



MARMARA UNIVERSITY
INSTITUTE FOR GRADUATE STUDIES
IN PURE AND APPLIED SCIENCES



LEAN, AGILE, RESILIENT AND GREEN SUPPLY CHAIN MANAGEMENT (LARG SCM)

HASAN ÇEKE

MASTER THESIS

Department of Industrial Engineering

Thesis Supervisor

Prof. Dr. B.Gültekin ÇETİNER

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Hasan ÇEKE, a Master of Science student of Marmara University Institute for Graduate Studies in Pure and Applied Sciences, defended his thesis entitled “**Lean, Agile, Resilient and Green Supply Chain Management (LARG SCM)**”, on Feb 17, 2022 and has been found to be satisfactory by the jury members.

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ÖZET

YALIN, ÇEVİK, ESNEK VE YEŞİL TEDARİK ZİNCİRİ YÖNETİMİ (YÇEYTZY)

Dört temel paradigma (Yalın, Çevik, Esnek, Yeşil) tedarik zincirinin performansını düzenler. Yalın yaklaşımı esas olarak israf azaltma ve maliyet küçültme hususları üzerine odaklanır. Çevik, bu paradigma ise esneklik ile ilgilidir. Aslında çeviklik denilen paradigma, çabuk değişen pazar koşullarına hızlı bir şekilde tedarik zincirinin yanıt verebilme yeteneğidir. Esnek (dayanıklı) yaklaşım, beklenmeyen duraksamalar ile ilgilenir. Yani, sistemlerin bir duraksama deneyimledikten sonra, bir önceki durumuna veya yeni, daha arzulanan bir duruma dönebilme yetenekleri ile uğraşır. Son ama aynı derecede önemli olarak, Yeşil paradigma, imalatın bütün safhalarını değerlendirerek ekolojik verimliliği arttırmak hakkındadır.

Günümüzde ticaretin ve buna bağlı olarak üretim hacminin artmasıyla birlikte tedarik zincirleri önemini artarak korumaktadır. Bundan ötürü, tedarik zinciri yönetimi kavramı da farklı yaklaşımların içerisine dahil olarak kapsamı genişlemektedir. Yalın, çevik, esnek ve yeşil tedarik zinciri yönetimi, bu paradigmaların arasındaki karşılıklı ilişkilerle ilgilenir. Bu anlayışın çok önemli olduğuna inanılmaktadır. Bunun nedeni, bu yaklaşımların imalat sektöründeki tedarik zincirinin tüm işlevsel alanlarında uyumlu olması gerektiğidir. Bu başarı, imalatçı firmalar için rekabetçi ve sürdürülebilir bir ortam için önemli bir katkı sağlayacaktır.

Bu çalışma ile bu yaklaşımların Türkiye'deki bir imalat firmasına uygulanabilirliği test edilmiştir. Seçilen firmaya özgü bir şekilde Analitik Ağ Süreci uygulanmıştır. Bunun yanı sıra, öncelik tablosunu elde etmek için bir uzmandan veriler toplanmıştır. Bu nedenle dört alternatif proje belirlenmiştir. Ayrıca, bu yaklaşımların bu projelere entegre edilip edilemeyeceğini göstermek için yalın, çevik, esnek ve yeşil uygulamalar sağlanmıştır. Bileşenleri buna göre önceliklendirip, tedarik zincirinin performansının artıp artmadığı konusunda derinlemesine bir anlayışa sahip olunmuştur.

ANAHTAR SÖZCÜKLER: Yalın, Çevik, Esnek, Yeşil, Tedarik Zinciri Yönetimi, Analitik Ağ Süreci

ABSTRACT

LEAN, AGILE, RESILIENT AND GREEN SUPPLY CHAIN MANAGEMENT (LARG SCM)

Four basic paradigms (Lean, Agile, Flexible, and Green) regulate the performance of the supply chain. The lean approach mainly focuses on waste reduction and cost reduction considerations. Agile, on the other hand, is about flexibility. This paradigm is about In fact, the paradigm called "agile" refers to the ability of the supply chain to respond quickly to rapidly changing market conditions. The resilience approach deals with unexpected pauses. That is, it deals with the ability of systems to return to a previous state or a new, more desirable state after experiencing a pause. Last but not least, the green paradigm is about increasing ecological efficiency by evaluating all aspects of manufacturing.

Today, with the increase in trade and, accordingly, production volume, supply chains maintain their importance increasingly. Therefore, the concept of supply chain management expands its scope by including different approaches. Lean, agile, resilient and green supply chain management deals with the interrelationships between these paradigms. This understanding is believed to be very important. This is because these approaches must be compatible across all functional areas of the supply chain in the manufacturing sector. This success will make an important contribution to a competitive and sustainable environment for manufacturing companies.

