UNCERTAINTY ASSESSMENT FOR THE SUPPLY CHAIN SYSTEM OF A CONCRETE COMPANY USING MONTE CARLO SIMULATION

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
OF
MIDDLE EAST TECHNICAL UNIVERSITY

BY

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IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR
THE DEGREE OF MASTER OF SCIENCE
IN
MINING ENGINEERING

FEBRUARY 2021

Approval of the thesis:

UNCERTAINTY ASSESSMENT FOR THE SUPPLY CHAIN SYSTEM OF A CONCRETE COMPANY USING MONTE CARLO SIMULATION

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ABSTRACT

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February 2021, 94 pages

Concrete is the primary construction material and may be supplied in varying strength values according to customer demand. The profitability of concrete operations is very low, with a profit margin changing between 0.1 and 0.2 percent (OYAK Concrete Company, 2019). Since multiple competitors are generally available for the sales region, it is not always likely to raise up the concrete prices. Therefore, operation profitability for concrete production and distribution systems may be achieved practically by monitoring and diminishing operating cost items. On this basis, transportation-related cost items in hauling operations cover about 70% of the total operating cost, and where half of this cost consists of fuel consumption. Truck-mixers are used in material hauling operations and may carry concrete from batching plants to construction site with a varying vehicle capacity of 7, 8, 9, 10, 12, and 14 m^3.

The current study intends to evaluate the uncertainties in the concrete supply-chain systems. At this point, the OYAK Concrete Company's operations in Ankara, where four different batching plants are used actively, were considered in the application part. It is observed from the recent records of the company that an annual concrete production of 4.5 million m^3 where truck-mixers should have 500,000 travels between the batching plants and the order points. When matching the order points and the supplier plant, the priority zone regarding destination lengths is evaluated. However, raw material costs used in the batching plants and transportation costs may differ between plants. Therefore, the priority zone may fail to ensure the highest profitability in all cases. Using the demand and supply uncertainties in different types of concrete and priority zones, the current study tries to build up a Monte Carlo simulation model to seek alternative supply chain scenarios to increase operational profitability. The results of the study show that operational cost could be decreased by changing distribution system. Main impact of the decrease is seen in transportation cost of the operations.

Keywords: Monte Carlo Simulation, Supply Chain Systems, Cost Analysis, Concrete Production and Distribution, Uncertainty Assessment

ÖZ

BİR BETON FİRMASININ TEDARİK ZİNCİRİNİN MONTE CARLO SİLUMASYONU İLE BELİRSİZLİK DEĞERLENDİRMESİ

Serbest, İnanç Taha
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Şubat 2021, 94 sayfa

Beton öncelikli bir yapı malzemesi olarak, müşteri talebine göre değişik mukavemet değerlerinde tedarik edilebilir. Beton üretim ve dağıtım operasyonları, %0,1 ve %0,2 arası değişen kâr marjı oranları ile düşük karlılık oranlarına sahiptir (OYAK Concreete Company, 2019). Belirli bir satış bölgesi için genellikle birden fazla filli rakip bulunduğundan, beton fiyatlarının her zaman yükseltilmesi olası değildir. Bu nedenle, beton üretim ve dağıtım sistemleri için işletme karlılığı pratik olarak, işletme maliyeti kalemlerinin takip edilmesi ve azaltılmasıyla sağlanabilir. Bu temelde, dağıtım operasyonlarında taşımayla ilgili maliyet kalemleri, toplam işletme maliyetinin yaklaşık %70'ini temsil etmektedir ve bu maliyetin yarısını yakıt tüketimi oluşturmaktadır. Beton santrallerinden sipariş noktalarına malzeme taşıma operasyonlarında transmikserler kullanılır ve 7, 8, 9, 10, 12 ve 14 m^3 olarak değişen araç kapasiteleri ile beton taşıyabilirler.

Bu çalışmada hazır beton tedarik zinciri sistemindeki belirsizliklerin değerlendirilmesi amaçlanmaktadır. Bu noktada, analizlerde OYAK Çimento Şirketi'nin Ankara ilinde aktif olarak kullanılan dört farklı santralinin operasyonları ele alınmıştır. Son raporlarda arşivlenen verilere göre, şirketin yıllık toplam 4,5

milyon m^3 beton üretimi yapması ve transmikserlerin beton santralleri ile sipariş noktaları arasında yaklaşık 500.000 kez seyahat etmesi gerektiği görülmektedir. Sipariş noktasını besleyecek beton tesisi seçilirken, sipariş noktası ile tesislerin arasındaki uzaklıkla belirlenen öncelikli bölgeler değerlendirilir. Ancak, beton tesislerinde kullanılan hammaddelerin maliyetleri ve nakliye maliyetleri tesisten tesise farklılık gösterebilir. Bu nedenle, öncelikli bölge her durumda en yüksek karlılığı sağlayamayabilir. Mevcut çalışmada, operasyonel karlılığı artırmak adına farklı beton tipleri ve farklı öncelikli bölgelerdeki talep ve arz belirsizlikleri kullanılarak, alternatif tedarik zinciri senaryolarını incelemek için bir Monte Carlo simülasyon modeli oluşturulmayı amaçlamaktadır. Çalışmanın sonuçları dağıtım sisteminde yapılan değişikliklerin operasyonel masrafları azalttığını göstermektedir. En önemli etki ise taşıma maliyetlerinde olmuştur.

Anahtar Kelimeler: Monte Carlo Simülasyonu, Tedarik Zinciri Sistemleri, Maliyet Analizi, Beton Üretimi ve Dağıtımı, Belirsizlik Değerlendirmesi

To “The Champ”

ACKNOWLEDGEMENTS

I would like to specially thank to my advisor Assist. Prof. Dr. Onur GÖLBAŞI from the Mining Engineering Department at METU for his support to my thesis and for his patience. I would like to thank him for his friendship, empathy, and a great sense of humor. His guidance helped me in all the time of research and writing of this research study.

Besides my advisor, I would like to thank the members of my thesis committee: Assoc. Prof. Dr. Mehmet Ali Hindistan and Assist. Prof. Dr. Mustafa Erkayaoğlu, for their encouragement, insightful comments, and contributions.

I am extremely grateful to my parents for their love, effort, and sacrifices to educate and prepare me for my future. I commemorate with love and longing my late dear father, whose advices are always in my ear and who always supported me and helped me come to these days. My mother and my sister have been extremely supportive of me throughout this entire process and have made countless sacrifices to help me get to this point. I would especially like to thank my dear and best friend, Elif Kına, for her perfect companionship, continued support, and encouragement. She was always with me during this whole process, and she will always be with me after that.

Finally, I would like to say thanks to my friends, Bora Kara, Sena Şenses, Şahin Furkan Şahiner, Göksu Tunç, Efe Kaan Tunç, Merve Ölmez Turan, and Birgül Çoban for their constant encouragement and support during my research work.

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INTRODUCTION

1.1 Background

Concrete is an essential product used to construct industrial and non-industrial buildings, such as households, buildings, factories, dams, and roadways. Concrete is ranked as the second in the list of consumable products in the world, after water (Gagg, 2014). It is estimated that 21 to 31 billion tonnes of concrete were consumed in 2006, while around 2.5 billion tonnes in 1950 (Cement Sustainability Initiative, 2009). Since cement is an essential substance in concrete production, there is a direct correlation between concrete and cement consumption rates. Variation in cement demand in the global market can be observed in Figure 1.1. According to the projection data given, an ascending trend in the total cement demand is expected in the following years. Therefore, a sustainable cement supply chain should be ensured to meet the construction industry's requirements in the near future.

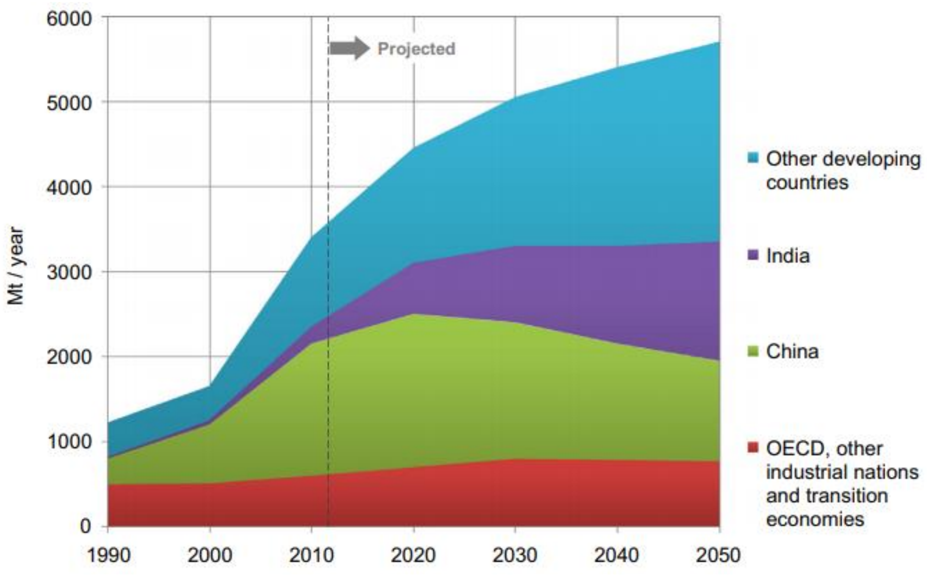

Figure 1.1 Global Cement Demand by Region and Country (Imbabi *et al*., 2013)

Cement is used as the primary binding agent in concrete material. It is important to mix the raw materials properly to ensure the strength and durability of concrete according to its class. Concrete production is achieved by mixing the paste, which combines water and cement with sand and rock materials to be bound and hardened. Concrete can be characterized according to paste quality, the ratio between water and cement. If this ratio is lowered, then a high-quality concrete is produced or vice versa. However, the reduction in the water/cement ratio can cause problems in the concrete workability, so that some chemical additives are used in the mixture to improve the strength and workability. By adding these additives, the water requirement in the mix is reduced where the durability is ensured.

Production of the concrete is a physical process carried out in the batching plants located close to potential customer destinations. After the process, the material is called ready mixed concrete (RMC), and the material distribution between the plants and customers is achieved using truck-mixers. At this point, transportation time just after loading the mixed material is so critical that the delivery should be completed as soon as possible, not to induce any material hardening. Therefore, transportation time can, which is limited to 2 hours maximum where the material loses its homogeneity and starts to be hardened after that time, should be considered the most critical constraint in the distribution operations. Concrete demand is received from the destinations, generally in the accommodation area where a high traffic intensity and traffic congestions are observed frequently. On this basis, the hauling operation period in a day and the available traffic conditions have an observable effect on the extension of hauling time. Each batching plant's service area is restricted for certain regions to mitigate the probability of material hardening during transportation. At this point, concrete companies locate different batching plants in a city so that maximum material hauling time is not violated. Besides, there may be multiple service areas of other concrete companies for the regions where a high demand rate is observed. The ready mixed concrete market is highly competitive with multiple suppliers, and these suppliers should decrease the product price to dominate the market. Therefore, the profit margin of concrete sales is highly low such that the customers may procure high-quality concrete at very affordable prices. Due to high competition in the market, companies may improve the profitability only by decreasing the operating cost since revenue per unit sales cannot be increased enough. In this sense, cost items arising from raw materials, whose weights vary depending on concrete class, and transportation operations are the major factors to be improved practically.

Good quality concrete needs proper mixing, and a precise quantity of raw material should be used. The proper mixing process relies on good coordination of feeding order and feeding time. Each concrete class, which determines the concrete's strength, requires different recipes in which feeding orders of raw materials, feeding, and mixing times are indicated. If the mixing time is reduced, then concrete quality is observed to be decreased. On the other side, an increase in mixing time improves product quality but may lead to financial loss due to time restrictions. Besides, the slow mixing process may cause an adverse effect on the daily production amount. Therefore, applying a proper production recipe for a concrete type is a significant factor to produce good quality concrete in optimal time.

The raw material is another important parameter in concrete production. Since the concrete production process is a single-stage process, a physical mixture of materials, the product's quality is seriously affected by the raw materials. At this point, four primary raw materials are cement, water, aggregate, and sand, are used in concrete production. Cement is combined with water and creates the paste between the aggregate and holds the aggregate together. Sand is used to filling the concrete gaps and reduce the air amount in the material to improve concrete strength. Although cement leads to only 11 percent of the concrete by volume, it is still the mixture's primary cost. Therefore, a good quality aggregate or sand reduces the cement content in one unit of concrete and the raw material cost.

Following concrete production, it is transferred to truck-mixers for the distribution operations. There are two main constraints for hauling operations that are hauling time and speed limitations. As mentioned previously, hauling time can cause an observable issue since the transportation of material from batching plants to order points is generally achieved using an urban road network. There are some speed limitations determined by the state that are applicable to truck-mixers. Thus, both traffic intensity and speed limits may set a robust constraint for achieving a hauling process without concrete material hardening. In addition, maximum loads that can be carried for vehicles are stated by the laws, and periodic inspections are performed continuously by the state authorities. The main factor influential in load limit is the equipment specification, i.e. truck's axle number.

In some cases, truck-mixers have physical capacities higher than the legal load capacity. Therefore, the transportation process is managed in such a way that each vehicle is not loaded more than the allowable limits to avoid penalties. In these conditions, the number of cycles per truck or truck numbers used in operation is increased to provide the total concrete demand. These cases increase fuel consumption per unit of material hauled and cause a jump in the total transportation cost, which is the major cost item in material transportation. Therefore, the profitability of concrete production and distribution operations can be enhanced by properly matching demand and supply points and reducing fuel consumption rates depending on payload.

1.2 Problem Statement

The marginal profit rate is very low in concrete production and distribution operations, reducing to 1,82% in US market (Macrotrends, 2021). In some cases, companies hold performing operations not to lose that market share even though sales revenue cannot compensate for the total cost. Therefore, concrete companies must monitor the details of operations very carefully and look for some solutions to improve profitability, which can be either increasing revenue or decreasing cost. Since the concrete market is highly competitive with multiple companies even in the same region, concrete revenue is tough to be improved since the concrete price is kept almost stable not to lose market share. Therefore, the only practical way of improving profitability in the current concrete market condition is to decrease production and transportation costs.

Various fixed and variable costs contribute to the total cost of one unit of concrete by volume. When the cost items are examined, raw materials and transportation costs, including equipment and fuel, dominate the total cost. These items show a remarkable variation depending on the supply chain operations of each batching plant. Raw material costs of the same concrete recipes may change for the plants in the same city. Therefore, a distance-based approach when matching the supplier plant and the order point cannot always be optimal since raw material may cost higher for the plant closer to the order point. At this point, a trade-off appears between these cost items and should regard the time restriction of the material hauling time. On this basis, periodic demand and supply fluctuations in the past operation are required to be evaluated together with the total cost variations to draw a conclusion for the future decision.

1.3 Objectives and Scopes of the Study

This study mainly intends to develop a Monte Carlo simulation model to evaluate the uncertainty in the profitability of a concrete company’s Ankara operations and check some potential solutions to decrease operational costs. Sub-objectives of the study are mentioned as follows:

i. Four batching plants of the company located in Ankara, Etimesgut, Temelli, Bilkent, and Batıkent Plants, are examined for their effective operational zones and the parameters contributing to the total cost.

ii. Production and distribution operations of Etimesgut Plant are examined in detail by investigating historic order amounts and cost correlations,

iii. Uncertainties are evaluated in a simulation environment to optimize the supply chain system by finding alternative solutions to minimize the company's operating cost and increase profitability.

Under the thesis's scope, a dataset of Etimesgut Plant operation that belongs to the first six-month of the year 2019 is used. This dataset covers 7,072 travels of the truck-mixers performed for 115 different order destinations. Besides, 55 different truck-mixers are included in the data where each truck-mixer is assumed to operate only for one batching plant. In addition to the Etimesgut Plant, the other plants are also incorporated into the analyses in terms of their priorities for the orders received by Etimesgut Plant. In the cost estimations, up-to-date raw material and transportation cost items are included.

1.4 Research Methodology

In this study, deterministic and stochastic approaches are used to evaluate the cost and profitability variation of the concrete production and distribution operations for a batching plant located in Ankara. Methodology steps, shown in Figure 1.2.

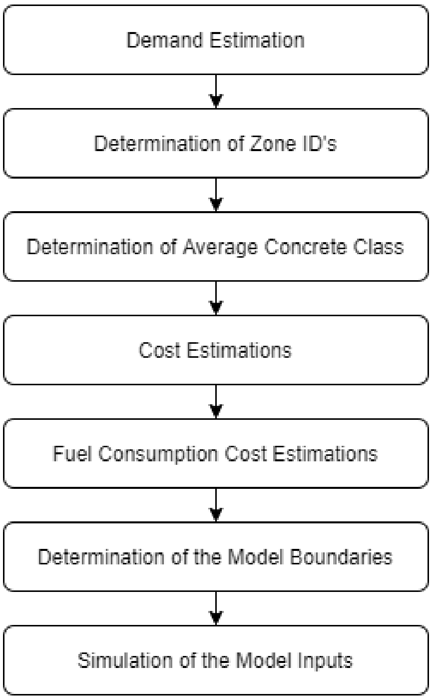

Figure 1.2 Flowchart of the Research Methodology

Methodology steps are discussed as follows:

i. Demand Estimation: Daily demand estimation is performed according to order locations and type and amount of the concrete to be ordered. The first six-month performance of the company in the year 2019 is regarded when forecasting the demand profile. Some distributions are used in the model to assign demand amounts randomly.

ii. Determination of Zone IDs: Each demand location is categorized under Zone IDs for individual batching plants. Zone ID is determined using the distance between the order points and the batching plants.

iii. Determination of Average Concrete Class: Each demand has its own specifications. Depending on the usage area, several types of concrete class can be supplied to the market. When an order is received, the required concrete class is produced in the supplier batching plant. The average concrete class is determined by taking the weighted average of the concrete classes produced in a plant throughout the observation period.

iv. Cost Estimation: For individual batching plants, raw material prices, variable and fixed costs are estimated considering transportation and raw material cost items varying for each plant and each concrete class.

v. Fuel Consumption Cost Estimation: There are 55 truck-mixers used in the operations. Each truck is registered to a batch plant. In terms of lt/km and lt/m^3, production and fuel consumption information are recorded separately for individual trucks and matched with the vehicle plate numbers. Therefore, fuel consumption cost can be estimated differently for distances between the plants and the order point regarding the vehicle and legislative capacity restrictions.

vi. Determination of the Model Boundaries: Several boundaries in the model are applied differently for each batching plant. One is the capacities since each batch plant has varying mixers capacities. Besides, retention times in production phases also show a variation according to the concrete classes. Another consideration is that operations are tried to be finalized within the shift hours to avoid overtime pay. Hauling time, which changes according to the supplier plant, is another parameter that should be limited to 2 hours for the traveling not to cause any material freezing in the vehicle. Therefore, traffic information of each zone should be a constraint that should be regarded according to the active hauling period in a day.

vii. Simulation Stage: Minimizing the total cost is achieved by developing alternative scenarios in the Monte Carlo simulation environment to provide the order demands more economically.

1.5 Expected Industrial Contributions

The study's main focus is to evaluate the uncertainties on production and distribution operations of concrete to derive alternative scenarios from improving the profitability. Since the concrete sector is characterized with low-profit margin, a small improvement in cost items may bring an observable benefit to the companies. In the study, raw material, transportation, and fuel costs of the operations are examined differently from the traditional way so that concrete demand is supplied from the plant with less operational costs. In the industry, this model can be used to reorganize available companies' distribution operations or locate the plants in the planning stages of companies gaining a place in the market.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This study investigates concrete production and distribution systems and offers some solutions, which may increase operational profitability. Since the concrete market is a competitive market with various available concrete suppliers, profitability depends more on cost values than price. Therefore, improving profitability relies on lowering operational costs. The current research study simulates a concrete batching plant's distribution network and seeks financial improvement opportunities in the hauling operations. In this sense, the literature review presents a background for the study and discusses various related topics such as the lifecycle of concrete and its cost items, Monte Carlo Simulation, and supply chain systems.

2.2 Lifecycle of Concrete and Cost Factors

For a comprehensive evaluation of the contributing parameters in concrete production and distribution systems, the material's lifecycle needs to be discussed. This discussion will also allow revealing the effective cost parameters per unit volume of concrete.

2.2.1 Life Cycle of Concrete

A conventional lifecycle of concrete starts with supplying concrete raw material from different suppliers and finalizes after delivering the requested concrete to the customer. On this basis, the lifecycle of concrete can be examined in two sections, as shown in Figure 2.1, which are production and transportation.

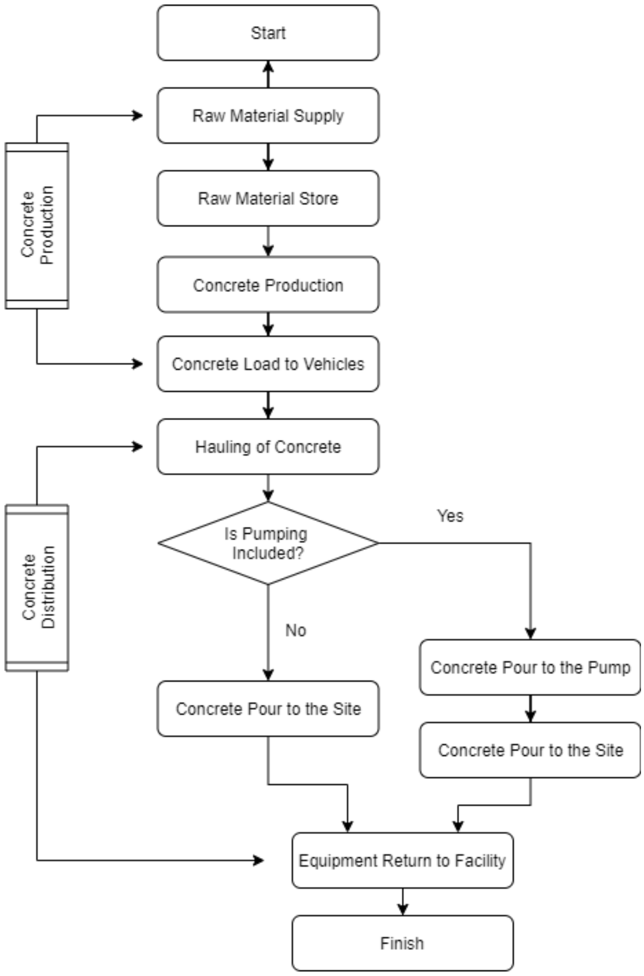

Figure 2.1 Lifecycle of Concrete

Producing concrete occurs in batching plants that are generally located close to residential zones or in a location where conveying concrete to residential zones by using the close road network is financially feasible. Just after supplying raw materials to be used in concrete production, they are stored in the facility. When any concrete order is received from a customer, raw materials are transferred to the batching plant's mixer. Once the mixing process is completed, where different amounts of raw materials are mixed for different concrete types, the material is transferred to truck-mixers. The concrete production stage is assumed to be completed when the truck-mixers start to move to the order's destination. Then, the distribution stage is activated. At this point, there are two operational possibilities in the concrete distribution. When the customer demands an additional pumping service, then the concrete material is poured into the pumps at the final destination point and pumped to the workspace. Suppose there is no demand for the concrete company's pumping process, or the customer will perform its own pumping operation. In that case, concrete is poured into an area following the demander's guidance. The distribution stage is finalized when the truck-mixers arrive back at the plant.

The concrete production process is a fast and physical process where raw materials, cement, aggregate, natural sand, slag, fly ash, water, and some chemicals, are mixed homogeneously in the batch plants. Raw material content shows a variation in producing a desired concrete class, which specifies the concrete strength. The formula of each concrete type, which considers the amounts and types of raw materials to be used, is constrained by some particular standards stated in TR EN 206 Concrete - Specification, Performance, Production, and Conformity. A homogeneous mixture of cement, coarse and fine aggregates and water should be ensured in concrete production. Each raw material has a particular function in concrete. A major portion of concrete is occupied by a mixture of water and cement, acting as a binder to keep aggregate together. The aggregate part covers both coarse and fine materials where coarser aggregate acts as cementer and finer aggregate fill the mass' void. Chemical admixtures ensure some specifications, such as mobility, quick set, durability, or water resistance. Halepciuc (2017) states that some mineral additives such as furnace slag and fly ash can be used as binders in concrete production. These additives enable improving concrete strength, reducing permeability, and leveling down the water requirement. Besides, using mineral additives alternative to the cement has the potential to decrease the raw material cost in concrete operation. (Adesina & Awoyera, 2019)

Aggregate and natural sand materials are stored in the bunkers located in the plants and hauled to the mixers by conveyor band. On the other hand, cement, slag, fly ash, and chemicals are stored in the silos. Whenever an order is requested, raw materials are conveyed to the mixer in a sequence with a specific period. Figure 2.2 illustrates the components of a batch plant and truck-mixer.

