130	6,567	5066	21,01
P019_51	5136	5,639	5146	9,084	5108	27,294
P019_52	5124	17,574	5124	17,477	5082	18,175
P019_53	5124	4,13	5110	5,147	5129	5,889
P019_54	5117	8,72	5161	6,62	5124	5,153
P019_55	5110	2,775	5124	2,765	5246	2,35
P019_56	5124	9,766	5110	5,603	5108	10,677
P019_57	5059	22,272	5068	20,99	5106	22,644
P019_58	5124	3,751	5310	3,733	5124	4,015
P019_59	5061	22,639	5103	18,615	5068	16,777
P019_60	5099	33,63	5108	15,438	5068	9,705
P019_61	5310	4,772	5075	5,179	5124	5,603
P019_62	5122	4,731	5108	26,348	5118	25,017
P019_63	5118	31,609	5124	3,607	5064	49,019
P019_64	5254	2,944	5310	2,938	5124	2,914
P019_65	5068	12,791	5110	12,215	5136	3,574
P019_66	5061	25,272	5110	2,965	5105	4,573
P019_67	5124	4,67	5308	4,53	5124	4,12
P019_68	5066	18,832	5101	24,065	5110	20,96
P019_69	5106	38,453	5067	33,416	5064	29,657
P019_70	5124	5,348	5124	5,557	5249	5,323
P019_71	5112	25,083	5097	25,948	5080	5,117
P019_72	5110	5,353	5129	3,227	5100	31,791
P019_73	5310	2,964	5124	2,327	5254	2,966
P019_74	5078	11,769	5118	12,51	5110	4,892
P019_75	5108	23,658	5132	3,642	5124	3,412
P019_76	5249	4,222	5310	4,08	5296	4,205
P019_77	5115	7,944	5068	18,21	5124	17,322
P019_78	5107	8,172	5102	2,945	5162	2,339
P019_79	5254	4,185	5249	4,177	5124	4,664
P019_80	5061	21,095	5124	5,009	5066	21,571
P019_81	5114	39,03	5105	40,498	5062	33,348

Appendix 13: Solutions Neglecting Service Time Restriction in SA

Initial Solution= 1092						
	Run 1		Run 2		Run 3	
Problem No	Obj	CPU (sec.)	Obj	CPU (sec.)	Obj	CPU (sec.)
P01_6	650	25,986	664	5,857	677	15,344
P01_9	650	33,482	655	42,31	650	41,233
P01_12	661	12,171	689	2,521	685	4,61
P01_15	653	26,921	678	24,035	653	19,883
P01_27	650	30,392	673	7,721	658	26,327
P01_33	668	7,272	667	6,44	670	6,885
P01_42	669	9,485	686	3,251	673	2,335

Initial Solution = 3140						
	Run 1		Run 2		Run 3	
Problem No	Obj	CPU (sec.)	Obj	Problem No	Obj	CPU (sec.)
P07_6	2251	6,779	2119	109	2182	23,568
P07_9	2148	82	2107	158	2170	52,876
P07_12	2179	23,724	2148	30,377	2097	82
P07_15	2224	9,866	2114	121	2245	7,066
P07_27	2148	8,221	2173	8,836	2097	30,315
P07_33	2188	29,469	2161	39,355	2171	25,952
P07_42	2147	13,805	2185	11,824	2164	43,521

Initial Solution= 2522						
	Run 1		Run 2		Run 3	
Problem No	Obj	CPU (sec.)	Obj	Problem No	Obj	CPU (sec.)
P013_6	1642	14,791	1658	12,61	1637	110
P013_9	1640	77	1637	141	1655	117
P013_12	1658	6,398	1858	10,881	1658	64
P013_15	1658	8,27	1640	8,712	1647	18,152
P013_27	1637	11,694	1655	7,274	1641	19,874
P013_33	1655	5,789	1658	8,597	1658	27,68
P013_42	1658	6,991	1658	2,351	1655	2,554

Initial Solution= 5232						
	Run 1		Run 2		Run 3	
Problem No	Obj	CPU (sec.)	Obj	Problem No	Obj	CPU (sec.)
P016_6	3693	22,012	3613	49,416	3698	17,439
P016_9	3714	51,713	3691	147	3679	13,173
P016_12	3646	31,998	3665	33,082	3630	101
P016_15	3666	89	3619	131	3651	51,632
P016_27	3613	13,996	3671	12,413	3690	14,294
P016_33	3707	9,681	3677	4,736	3633	58,219
P016_42	3700	4,831	3671	7,322	3698	5,994

Initial Solution= 6238						
	Run 1		Run 2		Run 3	
Problem No	Obj	CPU (sec.)	Obj	Problem No	Obj	CPU (sec.)
P019_6	4434	5406	4479	24,81	4441	190
P019_9	4573	26,049	4609	135	4590	22,791
P019_12	4590	14,24	4545	18,55	4456	19,503
P019_15	4437	144	4482	31,239	4575	52,077
P019_27	4569	273	4632	29,971	4434	97
P019_33	4568	75	4614	53,076	4572	77
P019_42	4631	7,892	4456	9,368	4576	75