In this study, the applicability of these approaches to a manufacturing company in Turkey has been tested. The Analytical Network Process has been applied in a way specific to the selected company. In addition, data was collected from an expert to obtain the priority table. For this reason, four alternative projects were determined. In addition, lean, agile, flexible, and green practices are provided to demonstrate whether these approaches can be integrated into these projects. By prioritizing the components accordingly, an in-depth understanding was gained of whether the performance of the supply chain was improving or not..

KEYWORDS: Lean, Agile, Resilient, Green, SCM, ANP

SYMBOLS

& : Ampersand

λ : Lambda



ABBREVIATIONS

AHP	: Analytic Hierarchical Process
ANP	: Analytic Network Process
CBR	: Case-Based Reasoning
DEA	: Data Envelopment Anaysis
ELECTRE	: ELimination Et Choice Translating REality
LARG	: Lean, Agile, Resilient, Green
MAUT	: Multi-Attribute Utility Theory
SAW	: Simple Additive Weighting
SC(s)	: Supply Chain(s)
SCM	: Supply Chain Management
SMART	: Simple Multi-Attribute Rating Technique
TOPSIS	: Technique for Order of Preference by Similarity to Ideal Solution

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1. INTRODUCTION

Companies look for new methods in earning money rather than by enhancing their market shares or profits. Consequently, supply chain management became more crucial than revenue generation alone. Four attributes, namely, Lean, Agile, Resilient & Green, joined as new, original methods to the global competition. Competence changed dimension. As the supply chains grow enormously, the importance of those approaches increase.

These four main paradigms regulate the performance of the supply chain. One of them is the Lean paradigm. It mainly focuses on waste reduction and cost minimization. Lean approach tries to minimize inventory level. And also it aims to reduce work-in-process. The other one is the Agile paradigm, it is about flexibility. Actually, the capacity of a supply chain to adjust swiftly to volatile markets is known as agility. Resilient paradigm is concerned about the unexpected disruptions. It's all about a system's capacity to get rid of a disruption and return to its original condition or a new, more desirable manner. Lastly, green paradigm is about increasing the ecological efficiency by evaluating all the phases of manufacturing.

The combination of LARG paradigms is the key to long-term corporate growth and competitive advantage. The majority of articles on LARG SCM (Lean, Agile, Resilient, and Green Supply Chain Management) recommend research into the influence of LARG methodologies on industrial supply chain performance. In addition, several of the articles developed models based on anecdotal and empirical evidence collected in the literature. There was no validation either. The number of real-life case studies has been underestimated. This might be because the LARG (Lean, Agile, Resilient, and Green) idea is fresh and wide.

In general, criteria in the literature were provided. The importance of the criteria was mentioned later on. The effect of LARG paradigms to the criteria were investigated. Afterwards, the problem was given and sub-criteria were mentioned in terms of their significance for the company that we worked together in order to obtain the results. Criteria and sub-criteria list was provided and some graphs were also provided so as to illustrate the interrelationships between lean, agile, resilient and green paradigms. In the graphs, the effects were mentioned and the content was explained wherever it is needed.

There are three different parts about those relevant criteria. In the following sections, they will be shared and commented to clarify and simplify the paradigms. In the first part paradigms and practices will be explained, secondly, criterions and sub-criterions and their effects, lastly the problem will be provided.

In this thesis, we aimed to indicate that whether LARG paradigms can be integrated or not to the supply chains of manufacturing companies in Turkey. Finally, the contribution of this thesis will be the opportunity that it provides to test the applicability of all these four paradigms (approaches) in detail. And also, to contribute in an area where literature is lacking.

1.1. Definition of Supply Chain

Supply-chain is mainly concerned about stages that can be directly or indirectly included to the process of meeting a customer request. Extensively, it is known as a system of components. Beginning with the supplier to the customer or to the end-user, supply chains deal both with the components of the system and the flow of the goods, materials, money and information.

Customers or end users buy products from the retailers or wholesalers. They can also make their purchases from a shop which is both a wholesaler and a retailer. Wholesalers and / or retailers buy products in order to sell from distributors or the manufacturers. Distributors are the transporters. Manufacturers purchase raw materials from suppliers. Manufacturers can buy semifinished products. They add them value so as to sell to the customers afterwards. Below, material flow has been shown from suppliers to customers.