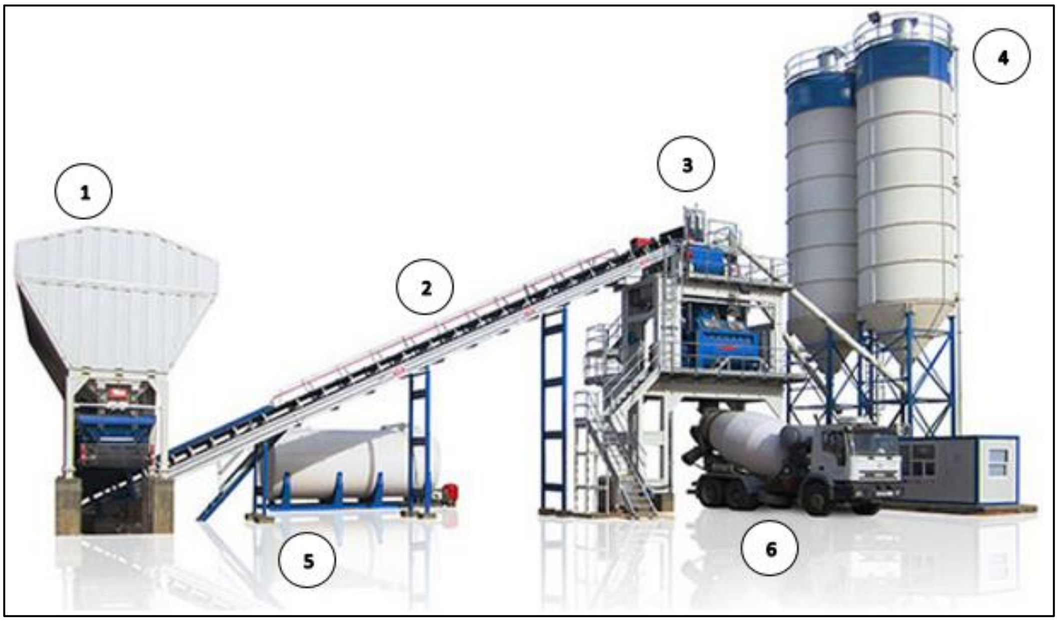

Figure 2.2 Components of a Batch Plant: Raw Material Bunker (1), Conveyor Belt (2), Mixer (3), Silos (4), Water Tank (5), and Truck-Mixer (6) (Mphahlele, 2017)

Truck-mixers hold varying capacities with 7, 8, 9, 10, 12, and 14 m^3. These capacities are important parameters in a concrete distribution system and lead to a fuel consumption conflict. When a significant number of orders are received from a customer, higher capacity truck-mixers will make less travel than lower ones; thus, the plant's total fuel consumption will decrease. However, when the capacity gets higher, the truck's payload will be higher, and the fuel consumption rate will be higher. This conflict must be examined well to improve the unit fuel consumption amounts of the plants.

When concrete is produced in a batch plant, there is a limited time before the concrete gets hardened. While truck-mixer travels, dumper swings around continuously, and the concrete flow in it. This movement protects the hardening of the concrete for about two hours. After two hours, the dumper rotation will not be enough to sustain the liquidity. At this point, a manual intervention, which is adding chemical admixture to concrete, is required. Truck-mixer operators perform this step carefully not to affect the concrete quality. Besides, hauling time limitations need to be evaluated well. There are two main constraints for the hauling time limitation, which are traffic and speed limitations. After truck-mixers are loaded in the batching plants, they start moving through the order point. Ready-Mix Concrete (RMC), i.e. batching, plants are located in the residential areas, so they travel on streets or avenues. On the weekdays, especially in starting and ending periods of the working hours, traffic volumes are higher on these roads. Traffic jams may cause delays in the hauling time. Also, since the residential roads are used in hauling, vehicle speeds are limited by the government's rules. These limitations may increase the travel time of the hauling operations. Thus, the concrete quality is affected by the hauling operations. When selecting the RMC plant to supply the concrete demand, hauling time is the most determinant factor.

As discussed, two types of orders can be received from the customers. The first one is the order without pumping service. In this type, only transportation of the concrete is met by the concrete company. When the concrete is hauled from the RMC plant to the order point, concrete is poured to the site at the customer point or the customer's pumping equipment. The second one is the order with the pumping service. In this order type, truck-mixers pour the concrete to the pumping equipment of the concrete company. In this type, pumping price is added to the concrete price, and the concrete company meets all expenses of the pumping operations.

There are two types of operations used in transportation that are company-owned operations and subcontracted operations. In company-owned operations, the concrete company meets all expenses related to labor, maintenance, and maintenance crew. In subcontracted operations, all operational cost items are in charge of the subcontractor. The operation type of the plant depends on its specifications. If a plant is expected to operate for an extended period, a company-own transportation system can be preferred since capital investment will be recovered through the years. On the other hand, subcontracted operations can be preferred. Also, the plant profitability is an important parameter for deciding the transportation type. If the plant’s financial conditions can compensate for the transportation equipment's capital investment, company-owned operations can be preferred regardless of the operating life. These decision parameters and their triggering factors will be discussed in detail in Section 3.3.

2.2.2 Cost Factors

The cost of a unit volume of concrete is affected by the decisions in the production and distribution stages. The cost factors should be examined well to develop a holistic evaluation for improving operational profitability. In the production stage, raw material cost dominates the primary part of the expenses. Different amounts of raw materials are used concerning the ordered concrete type. Even though alternative raw materials such as fly ash or slag can be used instead of cement or coarse aggregate can be substituted with recycled aggregate (Shaker *et al.*, 2020), cement and coarse aggregate are still used commonly for logistic and capacity concerns. Alternative materials have the potential to decrease the cost of unit concrete production.

On the other hand, vehicle, fuel, maintenance, and personnel-related cost factors vary depending on the type of transportation system used by the batching plant. In brief, the concrete orders' raw material types and costs, ownership of the transportation systems, truck-mixer models and capacities, and the routes between the production points and demand zones are highly different for each plant. These variations change the operating costs of plants. The cost factors effective throughout the life cycle of concrete can be examined in Table 2.1. These factors are grouped into two main cost analysis categories, which are production and transportation.

Table 2.1 *Cost Factors Effective in Concrete Lifecycle*

Raw Material Cost	Raw Material Items	Cement
		Fly Ash
		Slag
		Sand
		Natural Sand
		Aggregate
		Chemicals

Table 2.1 *Cost Factors Effective in Concrete Lifecycle (continued)*

Total Production Cost	Variable Items	Overtime Maintenance Loader Waste Concrete & Waste Aggregate Temporary Work Other Production Cost
	Fixed Items	Worker Loader Depreciation Other
Total Transportation Cost	Variable Items	Overtime Maintenance Fuel Temporary Work Other Transportation Cost Subcontracted Transportation
	Fixed Items	Worker Depreciation Other

2.2.2.1 Raw Material Cost

In concrete operations, the highest share in operational cost is occupied by the raw materials. Cement, fly ash, slag, sand, natural sand, aggregate, and chemicals are the main raw materials used in concrete production. At this point, the usage of materials like fly ash, slag, or natural sand can show regional variations. A different type of material used in the mixture changes unit raw material cost. In this sense, two main parameters directly affect the raw material cost: raw material prices and concrete formulas.

There are multiple raw material suppliers available in the market. Each supplier has different prices and different qualities for the same raw material. This situation affects the unit cost so that RMC plants generally refers to collaborate with different suppliers depending on their locations and unit raw material cost since the distance between the raw material suppliers and the plants may change the raw material price.

As mentioned in Section 2.2.1, concrete formulas are specified by the standards. These standards basically indicate the minimum and maximum strength levels of the concrete classes. On this basis, the concrete's final strength should satisfy the values on the 28th day after pouring. Its strength determines a concrete class, and the limit strength values are ensured by different mixture formulas. Within the standard limitations, concrete companies should design the concrete formulas by changing raw material proportions in a unit concrete volume. When the concrete class gets higher, binder content and chemical admixture content are improved proportionally.

2.2.2.2 Production Cost

Concrete production is carried out in batching plants. Expenses related to production operations, excluding raw materials, are examined under production cost. This cost type covers the costs of personnel working in production operations, equipment maintenance, removal costs of waste aggregate and concrete, and equipment depreciation. Production cost items can be classified under fixed and variable cost parameters.

Variable costs depend on the concrete production amount. When concrete production increase, these expenses tend to raise. For example, if the customer operates out of the shift time, the concrete company should pay overtime wage to sustain the production. Loaders also create variable expenses such as maintenance and fuel since aggregate, natural sand, and sand stored in the stockpiles are fed into the bunkers by loaders. Maintenance and spare part costs of the production equipment, such as bunker, belt conveyors, silos, mixer, and batching plant parts, are also examined under production maintenance cost.

On the other hand, fixed production cost items are not directly correlated with short-term concrete production but affect total production cost. For instance, regular wages of personnel employed in production operations and the loader operator wages are generally continuously paid each month. These monthly-basis constant expenses, equipment depreciation, and other production-related expenses are examined under the fixed production cost.

2.2.2.3 Transportation Cost

Transporation-related cost items show a variation depending on the vehicle ownership condition. Capital investment and depreciation of the equipment, wages of drivers, and equipment maintenance should be regarded in company-owned operations. In contrast, subcontractors in subcontracted operations meet all the vehicle-related expenses.

As mentioned briefly in Table 2.1, transportation costs can be handled in the fixed and variable cost groups. Overtime payment, maintenance cost, fuel cost, other transportation-related costs, and subcontractor cost are examined under variable transportation cost. These costs are directly related to the amount of concrete hauled. On the other hand, personnel cost, depreciation, and other constant expenses independent of the amount of concrete hauled are examined under fixed production cost. Since personnel cost and depreciation expenses are met by the concrete company in company-owned operations, the fixed transportation cost portion is expected to be higher than the variable transportation cost. In the subcontracted ownership, the variable transportation cost portion will dominate more in total production cost. Transportation cost in concrete operations occupies almost 70% of total operations cost (OYAK Concrete Company, 2019). At this point, fuel cost is observed to be half of the transportation cost. The fuel consumption rate of a mixer depends on various parameters. Length of roads, road gradients, road conditions, and vehicle speed may increase or decrease the fuel consumption rates (Kecojevic & Komljenovic, 2010). Besides, the idling time accelerates the vehicle fuel consumption rates (Parreira, 2013). Therefore, any decision on which batching plant will supply an ordered concrete is remarkably affected by traffic and distance-related concerns that may change the fuel consumption rate of the unit volume of concrete.

2.3 Monte Carlo Simulation

The current study evaluates the uncertainty in a concrete company's transportation operations and tries to optimize the distribution system parameters by using Monte Carlo simulation. As mentioned in Section 2.2, several factors affect the profitability of concrete operations. These factors induce different cost amounts in different batch plants and result in changeable operating costs. Therefore, production and transportation cost parameters should be assessed carefully to improve profitability. Fuel cost occupies a significant part of the total transportation cost and is directly related to the distance between the batch plant and the order destination. The current research seeks different alternatives in the concrete demand-supply network, dynamically renewed in different periods and zones between ready-mix concrete (RMC) plants and destinations, to increase operational profitability. In this sense, the Monte Carlo simulation was used to highlight the operational uncertainties.

Monte Carlo simulation is a simulation technique where a system's stochastic behavior is revealed by using random variables to derive all potential outcomes. Mathematical models can be used to show the interactions within a system. The models generally depend on an input parameter computed with the mathematical model and give one or more outputs. The generation of input parameters relies on statistical distributions. For each set of input parameters, a different set of output parameters are obtained. For each simulation run, outcomes are stored, and statistical analyses are done to evaluated outcome sets (Raychaudhuri, 2008).

Various external factors affect input parameters. Systematic variations can be observed in input parameters due to these factors. The developed mathematical model can be computed using deterministic values to create a base case to avoid risk of variation. In the base case, the input parameters are the most likely values. To check the model's effectiveness, the best and worst cases can be used, which are the best and worst scenarios of the input variable values.

Identifying input parameters is an important step in the Monte Carlo Simulation. When historical data is available, distribution can be determined with numerical methods by fitting the data to one theoretical discrete or continuous distribution. Distribution fitting methods, such as Method of Maximum Likelihood, Method of Moments, and Nonlinear Optimization, can be used in detecting the best-fit distribution for the given dataset. Besides, the Chi-square test and EDF (Empirical Distribution Function) Statistics can be used to measure the goodness-of-fit values. There are two types of distributions. One of them is discrete probability distributions, such as binomial distribution, Poisson distribution, and hypergeometric distribution. In this type, the variables are discrete values. The other one is continuous probability distributions, where the random variables are continuous values. The normal distribution, exponential distributions, and gamma distributions are examples of this type. By using these distributions, random numbers can be generated by Random Number Generators (RNG). A generator is a computational or physical device used for generating independent numbers from statistical distributions (Raychaudhuri, 2008).

Statistical analysis must be performed for the output sets after introducing input parameters to a simulation model, and simulation runs are completed. At this point, the frequency histogram, i.e. frequency graph, is used to obtain the probability density function (PDF) of the results. Then, the theoretical statistical parameters of the distribution can be calculated. For instance, any normal distribution PDF capture information about the mean, median, standard deviation, variance, and min. and max. values of the dataset.

There are various areas where Monte Carlo Simulation methods are applied effectively. Monte Carlo Simulation is used extensively in financial analysis to evaluate alternative options, the net present value of the projects, portfolio, option, or personal financial planning. Besides, Monte Carlo Simulation is generally embedded in the models related to reliability analysis, six sigma strategies, statistical physics, and engineering areas with uncertainty. In brief, this simulation technique is a very useful mathematical method for solving and analyzing uncertain scenarios.

There are some research studies in the literature investigating supply chain management systems with Monte Carlo Simulation. Fabianova *et al.* (2019) used two approaches, which are ARIMA (Auto-Regressive Integrated Moving Average) and MAPE (Mean Absolute Percent Error). The Monte Carlo Simulation method was used in the MAPE approach for demand forecasting and production planning in a single production line. Wang *et al.* (2019) used Monte Carlo in demand-side management of supply chain systems. In the study, demand, production, and inventory uncertainties were effective in the refined products supply chain. Weak points in the supply chain system were evaluated in the model for different demand, production, refinery disruption, and pipeline interruption levels.

Farsi and Zio (2020) investigated the effects of load-sharing dependence, adaptive control with feedback, and a supporting system's economic dependence by using the Monte Carlo model. In a study by Bhosale and Pawar (2020), production planning and scheduling problems were solved with a mathematical model so as to decrease operational expenses. In the model, a soap manufacturing industry was examined, and the demand values were generated by using Monte Carlo simulation.

Zhou and Liu (2019) investigated proactive preventive maintenance strategies. By using Monte Carlo Simulation, the impacts of different maintenance thresholds on the energy efficiency are investigated. Similarly, Cheng and Li (2020) examined the production, maintenance, and quality control of a serial-parallel multistage system. The correlation between production planning and maintenance policies was evaluated to reveal the effect of maintenance policies on production quality. In the study, the Monte Carlo Simulation model is used to find out production run, quality control-thresholds, and maintenance threshold where the cost rate is minimum.

Wang and Lin (2013) analyzed vehicle routing problem with stochastic travel times. Monte Carlo simulation algorithms were used to determine the cost and reliability of different scenarios. In the model, vehicles are operating with their actual maximum vehicle working time to use the time surplus of the vehicle. Also, the stochastic travel times are limited with the maximum working times of the vehicles. La Scalia *et al.*

(2019) examined warehousing operations of a food supply chain. The deterioration level of the products was correlated with inventory storage conditions. In the study, a Monte Carlo Simulation model is used to implement shelf life-based picking policy and pricing strategy.

In the current study, the simulation model relies on a financial conflict from the variety in raw material, truck-mixer, and fuel cost items for different plants. Even though transportation cost seems to be lower for some plants close to the order destinations, they may cause higher raw material costs if they prove raw materials from suppliers in more distant points comparatively. Second, concrete demand amounts, available capacities of plants in the order times, the plant's active zone, and average concrete class are also effective in the distribution system's decision process. Therefore, system profitability can be evaluated by including the dynamic interactions of these parameters in a time horizon, using a simulation tool capable of expressing production and distribution-related uncertainties.

2.4 Supply Chain Model

In a supply chain system, a network is constructed to combine the locations to process and transform raw materials into intermediate and finished products and distribute these products to customers at pre-specified order destinations. There are four essential components in a conventional supply chain system: suppliers, production sites, storage facilities, and customers. Two basic operations are performed in these systems (Tsiakis *et al.*, 2001): The first one is the production planning and inventory control process related to manufacturing and storage. On the other hand, the other operation is related to the distribution and logistics operations, which determine how products are transported from the production sites to retailers.

In other words, a supply chain can be described as material flow between the companies. In general, more than one company will be located in this material flow, which can be either raw material and component producers, product assemblers, wholesalers, retailer merchants, and transportation companies. Also, supply chain operations can be summarized as a system that firms bring products or services to the market (Mantzer *et al.*, 2001).

There are three types of channel relationships in a supply chain: Direct Supply Chain, Extended Supply Chain, and Ultimate Supply Chain, as illustrated in Figure 2.3. In the direct supply chain, all operations, such as upstream and downstream of the products, services, finances, are performed by the company, supplier, and customer. In the extended supply chain, the chain's supplier and customer sides may have more than one stage, and all media are involved in all operations. In an ultimate supply chain, all organizations are located in the operations (Mantzer *et al.*, 2001).

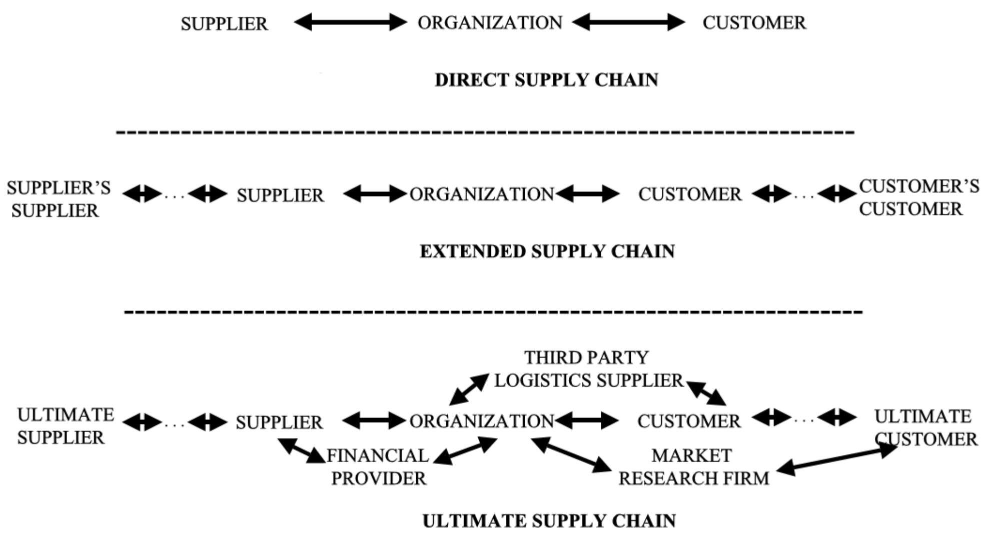

Figure 2.3 Types of Channel Relationship in a Supply Chain System (Mantzer *et al.*, 2001)

Characterization of each supply chain system is started by defining the potential supplier(s) capable of producing and/or providing raw materials, intermediate products, and/or final products. In the raw material market, there is generally more than one supplier for each material type. These companies provide raw materials to the manufacturing/production companies where intermediate and/or final product is achieved. A company that orders raw materials from the market in a demander position becomes a supplier once raw materials are processed in its production facilities to be served as an intermediate or final product. In this phase, raw materials need safe storage. How they will be stored can be changeable according to the material types. After the production stage, final products may be stored in warehouses or small distribution centers or directly distributed to the customers. Warehouses may be built as a shared area by multiple companies and may include different types of products. The storage and handling capacities of warehouses and distribution centers are limited with certain bounds. Profile of customers constitutes the ultimate and the most critical part of a supply chain system with a varying demand capacity, destination point, and demand type. Each customer can be supplied by a single or multiple distribution centers. Components of a conventional supply chain system can be viewed in Figure 2.4.

Figure 2.4 Supply Chain Flow Chart

Especially, large-scale supply chain operations are complex systems due to massive physical production and distribution network flows, uncertainties associated with the external customer and supplier interfaces, and nonlinear dynamics associated with the internal information flows. In competitive market conditions, the supply chain system's effectiveness can be improved by minimizing costs, delivery delays, inventories, and investment or maximizing deliveries, profit, return on investment (ROI), customer service level, and production. The system tasks involve strategic and operational decisions for a time horizon ranging from several years down to a few hours, respectively. At this point, the main factors that are effective in the decisions on a supply chain system from the perspective of supplier can be listed as follows (Tsiakis *et al.*, 2001):

i. Locations of production plants, warehouses, and distribution centers

ii. Production planning and scheduling for each plant

iii. Inventory level decisions

iv. Capacities and types of hauling vehicles used

Products are distributed through some warehouses and distribution centers with complex distribution network flow. These warehouses or distribution centers other than production factories are called an echelon. Single or multi-echelon systems are applied depending on the complexity and range of the distribution.

A single-echelon inventory system contains a single distribution center between the inventory of the supplier and the customer. In a single-echelon network, this individual material-location combination is not affected by any other material or location. On the other hand, a multi-echelon inventory system contains supplier layers where multiple distribution centers are employed with an outsourced manufacturer. In such a system, new inventory shipments are first stored at a central or regional distribution center. Multi-echelon inventory optimization across the entire supply chain considers the complex interdependencies between stages, as well as variables that cause chronic excess inventory, such as long lead times, demand uncertainty, and supply volatility (Multi-Echelon Inventory Optimization, 2014).

When an inventory optimization for each component in the distribution network is performed without regarding other networks or effective zone of the supply chain, individual warehouses may expose to excessive storage more than required or underestimated storage policy so that these conditions lead to redundant storage cost and unsatisfied demand amounts, respectively. Multi-echelon problems inquire if it is more cost-effective to store stock at the beginning of the supply chain or towards the end of the supply chain, closer to the customer. The concept enables to analyze the variety in inventory configurations to determine the optimal stock situation. Thus, the distribution network may show a better response to customer demands with improved flexibility. Furthermore, through reducing inventory levels, capital usually tied into redundant stock can be freed up and reinvested. Multi-echelon optimization offers an innovative approach for enterprises to manage network-wide inventory planning more effectively (Horn, 2013).

There are various examples of multi-echelon systems observed in the literature. In this sense, Rau *et al.* (2003) worked on a multi-echelon inventory model to define dependencies between suppliers, producers, and consumers in a market. Jain and Raghavan (2008) constructed a single warehouse model where inventory levels were analyzed to minimize the operational cost. You and Grossmann (2010) examined inventory models with uncertain demand conditions where demands were categorized with their zonal information.

Various literature studies have concentrated mainly on concrete supply chain problems. Park *et al.* (2010) developed a dynamic simulation model to analyze the time and cost-effectiveness of the concrete supplying systems. In the study, the RMC supply process was analyzed for different parameters and different operational conditions. The analyses focused on the distribution systems in the supply operations, such as truck-mixer dispatching interval and queuing time on-site. The study results indicate that the developed model positively affects the operation's economy by maintaining the number of queuing truck-mixers at the desired level while meeting the customer’s needs.

