Chapter 1

Introduction and Theoretical Framework

This chapter describes the study of facility location problems and several kinds of logistics networks under different uncertainties. Thereafter, we briefly discuss several uncertain environments like fuzzy environment, intuitionistic fuzzy environment, neutrosophic environment, type-2 fuzzy environment. To solve the proposed optimization problems, we employ various techniques in short such as Loc-Alloc heuristic, alternating Loc-Alloc heuristic, approximation approach, fuzzy programming, intuitionistic fuzzy programming, neutrosophic compromise programming, hybrid approach, global criterion method. Ultimately, we present the motivation and objective, and layout of the dissertation.

1.1 Introduction

"***Operations Research is essentially a collection of mathematical techniques and tools which in conjunction with a system's approach, are applied to solve practical decision problems of an economic and engineering nature***"– **Daellenbach and George, 1978**.

As its name recommends, "*Operations Research* (OR)" incorporates "research on operations." Consequently, OR is broadly applied to present-day numerical and logical techniques that deal with how to manage and integrate the operations or tasks with an administration. The characteristic of the administration is significantly immaterial, and in fact, OR has been applied broadly in various different areas as financial planning, distribution system, manufacturing, construction, telecommunications, health care, the military, public services, etc. Consequently, the breadth of application is unusually wide. The establishments of OR can be pursued back various decades when early tries were made to use a sensible approach in the organization of affiliations. Nevertheless, the beginning of the activity called OR to investigate has generally been credited to the military organizations directly off the bat in World War II. Because of the war effort, there was a crisis need to administer uncommon advantages for the diverse military undertakings and to the activities inside each movement in an effective manner. In this manner, the British and a while later the U.S. military organization called upon a large number of scientists to apply a scientific approach to dealing with this and other strategic and tactical problems. Basically, they were asked to do research on (military) operations. These groups of scientists were the first OR groups. By introducing efficient techniques of utilizing the novel system of radar, these teams were instrumental in winning the Air Battle of Britain. At the point when the war finished, the achievement of OR in the war exertion prodded enthusiasm for applying OR outside the military also. As the mechanical blast following the war was running its course, the issues brought about by the expanding multifaceted nature and specialization in associations were again going to the cutting edge. It was getting obvious to a developing number of individuals, including business specialists who had served on or with the OR groups during the war, that these were fundamentally similar issues that had been looked by the military yet in an alternate setting. By the mid-1950s, these people had acquainted the utilization of OR with an assortment of associations in business, industry, and government. These organizations mainly comprise of a gathering of scientists or experts who can handle real-life decision-making optimization problems in a scientific way.

Decision making is one of the fundamental capacities of individuals that recognizes them from different creatures. These days, the decision-making problem is a significant part of the OR, and perhaps it is as old as the historical backdrop of humankind. In some real-life issues, the DM likes to seek more than one objective or to think about more than one factor. Such type of thought changes the optimization problem into a multi-objective problem. There are numerous optimization problems whose data is spatial or location-based. These sorts of choices are called location decisions. Location decisions are presently a significant piece of OR. Facility location problems, location theory, and location problems are termed that can be utilized then again.

1.1.1 Facility location problem

One of the most significant geographical issues for organizations is where to determine different workplaces and customer facilities. *Facility location problem* (FLP), an NP-hard problem (Non-deterministic Polynomial-time) plays a vital role in making a strategy, where and how to trace new facilities among several existing facilities so that at least one of the goals (e.g., logistics cost, conveyance time, carbon outflow cost and customer coverage) will be optimized. FLP is illustrated with four sets, namely: *(a)* a set of facilities which are situated, addressed as existing facilities, *(b)* a set of weights corresponding to the existing facilities, and *(c)* a set of facilities which are to be located, designated as potential facilities, and *(d)* a distance metric. In FLP, warehouses, suppliers, and producers are treated as facilities; and purchasers, retailers and service users are concerned as customers. Industries locate assembly plans and warehouses. Stores are located by retail outlets. The efficiency of the manufacturing and marketing of products is dependent on the location of facilities. Besides, governments also choose the locations of health centers, workplaces, telecommunication networks, fire stations, police stations, distribution centers, emergency medical services and so on. The performance of the assembling, efficiency, and promoting of products is reliant on the locations of sites. All over the places, the quality of services is contingent on the locations of facilities in connection to other facilities. In particular, FLP plays an important role in the distribution and transportation network industries, public facilities, private facilities, military environment and business areas, etc. FLP can be characterized into different subcategories relying upon the properties. The location space might be continuous or discrete. Mainly, FLP is categorized into four wide areas. They are as follows:

(I) **Continuous facility model:** The continuous model is the ancient facility location models to handle the geometrical portrayals of the real world and depends on the continuous location of the region. The Weber problem is a well-known model in this field. The Euclidean or straight-line metrics are regularly utilized around there. This sort of model is now and then alluded to as the facility generation model.

(II) **Analytic facility model:** This type of model is dependent on various assumptions. Manhattan distance is usually utilized in this area.

(III) **Discrete facility model:** The discrete model depends on a discrete collection of facility locations. The popular models in this direction are the coverage model, uncapacitated location model and p-median model. All types of metrics like continuous model are employed in this field. This kind of model is once in a while referred to as the facility selection model.

(IV) **Network facility model:** This model is formulated based on paths and nodes. 1-median, L-median and 2-center are more familiar in this sort. Here, distances are calculated for the shortest path.

In this dissertation, we mainly study the continuous facility models or more precisely we can say the Location-Allocation problems.

Various kinds of distances

Several types of metrics are utilized in FLP models. A few of them are annexed here

- Euclidean or 2-norm distance.
- Rectilinear, 1-norm, Manhattan, taxicab norm or right angle distance.
- Chebyshev or infinity norm distance
- Aisle distance
- Minimum length path

- Block distance
- Hausdroff distance
- Hamming distance
- Hilbert distance

Classification of Multi-criteria FLP

There are various classifications for FLPs, however, based on the decision-making criteria, we categorize them into "multi-objective" and "multi-attribute" FLPs. Fig. 1.1 is shown the classification of multi-criteria FLPs.