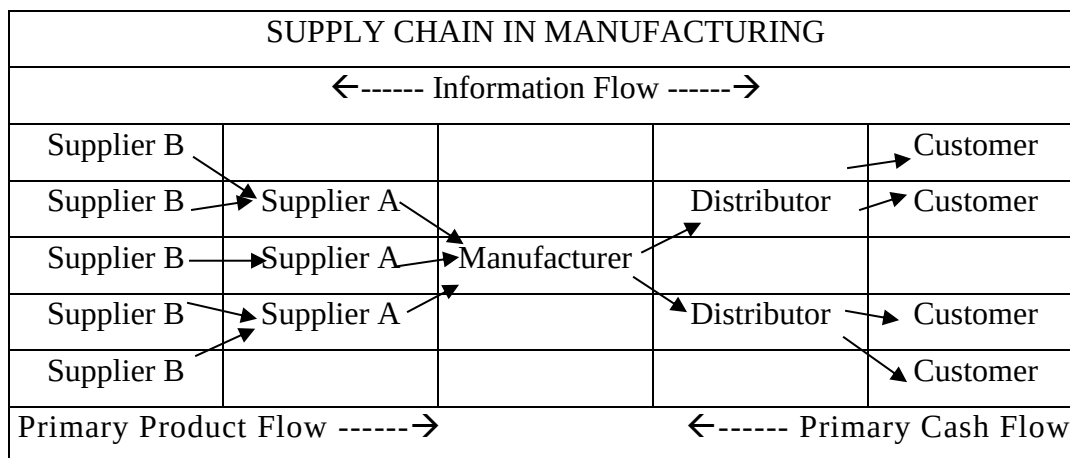


Figure 1. 1 A schema for supply chain processes in manufacturing

Logistics is also a widespread term used in this field. The main difference between logistics and the supply chain definitions is the purchasing and inventory processes. Eventually, supply chain consists of processes.

1.2. Definition of Management

Management is a function of a business. This function consists of planning and forecasting, command and coordination, control of the whole process within the organization. Management part of a business environment should have a plan and guess the future in order to follow the organizational goal. So, plans should be adjusted. While doing this, commanding and coordination which means a good communication among the human resources of the business. Controlling and arrangement of all the above features makes any businesses to be managed properly.

1.3. Definition of Supply Chain Management

"SCM engages the management of flows between and across stages in a supply chain to reduce total cost," according to Chopra and Meindl (2001). According to this definition, SCM is the management of product, information, and financial flows both upstream and downstream in the supply chain. SCM has slowly acquired respect as a tried-and-true managerial strategy for providing long-term profits and growth in the face of fierce competition across all industries. This is often accomplished by focusing on the whole SCM process in order to provide the relevant commodities or services, in the correct quantity, to the correct location, at the correct time, and with the highest potential advantages.

Significant influences were discovered as supply chain structure, inventory management policy, information interchange, customer demand, forecasting technique, lead time, and review period duration. The appropriate selection of the features of these components improves supply chain performance.

1.4. Literature Review

A causal loop modeling technique was utilized to aid in the construction of a conceptual model focusing on SC performance and the integration of lean and green practices. The major goal is to offer a typology of performance indicators that would allow SCs to be

evaluated on three levels: operational, economic, and environmental (Carvalho et al., 2010).

This research presents a theoretical framework for developing a LARG ICT platform system. Use Case Diagrams, Class Diagrams, Core LARG Classes, and Attributes were all utilised. An information (ICT) model for an SCM platform to support current integrated LARG paradigms will be presented and discussed (Cruz-Machado et al., 2010) (Azevedo et al., 2011) proposes practices about LARG and provides a conceptual model. To propose a conceptual model for LARG supply chain to develop their functional, financial and environmental maintainability.

(Cabral et al., 2011) propose two models (ANP, AHP) that can be used to aid decision-making when it comes to LARG practices and interoperability. The ANP model aims to rank LARG practices according to their interoperability levels, whereas the AHP model seeks to pick the best LARG practices to be the supply chain competitiveness.

The integration technique incorporates the primary variables that affect SCM, allowing for a thorough knowledge of the effects of SC's paradigms on the ground. The goal is to boost SC's competitiveness and creativity (Maleki et al., 2011)

.(Parveen et al., 2011) examine lean supply chain tools using data from industries that employ lean manufacturing principles. In the examination of the environmental performance of the lean supply chain, environmental waste reduction is employed as a key performance measure. The purpose of this research is to investigate the lean supply chain's capabilities in terms of green technology and environmental performance.

(Carvalho et al., 2012) present a mapping framework for improving SC resilience in the face of such catastrophes while minimizing potential failure mechanisms. The suggested mapping approach enables the identification of the current SC functioning, as well as possible transition phases and susceptibility areas. An example of the framework in action on a real-world wine SC is provided. The goal of this study is to create a SC mapping methodology for resilience assessment with the following goals:

- comprehend the SC network and determine the present SC operation state
- determine possible transition states
- determine the SC's critical activities/vulnerabilities.

(Lenort and Wicher, 2012) modified the article's structure to meet its goals. The core ideas of lean, agile, and resilient supply chains are gradually described in the first three

chapters. They are followed by a comparison of the separate techniques' characteristics and proposals for their integration into a compact unit - the LAR supply chain. The article's main goals are dual. The first is to describe the fundamental characteristics of the various approaches to supply chain management and to demonstrate the concepts that are utilized to put these methods into practice. The second goal is to analyze the various approaches and see if there are any opportunities to combine them.