Tommelein and Li (1999) examined a supply chain system problem to reveal the differences between traditional and lean production processes. The concepts of just-in-time production systems were included. At this point, concrete is a perishable material and needs to be produced upon customer order. Therefore, the concrete supply chain process, as a good example of the just-in-time process, was investigated in the study.

Naso *et al.* (2005) discussed just-in-time production stages to evaluate production and distribution systems' coordination. Due to its time-dependency, concrete operations were considered in the study as a hybrid combination of production, scheduling, and routing problems. The tradeoffs between the potential risks and benefits were analyzed. A new meta-heuristic approach based on a hybrid genetic algorithm combined with constructive heuristics is proposed in the model.

2.5 Summary

This chapter first gives some background information to highlight the effective parameters of concrete production and distribution systems. Then, Monte Carlo Simulation, used in the current study to discuss the uncertainties of concrete operations, was mentioned briefly. Since the concrete operations are good examples of just-in-time supply chain systems and observably affected by the coordination between demand and supply points in terms of profitability, a brief theoretical knowledge and some particular studies about the supply chain systems were also provided.

CHAPTER 3

MODEL DEVELOPMENT

3.1 Introduction

This study intends inquire alternative scenarios for a concrete distribution system by i) evaluating the uncertainties in demand supply, concrete type and cost, and ii) trying to decrease the operational cost of unit concrete production and distribution, using Monte Carlo Simulation. The model generated in the study uses the dataset of a concrete company, which belongs its active operations in Ankara, Turkey. On this basis, the company has four batching plants located in Etimesgut, Batıkent, Bilkent, and Temelli. Different concrete ingredients are combined when the clients demand various concrete types with different technical abilities in Ankara. In the current research, Etimesgut batching plant is concentrated mainly for a better understanding and investigation of how orders can be re-scheduled by shifting the orders between the plants depending on the demand and supply chain's zonal priorities. This section discusses the development of the model via explaining its effective parameters and variables in detail.

3.2 A General Assessment of Concrete Transportation Systems

Significant parameters of the profitability valid in a concrete distribution operation are investigated in the study. A concrete distribution system is triggered first in batching plants where main concrete elements, such as cement, aggregate, water, and chemicals, are mixed in the mixers following a demand for a particular type of concrete with a definite amount is received. Raw materials required to prepare concrete are kept available in batch plants to cover any instant demand. On this basis, aggregate materials are stored in stockpiles where cement and chemicals are kept in silos, and water stored in the tank. According to a concrete class, a mixture process is carried with varying proportions of raw materials, takes one to two minutes to complete. Following the mixing process, concrete is loaded to truck-mixers and transported to the target destination. Concrete is a special mixture that cannot be stored and should be conveyed to the request location within two hours, just after the mixture time. If the available mix of concrete fails to be transported within two hours, it starts to freeze in truck-mixers and/or pumping systems. This condition leads to severe damage of truck-mixer components such that the pieces in contact with the frozen concrete cannot be recovered and should be replaced with new ones. Traffic conditions may have different characteristics depending on the active location and day time period of transportation from the batching plants to the order point. Therefore, it may be chaotic and challenging to overcome the two-hour time limitation of concrete in heavy traffic and congestion conditions. To facilitate the distribution network's practicality, the company utilizes a zonal priority index where each batching plant's influence area is divided into multiple sub-areas according to distance lengths (in km) from the order points. Besides, each batching plant's location is decided concerning the city's concrete demand configuration, including amounts, frequency, and locations of the demands for different concrete classes.

Raw materials to be used to prepare concrete are provided from the potential suppliers via trucks or cement trailer. There are multiple suppliers available in the market. Location, material price, material quality, and supply ability are the main effective parameters when deciding supplier(s), and materials supplied should meet the company's minimum standards. Each batching plant can collaborate with single or multiple suppliers. Material transportation is ensured by the supplier(s), and its cost is involved in purchase cost. In cases where a similar supplier provides similar raw materials for different batching plants, the unit cost of material may show a variation depending on the transportation cost affected by the distance between supplier and plant. This condition causes a variation in the production cost of concrete in different plants of the same city.

Transportation operation of the concrete is generally achieved in two ways. In the first alternative, the company performs transportation with its own means. In that case, the company employs its own human resource and truck-mixer fleet in the distribution network, and the company itself carries out truck-mixers maintenance. When choosing this option, transportation cost includes the cost items related to the driver, maintenance, general and administrative, and fuel. The other alternative requires a subcontractor in transportation operations to meet all the human resources, equipment, and maintenance requirements. The cost of this rent-a-fleet option is affected by the amount of concrete to be transported and fuel cost in the active distribution flow. Base rental cost is valued in terms of Local Monetary Unit (LMU)/m^3 and taken as constant for each truck-mixer type. However, the fuel cost of a truck-mixer may show a variation depending on the distance transported. According to the corporate decision, the company is allowed to employ a single subcontractor for each batching plant. At the same time, multiple subcontractors can be operated in the different batching plants of the city. In this renting alternative, transportation cost varies according to rental expenses that may change depending on subcontractors' offers.

In the concrete production and distribution system, transportation cost is detected to occupy 70% of the total operating cost, where 50% of this cost item is caused by fuel cost alone (OYAK Concrete Company, 2019). The operational reliability of truck-mixers leads to fluctuations in the cost and availability values, depending on truck-mixer components' wear and tear behaviors. Therefore, up-time and down-time profiles of this equipment and any variation in the operating cost of unit material haulage are effective when deciding among two transportation alternatives. If the equipment is at its early ages without any indication of deterioration and/or if the equipment is well-maintained and operated properly by drivers, fuel consumption per unit material is expected to drop. On the other side, any deteriorated equipment is expected to cause a jump in maintenance and fuel costs, together with decreased operational availability. These aspects help to decide on whether subcontractors or company-own resources should perform transportation operations.

Independently of transportation type in charge of material distribution, the company applies zonal priority information when deciding on which amount of concrete will be supplied from which batching plant for a demander in a specific coordinate. On this basis, transportation distance between each plant site and order point is categorized into twelve different classes, as shown in Table 3.1.

Table 3.1 *Zonal Priorities of Supply System for the Batching Plants*

Zone ID	**One Way Travel Distance (km)**
Zone 1	1-5
Zone 2	5-10
Zone 3	10-15
Zone 4	15-20
Zone 5	20-25
Zone 6	25-30
Zone 7	30-35
Zone 8	35-40
Zone 9	40-45
Zone 10	45-50
Zone 11	50-60
Zone 12	>60

Assuming that a purchase request for a specific amount of a particular concrete class is activated at the order point B. In that case, a one-way distance between the order point and the batching plants is calculated. For instance, if the assigned truck-mixer at Plant B should convey concrete material for 12 km, then Plant B's order point is categorized in Zone 3. Therefore, all the related cost estimations are carried out after matching order points and batching plants. The concrete to be delivered is priced accordingly. In cases where demand is not supplied from a batching plant with a higher priority, a partial or complete delivery can be achieved from the other batching plant with a less zonal priority, i.e. higher Zone ID. With the increase of Zone ID, transportation costs and the resultant concrete price are expected to be higher. In some cases, the difference between the increasing prices and costs, i.e. profit, may also show an upward trend. It means that an increase in transportation cost does not always imply a negative condition and may also increase the profit margin.

This study analyzes and evaluates the conflict resulting from the variation in operating costs and concrete prices of different batching plants and other concrete classes. Each class requires a mixture of varying raw materials in particular weights. On this point, not just transportation cost differs depending on the distance of delivery, but also the unit cost of raw materials stored in each batching plant differs from the other plants since raw materials are supplied from varying distances with different subcontracting and company-owned transportation systems. These uncertainties are analyzed in the study using the Monte Carlo Simulation method so that profitability and performance ranges of a batching plant in a predetermined time interval can be interpreted considering dynamic decisions on operational cost, the production amount of concrete with different classes, and concrete price.

As discussed previously, the company holds four batching plants in Ankara that are located in the districts of Etimesgut, Batıkent, Temelli, and Bilkent. The current study will concentrate mainly on the operations of the Etimesgut plant. Under normal circumstances, each plant operates dominantly in its own district. Besides, multiple plants can supply concrete for the same order point if traffic intensity and distribution limitations are appropriate for such a joint operation. Zone information is evaluated and compared whenever an order is activated. Herein, even though a decrease in the priority may increase both transportation cost and concrete price, profit and profit margin may show a contradiction in some cases. For instance, in a case where Bilkent and Etimesgut Plants are referred to be Zone 3 and Zone 4 for an order point, assume that transportation costs and concrete prices will be 100 and 104, and 150 and 160, respectively (OYAK Concrete Company, 2019). For such a condition, the Etimesgut plant can be called the leading supplier since it offers a higher profit. This type of uncertainties in both location, amount and concrete class of order, and operating cost and concrete price of each batching plant cause an increase of gap in the optimality of demand and supply decisions. A specific discussion on these factors will be performed at Section 4.

For a detailed evaluation of the uncertainty, the model is computed for both the real case, in which the dataset is generated using the company's ongoing and past operations, and the potential instances in which supply decisions may show a variation. The first computation of the model intends to verify the model by comparing the model outputs with the real operational dataset. The second computation aims to perform an analysis in cases such that orders are evaluated considering only zonal information. In this way, variability in demand and supply amounts and validity of the zonal priority policy will be discussed considering significant decision parameters such as fuel cost, raw material cost, total operating cost, demand and capacity constraints, transportation type, transportation time constraint, and class type of concrete. These parameters will be mentioned in detail in Section 3.3.

3.3 Cost and Operational Parameters of the Concrete Distribution System

For a better understanding of uncertainty in the concrete distribution network, effective parameters related to concrete production and distribution operations need to be discussed. On this basis, several parameters have a direct influence on the total cost and especially trigger the variation in cost items related to raw material and transportation. These parameters can be different for each plant so that unit production and transportation costs will not be the same for the batching plants. Although the production cost of concrete in the plant sites is more predictable, any shift from one plant to another as the main supplier can be more complicated in terms of transportation cost, profit margin, plant capacity, and transportation time. Therefore, the current section will focus more on the major parameters considered in the distribution decisions. The data acquisition process related to these parameters will be discussed in Sections 4.1 and 4.2.

3.3.1 Seasonal Effect

Weather conditions caused by seasonal changes have an observable effect on the construction sector and determine the market demand for concrete accordingly. In rainy and cold seasons, concrete demand is detected to have a decreasing trend by 30% (OYAK Concrete Company, 2019). Besides, ambient temperature affects fuel consumption per unit of concrete hauled. Any decrease in temperature causes a higher fuel consumption and fuel cost such that this variation is also observable in the company records. The first half of a production year, where cold and rainy weather conditions are dominant in its first and second quarters, has a foreseeable and smooth demand rate. On the other hand, the second half has a more nonlinear and unsteady demand rate since construction works and concrete demand have an ascending trend in the third quarter but a remarkable drop in the fourth quarter. The first half operations of the Year 2019 is considered in the current study and will be discussed in Section 4.2.

3.3.2 Transportation and Auxiliary Services

In a concrete distribution system, transportation service is provided by the company, and its cost is included in the concrete price. In some cases, upon request of the demander, pumping service can also be provided with the transportation service. In these conditions, some extra fee is charged for handling and utilization of portable pumps. Mobile pumps are operated with fuel as an energy source and consume a severe amount of fuel. Therefore, this additional expense of fuel consumption is also regarded in the pricing phase. As discussed in Section 3.2, transportation service can be achieved by company-owned or subcontractor truck-mixers. This condition is also valid for pumping service so that subcontractor will ensure any mobile pump request by the demander if this option is available in that batching plant. The pricing of mobile pumps shows a variety depending on boom length. If a portable pump with a 37 m or 52 m boom length is provided for the pumping service and their rental fees will be charged differently even though the total amount of concrete to be pumped is the same. In addition, the fuel consumption rate of each portable pump type is not identical. Since pumping service is optional and has an extra fee apart from the concrete price, the company evaluates the operational and financial KPIs (Key

Performance Indicators) of transportation and pumping services separately. Since pumping service is not expected to affect the uncertainty in demand and supply fluctuation of the batching plants, it is neglected in the current study.

3.3.3 Daily Demand

The construction sector is the primary motivator of concrete production and dominates the demand rate in the market. Construction works can be performed by either the public or private sectors and cover a broad range of projects such as building construction, road construction, landscape activities, and dam construction. Since concrete is not a storable material due to its freezing behavior, in-place usage of concrete should be carried out soon after its production and distribution. Therefore, the daily demand for concrete directly relies on work intensity in the construction market. In improper weather conditions, which can be due to heavy rain or snow, the concrete demand rate tends to decrease. On this basis, January and February months are expected to reduce demand by 30% compared to the average of the first half of the year.

As mentioned in Section 3.3.1, the current study considered the first six months' concrete production data in 2019. The data acquired for the given time interval will be characterized using a distribution, and the daily demand amounts will be generated randomly in a simulation program.

3.3.4 Average Zone

Since concrete transportation is exposed to a time constraint, each plant's practical service areas are limited and numbered with particular Zonal IDs. The average Zone ID of a plant refers to the average of its service areas in terms of zonal information. Various variables such as rental costs of truck-mixer and fuel consumption rates are evaluated considering the order point's zonal ID concerning the supplier plant. Once a new order is received, an authorized person at the plant estimated the distance between the plant and order point and decides whether the order can be fulfilled, concentrating mainly on distance, travel time, and available haulage capacity.

Hauling time and hauling distance between order points and batching plants are time-dependent variables that can change depending on traffic conditions. Concrete produced and loaded to a truck-mixer may stay in the equipment container for less than two hours without losing its liquidity. Therefore, hauling time is one of the most influential parameters in determining proper distribution network routes. On this basis, traffic congestion, speed limitations in urban or rural traffic for truck-mixers, and queueing time in a construction site should be regarded when estimating total travel time. Since travel of these heavy-duty vehicles is constrained by regulations, service areas of batching plants are limited. If a plant is located near a residential area, then traffic congestion and speed limitations become dominant in the service area. The average service distance for these types of plants is generally classified in Zone 3, where the one-way travel distance is around 10-15 km. However, suppose traffic congestion between an order point and batching plant with the zonal priority is heavy. In that case, the order can be provided from a plant in Zone 6 with a distance of 30 km since travel time becomes more significant compared to travel distance. Zonal information of a plant is still an important KPI. For example, fuel consumption, average concrete price of the plant, and daily production schedules can be analyzed concerning the service zone. For calculating the plant's service zone, the weighted average method is used, and the one-way distance of each order is multiplied and divided by the daily production amount.

In the model, orders can be shifted from one plant to another by considering the order points' zonal priorities. Therefore, zone information of the plants requires a careful evaluation. On this basis, Zone IDs are calculated daily, and the frequency of order occurrences is determined for a target observation interval. The model uses this occurrence frequency to estimate the service zone's daily sales rates for the Etimesgut Plant.

3.3.5 Raw Material Cost

There are sixteen different concrete classes in the market, and each type is defined with its average strength (Table 3.2). These classes are named as, for example C8/10. In the notations, the former number gives the cylindrical strength of the concrete class and the latter one gives the cubic strength of the concrete. Depending on the quality and standard construction requirements, the demander can request concrete with a different class. From a supplier's perspective, the Average Concrete Class, which is the average class of the concrete produced in a time period, is considered an important KPI in the batching plants. Concrete production in each class necessitates a mixture of raw materials in varying quantities. Therefore, the raw material cost of a unit amount of concrete production shows a variation by the classes.

Table 3.2 *Concrete Class Types*

Concrete Class	Cylindrical Strength (MPa)	Cubic Strength (MPa)
C 8/10	8	10
C 12/15	12	15
C 16/20	16	20
C 20/25	20	25
C 25/30	25	30
C 30/37	30	37
C 35/45	35	45
C 40/50	40	50
C 45/55	45	55
C 50/60	50	60
C 55/67	55	67
C 60/75	60	75
C 70/85	70	85
C 80/95	80	95
C 90/105	90	105
C 100/115	100	115

For achieving a strength value of 1 MPA, approximately 9.5 kg equivalent binder that is a combination of cement, slag, and fly ash is used (OYAK Concrete Company, 2019). Equivalent binder ratio shows differences between concrete classes or between plants different raw materials are used. Chemical content is increased, and equivalent binder usage per MPa is decreased to improve concrete strength. Since raw material quality may change according to suppliers, different formulas become available in different batching plants for the same types of concrete classes to ensure quality control restrictions. Raw material quality may variate even for the same suppliers if production and storage conditions fail to keep the material above the standard values. For instance, the moisture content of aggregate can be higher than standards in case of improper storage. Therefore, different formulas in the preparation of concrete for a particular strength value are employed. In the formulas, a higher amount of equivalent binder content will increase the unit production cost of concrete. In the study, the concrete classes' raw material costs in each plant are estimated, considering their standard formulas.

As mentioned in Section 2.2.2.1, raw material prices vary among plants. At this point, depending on the concrete formula and raw material price, the total raw material cost for the unit volume of a concrete class is determined. For different plants, raw material costs for the same product will be different since raw material price and concrete formula may not be identical.

3.3.6 Average Daily Sales for Each Concrete Class

Concrete companies are generally capable of producing all concrete classes in accordance with the market requirement and standards. The average concrete class produced is only motivated by demand rates. Although concrete classes requested may show a variation according to country regions and urban and rural areas, there is no significant variation in the requested class types' frequency. Therefore, it is expected that a plant's average concrete class will be constant and will not deviate noticeably. Accordingly, daily sales of concrete classes are estimated by a weighted average. On this basis, the average concrete class is estimated with the weighted average of concrete class orders considering daily order rates for each class.

Different average concrete classes need to be observed in the simulation model of the current study. The raw material cost varies according to the concrete classes and holds a crucial role in estimating total operational cost and operation profitability. Therefore, percentile production rates of concrete types for each plant should be included in the model.

3.3.7 Transportation Operating Cost (Owned and Subcontracted)

As discussed in Section 3.2, there are two types of transportation operations in terms of ownership: company-owned and subcontracted operations. The operation type is decided following a cost analysis before a batch plant starts its operations. Each batching plant of the company can employ one subcontractor where multiple subcontractors can be worked all across the city.

Various variable and fixed cost items contribute to the total operating cost if company-own operations are decided for a batching plant. Personnel expenses, including gross and overtime wages, maintenance and inventory expenses, fuel consumption rate, depreciation, and other related expenses, determine the operating cost. In some periods where the amount of produced and transported concrete material decreases, depreciation used to benefit from the tax reduction can be overrated. Therefore, year to date operational results are used in the study model.

On the other hand, the subcontractor's equipment and personnel are operated in subcontracted operations where the subcontractor covers all the expenses, excluding fuel. Before starting a subcontracted process, a contract of reciprocity is signed with the subcontractor in which the progress payments for transportation works are made monthly regarding the contract items. Liabilities and responsibilities related to equipment, drivers, and operational limitations are stated in the contract together with all the legal enforcements. Payment to the subcontractor excluding fuel is made in terms of rent per equipment and cycle. In the model, the subcontracted operations' average cost for a six-month process in 2019 is used to eliminate fluctuations in price.

Since fuel consumption per volume of material transported is of particular concern to the profitability of operations, it should be analyzed and evaluated carefully. Fuel cost of the company is expected to reach up to 50% of the transportation cost equals 35% of the total operating cost (OYAK Concrete Company, 2019). In company-owned operations, fuel is provided by the concrete company itself. Fuel at the sites of the batching plants is stored in the tanks. Truck-mixers are fueled daily so that their tanks' fuel level should be above the threshold level. Whenever equipment is fueled up, the amount is recorded manually. At the end of each working day, the total fuel amount consumed by truck-mixers and the amount of concrete material transported to the order points are recorded. A similar calculation is also carried out at the end of each month. On this basis, fuel consumption per unit of material hauled is an important KPI for each batching plant. It gives comparative results among the plants to reveal their fuel consumption profiles. On the other hand, the fuel cost of transportation for orders in subcontracted operations depends on the available zonal information of the order point and the amount of concrete hauled. Therefore, according to the subcontractor's contract, fuel cost in subcontracted operations is deterministic for each zone in terms of TL per m^3 material hauled.

In the model, fuel consumptions in company-owned operations are taken deterministic for each batching plant. On this basis, fuel consumption for the plant is calculated cumulatively for six months in 2019. The total fuel consumed in the plant is divided by the total amount of concrete hauled for the target period. Finally, the resultant value in terms of lt/m^3 is multiplied by fuel price, taken as 5 TL/lt from the company, to determine the fuel cost for conveying a unit volume concrete. For the subcontracted truck-mixes, a calculation matrix is used for each plant according to zonal information. Details of the variable and fixed transportation cost items will be mentioned in Section 4.2.

3.4 Development of the Model

This section describes the steps of the developed Monte Carlo simulation model by evaluating priorities in the company's supply chain system and investigating the service area of a Batching Plant where there may be transitions among the plants for different order points.

Monte Carlo simulation replications are expected to derive random numbers for the operational data. The generated random values will be capable of representing the related distribution functions. The simulation is forced to run twice. In the first run, current operations are simulated to check whether the simulation works correctly and deviates real operational results. The simulation model enables the sequential evaluation of concrete demand, average concrete class, average zone, daily average concrete production, and distribution cost. Cost, demand, and production values are assigned randomly, considering their distributions.

The simulation model used the first half of the year 2019 as an input dataset. Simulation steps are performed on a daily basis with a sequential order between January 1st and June 30th. Daily concrete demand is assigned initially for the first day, $i = 1$, using the demand distribution function. Additionally, average service zone and average concrete class data are assigned for the same date. Cost items estimated from raw material consumption, transportation rent, and transportation fuel consumption are estimated. The simulation follows the steps sequentially until the end of the observation period. Once the observation period is over, average cost values and period statistics are stored, and the simulation is re-initiated by resetting the variables. The simulation modules used in the current study are illustrated in Figure 3.1.

In the second run, financially-improved operations are simulated, and the results are compared with the first run. The simulation modules used for the second run in the current study are illustrated in Figure 3.2.