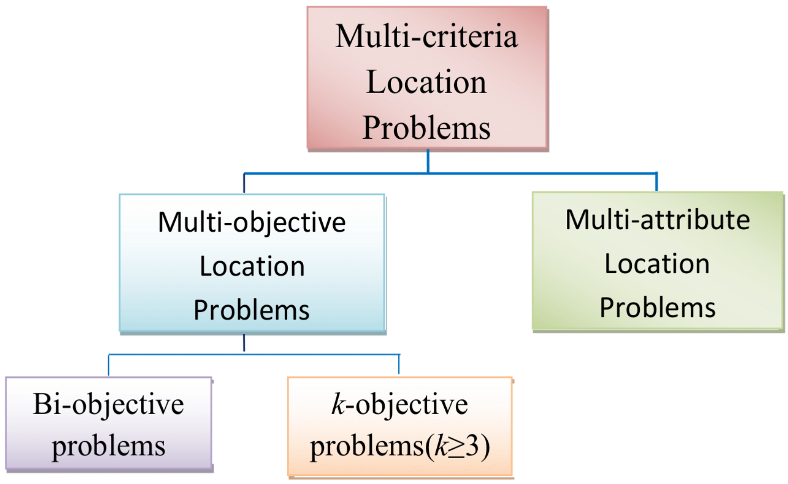

Fig. 1.1: The categorization of multi-criteria FLPs.

FLP objects

Aside from being a single or multi-objective, the objective functions that are typically considered in FLPs are mentioned as FLP objects. a few of them can be characterized as pursues:

- Minimizing the total logistics cost.
- Maximizing customer's satisfaction level.
- Optimizing the overall carbon emission cost.
- Minimizing the fixed cost.
- Minimizing the total inventory cost.
- Maximizing customer coverage.
- Minimizing the logistics time.
- Minimizing the number of potential facilities.

1.1.2 Different kind of logistics network problems

Herein, we describe several types of logistics problems in particular transportation problems.

Transportation problem

In recent times, the network system provides a useful way for communications, logistic as well as electronic systems. The well-known logistics network problem, *transportation problem* (TP), is a special kind of linear programming problem which asks for the minimum cost to transport goods from a set of sources to a set of destinations. Generally, a classical TP consists of three major components: *(a)* a set of all sources, *(b)* a set of all destinations, and *(c)* single-objective function as total transportation cost. Mainly, in a traditional TP, homogeneous goods are sent from sources to destinations, and the total transportation cost is directly proportional to the amount of goods to be transported. The amounts available at sources and demands at destination points are called supply and demand. Here, logistics cost is directly proportional to the flow of units to be distributed. In fact, TP plays a vital role in the global competition for minimizing transportation cost, time and providing service. However, a traditional TP is not sufficient for handling real-life application problems. Due to this reason, a multi-objective environment is introduced on the TP in which the objective functions are conflicting and non-commensurable in nature. This kind of TP is designated as *multi-objective TP* (MOTP).

Fixed-charge transportation problem

In the present scenario of reality, logistics plays a vital role in the global competition for minimizing transportation cost, time and providing service. The most important logistics modeling, *fixed-charge transportation problem* (FCTP) is one kind of integer programming problem, consists of two sets; a set of all sources, a set of all demand points; and a single objective function. It is assumed that the cost of sending a non-zero amount of items from each source to each demand is equal to a variable non-negative cost proportional to the amount of commodity sent includes a fixed non-negative cost. Due to that cost structure, the estimation of the objective function likes a step function for every time open or close a route the objective function jumps a step. FCTP finds the minimum cost (overall fixed and variable cost) to transport goods from a set of sources to a set of destinations.

Solid transportation problem

In the real World, the transportation networks play a crucial role in global economics for minimizing transportation costs and improving service. One of the most important transportation network problem, *solid transportation problem* (STP), is the augmentation of a classical TP, in which 3-dimensional properties are included in the objective function and the constraints. Thereafter, a classical STP is delineated by three stated sets, specifically: *(a)* a set of sources with known availability; *(b)* a set of demand points with given demand;

and *(c)* a set of transportation modes. The core idea of STP is to distribute homogeneous commodities from certain sources to some demand points by various transportation modes (e.g., vans, freight trains, trucks, ships, and air cargo) so that the total logistics cost gets reduced. STP has many real-life applications such as deciding plant location, scheduling, inventory control, production, and investment. Nevertheless, the traditional STP with a single objective function isn't adequate for dealing with real-life scenarios. Because of that, a multi-objective optimization is presented here on an STP wherein the objective functions are conflicting to each other and non-commensurable in nature. This type of STP is addressed as *multi-objective STP* (MOSTP).

1.1.3 Inventory management

In a highly competitive market, technologies and several innovative ideas are implemented in an inventory model to tackle a new and tough challenging problem. In fact, it becomes a challenge for the companies to optimize the total operational cost of ensuring a higher satisfaction level of the customers. An inventory model is always concerned with the total level of inventories and the location of inventories. The term "*inventory*" indicates a physical asset that a plant keeps in stock with the goal of selling or changing it into an increasingly significant state.

Types of Inventories: There are several kinds of inventories related to an inventory model, which are as follows:

- Raw materials & purchased parts
- Partially completed items
- Finished products inventories
- Products-in-transit to warehouses or customers
- Replacement goods

Different kinds of costs: There are various costs related to an inventory management system. They are recorded underneath:

- **Setup cost:** The price which is liable for setting up a system previously a production is started, addressed as setup cost.
- **Purchasing cost:** The cost is related to purchasing a product, designated as purchasing cost.
- **Ordering cost:** This expense is associated with the expense of buying merchandise, accepting the products, advertisements, lease for utilized space and quality assurance.
- **Screening cost:** The screening cost is for selecting the defective items from the items delivered by the supplier.

- **Holding cost:** This type of cost is connected to the storage and maintenance of items at the warehouse or rented places.
- **Deterioration cost:** This cost is related to the deterioration of items in an inventory management system.

Purpose of inventory management: The main purpose of inventory management is to smoothly conduct an organization or a management system. Having this in mind, we have to address two essential inquiries:

i. What amount of items to be ordered?

ii. When to be ordered?

iii. What is the maximum discount?

iv. To accomplish acceptable degrees of customer satisfaction while keeping the costs of operating inventory within a suitable bound.

1.1.4 Carbon emission

In recent decades, an unnatural weather change has drawn a lot of attention as there occurred increasingly extreme weather events. Recently, we have seen further cataclysmic events, e.g., the scorching temperature in Kuwait, water resources, glacier retreat, sea-level rise, drought and flood in some areas of Asia, declines in Arctic sea ice, global temperature high, changes in the timing of the seasonal events. It is well known that the increase of CO_2 emission is considered as one of the key factors of these incidents. On the other hand, as

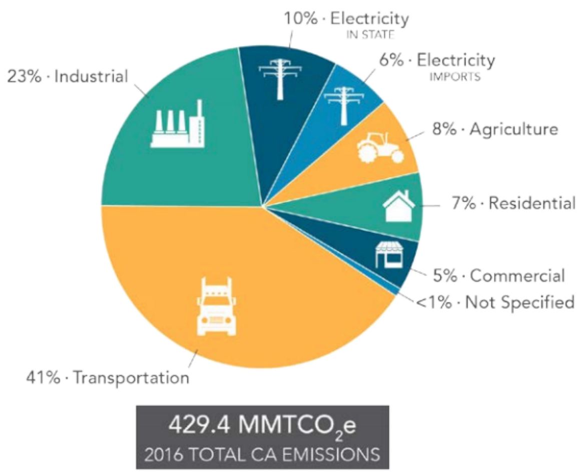

Fig. 1.2: Global carbon emission by different economic sectors in 2016-2017[4] (MMT: Million Metric Tones).

seen in Figure 1.2, transportation can be treated as a significant source of CO_2 emission. To reduce CO_2 discharge, governments and other policymakers endorse a couple of strategies,

[4] Source: https://ww2.arb.ca.gov/ghg-inventory-data

wherein *(a).* carbon tax; *(b).* carbon tax, cap and trade, and *(c).* carbon tax, cap and offset policies are commonly accepted.