(Cabral et al., 2012) provide an integrated LARG ANP model to help supply chain firms make decisions about the best practices and key performance metrics to adopt. A case study in an automobile producer supply chain is proposed to validate the model in an exploratory method. The major goal is to present a practical decision-making paradigm that firms and supply chains can simply implement to improve their LARG performance. (Wieland and Wallenburg, 2012) employ a confirmatory technique with the relational perspective as the primary theoretical background. The study is empirical. It employs survey data from manufacturing firms in three countries, which is then analyzed using structural equation modeling. The purpose of this research is to investigate the resilience domain, which is important in supply chain management; it investigates the impacts relational skills have on resilience, and resilience, in turn, has on the customer value of a supply chain.

(Wieland, 2012) discusses two supply chain techniques: agility and resilience. Mathematical models are used to determine optimal solutions and break-even points for the cost functions of the strategies in relation to p and i . The purpose of this paper is to offer a model that allows a company to select a supply chain strategy based on risk probability p and risk effect i .

(Wicher et al., 2012)

There are four fundamental steps in the process used to determine the degree of resilience.

- *Determination of the factors to be investigated.

- *Analysis of the consequences

- *Analysis of Relationships (incidental analysis).

- *Evaluation of the studies and recommendations for improving the supply chain's level of resilience.

The purpose of this article is to develop a mechanism for determining the degree of supply chain resilience.

(Azevedo and Cruz – Machado, 2012) constructed a conceptual model to explore the influence of lean, resilient, and green SCM strategies on SC sustainability. The conceptual model was created by a deductive research technique based on a survey of the literature. The primary purpose of this research is to propose a conceptual model for assessing the influence of lean, resilient, and green supply chain techniques on economic, social, and environmental sustainability.

The constructs' reliability and validity were evaluated using SPSS 19 and AMOS 19, as well as three CFA models that used the maximum likelihood estimation method. Confirmatory factor analysis was used because theory-based a priority linkages between item measures and constructs were constructed based on the literature. In today's volatile and turbulent markets, it's more critical than ever to remain resilient. While many academics are trying to figure out what characteristics might help businesses (and their supply chains) become more resilient, issues about how resilience ties in with leanness and agility remain unresolved. (Kocabasoglu, 2013) provides an answer to this question. (Carvalho et al., 2013) create a model to support the AR index. Then, an AR index for the automotive supply chain is developed, based on a collection of appropriate agile and resilient supply chain strategies. The Delphi technique was used to construct a set of weights for such activities. Finally, a case study approach is offered to explain how to use the AR index. The goal of this article is to propose the "AR index," a composite index for assessing the agility and resilience of automotive firms and their supply networks.

(Azevedo et al., 2013) use an illustrated case methodology to suggest a numeric-linguistic interface based on fuzzy logic. This chapter provides a fuzzy LARG index model to analyze the degree to which automotive supply chains have implemented Lean, Agile, Resilient, and Green management techniques (SCs).

(Mari et al., 2014) proposed a supply chain model. The major goal is to ensure that the supply chain network is both sustainable and resilient enough to withstand unforeseen disruption risks. The weighted goal programming (WGP) approach has been used to construct the mathematical model.

(Azevedo et al., 2014) use an exploratory case study approach to identify the trade-offs in the automotive SC context. This paper intends to identify and provide the necessary of those paradigms.

Toyota South Africa Motors (TSAM) was the subject of a descriptive case study to see if

a clear link could be formed between the company's environmental strategy, lean concepts, and established best practice culture. In addition, the case study examined if implementing all three principles at the same time benefited business outcomes. As a strategy for organizations to build sustainable competitive advantages, this study produced a framework to incorporate lean, green, and best practice ideas into an integrated business model (Wiese et al., 2015).

(Dev and Kumar, 2015) discuss about the various industrial perspective aspects of several researchers on agile manufacturing. It tells about agile manufacturing techniques.

(Govindan et al., 2015) use the interpretive structural modeling approach. To specify the crucial lean, green and resilient practices on which top management should focus so as to improve the performance of automotive supply chains.

Basic research, applied research, and developmental research are the three types of research classified by objective (Sarmad, Bazargan & Hejazi, 1999). In terms of nature and approach, the current study is descriptive and analytical. The researcher in descriptive and analytical investigations not only states the problem, but also explains and describes it and its dimensions (Hafez niya, 2007). With management techniques such as SWOT, BI, and RFID technology, the current study attempted to make LARG supply chain management smart and detect its conditions (Ghotbabadi et al., 2016).

In this study, the scenario planning technique is used to analyze various trade routes that originate in central China. The primary goal of this research paper is to validate the conceptually presented LARG paradigm through a case study of Chinese logistics (Mumtaz et al., 2016).

After an extensive search, 60 articles from 1996 to 2016 were identified as relevant to this study. (Hallam and Contreras, 2016) aim to perform a literature review of peer-reviewed journal articles investigating the relationship between Lean and Green management in light of developing an integrated management model.