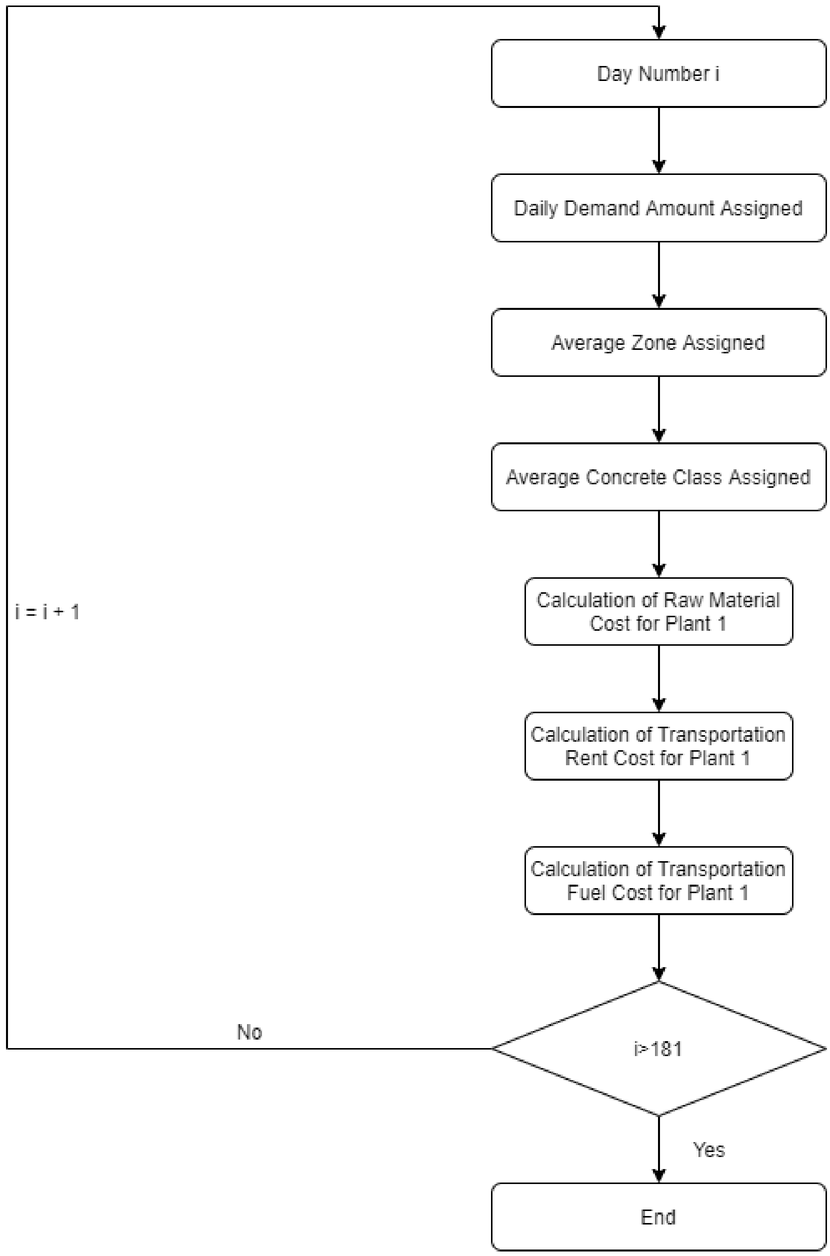

Figure 3.1 The Simulation Algorithm for the First Run

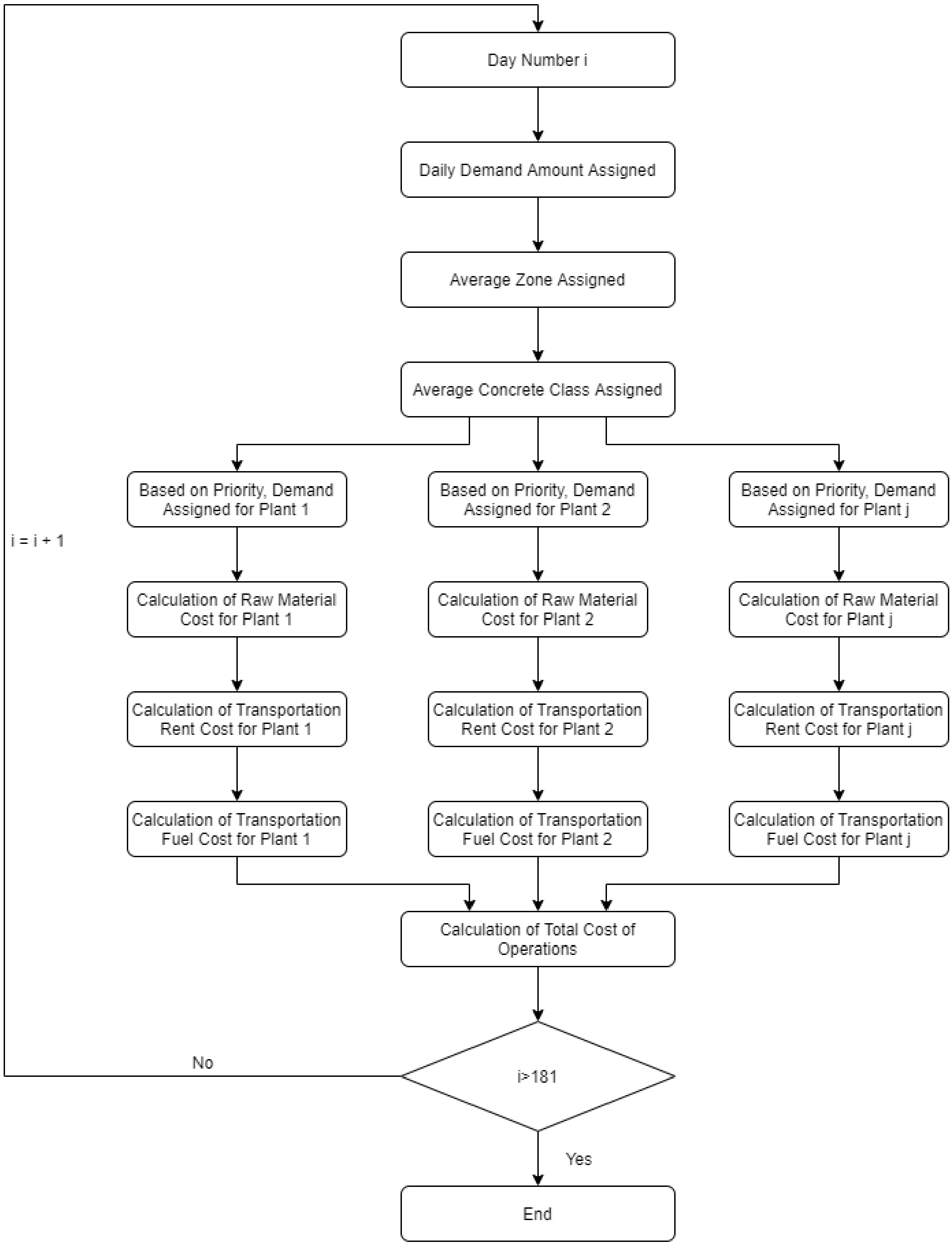

Figure 3.2 The Simulation Algorithm for the Second Run

The second run using the modules in Figure 3.2 allows a clear evaluation of uncertainty and improvements achieved using the simulation model. The second run simulation starts with assigning random demand values by initiating the day from January 1st, similar to the first run. Average service zone and average concrete class data are introduced to the model for the same date. Differently from the first run, the second run differentiated at the following steps by dividing daily demands with respect to the order points' zonal priorities.

As mentioned in Section 4.1.2., 7,072 orders were active in the first half of the year 2019 to be provided from the Etimesgut Plant. These orders were received from 110 different order points. Classification of the order points is carried out considering the zonal priorities of individual plants. When setting a priority, the distance between the plants and the order point is considered as given below.

i: order points; j: batching plant:

```
for (int i=1, i<=order.number, i++) {
        int j={1,..,4}
        sort.distance (i, j);
        for (int k=1, k<=j, k++) {
                set.priority (distance (i, j),k);
                k=k+1;}
```

For each order point, the priorities are determined concerning the batching plants. The priority values are taken between 1 and 4, where the plant coded with 1(one) refers to that order should be provided from this plant, considering the zonal priority table. Six-month period was divided into 15-day intervals. For each interval, the order points are specified with their estimated amounts. The order amounts are allocated between the plants. Each plant is weighted for its highest priority order amount. When a daily demand is assigned, these weights are used to divide concrete demand among four RMC plants. For each plant and concrete production amount, raw material, transportation, and fuel costs are calculated. Simulation is continued by incrementing the date one by one. The observation period is six months, and the simulation is repeated from the beginning, so that simulation results become representative of all the possible alternative scenarios.

CHAPTER 4

APPLICATION OF THE MODEL

4.1 Study Area and Data Acquisition

This chapter shows the model's implementation for a case study using the operational dataset presented. The model is applied using a real dataset to improve the profitability of concrete production and distribution operations for a concrete company named OYAK. Since the concrete market is competitive, drastic price variations are not observed frequently. Therefore, expected revenue tends to remain stable, and the profitability in a concrete operation can be improved by reducing operating costs. OYAK Concrete Company has a major share in the market, and its annual production rate can be up to 4 million m^3. Since concrete operations are with a low-profit margin, any reduction in the total costs by 1 LMU/m^3 can lead to an observable jump in profitability.

Concrete production and distribution cost are different for the same company's batching plants since raw material and transportation cost may show a high variation. Therefore, before constructing the model, distribution operations need to be examined in detail according to the batching plants. As discussed previously, four plants located in Etimesgut, Batıkent, Temelli, and Bilkent are operated to meet the concrete demand in Ankara (Figure 4.1). The model should capture the financial benefit by considering the trade-off induced by raw material costs of different concrete types. Each item may have a changing cost for the batching plants, and transportation cost affected by distance to order point and transportation type. Even though a zone priority matrix is used in the company considering only the distance between plant and order zone, it is seen that this matrix is not applicable for many cases since the production cost of concrete may be higher for plants located in a closer distance to customer, comparatively. In a recent case given in Figure 4.1, suppose that there are three order points where Point A is located closest to Temelli Plant. However, it is observed that this demand was provided from Etimesgut Plant since the production cost of raw materials compensates the drawback in transportation cost.

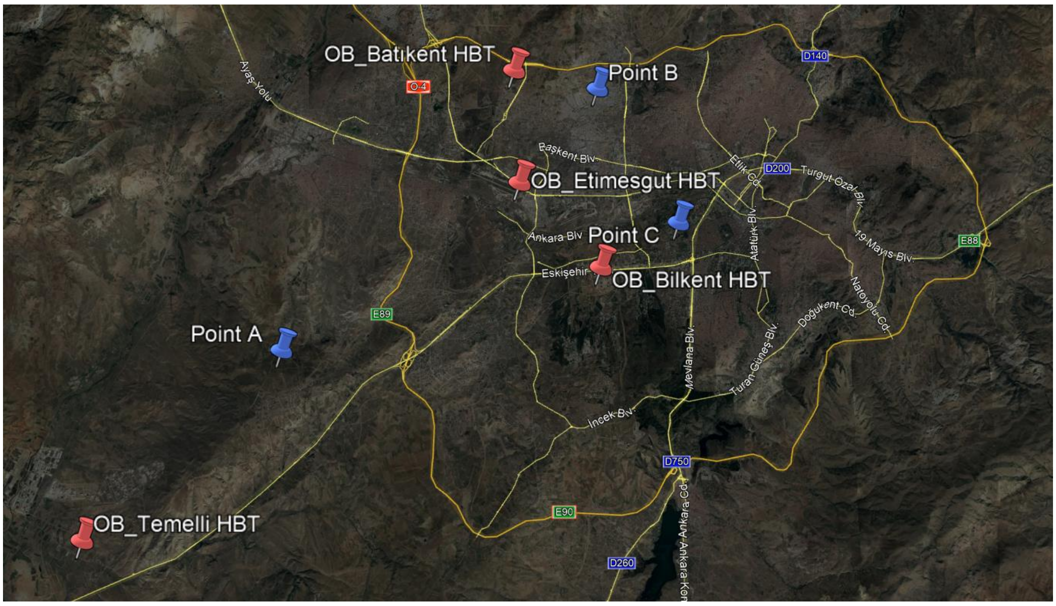

Figure 4.1 Locations of the Batching Plants

Although concrete production is not a complicated process, operational costs show a large variety, and the profit margin is highly restricted. There are too many competitors in the concrete market so that companies cannot use price volatility to increase their profits. In some markets where concrete demand is high, the leading companies' production rates can also become high, and then any improvement in operational cost can contribute to profitability remarkably. OYAK Concrete Company holds an annual production capacity of 9.5 million m^3. It means that any modification capable of decreasing the unit operational cost by one TL can return a decrease of 9.5 M TL in the expenses. In other words, there will be a positive effect of 9.5 M TL a year on the profit.

At this point, the current model intends to decrease the company's operational cost and improve profitability by evaluating the distribution network's effectiveness. On this basis, OYAK Concrete Company's batching plants located in Ankara were chosen in the study area. This selection was decided considering the following aspects:

- OYAK Concrete has four batching plants in Ankara, where each plant has the potential to perform its operation differently. The spectrum of customer profile and order configuration in terms of the amount and class of concrete requested can be changeable. This variety allows building up a model representative of alternative and challenging cases.
- Both company-owned and subcontracted operations are observed in the batching plant located in Ankara. In this way, a comparative evaluation of these two types of distribution systems can be achieved.
- Regional characterization of the plants shows a similarity in Ankara. On the other side, operations performed in Asia and the European sides of Istanbul differ drastically so that the trucks' fuel consumptions, raw material prices, demanded concrete class, and price of the concrete are highly different and unstable. Therefore, holistic and representative modeling of the concrete distribution system can be achieved better in Ankara since operational similarities all across the city can make the model more realistic and accordant with the factual cases.

The developed model examines the plants' flow of operational cost items and simulates the concrete distribution system's variation. The related variations and improvements in the supply and demand chain are determined regarding the order points' supply priorities. Even though the zonal regions' supply priorities are crucial, the plant capacities also set a constraint since an overrated quantity of demand may fail one plant to provide enough amount of concrete material to the order point. The capacity constraint here is not related to plant production capacity but about the capacity of available truck-mixers. Preparation of concrete by mixing the required raw materials takes a short time.

On the other hand, the transportation stage may take hours depending on the plants' route and the order points. Traffic intensity in the given path may show a variation depending on the daytime period and affect truck-mixers' travel time. In case that the cumulative available truck-mixer capacity is not enough to meet the total of order size, the remaining part of concrete material is provided by another plant. This type of shift leads to an additional cost for the company. Therefore, in the study, a decision on whether any partial or complete order will be provided from which plants is given considering the trade-off between the released cost items and benefit.

OYAK Concrete operates subcontracted operations in the Etimesgut and Batıkent plants with different subcontractors, while the company-owned operations are performed in the Bilkent and Temelli plants. In addition, even though raw materials of concrete are provided from the same suppliers, their prices are different from each other since transportation costs variate for each plant. Variability in both production and transportation systems in the four batching plants allows for modeling and analyzing different cases in a concrete distribution network.

The Etimesgut plant is located close to the city center at the junction of the other plants' service areas. Therefore, over-capacity conditions can be overcome practically by shifting the partial demands from the Etimesgut plant to the other plants or vice versa. Due to its advantage to reflect supply and demand interactions between the plants dynamically, the Etimesgut plant is concentrated in the study. Accordingly, the model's stochastic and deterministic data requirement, related to daily demand rates, the average zone of the plant, raw material costs, average concrete class, and transportation costs, is acquired from the company and discussed in the following sub-sections

4.1.1 Daily Demand

As mentioned before, the amount of daily demand is directly related to weather conditions. In case of rainy weather, snowy weather, and temperatures dropping below zero, concrete demands are negatively affected. Cold weather conditions are highly effective in the Central Anatolian Region in the first three months. The following months mostly have rainy weather, so that daily demand has a smooth curve in the first six months of the year. For this reason, the first six months are examined in the model.

Since the Etimesgut Batch plant's sales operations are examined in this work, the plant's daily concrete production amount is examined using MINITAB software to find out the daily demand distribution to be used as input data for generating random variables in the model. The seasonality of the daily demand was examined by splitting the overall dataset into monthly data.

Outlier tests were performed first to eliminate extremely low or high values that do not represent the majority of data in each group. The outlier test can be examined in Appendix A. Some outlier values were detected in the monthly demand values of February, March, and June, while demand values of January, April, and May do not cover any extreme values. As an example, first result of first outlier test can be seen in Table A. 2, where 1005.55m^3 is the outlier value of the dataset. Also, outlier plot of the February data can be seen in Figure A.2, where the outlier highlighted in red. Following the elimination of the outlier data, the demand values were fitted into common distributions to determine the best-fit distribution, using MINITAB software. The distributions with significance values more than 0.05 for 95% confidence interval are referred to be well-fitted for the dataset. Besides, the data values in the related probability plots are expected to align close to mid-line within the upper and lower limits of the confidence interval. Detailed explanations of the analyses are illustrated in Appendix B. The analysis results show that the normal distribution's parametric values can be expressed as monthly demand values, as shown in Table 4.1.

From the Table 4.1, it is seen that standard deviation over mean ratio is quiet high. This situation can be explained by using seasonality. In winter and bad weathers, there could be no concrete demand or very low concrete demand in some days. That’s why, standard deviation ratio is high in January and decreases to May. In June of

2019, there is a national holiday, in which there is not any concrete demand and production occur. That’s why standard deviation ratio is high in June.

Table 4.1 *Normal Distribution Values of Demands (m^3) in Monthly Basis*

Month	Sample Size	p-value	Mean (μ)	Std Dev (σ)	SD/Mean (%)
Jan	31	0.126	176.7	127.3	72.04
Feb	27	0.270	322.9	123.9	38.37
Mar	29	0.118	405.8	171.0	42.14
Apr	30	0.159	417.7	137.7	32.97
May	31	0.836	402.7	137.8	34.22
Jun	29	0.058	327.7	226.8	69.21

4.1.2 Average Zone

Average zone refers to the average one-way distance traveled from the plant to the construction site. Therefore, a Zone ID is obtained to determine the expected zone of order points and is an essential parameter for the batching plants. The average activity zone gives information about the average concrete price, approximate fuel consumption, fuel cost, and market share of the plant. An increase in the average activity zone of a plant may increase the unit concrete price due to the growth in fuel consumption of the truck-mixers and the resultant fuel cost. The profitability of the operation should be evaluated, considering both concrete price and Zone ID. The Etimesgut plant is detected to operate in different zones, with the changeable percentile weights throughout the first half of the year 2019 (Table 4.2). Its most common operating area is observed to cover Zones 3 and 4, where its operation could be extended to Zone 5 where a one-way travel distance is between 20-25 km.

The percentile weights given in Table 4.2 were estimated by using 7,072 orders provided in the first half of the year 2019. These orders were detected to be taken from 110 different order points. In some cases, it is seen that some part of the orders was supplied to the points that are actually close to the other plants. On this basis, it is understood that there are multiple cases where the Etimesgut plant is activated even for the order points at Zone 5 due to the other plants' capacity constraints. This argument can be examined more clearly in Table 4.3.

Table 4.2 *Order Statistics according to the Zonal ID of the Etimesgut Plant of the Jan-Jun Period*

Zone ID	**Order Weight**
Zone 1	6%
Zone 2	11%
Zone 3	43%
Zone 4	38%
Zone 5	2%
Zone 6	0%
Zone 7	0%
Zone 8	0%
Zone 9	0%
Zone 10	0%
Zone 11	0%
Zone 12	0%

Table 4.3 *Distribution of the Periodic Orders according to the Plant Priorities*

Period	**Etimesgut Plant**				**Bilkent Plant**				**Batıkent Plant**				**Temelli Plant**			
	Zone 1	**Zone 2**	**Zone 3**	**Zone 4**	**Zone 1**	**Zone 2**	**Zone 3**	**Zone 4**	**Zone 1**	**Zone 2**	**Zone 3**	**Zone 4**	**Zone 1**	**Zone 2**	**Zone 3**	**Zone 4**
Jan	358	152	49	31	133	219	189	49	19	219	344	8	80	0	8	502
Feb	516	413	70	38	413	173	381	70	0	451	347	239	108	0	239	690
Mar	966	464	104	7	459	248	730	104	5	829	491	216	111	0	216	1,214
Apr	748	469	32	121	453	379	506	32	16	522	510	322	153	0	322	895
May	844	393	102	27	390	323	551	102	3	650	433	280	129	0	280	957
Jun	897	215	50	6	205	255	658	50	10	698	324	136	56	0	136	976
Sub-Total	4,329	2,106	407	230	2,053	1,597	3,015	407	53	3,369	2,449	1,201	637	0	1,201	5,234
Total	7,072				7,072				7,072				7,072			

15-day intervals are used to detect the allocation of orders to the plants and their priority rankings. It is seen from the Table 4.3 that 590 orders were received in the January 2019. 358 out of 590 orders prioritize the Etimesgut plant as the major supplier, where the remaining 232 orders prioritize the other plants. These 232 orders, in fact, prioritized the Bilkent, Batıkent, and Temelli plants by 133, 19, and 80, respectively. Using the statistics in Table 4.2, the percentile weights of priority occurrences are estimated as in Table 4.3. It can be concluded from the table that the first 15-day demands set a major production intensity in the Etimesgut plant, and after, in Temelli, Bilkent, and Batıkent by the shares of 19, 16, and 8%. These values will be considered in the model when deciding the demand intensity and reprioritizing the plants for the orders that cannot be supplied in all by a single plant. (Table 4.4)

Table 4.4 *Percentile Weights of the Plant Prioritizations for the Periodic Orders*

Period	Etimesgut Plant (%)	Bilkent Plant (%)	Batıkent Plant (%)	Temelli Plant (%)
Jan	61	23	2	14
Feb	50	40	0	10
Mar	63	30	0	7
Apr	55	33	1	11
May	62	29	0	9
Jun	77	18	0	5

Once prioritization is completed, the order points concerning their prior supplier plant are also investigated. Zonal allocation of these orders and their percentile shares can be viewed in Tables 4.5 and 4.6.

Table 4.5 *Distribution of the Zonal ID's of Order Points according to the Plant Priorities*

Month	Bilkent Plant				Batıkent Plant				Temelli Plant			
	Zone 1	Zone 2	Zone 3	Zone 4	Zone 1	Zone 2	Zone 3	Zone 4	Zone 1	Zone 2	Zone 3	Zone 4
Jan	36	2	87	8	32	17	0	0	32	17	0	31
Feb	42	9	349	13	54	3	0	0	54	3	13	38
Mar	94	9	354	2	104	0	0	0	104	0	0	7
Apr	44	12	386	11	29	3	0	0	29	3	0	121
May	33	7	329	21	23	79	0	0	23	79	0	27
Jun	7	11	164	23	37	13	0	0	37	13	0	6
Total	256	50	1,669	78	279	115	0	0	279	115	13	230

Table 4.6 *Percentile Weights of the Plant Zone ID according to the Order Prioritizations*

Month	Zone ID	Bilkent	Batıkent	Temelli
Jan	Zone 1	27%	65%	40%
	Zone 2	2%	35%	21%
	Zone 3	65%	0%	0%
	Zone 4	6%	0%	39%
Feb	Zone 1	10%	95%	50%
	Zone 2	2%	5%	3%
	Zone 3	85%	0%	12%
	Zone 4	3%	0%	35%

Table 4.6 *Percentile Weights of the Plant Zone ID according to the Order Prioritizations (continued)*

Mar	Zone 1	20%	100%	94%
	Zone 2	2%	0%	0%
	Zone 3	77%	0%	0%
	Zone 4	0%	0%	6%
Apr	Zone 1	10%	91%	19%
	Zone 2	3%	9%	2%
	Zone 3	85%	0%	0%
	Zone 4	2%	0%	79%
May	Zone 1	8%	23%	18%
	Zone 2	2%	77%	61%
	Zone 3	84%	0%	0%
	Zone 4	5%	0%	21%
Jun	Zone 1	3%	74%	66%
	Zone 2	5%	26%	23%
	Zone 3	80%	0%	0%
	Zone 4	11%	0%	11%

4.1.3 Average Concrete Class and Raw Material Cost

Raw material mixtures by different portions are used in the plants to achieve the different concrete classes on demand. Each class has a particular strength characteristic where the quality of the raw material in the mixture plays a crucial role in ensuring the required strength values. In cases where raw material quality is below the intended level, a higher equivalent binder is required to be used to ensure the concrete quality standards. In these situations, the total raw material cost per unit of concrete production gets higher than the cost of the optimal formula for that concrete class. Using the order database of the target period, the percentile distribution of concrete classes for the Etimesgut plant is obtained as given in Table 4.7. It is seen from the Table 4.7 that C30-class concrete is demanded most frequently. It is also observed that seven out of fourteen different concrete classes are demanded by the clients. These rates will be included in the model when estimating the average concrete class of the demand.

Table 4.7 *Percentages of the Concrete Classes Produced in the Etimesgut Plant*

Concrete Class	Percentage (%)
C 8/10	-
C 12/15	-
C 14/16	-
C 16/20	8.7
C 20/25	2.1
C 25/30	24.7
C 30/37	38.5
C 35/45	19.1
C 40/50	1.0
C 45/55	5.9
C 50/60	-
C 55765	-
C 60/75	-
C 70	-

Using the standard formula of each concrete content, the total raw material costs per m^3 production of concrete are given in Table 4.8. As discussed in Section 3.3.5, different batching plants may produce the same class concrete with different raw material costs since the supplier's raw material transportation cost may vary.

In Table 4.8, the total raw material (cement, mineral additives, aggregate, chemicals, and water) costs are listed. Even though C 55/65 and C 70-type concretes are available in the market, there is no defined formula and up-to-date raw material cost estimation since the plants have not supplied these types previously.