Carbon tax: According to carbon tax policy, the carbon discharge holders have to pay the carbon tax for each unit of CO_2 emission to the government.

Carbon tax, cap and trade: Under carbon *tax, cap and trade policy* (TCTP), the companies are firstly allowed some emission cap with the usual tax basis from the government, and subsequently, they can also trade (i.e., buy or sell) the emission cap in the carbon trading market.

Carbon tax, cap and offset: According to this policy, organizations are initially constrained to a carbon cap in taxes per unit emission; if the cap is exceeded then they have to pay penalties. Nevertheless, organizations can support carbon offset projects to increase its carbon cap. The carbon offset project is also addressed as "*The Clean Development Mechanism*" (see https://cdm.unfccc.int) defined in the *Kyoto Protocol (2007)*; it aims at a reduction of CO_2 emission by compensating the organizations' emission.

1.1.5 Solution methodology

There are various kinds of techniques available in the literature to solve single or multi-objective optimization problems. A few techniques are adopted and developed to solve our six optimization problems which are as per the following:

- **Exact approach:** This is a novel method based on the Northwest-Corner method and the iterative procedure. In fact, it is a hybrid approach to find the nearest best optimal locations of our first FLP model. First, we apply the Northwest-Corner method to generate the initial basic feasible solutions; then for each such solution, we use the iterative formulas to find the best locations of potential facilities. LINGO software and C++ programming language are employed for the Northwest-Corner method and the iterative procedure, respectively.

- **Locate-allocate (Loc-Alloc) heuristic:** The Loc-Alloc heuristic approach was first introduced to solve the large-scale classical facility location problems by Cooper [29], which gives always a good solution in less computational time. We develop it to solve our optimization problem. The proposed heuristic is comprised of 2 parts. In Part 1, the heuristic seeks the initial location, and in Part 2 it finds the optimum locations. The Loc-Alloc heuristic is executed by the LINGO software and C++ programming language.

- **Alternating Loc-Alloc heuristic:** This heuristic approach was also proposed by Cooper [29] to solve the traditional FLP. Here, we employ a trick to reduce the possible cases obtained by the Loc-Alloc heuristic. Due to this matter, the alternating Loc-Alloc heuristic is more suitable for large-scale entries in less computational effort.

LINGO software and C++ programming language are also utilized for the alternating Loc-Alloc heuristic.

- **Approximation approach:** Here, a new approximation approach is presented based on the Balinski's approximation and a Loc-Alloc heuristic, which always provides an optimal solution within a relatively short computational time for large scale entries. The proposed approach comprises two parts. In the first part, the approach finds an initial location and in the second part, it develops steps for the optimum location. The process of finding an initial location for the proposed approach depends on a Loc-Alloc heuristic. We have used LINGO software for the feasible solution and C++ programming for the iterations.

- **Fuzzy programming:** This approach is employed to solve a multi-objective optimization problem in which the objectives are conflicting and non-commensurable in nature. The approach first finds the ideal solutions and anti-ideal solutions, and then we determine the upper and lower bounds for membership function for each objective function. Thereafter, the simplified fuzzy model is formulated to derive an optimal compromise solution. Moreover, it does not require trade-offs or complicated parameters or any other reference directions from the DM. In fact, the employing of the approach guarantees a solution that maximizes the global degree of satisfaction, and truly, it is a non-dominated optimal solution. This approach is coded in LINGO software to exact an optimal compromise solution.

- **Intuitionistic fuzzy programming:** The stated method is an extension of fuzzy programming in which a non-membership concept is introduced to deal with the uncertainty in practical problems. The major advantage of the aforementioned procedure is to provide a general structure for handling the membership and non-membership concept in available information. The model of the stated procedure has the potentiality to handle fuzzy concepts such as the number of objective functions and restrictions. Besides, it doesn't need trade-offs, complicated parameters or any other reference directions from the DM. Indeed, employing this ensures a solution that maximizes the satisfaction level and reduces the dissatisfaction level. The stated procedure gives a basic numerical structure which makes it simpler for comprehension and utilization. Moreover, it generally provides a Pareto-optimal solution with a less computational burden. LINGO optimization tool is used to exact an optimal compromise solution.

- **Neutrosophic compromise programming:** The mentioned approach is a generalization of an *intuitionistic fuzzy programming* (IFP), in which an indeterminacy idea is incorporated to handle the hesitancy in a better way. The main advantage of this approach is to give a general structure for dealing with the indeterminacy uncertainties in available data. Moreover, it does not require trade-offs or complicated parameters or any other reference directions from the DM. In fact, the employing of the approach guarantees a solution that maximizes the global degree of satisfaction and dissatisfaction and minimizes the indeterminacy level, and truly, it is a non-dominated optimal solution. The information about the data of multi-objective problems are not precisely defined, the mathematical formulation of our approach has the capability to manipulate vague ideas like the number of objective functions and constraints. The stated approach provides a simple mathematical structure that makes it easier for understanding and using. In fact, it always gives a compromise solution within a relatively short computational time for small scale entries. This approach is also coded in LINGO software to exact an optimal compromise solution.

- **Hybrid approaches:** In this dissertation, two hybrid approaches are presented. One is based on an alternating Loc-Alloc heuristic and an IFP, and another one is an alternating Loc-Alloc heuristic and a *neutrosophic compromise programming* (NCP). The mentioned procedures are divided into two parts. In the first part, each single-objective optimization problem is solved by the heuristic, and in the subsequent part, Pareto-optimal solutions for the multi-objective problems are derived by the IFP and NCP. In these procedures, we first find the initial allocations, optimal feasible solutions, optimum locations, ideal solutions, and anti-ideal solutions, and then we calculate the upper and lower bounds for membership and non-membership functions. Subsequently, the intuitionistic fuzzy optimization model and neutrosophic model for multi-objective location models are designed to get Pareto-optimal solutions. The heuristic is coded in C++; The IFP and NCP are coded in LINGO optimization tool (version 17.0).