(Duarte et al., 2016) provide a business model canvas perspective about the LARG paradigms. To contribute to the discussion about developing an ideal type of business models to be integrated into the LARG paradigm.

The experimental approach is the preferred method of measuring risk in this paper. Then, 81 simulation-based experiments with the ARENA simulator are run. (Rachid, 2017) presents a logistics academic case study in which simulation is used to illustrate all stages.

The authors' scientific literature review reveals a number of capabilities that influence supply chain resilience. Collaboration, flexibility, redundancy, and integration are the most influential supply chain resilience capabilities. (Gruzauskas and Vilkas, 2017) examine the critical capabilities that can aid in achieving resilience and to propose an IT-based approach to limiting the trade-offs in the process.

The empirical study technique included the selection and classification of 144 research articles in GSCM. (Singh et al., 2017) provide a critical assessment of empirical research content in GSCM.

An exploratory and qualitative research approach that explores practical views using theoretical concepts from the SCM literature. Through a case study of companies in the automotive SC, this paper first integrates empirical data and practitioner opinions to bridge the gap between theory and practice, and then extends existing conceptual frameworks on sustainable SCM and resilient SCM by proposing a novel SCM framework that includes both resilience and sustainability. (Karutz et al., 2018) investigate the interaction of sustainable and resilient SCM methods from both a conceptual and a practical standpoint, as well as to make recommendations for future research.

The above studies describe a positive relationship between LARG approaches and SCM. They mainly focus on managerial decisions in such a way that the supply chain performance improves. As the number of decisions to be dealt with increase, it gets hard to determine relevant information about the supply chain. So, these studies try to ease managerial decisions. The key to their effectiveness is hidden in their deployment of LARG approaches as a whole and also separately. Therefore, we have an expectation that these approaches are applicable in Turkey as well. Probably, it is a new and broad concept to expertise, there is deficiency in the literature on this concept in Turkey.

In the early years of LARG project which had been started by Unidemi, much more articles were published exactly on the same topic. Most of the articles were about the definition of the attributes and the interrelationships between them. However, the number of articles published have decreased during the last four years. Different point of views started to take place in the literature.

To sum up, researchers point out that resilience and sustainability may be a gap to be

fulfilled in supply chain management. Also, lean and resilient paradigms may be integrated more and deeply. Lean concept aims zero inventory, however resilience offers to have inventory. These concepts seem incompatible. This can be put in a compatible basis with further research. Last, but not least, the researchers propose making researches about different areas in both manufacturing and service sectors. In future researches, green, agile, resilient and green (together) should be focused according to analysis made. Lean, Agile, Resilient and Green Paradigms were mentioned 20, 18, 24 and 20 times respectively in 30 articles which were reviewed. Resilience is the most researched paradigm among these four paradigms. Agile is the least researched one.

Table 1. 1 Number of times each paradigm was mentioned respectively

<i>Articles Reviewed</i>	<i>Lean</i>	<i>Agile</i>	<i>Resilient</i>	<i>Green</i>
<i>Number of Articles</i>	20	18	24	20

Here, the table below shows the number of paradigms mentioned alone or together by the researchers. These 4 paradigms are mostly mentioned together. That is obviously about they complement each other and this way they are more effective on supply chain management. There is no article researched only about lean. The table 1.1 and table 1.2 complete each other and illustrate the content of the articles reviewed briefly.

Table 1. 2 Number of times articles mentioned

<i>Article Content</i>	<i>LARG</i>	<i>LAR</i>	<i>LRG</i>	<i>LG</i>	<i>A</i>	<i>AR</i>	<i>R</i>	<i>RG</i>	<i>G</i>
<i>Number of Article</i>	12	2	2	4	1	3	4	1	1

And the graphical representation of the distribution paradigms are shown in percentages beneath this line. Clearly %40 of the articles contain 4 paradigms together. The least researched paradigms are agile, green and resilient & green. Below, a subset of paradigms can be seen as a distribution.

This pie chart illustrates the percentages of the articles reviewed. All four paradigms constitute 40% of thirty articles reviewed. The least reviewed articles are about agile, green and resilient and green together as they constitute 9% of thirty articles.