Table 4.8 *Total Raw Material Costs of Batching Plants*

	Raw Material Cost (TL/m^3)			
Concrete Class	Etimesgut	Batıkent	Bilkent	Temelli
C 8/10	59.1	59.5	62.3	51.0
C 12/15	61.3	61.8	65.3	52.1
C 14/16	62.7	63.1	66.8	54.7
C 16/20	65.9	65.8	70.0	56.6
C 20/25	70.3	70.3	74.9	61.2
C 25/30	74.6	74.8	80.2	66.5
C 30/37	80.6	80.7	86.6	72.6
C 35/45	89.2	85.6	91.8	76.9
C 40/50	89.9	91.4	95.6	82.8
C 45/55	94.5	95.5	101.8	87.3
C 50/60	98.9	98.7	106.7	97.4
C 55/65	0.0	0.0	0.0	0.0
C 60/75	109.5	109.5	120.7	100.4
C 70	0.0	0.0	0.0	0.0

4.1.4 Transportation Costs

Since concrete transportation operations in the Etimesgut and Batıkent plants are performed by different subcontractors, the operations' rental and fuel cost should be charged per travel considering Zone ID and the plant. Rental costs of truck-mixer per travel are rated in TL per m^3 or material hauled and are constant for each plant, independent of equipment type and order point. The Etimesgut and Batıkent batching plants' rental costs are 11.12 and 9.33 TL/m^3, respectively. However, a multiplier regarding the order point's zonal region is applied when calculating the fuel cost. For instance, assuming that a truck-mixer travels to an order point in Zone 1 and fuel cost is rated 5.0 TL/lt, then 4.5 TL/m^3 of material is charged to the company considering the multiplier of 0.9. Cost estimation details of the subcontracted operations are tabulated in Table 4.9. Fuel multiplier is determined by the company and the subcontractor. It increases from Zone 1 to Zone 8. And after Zone 8, it is taken as constant.

Table 4.9 *Rental and Fuel Cost Values of the Subcontracted Operations*

Zone ID	**Rental Cost (TL/m^3)**		**Fuel Cost (TL/m^3)**	
	Etimesgut	**Batıkent**	**Fuel Multiplier**	**Cost**
Zone 1	11.12	9.33	0.9	4.5
Zone 2	11.12	9.33	1.9	9.5
Zone 3	11.12	9.33	2.5	12.5
Zone 4	11.12	9.33	3.0	15.0
Zone 5	11.12	9.33	3.5	17.5
Zone 6	11.12	9.33	3.8	19.0
Zone 7	11.12	9.33	4.1	20.5
Zone 8	11.12	9.33	4.5	22.5
Zone 9	11.12	9.33	4.5	22.5
Zone 10	11.12	9.33	4.5	22.5
Zone 11	11.12	9.33	4.5	22.5
Zone 12	11.12	9.33	4.5	22.5

Company-owned transportation operations are performed in the Bilkent and Temelli plants. Several cost factors such as overtime fees, maintenance costs, and other transportation cost items need to be regarded as variable cost factors. On the other hand, personnel wages and depreciation need to be included as fixed cost factors. The variable and fixed transportation cost items excluding fuel cost for the Bilkent and Temelli batching plants are given in Table 4.10. It can be referred from the table that the cost values show a variation depending on the plant. Since the plants' operational dynamics and sales amounts are different, unit prices are expected to vary. The overtime and worker costs are related to personnel employed in the plants and are similar for both plants due to identical personnel numbers. Therefore, unit personnel cost in terms of TL/m^3 is affected by the concrete sales amounts. If the production rate decreases, then the unit worker cost drastically increases. On the other hand, maintenance cost includes the maintenance-related expenditures of truck-mixers. The other cost, also registered as depreciation, points to the unit ownership cost of equipment affected by equipment age and purchase cost.

Table 4.10 *Cost Items (Excluding Fuel) of the Company Owned Operations*

	Bilkent	**Temelli**
Variable Transportation Cost Items (TL /m^3)		
Overtime	0.83	1.06
Maintenance	1.52	3.84
Other Transportation Cost	0.02	0.47
Subtotal	2.38	5.37
Fixed Transportation Cost Items (TL/m^3)		
Worker	6.47	8.53
Depreciation	1.41	1.93
Other	0.82	0.99
Subtotal	8.71	11.45
Total Transportation Cost Excluding Fuel (TL/m^3)	11.09	16.82

In addition to the company-owned operation's rental cost items, fuel consumption profiles of the plants were also revealed. According to the first half statistics of the year 2019, the fuel consumption rates of the Bilkent and Temelli batching plant operations are expected to be around 7.27 TL/m^3 and 11.06 TL/m^3, respectively. When the distribution operations and order points of these plants are investigated, it is observed that the average service zone of the Bilkent plant is Zone 2 where it is Zone 4 for the Temelli plant. A similar fuel multiplier is used to build up a scaled fuel consumption rate among company-owned and subcontracted operations, as given in Table 4.11.

Table 4.11 *Zonal Fuel Costs of Bilkent and Temelli Plants*

Zone ID	Mult.	Bilkent (TL/m^3)	Temelli (TL/m^3)
Zone 1	0.90	3.44	3.32
Zone 2	1.90	7.27	7.00
Zone 3	2.50	9.57	9.22
Zone 4	3.00	11.48	11.06

4.2 Model Implementation and the Results

The current study evaluates the uncertainty in a concrete company's transportation operations and tries to optimize the distribution system parameters by using Monte Carlo simulation. On this basis, the model randomizes various model variables that can be observed to variate daily and tries to obtain possible outcomes of different scenarios. For instance, assigning the demand amount of a batching plant randomly by using the related distribution functions will allow estimating the total cost of operation in a range. The simulation is computed for two runs where the first run simulates the current operation, and the simulation results are compared with the real data acquired from the company. The second run improves the model objective, and the results are compared with the actual data to reveal the increase in profitability.

As stated in Section 2.2, several factors are affecting the profitability of plant operations. These factors induce different cost amounts in different batch plants and result in changeable operating costs. Therefore, production and transportation cost parameters should be assessed carefully to improve profitability. At this point, fuel cost occupies a significant part of the total transportation cost and is directly related to the distance between the batch plant and the order destination. Apart from fuel cost, fixed costs such as personnel cost or depreciation, raw material costs, production, and transportation costs have a great portion in total cost, and they are different for each plant. By changing supplying points of the concrete demand, the operations' total costs are tried to be minimized. In brief, the current research seeks different alternatives in the concrete demand-supply network, dynamically renewed in different periods and zones between ready-mix concrete (RMC) plants and destinations, to increase operational profitability.

Table 4.12 lists the cost items contributing to the total cost for the one-unit volume of concrete supplied by Etimesgut Plant. As observed, raw material cost is the major cost item with a 56 percent share in the total cost. Costs of transportation and pumping, if available, are the following major cost items effective in the total cost.

Table 4.12 *Operational Costs of Etimesgut Batching Plant*

Cost	**Unit Cost (TL/m^3)**	**Ratio (%)**
Raw Material cost	80.11	56.2
Variable Production Cost	4.88	3.4
Fixed Production Cost	6.10	4.3
Total Production Cost	*10,98*	
Variable Transportation Cost	23.23	16.3
Fixed Transportation Cost	0.02	0.0
Total Transportation Cost	*23.25*	
Pumping Cost	28.32	19.9
Total Cost	142.66	100.0

The simulation model relies on a financial conflict from the variety in raw material, truck-mixer, and fuel cost items for different plants. Even though transportation cost seems to be lower for some plants close to the order destinations, they may cause higher raw material costs if they provide raw materials from suppliers in more distant point comparatively. Second, concrete demand amounts, available capacities of plants in the order times, the plant's active zone, and average concrete class are also effective in the distribution system's decision process. Therefore, system profitability should be evaluated by including the dynamic interactions of these parameters in a time horizon, using a simulation tool capable of expressing production and distribution-related uncertainties.

Each simulation run starts with assigning the random value of daily concrete demand from the distribution functions described in Section 3.4. After obtaining a demand value, the simulation algorithm continues with assigning the plant's average service zone. The average service zone is an important parameter to be used in calculating transportation costs. As mentioned in Section 4.1.4, there are two transportation types as company-owned and subcontracted. For the observation period, Etimesgut RMC plant orders are examined, and distances between the plant and the order points are estimated accordingly. In this way, Zone IDs' percentile weights considering the plant and the order destinations are determined and listed in Table 4.2 in Section 4.1.2. In brief, the preliminary calculations revealed that the Etimesgut RMC plant is active mostly in Zone 3 and Zone 4. Using the plant's service areas according to the percentile shares, the algorithm retrieves different zonal information of operation for each day.

Then, the average concrete class produced is assigned in the simulation for the active operating day. The concrete class determines the supply's raw material cost in that day since each class includes raw materials in different proportions. It is observed from the historical data that seven different concrete classes were provided from the Etimesgut plant in varying percentages, as tabulated in Table 4.2 in Section 4.1.2. When assigning the class, the simulation uses these probabilistic weights for the active day in the time horizon. The simulation algorithm was computed in YASAI, a Monte Carlo simulation add-in that can be operated in MS Excel. After the stochastic value assignment, operational cost estimations are performed deterministically. An example of the first run results can be viewed in Table 4.13.

The simulation algorithm works on a daily basis. The daily demand value of the active date is assigned using the command of *genNormal({Mean};{Standart Deviation})*. This command generates random variables for the prescribed normal distribution parameters. The nonnegativity constraint of demand values is ensured by reevaluating and setting negative values to zero. For instance, some negative demands are assigned for 14^{th} Jan and 17^{th} Jan in Table 4.13 to revise these values. These zero values inactive the total cost calculation of the related date. Then, zonal information and concrete class is generated, shown in the table, using the command of *genTable({V1, V2, V3};{P1, P2, P3})* where V_i=*value* and P_i= *occurrence probability of Vi*.

Table 4.13 *The First Run of the Simulation Model*

Date	Daily Concrete Demand (m³)	Daily Concrete Demand (m³) -revised-	Average Zone	Average Class	Raw Material Cost (₺/m³)	Transportation Cost (₺/m³)	Transportation Fuel Cost (₺/m³)
1-Jan	173	173	Zone 4	C 30/37	80.61	11.12	15.00
2-Jan	209	209	Zone 3	C 40/50	89.93	11.12	12.50
3-Jan	155	155	Zone 4	C 35/45	89.18	11.12	15.00
4-Jan	283	283	Zone 4	C 30/37	80.61	11.12	15.00
5-Jan	516	516	Zone 4	C 30/37	80.61	11.12	15.00
6-Jan	268	268	Zone 4	C 30/37	80.61	11.12	15.00
7-Jan	292	292	Zone 4	C 40/50	89.93	11.12	15.00
8-Jan	206	206	Zone 4	C 25/30	74.64	11.12	15.00
9-Jan	312	312	Zone 4	C 25/30	74.64	11.12	15.00
10-Jan	157	157	Zone 4	C 30/37	80.61	11.12	15.00
11-Jan	368	368	Zone 1	C 30/37	80.61	11.12	4.50
12-Jan	103	103	Zone 4	C 30/37	80.61	11.12	15.00
13-Jan	200	200	Zone 3	C 35/45	89.18	11.12	12.50
14-Jan	-74	0	Zone 4	C 45/55	94.53	11.12	15.00
15-Jan	409	409	Zone 4	C 35/45	89.18	11.12	15.00
16-Jan	27	27	Zone 4	C 30/37	80.61	11.12	15.00
17-Jan	-71	0	Zone 3	C 30/37	80.61	11.12	12.50
18-Jan	296	296	Zone 3	C 16/20	65.90	11.12	12.50
19-Jan	350	350	Zone 3	C 30/37	80.61	11.12	12.50
20-Jan	75	75	Zone 4	C 30/37	80.61	11.12	15.00

Table 4.13 shows that the cost values arising from raw material consumption, transportation, and fuel in the Etimesgut plant operations are calculated according to the previous random values. As mentioned in Section 3.3.5, each concrete class requires a varying amount of raw material where the unit prices of raw materials change for each plant (Table 4.8 in Section 4.1.3). It is expected that a concrete class having a higher strength will cost more comparatively. Besides, transportation of ready-mixed concrete is achieved by the subcontractor for Etimesgut and Batıkent RMC plants while company-own truck mixers are utilized for the Bilkent and Temelli operations, as discussed in Section 4.1.4. Therefore, the Etimesgut plant operations' transportation cost covers truck-mixer's constant rental price in terms of TL/m^3 and changeable fuel cost varying depending on the zonal information, not distance. Therefore, there is a multiplier to correlate the fuel cost for the plant's active order zone (Table 4.9 in Section 4.1.4).

The cost values are estimated using stochastic decisions of order zone, concrete class, order amount, unit raw material costs, and fuel cost parameters. The simulation time is daily-basis, and the observation period was run 1000 times to detect all the potential scenarios of six months. Weighted averages and standard deviations of cost item values and the total cost were determined as shown in Table 4.14.

Table 4.14 *Simulation Results of the First Run Scenarios (Real Case)*

Output Name	**Mean (TL/m^3)**	**Standard Deviation (TL/m^3)**
Fuel Cost	12.69	0.24
Raw Material Cost	80.13	0.63
Transportation Cost	11.12	0.00
Total Cost	*103.94*	*0.67*

Since the daily demand values are detected to distribute normally as mentioned in Section 4.1.1, the cost factors' resultant distributions are expected to be quasi-normal. The histogram chart of raw material cost values, taken from the software as an output, is given in Figure 4.2 The simulation algorithm reveals that raw material cost behavior can be characterized by a normal distribution with a mean value of 80.1 TL/m^3 and a standard deviation of 0.6 TL/m^3. The simulation results were compared with the company records, mentioned in Table 4.9, such that the difference between the simulation and actual cost values is detected to be negligible.

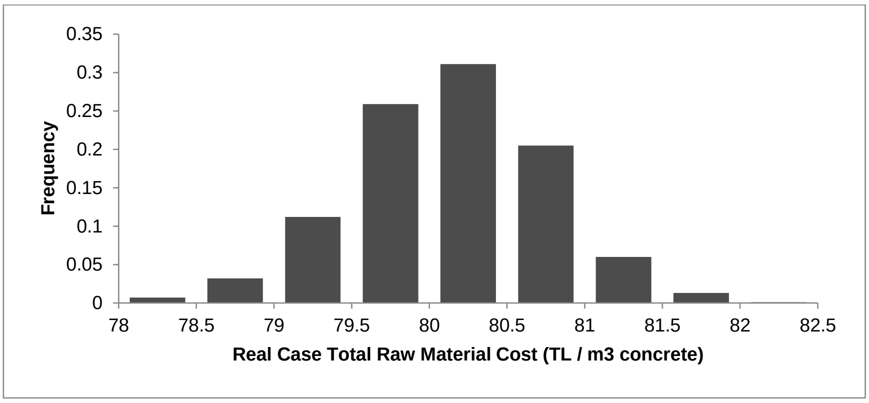

Figure 4.2 Raw Material Cost Histogram of the Real Case Simulation

A similar histogram chart for fuel consumption cost is illustrated in Figure 4.3. The simulation results show that fuel cost per unit volume of concrete transportation is expected to behave normally with a mean value of 12.7 TL/m^3 and a standard deviation of 0.2 TL/m^3. A negligible difference between the outputs and historical records was detected, following the company authorities' interpretation. In practice, sub-contracted equipment capacity may be insufficient for some operations of the plant. Therefore, company-owned truck-mixers of the other plants are put into the operations. In those conditions, the truck-mixers' fuel costs are met by the plants that these vehicles are actually registered. This situation creates an artificial reduction in the unit fuel cost of the plant. These types of equipment shift among the plants are eliminated in the model. The truck-mixers' rental cost is taken constant as 11.12 TL/m^3 since subcontracted operations are active in the Etimesgut Plant.

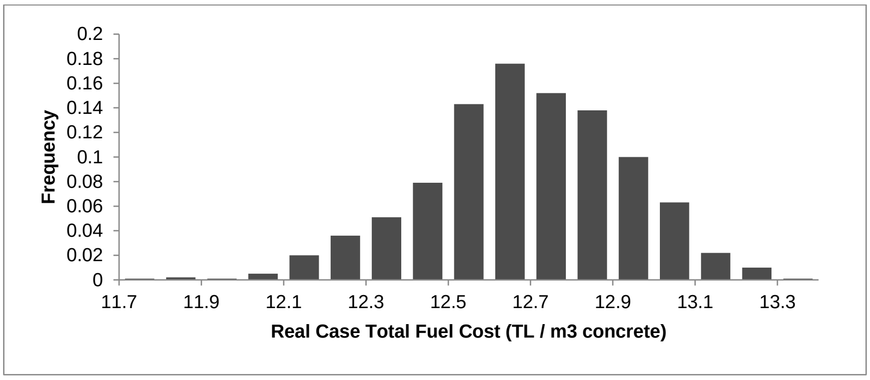

Figure 4.3 Fuel Cost Histogram of the Real Case Simulation

The simulation outputs show that the total cost of producing and transporting the unit volume of concrete can be expressed using a normal distribution with a mean value of 103.9 TL/m^3 and a standard deviation of 0.7 TL/m^3. The total cost histogram is illustrated in Figure 4.4.

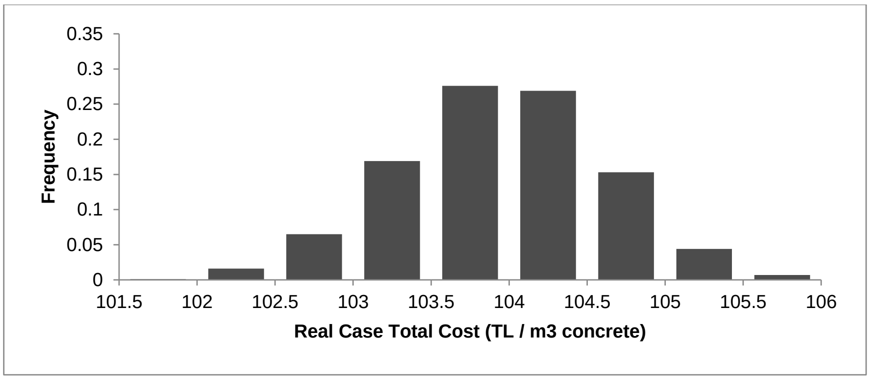

Figure 4.4 Total Cost Histogram of the Real Case Simulation

Since the outputs give reasonable results, a second run is computed for the conditions where daily demand is supplied by the order point regarding the zonal priorities. The second run results, according to the plants, are shown in Tables 4.15 and 4.16. The random and deterministic input data to be used in the simulation, daily demand values, average service zone, average concrete class, raw material cost, transportation cost, and fuel cost, are generated in the same way with the first run. The second run's main difference is that order allocation to the plants is achieved using the percentile weight values in prioritizing the plants for the monthly orders, as shown in Table 4.6. For each period assigned, daily demand is shared between plants. Allocation results of the daily demands for the plants are highlighted in Tables 4.15 and 4.16.

As mentioned in Section 4.1.4, the Bilkent and Temelli plant operations are performed using the company-owned vehicles to distribute the ready-mixed concrete orders. Their transportation types were converted to a subtracted version to achieve better comparability with the other plants. Therefore, transportation cost items of the Bilkent and Temelli Plants were modified accordingly.

Like the first run (real case), the second run (modified case) results were evaluated using the weighted averages of the cost items and the total cost. The run was performed with 1000 repetitions. The simulation results can be viewed in Table 4.17.

Table 4.15 *Simulation Results of the Etimesgut and Bilkent Plants for Second Run*

Random Input Generation			Etimesgut					Bilkent				
Date	Daily Concrete Demand (m^3)	Average Class	Daily Concrete Demand (m^3)	Average Zone	Raw Material Cost (₺/m^3)	Rent Cost (₺/m^3)	Fuel Cost (₺/m^3)	Daily Concrete Demand (m^3)	Average Zone	Raw Material Cost (₺/m^3)	Rent Cost (₺/m^3)	Fuel Cost (₺/m^3)
1-Jan	353	C 16/20	215	Zone 3	65.90	11.12	12.50	81	Zone 3	65.84	11.08	9.57
2-Jan	472	C 30/37	288	Zone 4	80.61	11.12	15.00	109	Zone 3	80.67	11.08	9.57
3-Jan	55	C 35/45	34	Zone 4	89.18	11.12	15.00	13	Zone 3	85.59	11.08	9.57
4-Jan	75	C 30/37	46	Zone 1	80.61	11.12	4.50	17	Zone 3	80.67	11.08	9.57
5-Jan	241	C 30/37	147	Zone 2	80.61	11.12	9.50	55	Zone 3	80.67	11.08	9.57
6-Jan	141	C 35/45	86	Zone 1	89.18	11.12	4.50	32	Zone 3	85.59	11.08	9.57
7-Jan	144	C 30/37	88	Zone 4	80.61	11.12	15.00	33	Zone 3	80.67	11.08	9.57
8-Jan	132	C 30/37	80	Zone 3	80.61	11.12	12.50	30	Zone 4	80.67	11.08	11.48
9-Jan	292	C 30/37	178	Zone 4	80.61	11.12	15.00	67	Zone 3	80.67	11.08	9.57
10-Jan	169	C 30/37	103	Zone 3	80.61	11.12	12.50	39	Zone 3	80.67	11.08	9.57
11-Jan	0	C 25/30	0	Zone 4	74.64	11.12	15.00	0	Zone 3	74.83	11.08	9.57
12-Jan	208	C 25/30	127	Zone 3	74.64	11.12	12.50	48	Zone 1	74.83	11.08	3.44
13-Jan	203	C 30/37	124	Zone 4	80.61	11.12	15.00	47	Zone 3	80.67	11.08	9.57
14-Jan	96	C 30/37	59	Zone 4	80.61	11.12	15.00	22	Zone 4	80.67	11.08	11.48
15-Jan	226	C 16/20	138	Zone 4	65.90	11.12	15.00	52	Zone 3	65.84	11.08	9.57

Table 4.16 Simulation Results of the Batıkent and Temelli Plants for Second Run

Random Input Generation			Batıkent					Temelli				
Date	Daily Concrete Demand (m³)	Average Class	Daily Concrete Demand (m³)	Average Zone	Raw Material Cost (₺/m³)	Rent Cost (₺/m³)	Fuel Cost (₺/m³)	Daily Concrete Demand (m³)	Average Zone	Raw Material Cost (₺/m³)	Rent Cost (₺/m³)	Fuel Cost (₺/m³)
1-Jan	353	C 16/20	7	Zone 2	70.02	9.33	9.50	49	Zone 4	56.61	16.82	11.06
2-Jan	472	C 30/37	9	Zone 2	86.56	9.33	9.50	66	Zone 4	72.58	16.82	11.06
3-Jan	55	C 35/45	1	Zone 2	91.81	9.33	9.50	8	Zone 4	76.87	16.82	11.06
4-Jan	75	C 30/37	2	Zone 2	86.56	9.33	9.50	11	Zone 1	72.58	16.82	3.32
5-Jan	241	C 30/37	5	Zone 1	86.56	9.33	4.50	34	Zone 2	72.58	16.82	7.00
6-Jan	141	C 35/45	3	Zone 1	91.81	9.33	4.50	20	Zone 2	76.87	16.82	7.00
7-Jan	144	C 30/37	3	Zone 1	86.56	9.33	4.50	20	Zone 1	72.58	16.82	3.32
8-Jan	132	C 30/37	3	Zone 1	86.56	9.33	4.50	18	Zone 2	72.58	16.82	7.00
9-Jan	292	C 30/37	6	Zone 1	86.56	9.33	4.50	41	Zone 1	72.58	16.82	3.32
10-Jan	169	C 30/37	3	Zone 1	86.56	9.33	4.50	24	Zone 1	72.58	16.82	3.32
11-Jan	0	C 25/30	0	Zone 1	80.23	9.33	4.50	0	Zone 4	66.46	16.82	11.06
12-Jan	208	C 25/30	4	Zone 2	80.23	9.33	9.50	29	Zone 2	66.46	16.82	7.00
13-Jan	203	C 30/37	4	Zone 1	86.56	9.33	4.50	28	Zone 4	72.58	16.82	11.06
14-Jan	96	C 30/37	2	Zone 1	86.56	9.33	4.50	13	Zone 4	72.58	16.82	11.06
15-Jan	226	C 16/20	5	Zone 2	70.02	9.33	9.50	32	Zone 1	56.61	16.82	3.32

Table 4.17 *Simulation Results of the Second Run Scenarios (Modified Case)*

Output Name	Mean	Standard Deviation
Fuel Cost	11.02	0.16
Raw Material Cost	79.19	0.61
Rent Cost	11.61	0.01
Total Cost	*101.82*	*0.62*

The raw material cost histogram for the derived outcomes is shown in Figure 4.5. It is observed that raw material cost can be characterized using a normal distribution with a mean of 79.2 TL/m^3 and a standard deviation of 0.6 TL/m^3. Therefore, the raw material cost is reduced by about 1 TL/m^3, compared to the real case in the first run.