- **Global criterion method:** The proposed approach is also used to solve a multi-objective optimization problem. The approach first finds the ideal solutions and anti-ideal solutions, and then we calculate the upper and lower bounds for each objective function. The distance between ideal values and the objective values in the feasible region is reduced. Usually, the Euclidean metric is considered in this approach. Thereafter, the simplified model is formulated to derive an optimal compromise solution. Moreover, it does not require trade-offs or complicated parameters or any other reference directions from the DM. In fact, the employing of the approach guarantees a solution is a non-dominated optimal solution. This approach is coded in LINGO iterative scheme to exact an optimal compromise solution.

For more explanations of the above solution techniques, we refer to the Chapter 2 to Chapter 7. This has been accomplished for fulfillment and better intelligibility of the solution methodologies and to keep up the independence of every chapter.

1.1.6 Uncertain environments

The parameters including in the objectives and restrictions in classical FLP models are generally considered in a precise and deterministic nature. However, the parameters of our optimization problems are vague because of lack of proper information of cost function, supply and demand of the items, limitations of transportation modes and so on for delivery the items from origins to demand points by means of various vehicles as a result of ambiguity or inadequacy of associated data. Uncertainty has a significant role in strategic planning problems. In these real-life problems, the frameworks and their related choices are turning out to be complicated gradually. For that reason, it will be inconvenient to select a precise choice within an appropriate time frame. In addition, the framework relies upon such a significant number of indeterminacy components that contain a lot of ambiguities during the information assortment stage. For the most part, this information is hesitant, hazy and vague in nature. These kinds of ambiguities generally happen for the following real-life situations which are listed below:

- lack of information about the data,
- absence of evidence,
- terrible factual investigation,
- climate and street conditions,
- fluctuating money related markets,
- ambiguities in supply and demand of the products,
- demand for occasional items,
- several routes or transportation modes selection,
- fluctuations in the rate of raw materials,
- during the time of delivery.

To handle such types of uncertainties in our optimization problems, we introduce several uncertain environments which are listed as follows:

- **Fuzzy environment:** In practical optimization problems, when at least one of the parameters is designated as a fuzzy number or fuzzy programming is employed to solve multi-objective real-life based problems, then such kinds of uncertainties are addressed as the fuzzy environment. There are several types of fuzzy numbers such as triangular, trapezoidal, Gaussian, exponential and so on to express the uncertainty of the parameters. To handle this environment, fuzzy logic, a generalization of the crisp set is treated as a primary mathematical tool in which membership function indicates the grade of the uncertainty.

- **Intuitionistic fuzzy environment:** This environment is considered as an extension of the fuzzy environment in which all or a few parameters are taken as an intuitionistic fuzzy number or an IFP is utilized to solve multi-objective optimization problems. Although *fuzzy set* (FS) deals with the satisfaction case of fuzzy uncertainty, still, it cannot tackle the dissatisfaction case of uncertainty. For example, a debate is held on a specific explanation, at that point, there are few people who are satisfied/not satisfied with this debate. The satisfaction level of the debate is 0.85 and the dissatisfaction level is 0.15. This dissatisfaction case is beyond the scope of FS, and thus managing this type of condition of vague data indeed becomes a truly challenging task. Based on this example, we introduce *intuitionistic fuzzy set* (IFS), a generalization of FS. Therefore, IFS gives a more general and suitable formulation to tackle the aforementioned uncertain cases. IFS is introduced dependent on an assumption wherein member is expressed by two degrees, namely, membership and non-membership.

- **Neutrosophic environment:** The mentioned environment is a generalization of an intuitionistic fuzzy environment, in which an indeterminacy idea is incorporated to handle the hesitancy in a better way. In application problems, when the parameter(s) is/are assumed a neutrosophic number or an NCP is utilized to solve the multi-objective problems, then this type of environment is said to be the neutrosophic environment. Although FS and IFS deal with all types of fuzzy uncertainty, still they cannot handle the indeterminate situation. For instance, a survey is done on a particular statement, then one may say that the possibility of the statement is true 0.7, the statement is false 0.4, and the statement is not sure 0.3. This issue is beyond the scope of FS and IFS, and thus dealing with a kind of indeterminate situations of uncertain information indeed becomes a true challenge. Based on this instance, we introduce the neutrosophic set, an extended form of FS and IFS. It provides a more general structure and suitable form to deal with the mentioned uncertainties. The neutrosophic set is formulated based on logic in which elements are represented by three degrees, explicitly, truth degree, indeterminacy degree, and falsity degree.

- **Type-2 intuitionistic fuzzy environment:** The stated environment is a generalization of an intuitionistic fuzzy environment as well as a type-2 fuzzy environment. There are a few application examples in which one uncertain environment is unable to handle the condition. For that reason, here, a novel 4-dimensional type-2 trapezoidal fuzzy number with the degree of hesitation is introduced to overcome the uncertainties in a green solid transportation system. In the proposed environment, membership and non-membership degree, as well as the degree of hesitation, is also considered. When this type of uncertainty occurs in the parametric value of an optimization problem, then corresponding circumstances are called as a type-2 intuitionistic fuzzy environment. For instance, if we consider a set young then the youthness is designated by the primary membership function. And the secondary membership and non-membership functions are the grades of youthness and adultness.

1.2 Theoretical framework

FLP frames an important class of integer programming problems with application in the transportation and distribution organizations from the ancient days to till today. Despite the fact that it is numerous years old problem however nowadays it is getting more emphasis as a result of its part of practical applications. Interested readers may follow the books to discover more about FLPs: Love et al. [93], Drezner and Hamacher [45], Farahani and Hekmatfar [53], Drezner [44] and Weber [165]. Meanwhile, to achieve better performance, scientists have studied FLPs extensively in the field of logistics design over the last few decades. In particular, Owen and Daskin [115] did a review on FLP. Bhattacharya et al. [14] employed a goal programming with a fuzzy membership function for a multi-objective FLP. After that, Bhattacharya et al. [15] also improved a goal programming for a bi-objective FLP with rectilinear metrics under fuzzy environment. ReVelle and Eiselt [127] also made a survey on different kinds of location problems. Later, Snyder [155] also published a survey article on facility location under various uncertain environments. In consequence, Farahani et al. [55] did a comprehensive survey of FLPs in a multi-objective environment. Gaidi et al. [90] analyzed a dynamic FLP with several retributions and they also introduced a primal-dual approach to solving it. Then, Bieniek [16] presented a note on FLP where the demands follow the arbitrary distribution. Later, Chen et al. [25] solved a single FLP with random weights. Albareda-Sambola et al. [4] developed an FLP with Bernoulli's demands. Gao [58] published a paper on uncertain models for FLPs on networks. Arbani et al. [6] gave an overview of classifications and applications on FLP. Yanga et al. [168] gave an algorithm based on a cut and solve approach for an FLP. Singh and Sharma [153] did a review of several approaches to an FLP. Dias et al. [42] utilized a primal-dual heuristic to solve dynamic FLPs. Hua et al. [68] investigated a FLP using fractional programming. Samarghandi [145] used particle swarm optimization for a single row FLP. Later on, Murali et al. [114] discussed FLP under uncertain environment. Li et al. [90] illustrated covering models and optimization techniques for emergency response facility location and planning. Matai et al. [103] gave a non-greedy systematic neighborhood search heuristic for solving an FLP. Kim and Kim [78] solved a public health-care FLP by the Lagrangian heuristic. Baïou and Barahona [10] studied a two-level facility location model. Linh and Muu [92] solved their location problem using an algorithm based on the convex hull concept. Bozorgi et al. [18] introduced tabu search heuristic for the efficiency of dynamic FLP. Wanka and Wilfer [164] studied minimax location problems under a multi-composed solution technique. Karatas and Yakıcı [75] analyzed an FLP under a multi-criteria environment and solved it by an iterative method. Atta et al. [9] employed two approaches to solve their uncapacitated location model under a multi-objective environment. Furthermore, FLP has been applied to a wide range of green logistics modeling, technology acquisition problem, and plant location problems such as Harris et al. [64], Yang et al. [167], Gadegaard et al. [57], Tokg*öz* et al. [161], Klose and Kurt [74], and references therein. Along these lines, it is concluded that the FLP consistently gives an efficient mathematical formulation for several network systems.