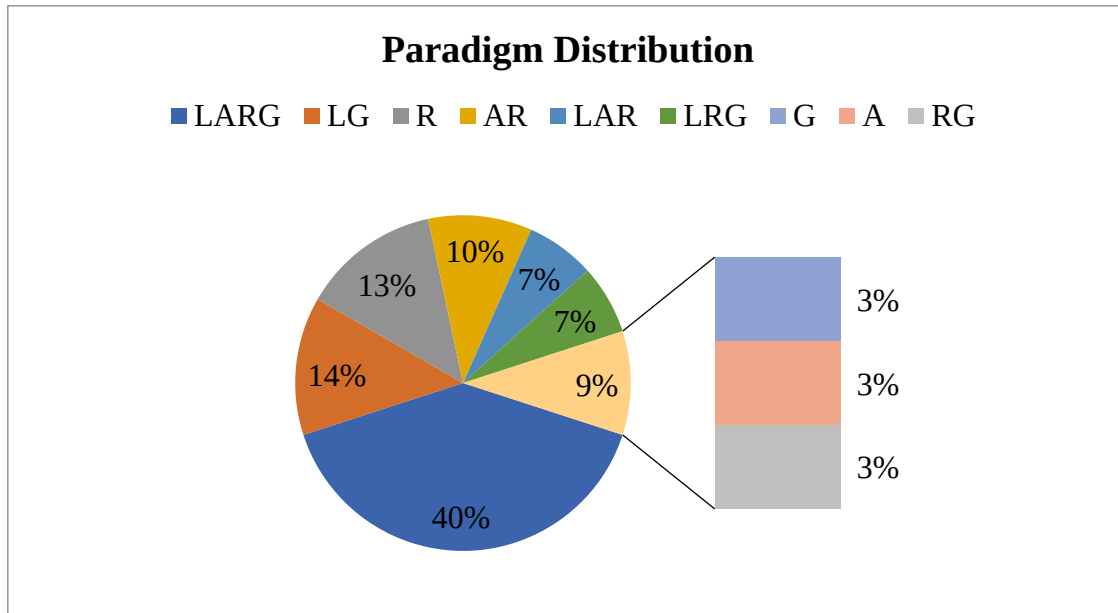


Figure 1. 2 A graphical representation of LARG paradigms

The quality of the approaches is more important than their quantity. Therefore, it is thought that it would be more accurate to deal with their content rather than their number. For this reason, in-depth research was carried out on the subject, and almost all sources in the literature were examined on the basis of articles.

In the next section, the aforementioned approaches are examined. In addition to these approaches, important performance measures that affect the performance of the supply chain are discussed. The approaches are briefly mentioned. The aim was to explain the detailed information available on the subject in a short and concise manner.

In the following section, the drivers/enablers will be mentioned. These enablers are given to evaluate the performance of the supply chain. And also, key performance indicators will be mentioned. Key performance indicators are called as sub-criteria. Criteria and sub-criteria list will be provided so that a deep understanding of the main problem become clear in minds.

2. LARG SCM

LARG paradigms have been explained to make a clear understanding on leanness, agility, resilience and greenness. All these four concepts together try to improve the performance of the supply-chain.

2.1. Lean Supply Chain Management

The lean or JIT (Just-in-time) management strategy was developed by Toyota Motor Company. It is based on two main philosophies. Autonomation and Just-In-Time. It means to produce the right quantity at the right time which means when needed. Lean struggles to spot and eliminate all non-value added activities in value stream including the continuous improvement of all of the processes in the business. According to Lean philosophy, there should be zero pieces in the inventory so that to prevent mass production. Because, it causes a huge amount of money. It is better to keep the working capital instead of making over-production. So, it is better to meet the demand according to the perspective of the customers. This is called Pull method. Another principle is one-piece flow, it improves the flexibility and increases the quality and also minimizes the work in progress. It is easier to control the production and to maintain the quality of the goods in this way. If we can control takt time, we can have a better and leaner supply chain management. Takt time is the ratio of how fast we need to manufacture to meet the customer demand. Another important thing is zero defects. Mistakes from the previous steps of manufacturing must be fixed before going on. Considering all the above, some of the lean practices are provided.

Lean Practices:

- Time
- Reducing costs
- Optimization of recipes (raw material composition) in the product
- Using the machines more efficiently
- Raw material development with suppliers that support the increase in efficiency in machinery
- Increasing workforce productivity
- Reduce energy consumption

- Supporting R & D
- Development of raw materials
- Efficient use of resources
- Wastage, waste and scrap
- Making profit
- Customer satisfaction
- Shortening the processes
- Delivery in favorable conditions and on time
- Improvement in deliveries
- Cost reduction
- Speed up production
- Increasing the efficiency of machinery and equipment
- Improvements to shorten cycle times of some machines
- Raw material improvement
- Cooperation with the supplier
- Making the layout of the workplace suitable for getting the job done in less time and easier
- Wastage, waste and scrap reduction studies
- Minimum stock usage

2.2. Agile Supply Chain Management

The definition of supply chain agility has taken a lot of time and work. Supply chain agility, according to Christopher et al. (2006, p. 281), is concerned "mainly with response." Similarly, many agility definitions use verbs like "react," "respond," "adapt," or "re-configure" to describe a system's ability to respond to change. Agility means moving quickly and easily. It primarily focuses on being responsive and flexible to changing customer needs while also mitigating disruption risks. In other words, it aims quickly responding to changing supply and demand conditions. This strategy is applied when the demand and the supply uncertainty is high.