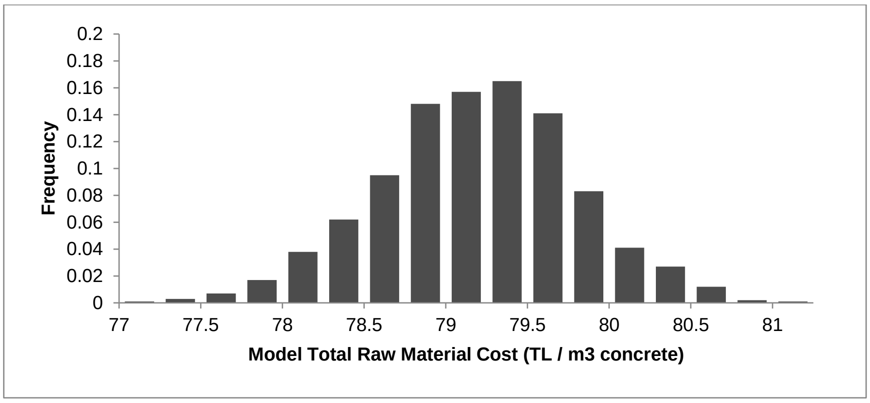

Figure 4.5 Raw Material Cost Histogram of the Modified Case Simulation

The fuel cost histogram chart of the modified case simulation is given in Figure 4.6. The mean value is 11.0 TL/m^{3,} where the standard deviation is obtained as 0.2 TL/m^3. A significant reduction by 1.7 TL/m^3 is achieved with the modified case, compared to the real case in the first run.

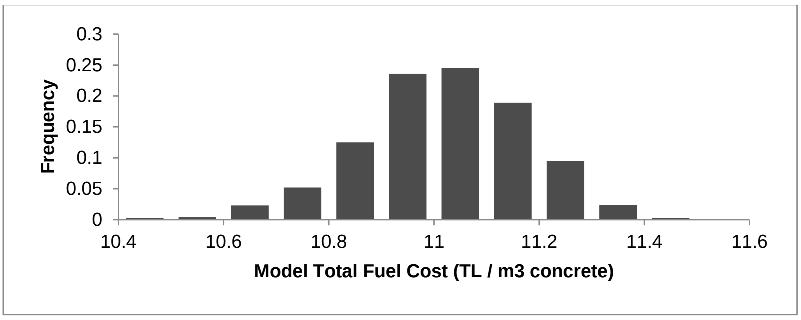

Figure 4.6 Fuel Cost Histogram of the Modified Case Simulation

The rental cost histogram was also generated, as given in Figure 4.7. Rental cost was detected to have a mean of 11.6 TL/m^3 and a standard deviation of 0.2 TL/m^3. The expected rental cost is increased by about 0.5 TL/m^3, compared to the real case value. Considering the cost items and their variations in the histograms, the total cost histogram was obtained as given in Figure 4.8. The total cost value is found to be with a mean of 101.8 TL/m^3 and a standard deviation of 0.6 TL/m^3.

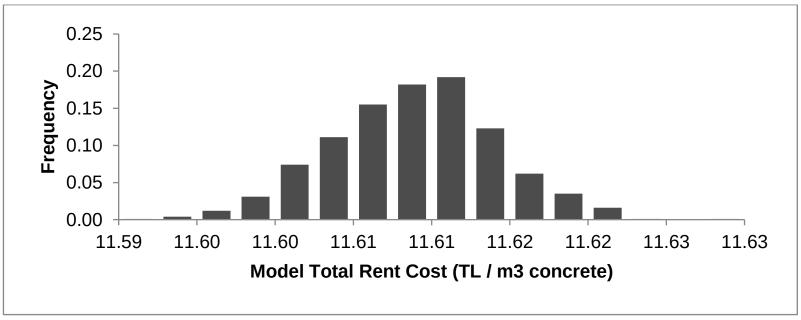

Figure 4.7 Truck-Mixer Rental Cost Histogram of the Modified Case

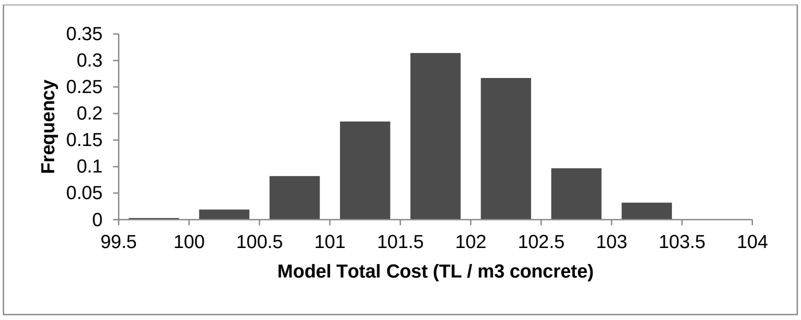

Figure 4.8 Total Cost Histogram of the Modified Case

Comparative evaluation of the cost items for the real and modified cases can be examined in Table 4.18. The simulation result shows that the total cost's expected value can be decreased from 103.94 TL/m^3 to 101.82 TL/m^3 with a 2% reduction.

Table 4.18 *Cost Comparison Between Simulation Runs*

	Real Case (TL/m^3)	**Modified Case (TL/m^3)**	**Difference (TL/m^3)**	**Difference %**
Fuel Cost	12.69	11.02	1.67	-13.2
Raw Material	80.13	79.19	0.94	-1.2
Rental Cost	11.12	11.61	-0.49	4.4
Total Cost	*103.94*	*101.82*	*5.76*	*-2.0*

The table reveals that the total raw material cost of the operations is decreased by approximately 1.2%. The main reason is that the Temelli and Bilkent plants' raw material costs, shown in Table 4.10, are lower than the other plants. Although the Batıkent plant has a high raw material cost, the total raw material cost was not affected much since there is a little shift to the Batıkent plant. On the other hand, fuel cost is observed to be reduced by 13.2%, and this reduction can be explained by the shifts to the plant prioritized according to destinations and neglecting vehicle shifts among the plant. The truck-mixers' rental cost is increased by 4.4%. The main reason is that when the orders shift to the other plants, variable costs such as maintenance cost and overtime cost will be relocated. Besides, the plant's total production amount will increase by decreasing the variable and fixed transportation cost of the unit volume material. In brief, there is a potential to lower the overall cost of producing and transporting unit volume concrete. It can be decreased by 2.0% (equals to 2.12 TL for each m^3) if vehicle capacities and order allocations are managed carefully. It means that the company's annual expenses in total will decrease in an amount of more than 20 M TL.

CHAPTER 4

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusions

Concrete is used in the construction of industrial and non-industrial buildings as a primary construction material. A concrete supply chain system needs to be adequately analyzed together with all the required raw material supply rates not to interrupt constructions and lose the market share. Profitability is a crucial parameter for the sustainability of concrete production. The profit margin of concrete sales is considerably low, and any improvement in the operating cost is expected to contribute to profitability. The current study aims to build a simulation model to reveal the demand and supply uncertainties in the batching plant operations of a company located in Ankara and investigates potential improvements that can be performed in the distribution network for increasing profitability.

Four batching plants of OYAK Concrete located in Ankara are included in the study. Each plant's cost factor shows a variation due to location specifications, supplier differences, and operational differences. These differences may lead to a conflict between production and transportation costs, such that a plant closer to the order point may supply the material with a higher operating cost because of the higher raw material cost. Among these batching plants, the Etimesgut plant's operations were mainly concentrated on investigating the transitions between the plants' priority zones and the supplier plant for a total of 7,072 orders for 115 different order points. According to the company's distribution policy, it is advised to provide the material from a plant with a priority in terms of location. However, it is observed that the distance factor is not enough to demonstrate the maximum profitability. Therefore, profitability is improved in practice by a joint evaluation of raw material and transportation cost where the plant capacities are also considered. The trade-off between the cost values is examined in a simulation model to reveal opportunities to improve profitability by re-allocating the plants' demands. In the simulation, batching plants are prioritized for each order point when order points are supplied from the nearest plants. At this point, cost items related to the raw material mixture, transportation, and fuel are estimated for the related plants, and overall costs are compared with the real operational results. In the model, daily demand assignments, average concrete class, average zone, and order shifting ratios are performed randomly using probabilistic functions.

Some particular outcomes drawn from the simulations are given as follows:

- The first run of the simulation is performed for the real case. The simulation results were compared and verified using the company cost analysis reports. There is a small difference in the plant's fuel cost, which can be explained by neglected factors. The Monte Carlo Simulation Method is observed to perform effectively in a supply chain management problem's cost analysis problems.
- The second run of the simulation is performed for a modified case, where the Etimesgut plant orders were reallocated among four different plants. A reduction by 2%, which equals 5,755 TL/m^3, is achieved in the total cost, compared to the real case. In practice, the company's cost analysis reports show that the total operational cost can be decreased by 2% so that a saving of ₺55M for an annual production of 9.5M m^3 can be achieved by managing the truck-mixer capacities and the plant priorities attentively.
- The simulation results show that the fuel cost factor may affect the total operational cost. Approximately 13% improvement in total transportation cost can lead to a 4% decrease in the total operating cost.
- Besides, the operations' total raw material cost can be decreased by 1.2% with a redistribution of supply chain systems. This decrease arises from the differences in the unit raw material prices of the different plants.

5.2 Recommendations

The current study intends to increase the profitability of concrete supply chain operations for the batching plants by decreasing cost factors. Outcomes of this study can be improved in future studies by regarding the recommendations stated below:

- Cement has an important place in concrete production operations. When viewed from the broadest perspective, the operations start in clay and limestone mines where raw material extracted. After that, cement is produced in factories, and concrete is produced in batching plants. Profitability of the operations are directly proportional to each other. In the future studies, to maximize the profitability of the operations, cost factors of mining, cement production and concrete production operations can be examined together.
- The simulation enables the re-allocation of supplier plants according to new random scenarios. In these operations, production capacity, transportation media capacity, and the batching plants' availability are not considered as binding constraints. On this basis, these capacities can set a bottleneck in the re-allocation process. A dynamic model can be constructed to simulate the instantaneous occupied capacities of each plant.
- Increasing production amounts of the plants tend to decrease the unit fixed cost. In the model, fixed costs are considered stable independent of the plants' achievable production ability. However, it can be observed from the real cases that the variable costs cover approximately 13% of the total cost for the Etimesgut batching plant. In comparison, this portion can increase up to 20% for a lower-capacity plant.
- Increasing material production and distribution rate for a plant causes a higher utilization of truck-mixers so that these vehicles start to deteriorate and fail with a higher frequency. This condition will increase the plant's total maintenance cost and the resultant operating cost per unit produced and

hauled concrete. Therefore, the correlation between equipment utilization rate and maintenance cost can be considered in future studies to evaluate the operational profitability in detail.

- Besides, the increasing failure rate will have an adverse impact on fuel consumption rates, with an increasing trend. In company-owned transportation operations, fuel expenses are covered by the concrete company itself. Therefore, any jump in the fuel rate of unit haul material per km will have an observable adverse effect on the operations' profitability. Joint simulation models, where the dependencies between production, distribution, maintenance, and fuel consumption are evaluated, can be constructed in future studies.

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APPENDICES

A. Outlier Analysis Results of the Demand Data

Table A. 1 *Grubb's Test Results of the First Outlier Test*

Variable	N	Mean	StDev	Min	Max	G	P
Jan	31	176.7	127.3	0.0	527..4	2.75	0.102
Feb	28	347.3	177.3	90.1	1005.5	3.71	0.000
Mar	31	476.6	320.1	0.0	1548.7	3.35	0.006
Apr	30	417.7	137.7	203.6	778.2	2.62	0.165
May	31	402.7	137.8	185.7	730.1	2.38	0.402
Jun	30	359.5	282.9	0.0	1282.2	3.26	0.009

Table A. 2 *Outlier Information of the First Outlier Test*

Month	Outlier Information		
January	There is no outlier		
February	**Variable**	**Row**	**Outlier**
	Feb	19	1005.55
March	**Variable**	**Row**	**Outlier**
	Mar	19	1548.7
April	There is no outlier		
May	There is no outlier		
June	**Variable**	**Row**	**Outlier**
	Jun	29	1282.22

Table A. 3 *Grubb's Test Results of the Second Outlier Test*

Variablee	N	Mean	StDev	Min	Max	G	P
Feb	27	322.9	123.9	90.1	640.5	2.56	0.171
Mar	30	440.9	255.0	0.0	1456.9	3.98	0.000
Jun	29	327.7	226.8	0.0	765.4	1.93	1.000

Table A. 4 *Outlier Information of the Second Outlier Test*

Month	Outlier Information		
February	There is no outlier		
March	**Variable**	**Row**	**Outlier**
	Mar	19	1548.7
June	There is no outlier		

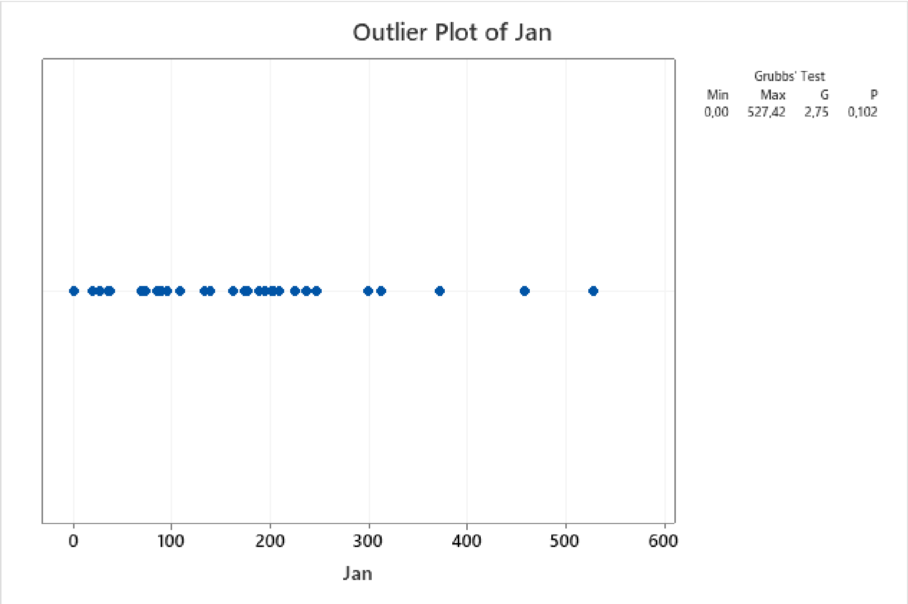

Figure A. 1 Outlier Plot of January (First Test)

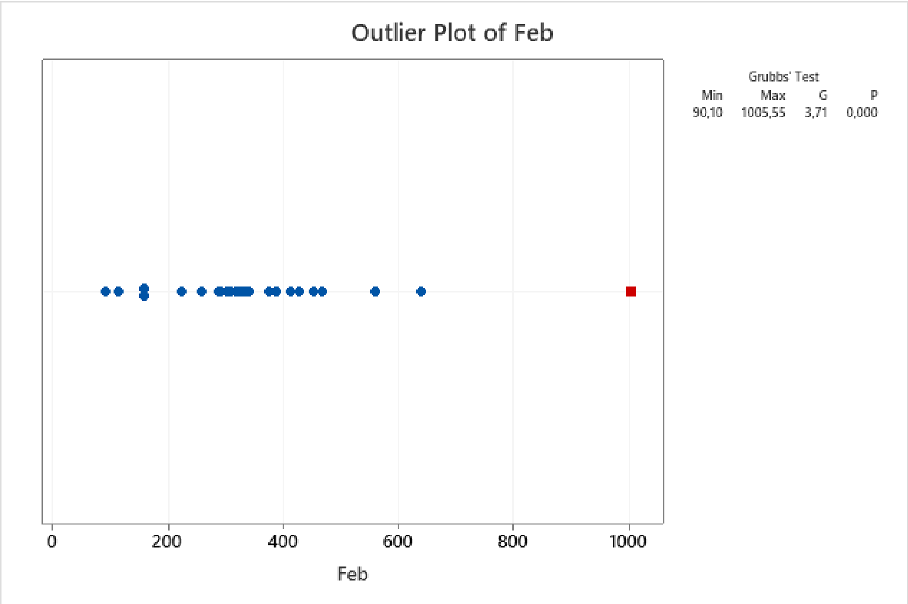

Figure A. 2 Outlier Plot of February (First Test)

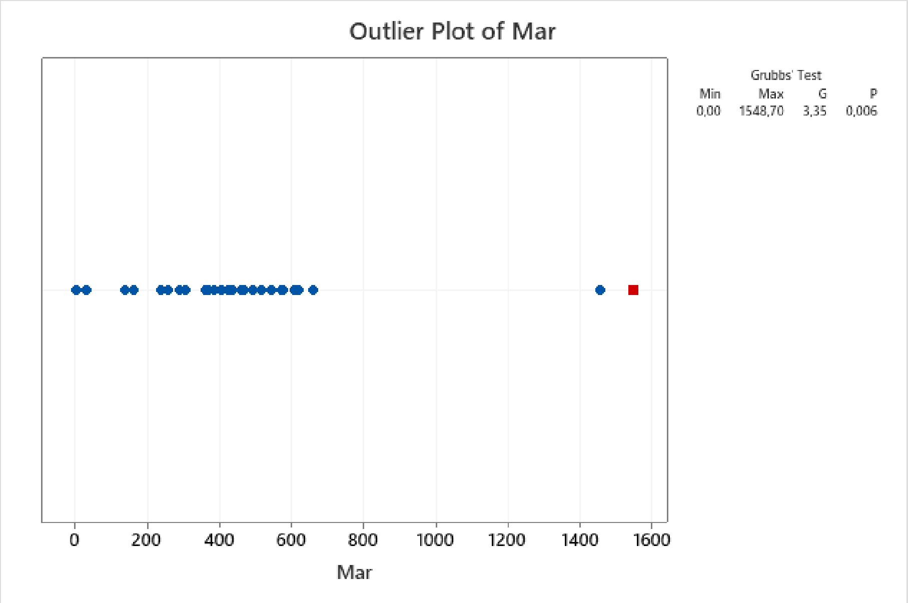

Figure A. 3 Outlier Plot of March (First Test)

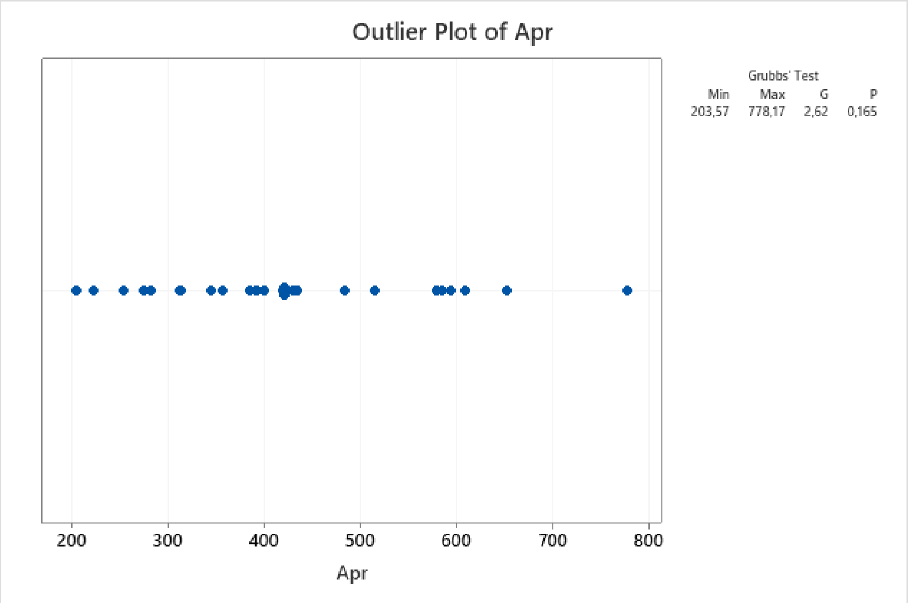

Figure A. 4 Outlier Plot of April (First Test)

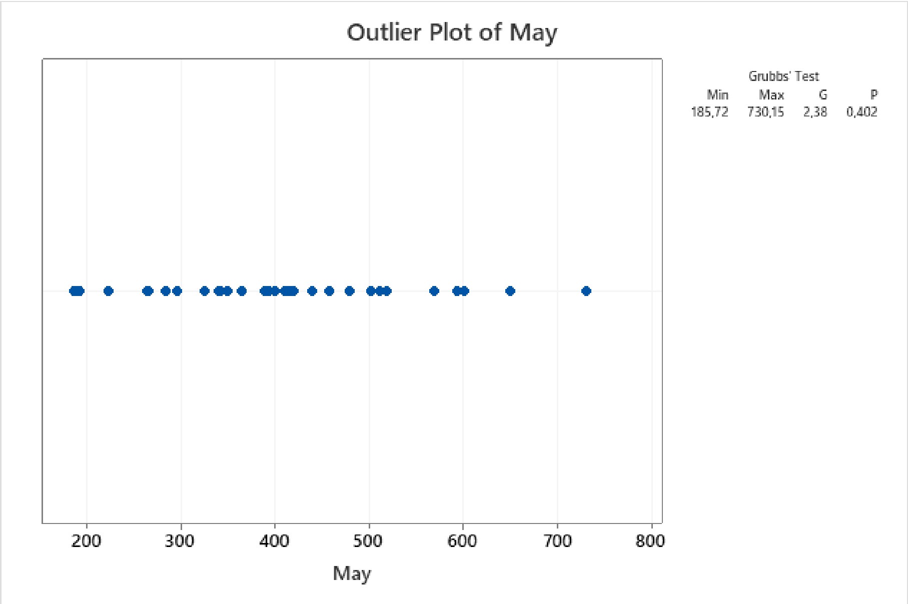

Figure A. 5 Outlier Plot of May (First Test)

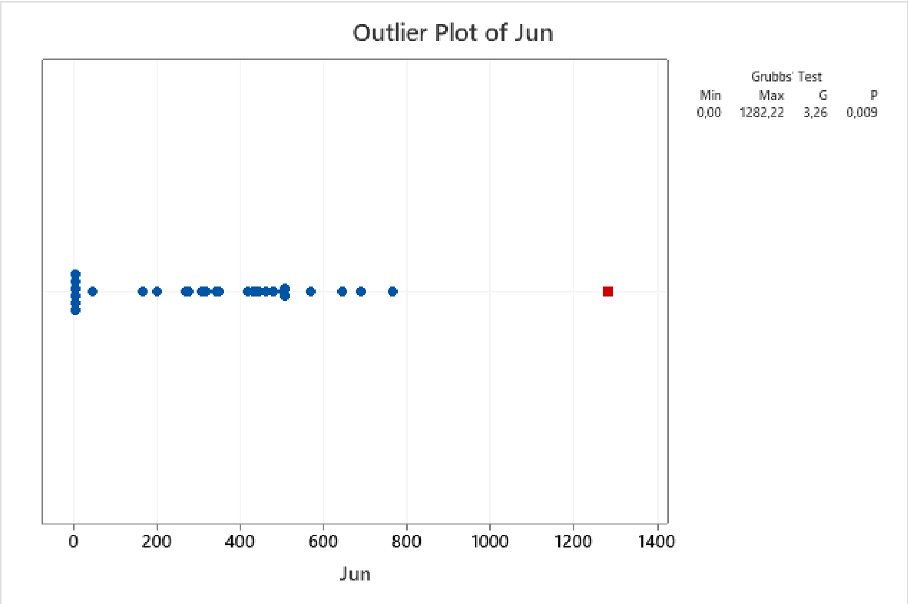

Figure A. 6 Outlier Plot of June (First Test)