The delineation of a transportation network is a strategic issue all over the place. In the real scenario, TP plays a vital role in the global competition for minimizing transportation cost, time and providing service. It was first introduced by Hitchcock [67]; then Koopmans [83] studied the optimal utilization of the transportation system. Charnes and Cooper [23] first introduced several solution techniques to solve different kinds of optimization problems in which the nature of objective functions is a conflict with each other. Thereafter, they [24] also developed a chance-constrained model to solve uncertain optimization problems. Interested readers may follow the books Hadley [62] and Dantzig [32] for details about TP. However, traditional TP is not sufficient for handling real-life application problems. Due to this reason, the multi-objective environment is introduced here on the TP in which the objectives are conflicting and non-commensurable in nature. In fact, the MOTP was analyzed by so many researchers in different environments. Some works are annexed here. El-Wahed [50] studied an MOTP under fuzzy environment and then he solved the problem by a fuzzy programming. Thereafter, Mahapatra et al. [94] solved a multi-choice stochastic TP where the supply and demand parameters follow extreme value distribution. Sabbagh et al. [143] proposed a hybrid approach for the balanced TP. Maity et al. [99] discussed an MOTP with cost reliability in an uncertain environment. Later on, Roy et al. [137] described an MOTP where cost, demand, and supply parameters are in multi-choice nature. And they solved the problem using two approaches multi-choice goal programming and conic scalarizing function. Kaur and Kumar [76] introduced a novel approach to solve a TP under a fuzzy environment and they also employed a ranking function to convert the fuzzy model into a deterministic. After that, Zangiabadi and Maleki [171] developed a fuzzy goal programming to handle their MOTPs in which they considered a few non-linear membership functions instead of linear. Maity and Roy [96] discussed an MOTP in which the nature of cost, supply and demand parameters is a multi-choice type and they solved it by using a utility function. Roy [131] developed a method based on Lagrange interpolating polynomial for solving a multi-choice TP. Maity and Roy [97] utilized a utility function to tackle an MOTP under an interval environment. Roy [132] studied a multi-choice TP under stochastic environment. Ebrahimnejad [48] studied TPs under an interval-valued fuzzy environment, then he used Zimmerman's approach to obtain optimal solutions. Thereafter, he [49] also introduced an approach to solving TPs where the parameters are in LR flat fuzzy nature. Roy and Maity [135] investigated a multi-choice interval-valued TP in which they reduced the total logistics cost and time simultaneously. Maity and Roy [98] developed a multi-choice goal programming to handle a fuzzy TP. Roy et al. [136] analyzed a two-stage TP in which uncertainties of the parameters are displayed by grey numbers under a multi-criteria environment. Maity et al. [101] introduced a sustainable environment in an MOTP under the time window. Thereafter, Maity et al. [95] developed a novel method to solve a TP under a dual-hesitant fuzzy environment. Recently, Maity et al. [100] incorporated the concept of multi-modal TP and applied this idea in an artificial intelligence application problem.

In recent times, FCTP, an augmentation of classical TP which is attracted by the researchers. The fixed charge problem was initially introduced by Hirsh and Dantzig [66]. When the idea of a fixed charge problem is incorporated into a TP, then the problem is addressed as FCTP. Balinski [11] formulated a new approximation approach to solve an FCTP which is known as Balinski's approximation. Such a large number of researchers analyzed FCTPs in several environments. For instance, Adlakha and Kowalski [1] gave a note on an FCTP. Then, they [2] introduced a simple heuristic to solve it. Klose [80] developed several approaches to solve a single-sink FCTP. Thereafter, Kundu et al. [86] studied an FCTP under a type-2 fuzzy environment. Adlakha et al. [3] discussed a novel approximation to solve an FCTP by calculating an efficiency lower bound. The stated approximation was proved as much better than Balinski's approximation. Buson et al. [20] analyzed an FCTP and solving it by an iterated based heuristic approach. Midya and Roy [107] studied a single-sink multi-objective FCTP in the light of a stochastic environment. Mingozzi and Roberti [109] solved an FCTP using an exact algorithm based on an unprecedented integer programming. Midya and Roy [108] analyzed interval programming in different environments and their application to a fixed-charge transportation problem. Afterwards, Roy et al. [139] discussed an FCTP in the shadow of a multi-criteria environment and they considered the nature of parameters as a two-fold uncertainty. Recently, Mehlawat et al. [104] studied a multi-stage FCTP with three multiple conflicting objective functions and they applied it in a sustainable transportation example. Nowadays, product blending assumes an important part in setting up the refinery items for the market to fulfill the item determinations and ecological guidelines. Motivated by this idea, Roy and Midya [138] introduced it into a multi-objective FCTP and they are taken the parameters as an intuitionistic fuzzy number. Hashmi et al. [65] studied a MOFCTP model under a two-stage environment. Roy et al. [140] made a formulation on a multi-item FCTP under a two-fold uncertain environment. Moreover, they incorporated the concept of various transportation modes in this formulation.