Agile Practices:

- Understanding market requirements
- Future prospects

- Building markets, predicting new needs
- Timely delivery
- Differentiated product variety
- Ad, promotion, marketing
- Product storage
- Reduce dead times in production
- Increasing the competence of the workforce
- Speeding up shipping
- Production development
- R&D
- System improvement
- Evaluating customer expectations and demands
- To give necessary and detailed information to the questions coming from the customer about the work done
- To develop new and different product types
- If there is a loss in the market, it can be replaced immediately

2.3. Resilient Supply Chain Management

Resilient systems have two distinctive attributes. The first is the capability to resist a disruptive force and the second is to recover from an event. Clearly, supply chain resilience is connected to flexibility and redundancy. It ought to be both responsive and be leaner. However, leanness and resilience may contradict somehow. For example, resilience requires having inventory on hand but leanness proposes to have no inventory. Practices which can be integrated to business model are given below.

Resilient Practices:

- Opening to new markets, expanding the market
- Increasing productivity with flexible working model
- Strengthening the financial structure against exchange rate volatility
- Minimum stock usage
- Things to be done to increase exports
- Promotion

2.4. Green Supply Chain Management

Greenness, like resilience, has become an issue of concern for SCM in recent decades, resulting in a shift in industrial production philosophy. The environment is the primary emphasis of green SCM, but rather than focusing on how environmental agents affect SC, green SCM is more concerned with the environmental implications of SC's activities (Rao & Holt, 2005).

The idea behind why supply chains should be green is the wish for more sustainable manufacturing areas or facilities that give no harm to the environment for future generations.

No pollution is the key to greenness. And also, green supply-chain is much related to produce ecological goods. Therefore, manufacturers should take the responsibility from the very beginning of the goods to be produced, in the design phase. If the product is green, as a result, supply-chain will be greener.

Green Practices:

- Waste prevention
- Recycling powder granules
- Making packaging materials reusable
- Use of raw materials
- Using less energy
- Minimize chemical waste
- Efficient use of resources

2.5. Performance Measurement

From different perspectives, performance measurement was evaluated in this study. In this section, criteria and sub-criteria lists were given and the interrelationships of the approaches were investigated. These lists can be altered and increased. At least, in order to make a quantitative contribution, the list of some of the criteria in the literature were provided. However, our goal is to make a qualitative contribution as well. Hence, collected data on enablers and key performance indicators are as follows:

List of criteria and sub-criteria for evaluating supply chain performance:

1. Quality
 - Customer satisfaction
 - Customer response time
 - Lead time
 - On-time delivery
 - Fill rate
 - Stock out probability
 - Accuracy
 - Communication base
 - Process flexibility
 - Percentage rejections
 - Inspection methods and plans
 - Warranty claims
2. Accuracy
 - Time
 - Visibility
3. Consistency
 - Trust
4. Creativity
 - New product introduction
 - New technological application
5. Order fulfillment reliability
 - Order fulfillment performance
 - Fill rate
 - Order fulfillment lead time
 - Order fulfillment perfection
6. Flexibility and responsiveness
 - Supply chain response time
 - Production flexibility
7. Resource utilization
 - Manufacturing resources

- Storage resources
- Logistics resources
- Human resources
- Financial resources

8. Cost

- Total logistics management cost
- Process capability
- Defects
- Distribution cost
- Manufacturing cost
- Inventory cost
- Warehouse cost
- Incentives cost and subsidies
- Intangible cost
- Overhead cost
- Sensitivity to long term cost

9. Assets

- Cash-to-cash cycle time
- Inventory days of supply
- Assets turns

10. Technological capability

- Product and process facilities
- Skill and manpower
- Customised services
- Cost evaluation

11. Service

- On-time delivery
- Base of communication
- Response to changes
- Process flexibility
- Customer satisfaction

12. Time to market

- Delivery product to market quickly
- First in the market in introducing new product
- Time to market lower than industry average
- Fast development cell

Today, having a competitive supply chain is essential for having a competitive product in the marketplace (SC). In order to improve SC competitiveness, a company's LARG procedures are insufficient. It is vital to assess the impact of these activities on overall SC performance. (Cabral et al., 2011).

Table 2. 1 Some of the supply chain performance measures

OPERATIONAL PERFORMANCE		ECONOMICAL PERFORMANCE		ENVIRONMENTAL PERFORMANCE
Time	Quality	Cost	Delivery	Business Wastage
Lead time	Customer reject rate	New product flexibility	On time delivery	Total flow quantity of scrap
Cycle times	In plant defect fallow rate	Manufacturing cost	Delivery reliability	Percentage of materials remanufactured/recycled/reused
Delivery lead time	Increment products quality	Cost per operating hour	Responsiveness to urgent deliveries	Solid and liquid, hazardous and toxic material output

In the table below, lpi, which is the short form of logistics performance index, is shown. The table below shows the performance index for the performance of logistics sector in Turkey. This table is important in terms of guiding us. Knowing our position in the world is of vital importance in terms of understanding the importance of the subject and developing an appropriate approach to it.

In today's world, it is very difficult for a company without a competitive supply chain to ensure sustainability.