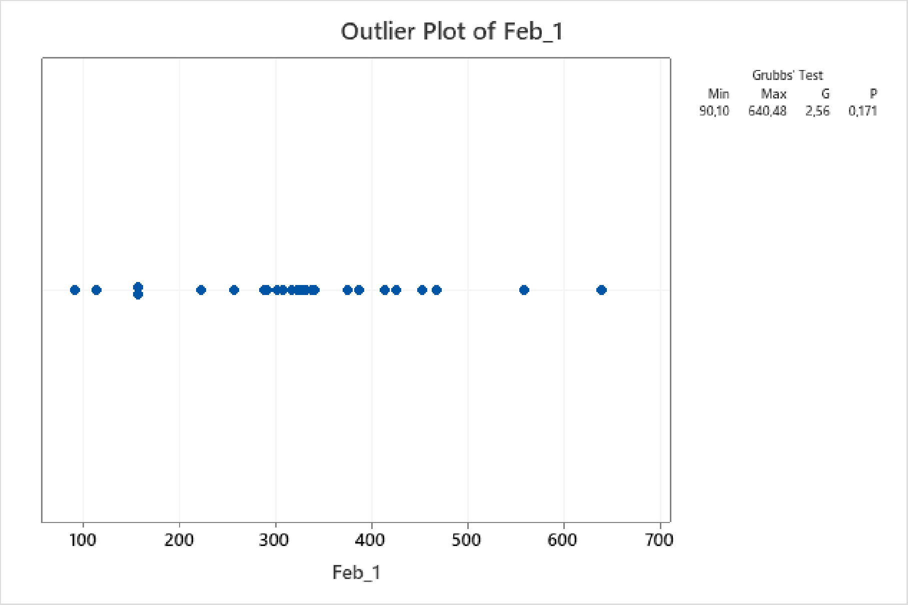

Figure A. 7 Outlier Plot of February (Second Test)

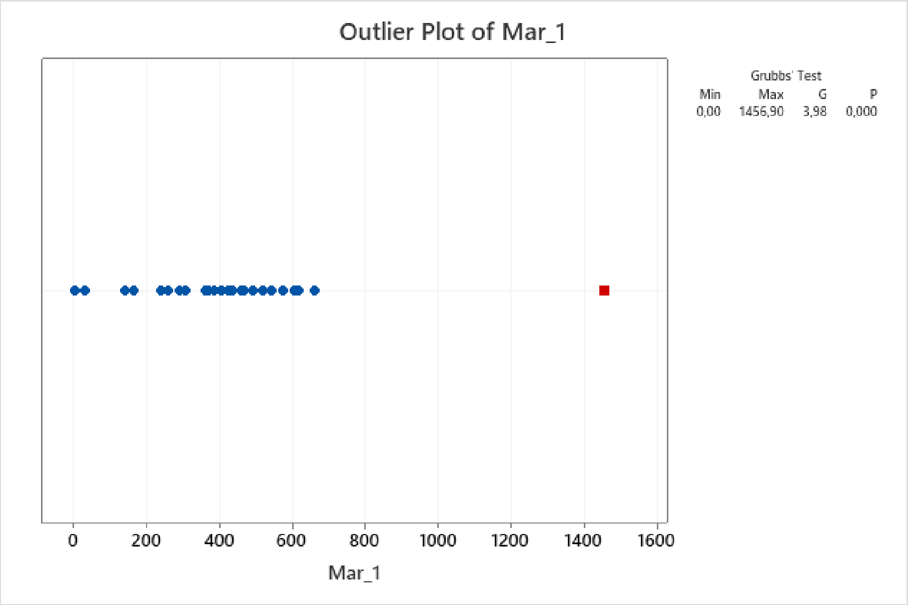

Figure A. 8 Outlier Plot of March (Second Test)

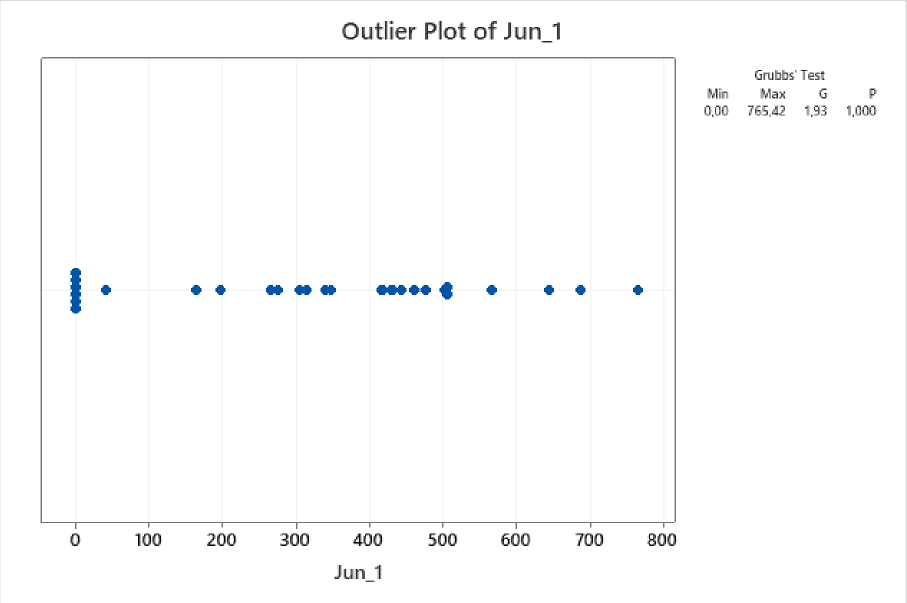

Figure A. 9 Outlier Plot of June (Second Test)

B. Distribution Analysis Results of the Demand Data

Table B. 1 Descriptive Statistics Results of the Demand Data

Month	N	N*	Mean	StDev	Median	Minimum	Maximum	Skewness	Kurtosis
January	31	0	176.677	127.324	172.98	0	527.43	0.967	0.888
February	27	0	322.921	123.928	322.15	90.1	640.48	0.432	0.874
March	29	0	405.846	170.953	434.35	0	659.60	-0.842	0.190
April	30	0	417.718	137.735	420.33	203.58	778.18	0.599	0.337
May	31	0	402.681	137.762	393.13	185.73	730.15	0.398	-0.184
June	29	0	327.675	226.849	346.8	0	765.43	-0.127	-0.877

Table B. 2 Goodness of Fit Test Results of the Demand Data

Month	Goodness of Fit Test Parameters			
	Distribution	**AD**	**P**	
January	Normal	0.572	0.126	
	3-Parameter Lognormal	0.220	*	
	2-Parameter Exponential	1.203	0.043	
	3-Parameter Weibull	0.197	>0.500	
	Smallest Extreme Value	1.583	<0.010	
	Largest Extreme Value	0.220	>0.250	
	3-Parameter Gamma	0.194	*	
	Logistic	0.406	>0.250	
	3-Parameter Loglogistic	0.263	*	
	Distribution	**AD**	**P**	**LRT P**
February	Normal	0.440	0.270	
	Box-Cox Transformation	0.504	0.187	
	Lognormal	0.923	0.016	
	3-Parameter Lognormal	0.411	*	0.047
	Exponential	5.034	<0.003	
	2-Parameter Exponential	3.140	<0.010	0.000
	Weibull	0.466	0.240	
	3-Parameter Weibull	0.483	0.207	0.686
	Smallest Extreme Value	1.155	<0.010	
	Largest Extreme Value	0.663	0.078	
	Gamma	0.612	0.121	
	3-Parameter Gamma	0.656	*	0.697
	Logistic	0.309	>0.250	
	Loglogistic	0.611	0.072	
	3-Parameter Loglogistic	0.309	*	0.109
	Distribution	**AD**	**P**	
March	Normal	0.585	0.118	
	3-Parameter Lognormal	0.615	*	
	2-Parameter Exponential	4.663	<0.010	
	3-Parameter Weibull	0.150	>0.500	
	Smallest Extreme Value	0.139	>0.250	
	Largest Extreme Value	1.395	<0.010	
	3-Parameter Gamma	6.560	*	
	Logistic	0.448	0.221	
	3-Parameter Loglogistic	0.465	*	
	Distribution	**AD**	**P**	**LRT P**
April	Normal	0.533	0.159	
	Box-Cox Transformation	0.402	0.338	
	Lognormal	0.453	0.253	
	3-Parameter Lognormal	0.411	*	0.627
	Exponential	6.543	<0.003	
	2-Parameter Exponential	1.969	<0.010	0.000
	Weibull	0.533	0.178	
	3-Parameter Weibull	0.469	0.256	0.086
	Smallest Extreme Value	1.253	<0.010	
	Largest Extreme Value	0.456	>0.250	
	Gamma	0.407	>0.250	
	3-Parameter Gamma	0.405	*	1.000
	Logistic	0.475	0.192	
	Loglogistic	0.431	0.241	
	3-Parameter Loglogistic	0.400	*	0.714

Table B. 3 Goodness of Fit Test Results of the Demand Data (Cont'd)

Month	Distribution	AD	P	LRT P
May	Normal	0.214	0.836	
	Box-Cox Transformation	0.161	0.942	
	Lognormal	0.305	0.549	
	3-Parameter Lognormal	0.175	*	0.392
	Exponential	6.296	<0.003	
	2-Parameter Exponential	1.861	<0.010	0.000
	Weibull	0.202	>0.250	
	3-Parameter Weibull	0.241	>0.500	0.179
	Smallest Extreme Value	0.786	0.038	
	Largest Extreme Value	0.275	>0.250	
	Gamma	0.197	>0.250	
	3-Parameter Gamma	0.190	*	0.973
	Logistic	0.199	>0.250	
	Loglogistic	0.262	>0.250	
	3-Parameter Loglogistic	0.178	*	0.515
	Distribution	**AD**	**P**	
June	Normal	0.707	0.058	
	3-Parameter Lognormal	3.500	*	
	2-Parameter Exponential	2.730	<0.010	
	3-Parameter Weibull	2.220	<0.005	
	Smallest Extreme Value	0.510	0.199	
	Largest Extreme Value	1.272	<0.010	
	3-Parameter Gamma	3.447	*	
	Logistic	0.706	0.038	
	3-Parameter Loglogistic	2.615	*	
	Johnson Transformation	0.501	0.191	