STP is the augmentation of a classical TP, in which 3-dimensional properties are included in the objective function and the constraints. Shell [150] first introduced the concept of STP, however, Haley [63] gave the methodology of a classical STP. Jiménez and Verdegay [72] incorporated the concept of uncertainty into the STP. Thereafter, they [73] introduced a parametric approach to solved a fuzzy STP. Nevertheless, the traditional STP with a single objective function isn't adequate for dealing with real-life scenarios. Because of that, a multi-objective optimization [69, 163] is presented here on an STP wherein the objective functions are a conflict to each other and non-commensurable in nature. MOSTPs are investigated by such a large number of researchers in various environments. A few research studies on MOSTP are attached, for instance, Bit et al. [17] incorporated a multi-objective optimization concept in an STP and they solved it by a fuzzy programming technique. Kundu et al. [85]

presented a MOSTP in which parameters are considered as fuzzy numbers. After that, they [87] presented an STP in which several kinds of products are distributed under a type-2 fuzzy environment. In transportation systems, researchers have mainly reduced the total transportation cost. However, Das et al. [33] developed an STP under a rough environment in which they focused to maximize the profit of the DM. Product blending is a significant process in setting up the refinery items for the market to fulfill the item determinations and ecological guidelines. Kundu et al. [84] implemented this concept in an STP with rough variables. Nowadays, due to enormous transportation systems, huge quantities of carbon dioxide emitted into the atmosphere, which is the crucial clarification for an unnatural climate change. To reduce carbon discharge, Sengupta et al. [148] considered carbon emission in an STP. Das et al. [34] studied an STP in which the parameters were taken as type-2 fuzzy variables. Disaster relief activity needs rapid essential logistics systems to allocate the resources among the affected people. Regarding this, Sarma et al. [147] made a formulation based on a MOSTP to handle the emergencies under neutrosophic environment.

In a highly competitive market, technologies and several innovative ideas are implemented in an inventory model to tackle a new and tough challenging problem. In fact, it becomes a challenge for the companies to optimize the total operational cost of ensuring a higher satisfaction level of the customers. An inventory model is always concerned with the total level of inventories and the location of inventories. This type of concept was first introduced by Goyal [61]. Later on, Sarkar et al. [146] found the impact of variable transportation in a three-echelon supply chain model. Pervin et al. [120] described a production quantity model for deteriorating products to find an optimal replenishment decision under a trade credit environment. Then, they [121] studied a two-echelon ordered quantity model in which demand rate is considered stock dependent. Pervin et al. [122] introduced a stochastic inventory model with time-dependent demand and time-varying holding cost. Roy et al. [141] investigated an inventory model with price and stock dependent demand to control the date of deterioration. Thereafter, Pervin et al. [126] exhibited the effect of price and stock dependent demand for a multi-item deteriorating inventory model. Pervin et al. [123] solved a vendor-buyer model to get an optimal order quantity with the goal that the total inventory cost will be reduced. Roy et al. [142] introduced an inspection policy and a deterioration factor in a production inventory model under the trade-credit policy. Then, Pervin et al. [124] incorporated a preservation technology in their deteriorating inventory model. Recently, Pervin et al. [125] studied an integrated model in which demand rate was considered in quadratic type.

A fast-flowing of transportation emits tremendous amounts of carbon, which is the fundamental explanation for global warming. To control carbon emanations, the government endorses several policies which we already discussed in our introductory section. This sort of study has been actualized by numerous researchers. Among them, Paksoy et al. [116] introduced the green activities in a supply chain framework to control greenhouse gas emission and therefore they employed a multi-objective optimization technique to solve their formulation. Elhedhli and Merrick [52] provided an integrated model between carbon emission and vehicle weight. Benjaafar et al. [13] analyzed the impact of several carbon emission policies such as carbon tax, cap, cap and trade, and cap and offset in supply chain models. Specifically, they displayed that the nearness of discharge guidelines can essentially build the estimation of production network coordinated effort. Chen et al. [26] also discussed various environmental regulations in an economic order quantity model and thereafter, they gave a restriction to control emission without importantly increasing the operational cost. Konur et al. [82] made a bridge between inventory management and logistics planning problems with truckload constraints under several carbon emission policies. Tang et al. [160] further investigated the effect of controlling carbon emission by minimizing shipment frequency in inventory management decisions. Du et al. [46] employed low-carbon technologies in a production problem under the cap-and-trade policy. Chen and Wang [27] examined the insights of several policies related to control carbon emission in an inventory problem. In fact, they also considered different kinds of transport modes with stochastic customer demand. Turken et al. [162] highlighted the impact of carbon emission due to transportation in the environment. Wu et al. [166] studied the effect of the carbon emission cost of an integrated production-location model. Cao et al. [21] introduced low carbon subsidy, and cap and trade policies in a production model to reduce carbon emission as well as promote sustainable development. Song et al. [156] particularly considered two carbon emission reduction regulations (carbon tax and cap-and-trade) and also investigated their impacts on production planning decisions. Tang et al. [159] provided three analytical models, the first one is based on carbon footprint, the second one is incorporated carbon tax scheme and the rest one is introduced carbon offset policy and then discussed the significant insights about the policies.