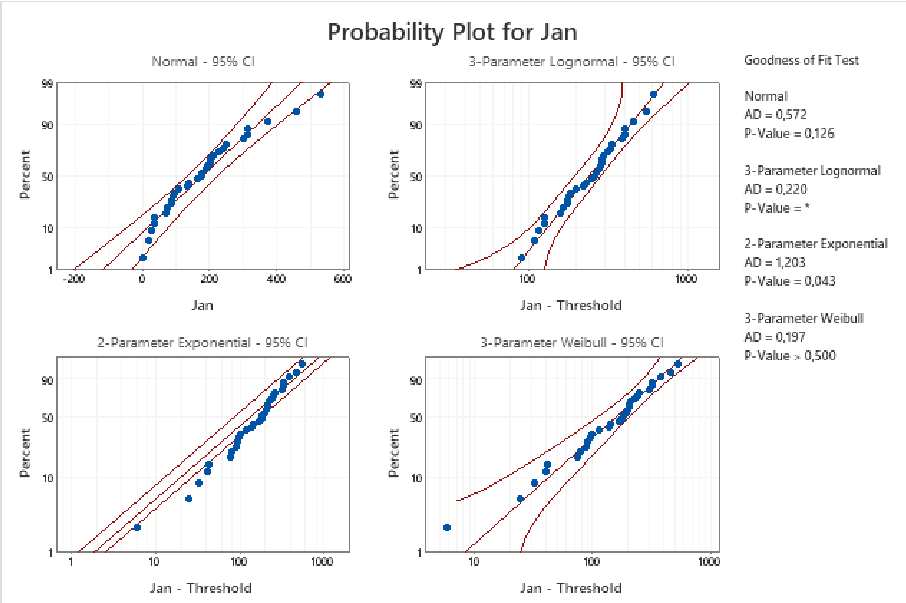

Figure B. 1 Probability Plots of January Demand Data-1

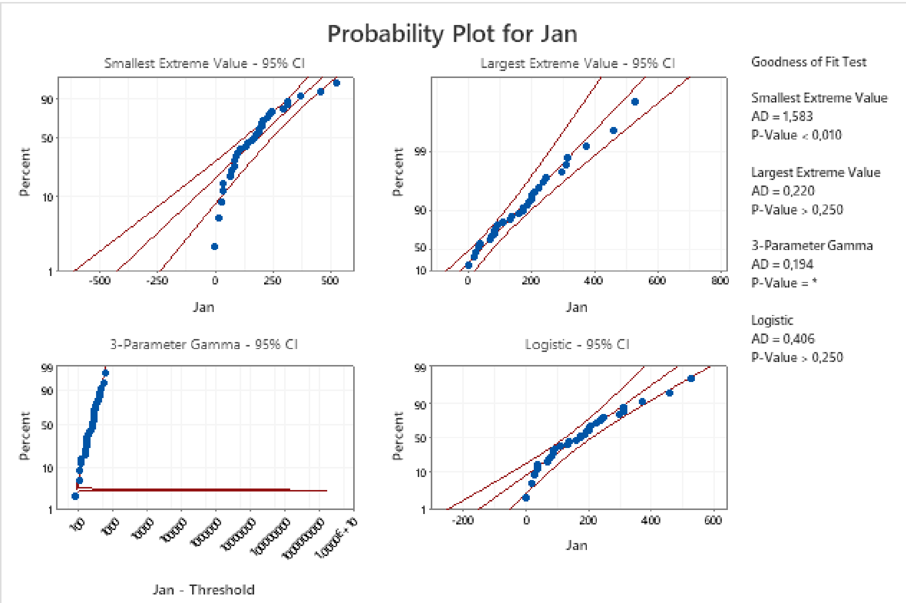

Figure B. 2 Probability Plots of January Demand Data-2

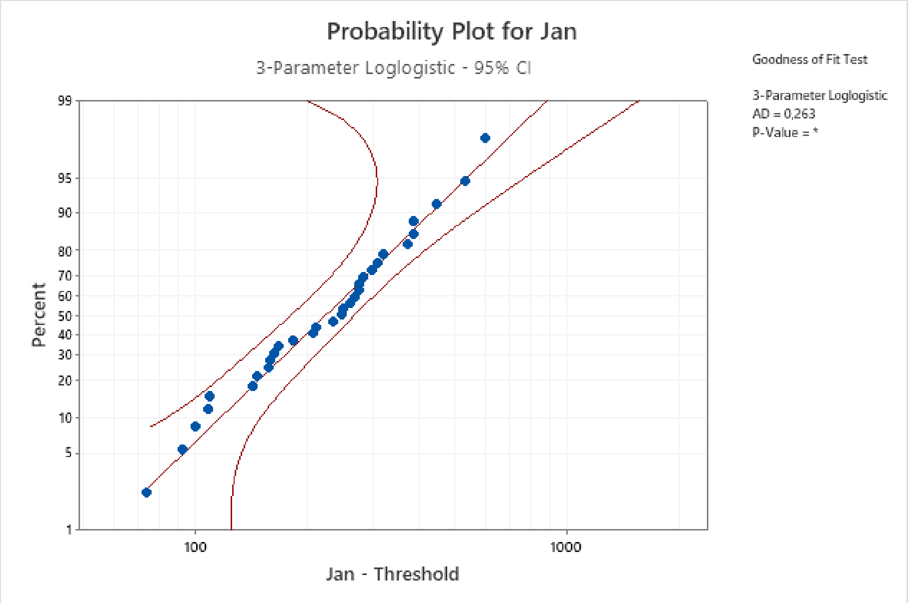

Figure B. 3 Probability Plots of January Demand Data-3

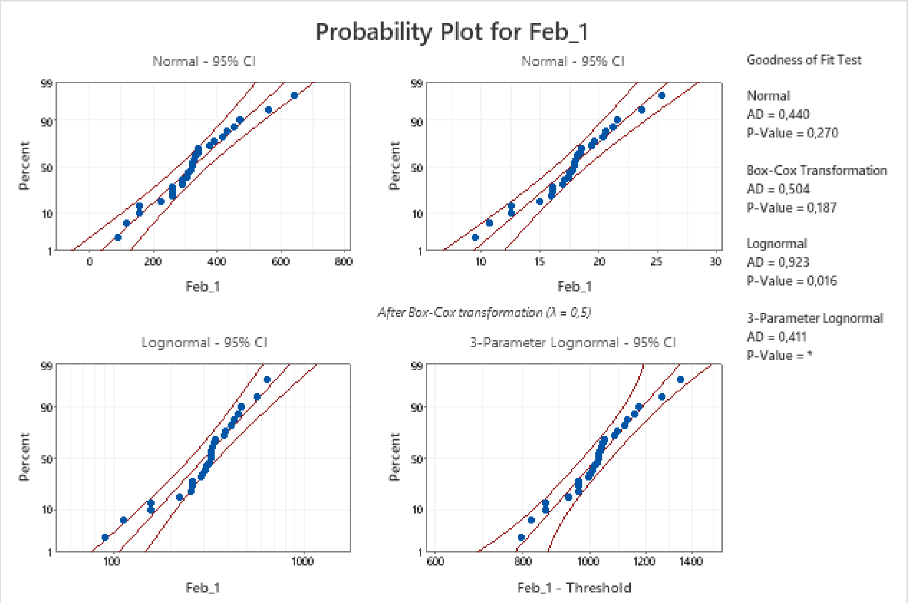

Figure B. 4 Probability Plots of February Demand Data-1

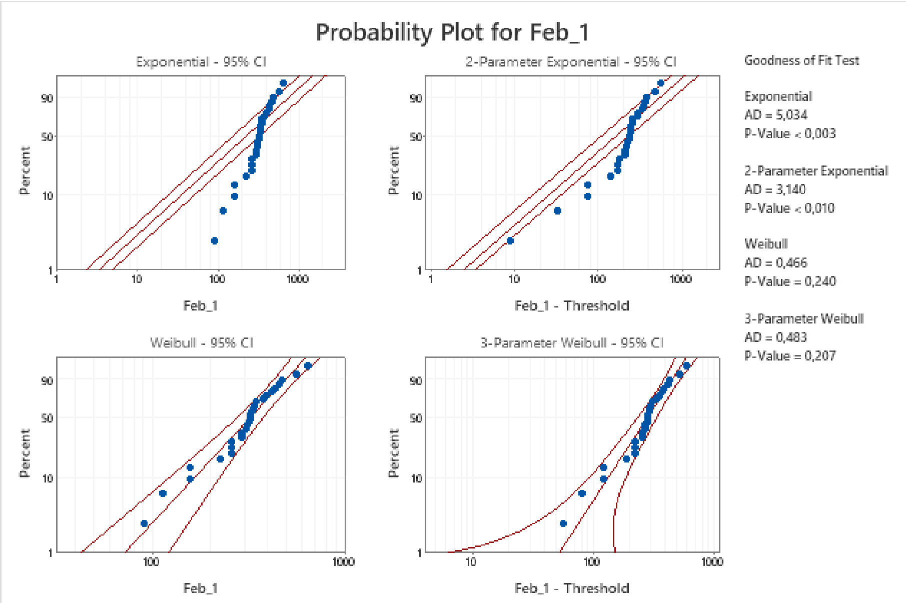

Figure B. 5 Probability Plots of February Demand Data-2

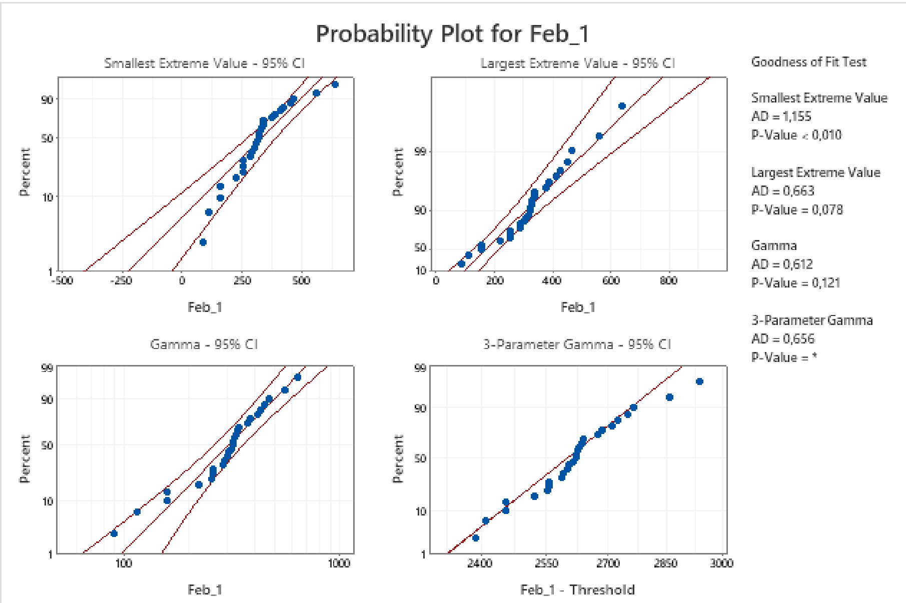

Figure B. 6 Probability Plots of February Demand Data-3

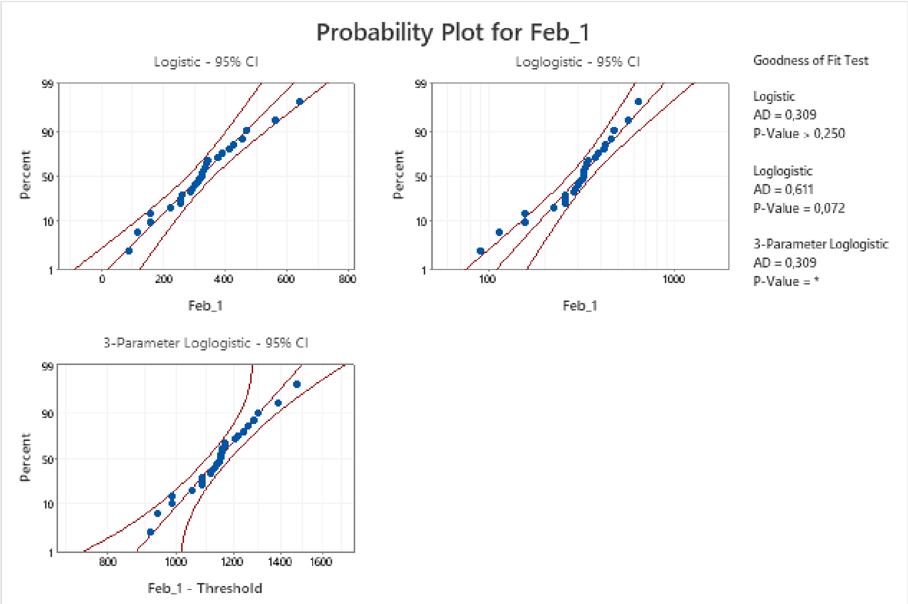

Figure B. 7 Probability Plots of February Demand Data-4

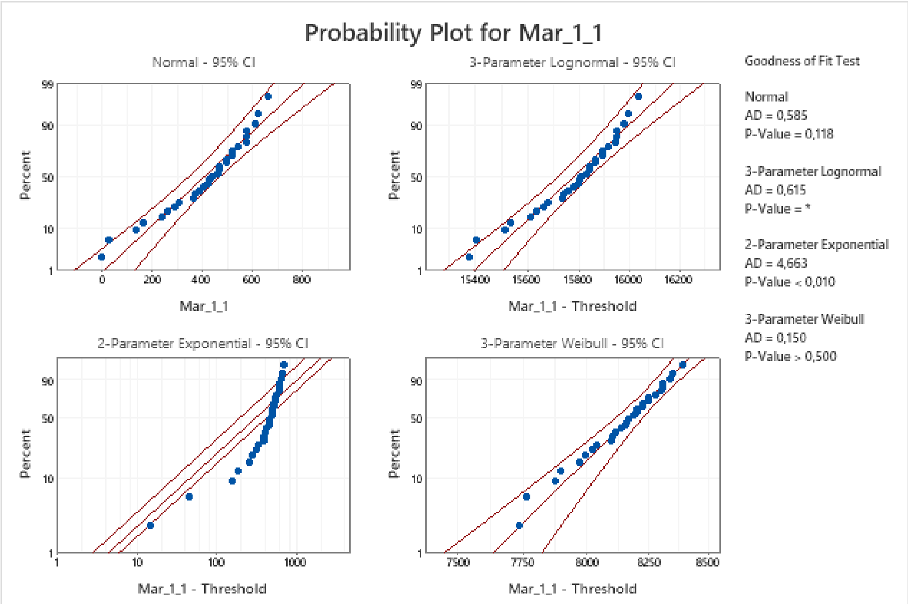

Figure B. 8 Probability Plots of March Demand Data-1

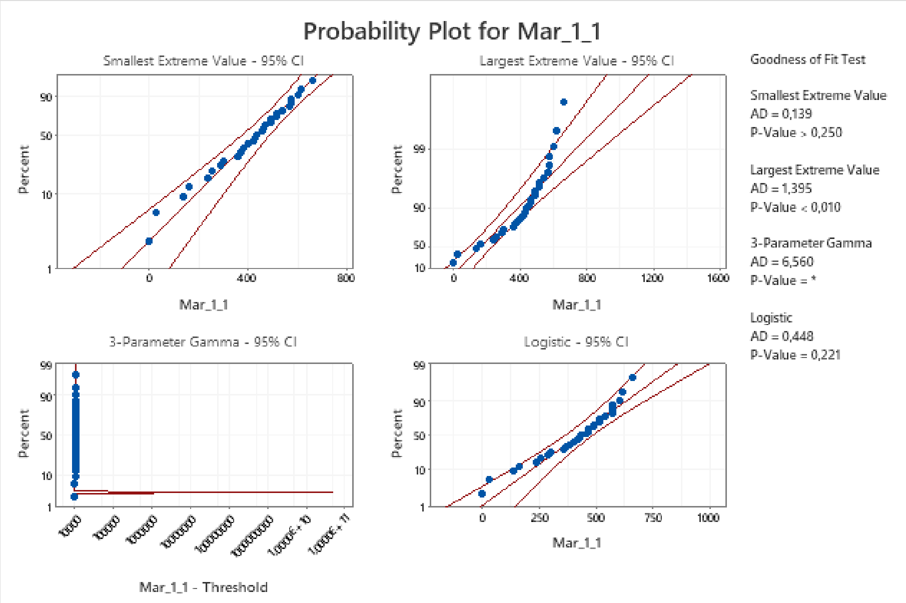

Figure B. 9 Probability Plots of March Demand Data-2

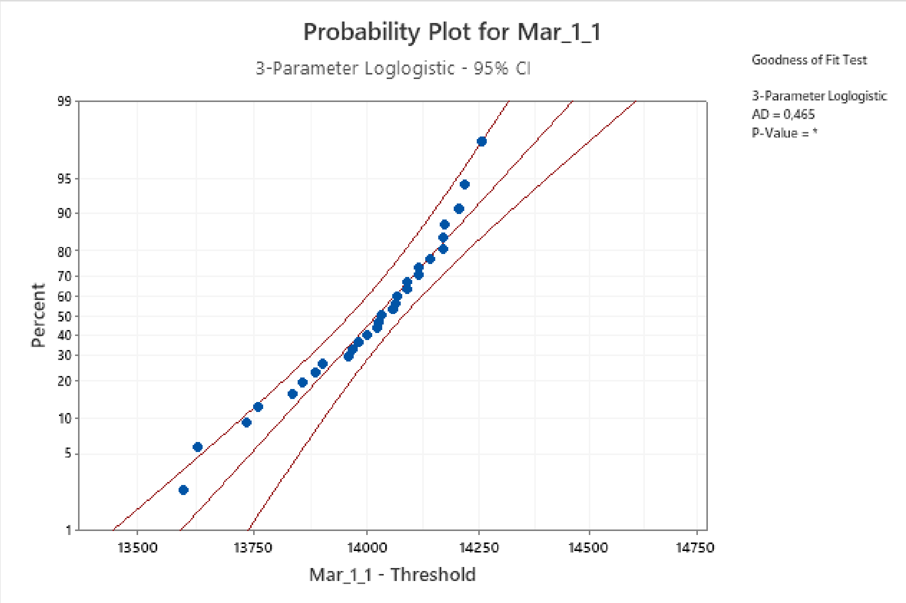

Figure B. 10 Probability Plots of March Demand Data-3

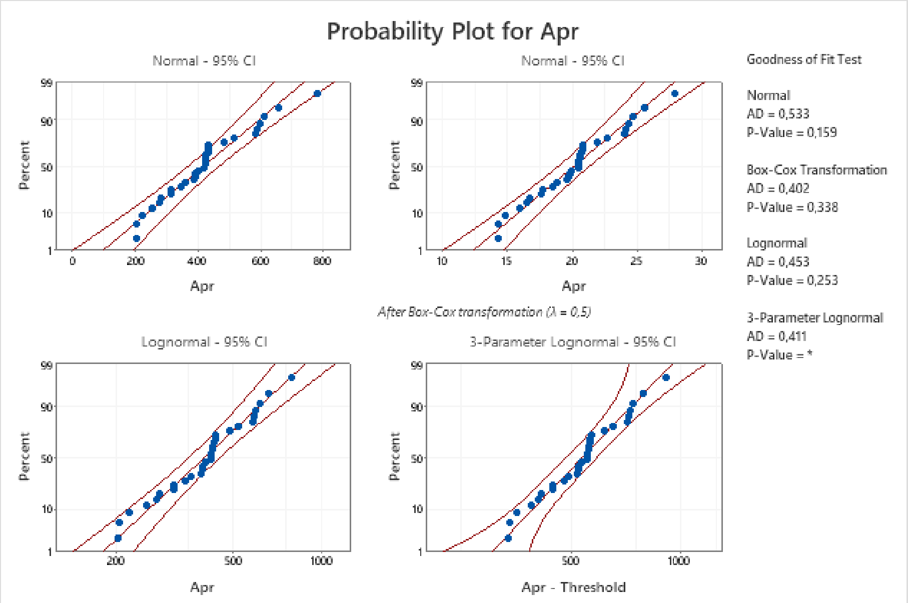

Figure B. 11 Probability Plots of April Demand Data-1

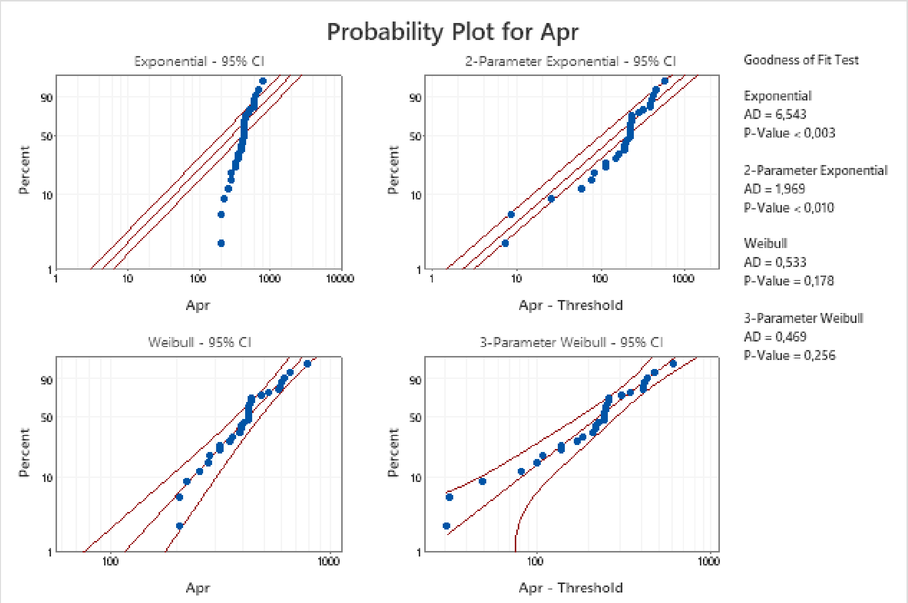

Figure B. 12 Probability Plots of April Demand Data-2

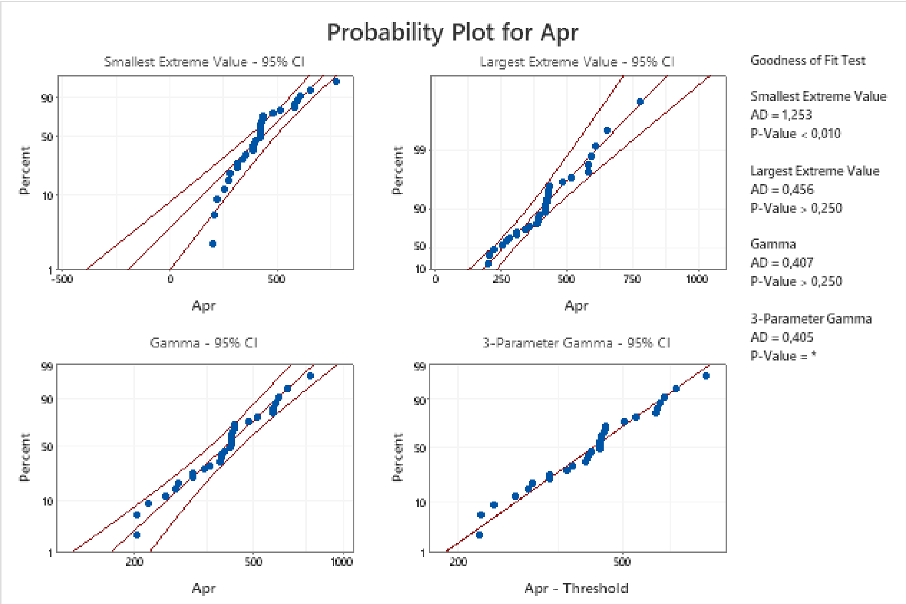

Figure B. 13 Probability Plots of April Demand Data-3

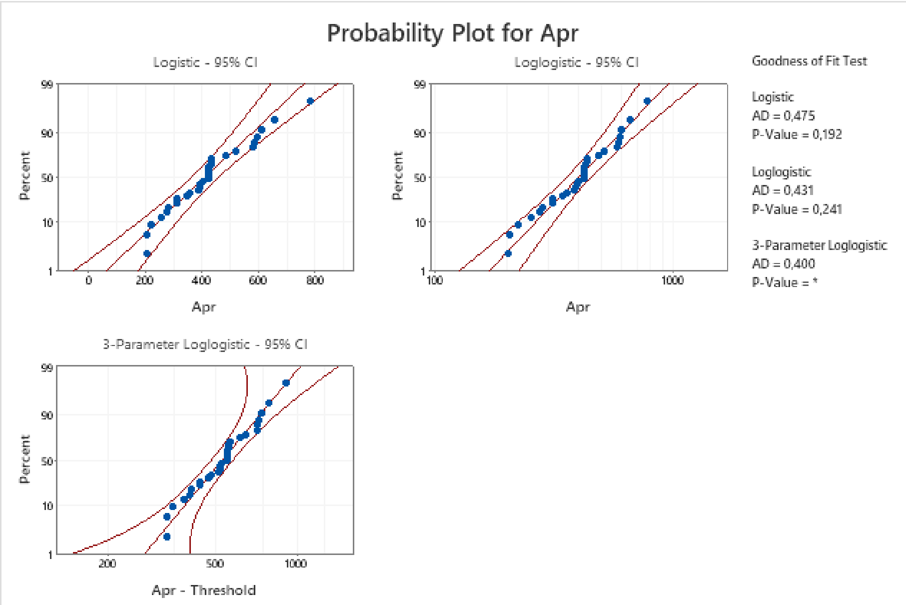

Figure B. 14 Probability Plots of April Demand Data-4

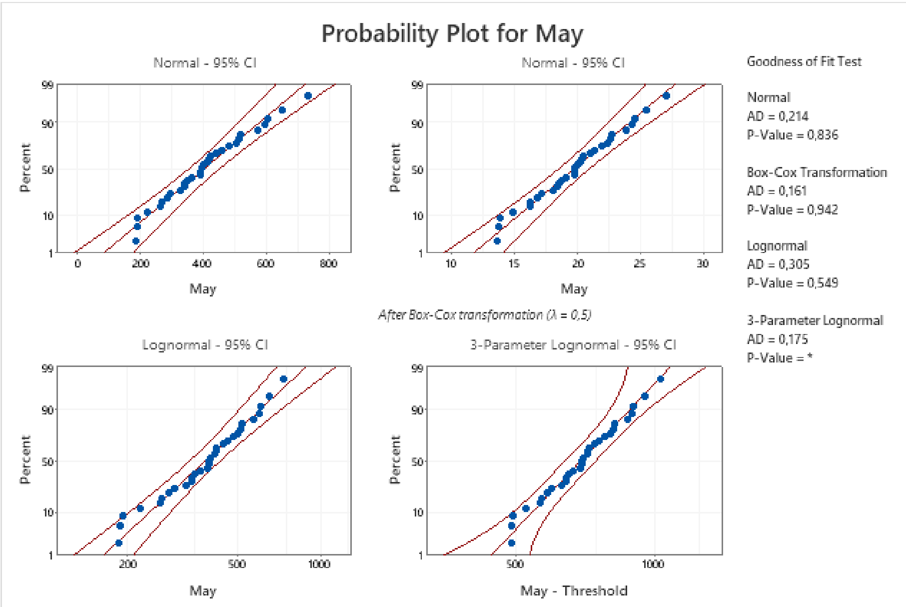

Figure B. 15 Probability Plots of May Demand Data-1

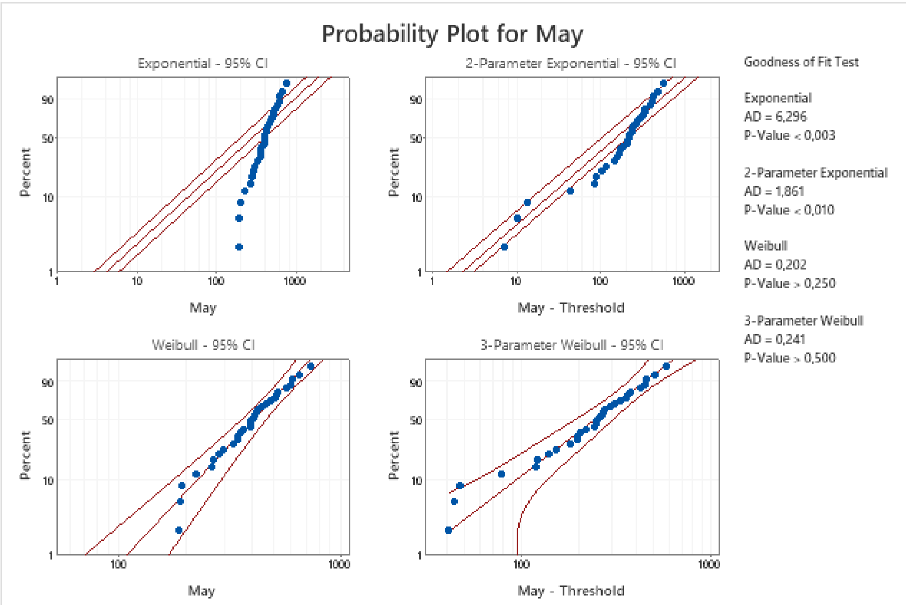

Figure B. 16 Probability Plots of May Demand Data-2

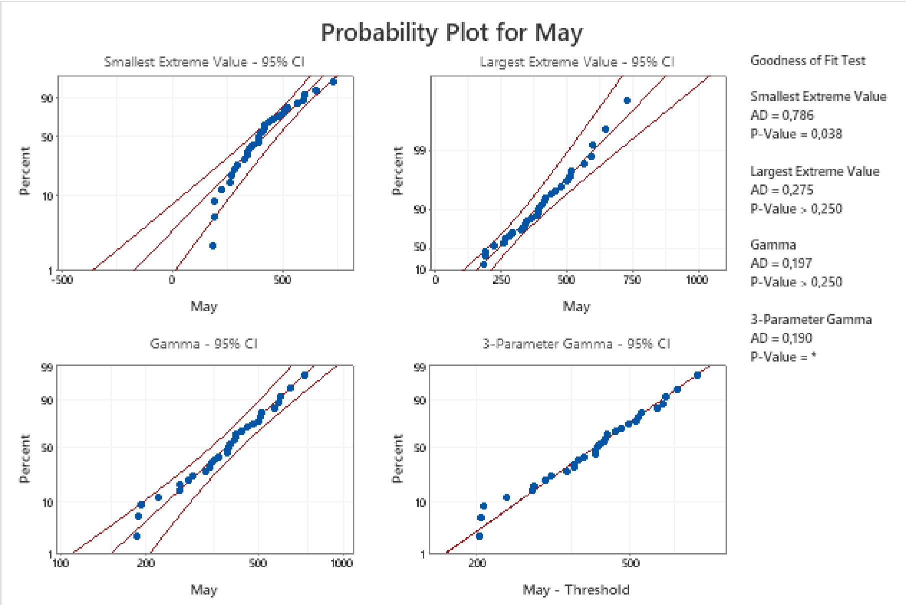

Figure B. 17 Probability Plots of May Demand Data-3

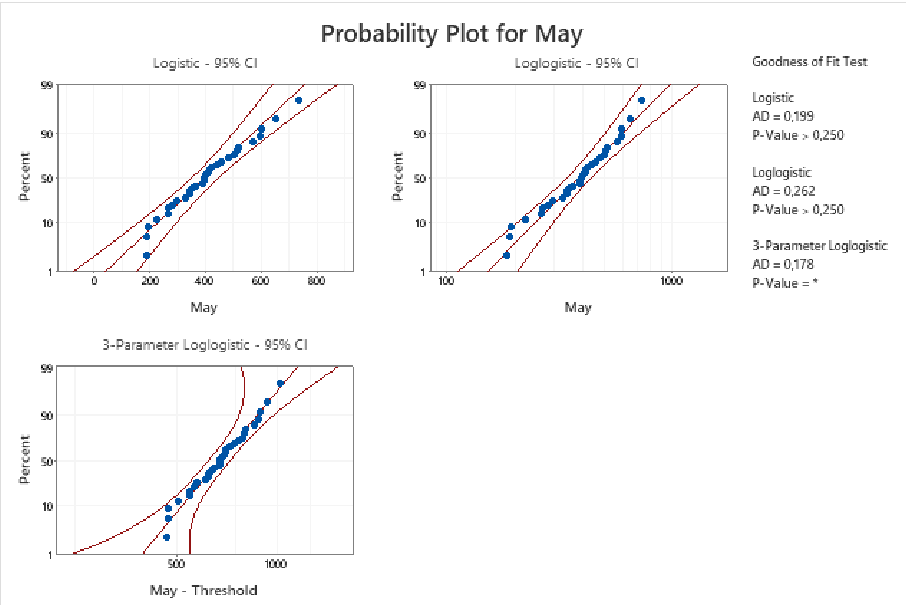

Figure B. 18 Probability Plots of May Demand Data-4

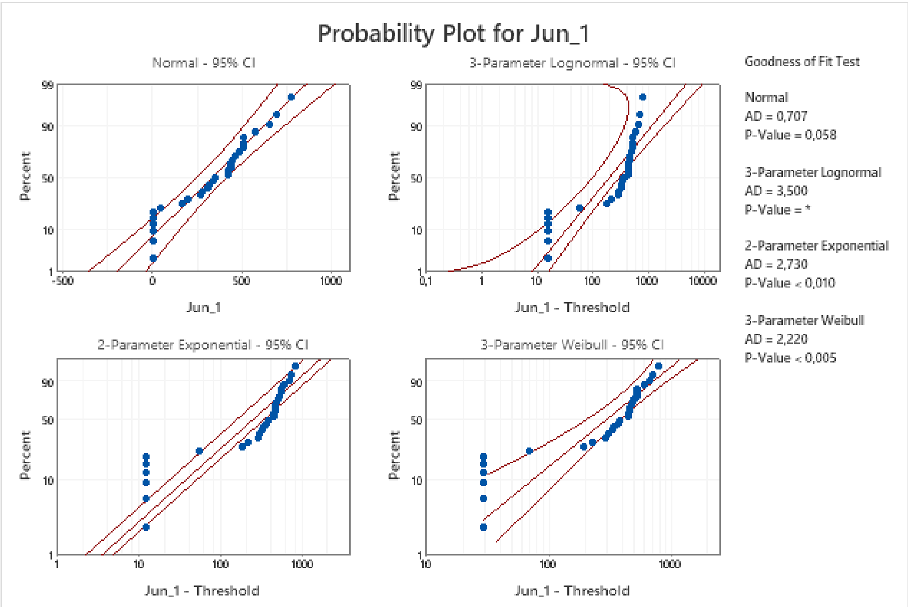

Figure B. 19 Probability Plots of June Demand Data-1

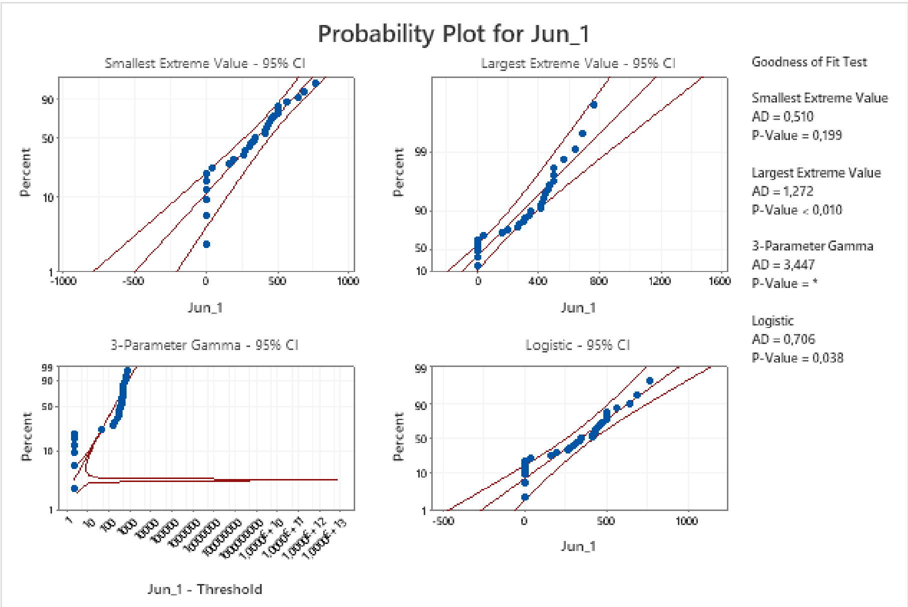

Figure B. 20 Probability Plots of June Demand Data-2

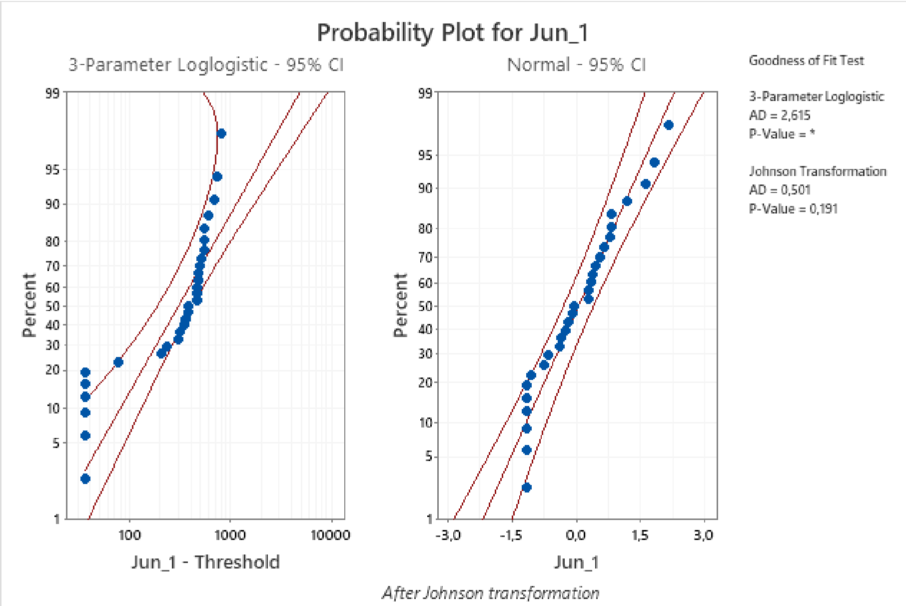

Figure B. 21 Probability Plots of June Demand Data-3