FLP, different kinds of logistics systems and inventory management are the core components of supply chain management. Deciding the optimal locations for the facilities such as retailer-outlets, plants, terminals, workplaces, fire stations, railroad stations, and so forth and optimizing the overall logistics cost, transportation time and inventory cost by different transportation modes can significantly affect the management system. Many researchers have engaged to find the utilities of an integrated model. In fact, Cooper [30] first introduced an association among FLP and TP and is otherwise called a transportation-location problem. Thereafter, he [31] studied the problem under a stochastic environment. Sherali and Tuncbilek [151] utilized a Euclidean metric in a location-allocation problem and also gave a solution technique to solve large-scale instances. Dohse [43] explored a connection between FLP and transportation system and therefore, they solved it to obtain an optimal solution. Then, Melo et al. [105] presented a review to coordinate FLPs with other decision-making problems of a supply chain network. Tadei et al. [157] made a bridge between a capacitated location model and a transshipment problem under a stochastic environment. Gabrel et al. [56] illustrated a transportation location problem and they discussed a robust optimization technique to solve it. Saif and Elhedhli [144] developed an FLP with concave objective function and applied in a plant location problem. They also gave a Lagrangian heuristic to solve it. Mišković et al. [111] described an integrated model between a capacitated FLP and a logistics system and they solved by using robust optimization. Jaafar and Delage [7] presented a capacitated location-transportation problem in which they incorporated the concept of fixed charge problem. Further details on the different types of connections between FLP and TP can be found in Klibi et al. [79], Klose and Drexl [81], Amin and Baki [5], Das et al. [38] and references therein. Later, Carlo et al. [22] extended the problem with an unknown number of facilities. Recently, Das et al. [39] have first built a bridge between an FLP and an STP. Thereafter, Das and Roy [36] formulated a novel integrated transportation-location model under the neutrosophic environment. They considered variable carbon emission as it depends on the locations of facilities as well as the amounts of transported items. This concept is totally new; it was not incorporated previously by researchers. Thereafter, they displayed the impact of a tax, cap and trade policy in their problem and applied it in a green logistics problem. The significance of an integrated location-inventory model helps an organization to increase the efficiency and decrease the wastage. Not only that, but it also allows eliminating the redundant activities, to save fuel and energy which alternately increase the money-saving, and deduce the complexity of a higher level of cost. The primary level of an integrated location-inventory model consists of location cost, inventory cost, and transportation cost. Therefore, the trade-off between these cost factors is a major undertaking of this type of model. Several researchers were engaged to find the utilities of an integrated model. Among them, Perl and Sirisoponsilp [119] were the first to develop an integrated location-inventory model, but they did not verify their model by giving numerical examples. However, in the next couple of years, Jayaraman [70] investigated the trade-off between an integrated model by designing a distribution network chain. Later, several researchers were engaged to find the effect of an integrated location-inventory model under different environments. Among them, Miranda and Garrido [110] were first who have found the integration between inventory management and facility location to reduce the total operations cost. Bashiri and Tabrizi [12] developed a multi-objective model for finding the location of a decision center with multiple retailers and solved the model by using the PSO approach. Silva and Gao [152] formulated a joint model for inventory location to minimize the total inventory cost in order to locate related costs also. Shahabi et al. [149] developed an optimization model to integrate FLP and inventory control designing a distribution network. Not only in that direction, Diabat and Theodorou [41] derived an integrated model with integer programming and piecewise linearization. Farahani et al. [54] formulated a location-inventory model by using strategic supply chain designing and tactical planning. Manatkar et al. [102] studied an integrated inventory, location-allocation problem with multi-objective optimization. Loaiza et al. [118] designed an integrated location and inventory management under a multi-objective environment. They also employed an evolutionary algorithm to tackle the proposed problem. Mogale et al. [112] presented a new integrated multi-modal location-allocation problem for the food supply chain in India. They considered docking time in the path to increase customers' satisfaction level. Furthermore, they solved it by employing a new Pareto based algorithm. Das et al. [37] introduced a type-2 fuzzy logic in a multi-objective green solid transportation-location problem with dwell time under carbon tax, cap and offset policy. Recently, Das et al. [35] studied a multi-objective solid transportation-location problem with variable carbon emission in inventory management.

Nowadays, when managing real-life FLP models, the unpredictability may occur due to a large competitive global market. In fact, this type of mathematical formulation is difficult to tackle by traditional approaches. To overcome this situation, Zadeh [169] introduced the *fuzzy set* (FS). Thereafter, Zimmermann [172] incorporated fuzzy programming to solve a multi-objective linear programming problem. But, there is a drawback of the FS, it could not manage a certain case of uncertainty. Because of that, the *intuitionistic fuzzy set* (IFS) was developed by Atanassov [8] as a generalization of the FS. The IFS was applied in a multi-objective optimization problem like Roy et al. [134] and Garg et al. [59]. Although the FS and IFS deal with all types of fuzzy uncertainty, still they cannot handle the indeterminate situation. For instance, a survey is done on a particular statement, then there are a few who said the possibility of the statement is true 0.7, the statement is false 0.4, and the statement is not sure 0.3. This issue is beyond the scope of the FS and IFS, and thus dealing with a kind of indeterminate situations of uncertain information indeed becomes a true challenge. Based on this instance, the neutrosophic set, an extended form of the FS and IFS was developed by Smarandache [154]. It provides a more general structure and suitable form to deal with the mentioned uncertainties. The neutrosophic set is formulated based on logic in which elements are represented by three degrees, explicitly, truth degree, indeterminacy degree, and falsity degree. The choice of membership functions related to various kinds of fuzzy sets and numbers are formulation based. In contrast, trapezoidal or triangular fuzzy numbers are accepted commonly for handling vague information in application problems. In view of those many research works, we analyze that the trapezoidal form of fuzzy number is generally utilized due to obtaining more adequate information by its simple form. However, its two-dimensional form sometimes cannot tackle all the uncertainties, received by the data. Thereafter, Zadeh [170] also gave the idea of a type-2 fuzzy set to overcome this kind of situation.

1.3 Motivation and objective of the thesis

Facility location and logistics network problems including carbon emission and several uncertain environments have drawn a lot of attention due to their broad applications in green logistics modeling, plant location problems, extensive natural calamity events. Nevertheless, a few types of research have been done on integrating facility location decisions and transportation systems. From the aforementioned prior related works, it is uncovered that several theoretical and computational avenues for facility location models are left unexplored. This inspired us to design some strategic transportation networks in several uncertain environments. The objective of this dissertation is to explore FLPs in light of various uncertain environments. The main focuses of this thesis which are described as follows:

(i). A connection between FLP and TP is introduced, which is referred to as T-LP. Thereafter, some fundamental propositions and a theorem on T-LP have been introduced to investigate the nature of the problem. In addition to the aforementioned achievements, the development of novel versions of two approaches is analyzed to solve the proposed problem efficiently.

(ii). The concept of additional cost (i.e., fixed-charge) in T-LP is analyzed, which is addressed as FCT-LP. Therefore, a few characteristic properties and a theorem on FCT-LP have been added to examine the nature of the formulation. Despite the over, the development of a new version of approach has been incorporated to tackle the proposed problem proficiently.

(iii). The idea of different types of transportation modes on the entire supply chain in T-LP is incorporated. Afterwards, a theorem and a few structural propositions on the above formulation have been stated. In addition to the preceding achievements, two heuristic approaches are introduced to solve the stated problem effectively.

(iv). An integrated nonlinear optimization model based on FLP and TP under a carbon tax, cap and trade policy is introduced. The model finds the decision regarding the assignment from multiple existing facilities to multiple potential facilities in the continuous planner surface with a hyperbolic approximation of Euclidean distance.

(v). An unprecedented non-linear mathematical formulation based on FLP, inventory management, and MOSTP is presented, which is designated as MOST-LP. The overall logistics cost and time, and inventory cost by different modes of transportation are also considered. Variable carbon emission cost is incorporated which is a significant issue in modern time. A hybrid approach is described to get the Pareto-optimal solution of MOST-LP.

(vi). Type-2 intuitionistic fuzzy green MOST-LP model is designed. Using a new ranking function to convert type-2 intuitionistic fuzzy MOST-LP into a deterministic form. Therefore, fuzzy and non-fuzzy approaches are introduced to solve deterministic MOST-LP. The performances of our findings are discussed with industrial-based application examples. Moreover, a comparative study with particular cases is explored among the other existing techniques.

In the end, profitable and vital managerial insights are received through this dissertation, which would be valuable to the different kinds of governmental and private organizations associated with the logistics system. From the outcome, organizations can select the best potential sites so that they can distribute the commodities with the stated objectives. A brief discussion of the impact of carbon emission under several carbon policies is analyzed. From that analysis, organizations can understand when their profit will be less (more). Accordingly, they can adjust their benefits and environmental awareness, which may lead to a gain of reputation in the worldwide market. On the other hand, the fuel consumption of the vehicles is displayed in conveyance cost and emission functions. In cases where the fuel consumption is less, then the overall logistics cost along with carbon discharge will be reduced. Hence, organizations can easily select which kinds of vehicles are most suitable for distributing products. Once more, the dwell time for the barriers of the paths is also incorporated into the conveyance time, so that organizations are ready to calculate a more accurate delivery time which improves their customers' service.

1.4 Organization of thesis

This dissertation is cataloged by eight (08) chapters of which Chapter 1 is delineated the background associated with the proposed research studies and prior related works in the theoretical framework. This thesis is sorted out as indicated by the particular optimization models that we have investigated. Especially, here, six (06) optimization problems in FLPs are presented in Chapters 2 to 7. These chapters are presented the proposed works in a similar way. All the more solidly, in each chapter, we initially describe the problem backgrounds and afterwards mathematical models are formulated. Subsequently, several solution procedures and numerical examples are presented to validate the proposed problems. Furthermore, the other key performances like result discussion, sensitivity analysis, and managerial insights are given. One may discover the reiteration of a few definitions, propositions, theorems, lemmas, and mathematical expressions in these chapters. This has been accomplished for fulfillment and better intelligibility of the model and to keep up the independence of every chapter. Eventually, conclusions and avenues of future studies of these optimization problems are offered in Chapter 8. Some derivations in the appendix section, an extensive bibliography, the list of publications and conferences, and about contributors are given at the end of this thesis. The chapter-wise layout of the proposed dissertation is depicted below:

The Chapter 1 describes the study of facility location problems and different types of transportation problems under several uncertain environments. Thereafter, we briefly discuss several uncertain environments like fuzzy environment, intuitionistic fuzzy environment, neutrosophic environment, type-2 fuzzy environment. To solve the proposed optimization problems, we employ various techniques in short such as Loc-Alloc heuristic, alternating Loc-Alloc heuristic, approximation approach, hybrid approach, fuzzy programming, intuitionistic fuzzy programming, neutrosophic compromise programming, global criterion method. Ultimately, we present the motivation and objective, and layout of the dissertation.

The Chapter 2 delineates the transportation network is a strategic issue for all over the place. The problem of locating new facilities among several existing facilities and minimizing the total transportation cost are the main topics of the location network system. This chapter addresses *transportation-location problem* (T-LP) which makes a connection between FLP and TP. In fact, T-LP is a generalization of the classical transportation problem in which one has to seek where and how to impose the potential facilities such that the total transportation cost from existing facility sites to the potential facility sites will be minimized. The exact approach, based on the iterative procedure, and a heuristic approach as applied to T-LP are discussed and corresponding results are compared. An experimental example is incorporated to explore the efficiency and effectiveness of this study.

The Chapter 3 describes *fixed-charge transportation-location problem* (FCT-LP) that integrates FCTP and FLP. In fact, FCT-LP, speculation of an FCTP looks for where and how to impose the facilities with the goal that the overall transportation cost with the fixed-charge cost from the existing facility sites to potential facility sites is reduced. A novel approximation approach is incorporated to solve the proposed model for extracting optimal solution. An experimental design is consolidated to demonstrate the proficiency and viability of the proposed consideration. The chapter ends with conclusions.

The Chapter 4 presents *solid transportation-location problem* (ST-LP) is an integration between FLP and STP. This chapter delineates ST-LP, a generalization of the classical STP in which location of potential facility sites are sought so that the total transportation cost by means of conveyances from existing facility sites to potential facility sites will be minimized. This is one of the most important problems in the transportation system and the location research areas. Two heuristic approaches are developed to solve such type of problem: a locate-allocate heuristic and an approximate heuristic. Thereafter, the performance of the proposed model and the heuristics are evaluated by an application example, and the obtained results are compared. Moreover, a sensitivity analysis is introduced to investigate the resiliency of the proposed model. Finally, conclusions are provided.

The Chapter 5 investigates a *multi-objective transportation-location problem* (MOT-LP) under neutrosophic environment. The main focus of the chapter is to locate a pre-assigned number of facilities to determine a transportation way for optimizing the objective functions simultaneously. MOT-LP is an optimization-based model to integrate the facility location problem and the transportation problem under the multi-objective environment. This chapter delineates the stated formulation in which one needs to seek the locations of facilities in the Euclidean plane, and the amounts of transported products so that the total transportation cost, transportation time, and carbon emission cost from existing sites to potential facilities will be minimized. In fact, variable carbon emission under carbon tax, cap and trade regulation is considered due to the locations of potential facilities and the amounts of transported flow. Thereafter, a hybrid approach is improved based on an alternating locate-allocate heuristic and the neutrosophic compromise programming to obtain the non-dominated solution. Additionally, the performance of our findings is evaluated by an application example. Furthermore, a sensitivity analysis is incorporated to explore the resiliency of the designed model. Finally, conclusions end the chapter.

The Chapter 6 acquaints a streamlining model with incorporate FLP, STP, and inventory management under a multi-objective environment. The aims of the chapter are multi-fold: *(i)* seek the optimum locations for potential facilities in Euclidean plane; *(ii)* find the amount of distributed commodities; and *(iii)* reduce the overall logistics cost and time, and inventory cost along with the carbon emission cost. Here, variable carbon emission cost is taken into consideration because of the variable locations of facilities and the amount of distributed products. After that, a new hybrid approach is introduced dependent on an alternating locate-allocate heuristic and the intuitionistic fuzzy programming to get the Pareto-optimal solution of the proposed formulation. The performances of our findings are discussed with a numerical example. Sensitivity analysis is executed to check the resiliency of the parameters. Ultimately, managerial insights, conclusions, and avenues of future studies are offered at the end of this chapter.

In Chapter 7, we develop a multi-objective green solid transportation-location problem with a carbon tax and offset policy in a two-fold uncertainty environment. The parameters of the proposed model are considered to be a type-2 fuzzy number. Then, a ranking function is employed to deal with the fuzzy parameters. In fact, variable carbon emission under a carbon tax and offset regulation and variable budget constraints are also considered due to the locations of potential facilities and the amounts of transported flow. Thereafter, fuzzy programming and non-fuzzy programming are introduced to obtain the non-dominated solution. Additionally, the performance of our findings is evaluated by application examples. Furthermore, a sensitivity analysis is incorporated to explore the resiliency of the designed model.

Lastly, concluding remarks and scope of future studies about the research works in Chapters 2 to 7 are discussed in in Chapter 8.