Therefore, in this competitive market environment, knowing the factors that positively affect the supply chain in terms of maintaining and developing sustainability will not only change our view of events in a positive way, but will also ensure that we are in control. Therefore, the previously mentioned criteria should be well understood. In the literature or considering today's conditions, it is more or less known what all of them mean as terms.

Instead of addressing them as a whole, we considered and evaluated some of them and reached the part from the whole which we can call as deduction.

Table 2. 2 Logistics performance index rankings from World Bank website

Country	Year	LPI Rank	LPI Score	Customs	Infrastructure	International shipments	Logistics competence	Tracking & tracing	Timeliness
Turkey	2018	47	3,15	58	33	53	51	42	44

The following ten variables were also studied in order to investigate the impact of lean, green, and resilient supply chain techniques on supply chain performance:

1. JIT
2. Total quality management (TQM)
3. Strategic stock
4. Flexible transportation
5. Green packaging
6. ISO 14001
7. Operational cost
8. Business wastage
9. Environmental cost
10. Customer satisfaction

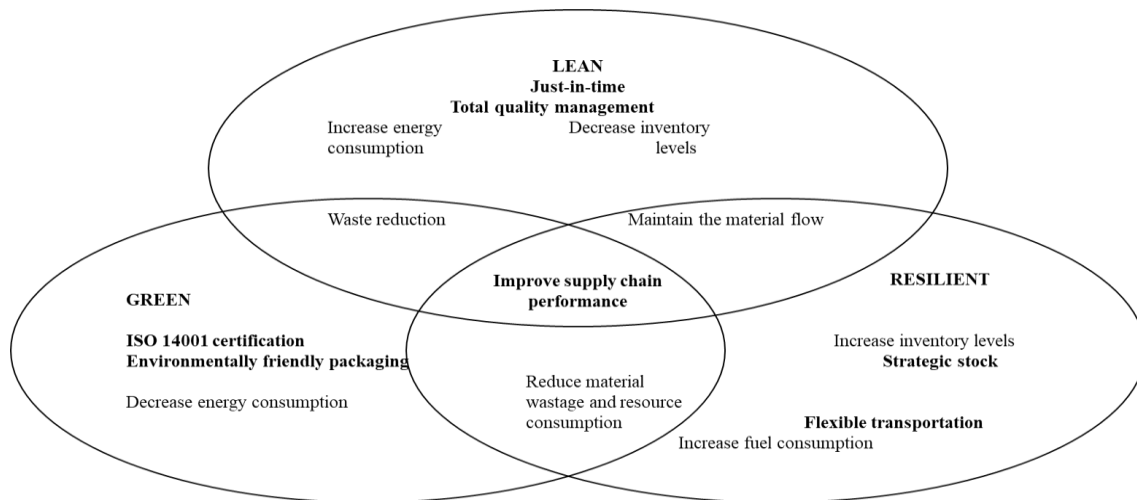


Figure 2. 1 Lean, green and resilient main features and their effects on the performance of supply-chain (Govindan et al., 2015)

Another approach to the relationship between LARG practices and their contribution to the performance of the supply chain has been given below. We can make comments on this table like this, for example, if we integrate lead time reduction to our manufacturing system, a positive effect will be in customer satisfaction. These practices and criteria can be altered and increased as in the below example.

LARG SUPPLY CHAIN PRACTICES	SUPPLY CHAIN PERFORMANCE	OPERATIONAL PERFORMANCE				ECONOMIC PERFORMANCE			ENVIRONMENTAL PERFORMANCE
		Inventory Levels	Quality	Customer Satisfaction	Time	Cost	Environmental Cost	Cash-to-cash cycle	Business Wastage
Just in time		↓		↑	↓	↓		↓	
Supplier relationships		↓	↑		↓	↓			↓
Cycle/setup time reduction					↓	↓		↓	
Speed in improving responsiveness				↑	↓			↓	↓
Producing in large or small batches		↓		↑	↓				
Ability to change delivery times of supplier's order		↓			↓				
Developing visibility to a clear view of upstream inventories and supply conditions		↓	↑			↓			↓
Lead time reduction				↑	↓				
Demand- based management		↓		↑				↓	
Reduction in the variety of materials employed in manufacturing the products		↓				↓	↓		↓
Working with product designers and suppliers to reduce environmental impacts			↑				↓		↓
Number of practices		7	3	5	7	5	2	4	5
↑ increase the performance measure; ↓ decrease the performance measure									

Figure 2. 2 LARG supply chain practices and their effects on the improvement of the performance of the supply chain (Azevedo et al., 2011)

Because of the fact that LARG is a broad concept, we can emphasize practices in more detail. At the below chart, the qualities of being lean, agile, robust and environmentally friendly (LARG) are highlighted in blue, yellow, purple and green respectively. If it is to evaluate some of those paradigms, it can be seen that there are Ps and Ns. P sign mean that there is a positive relationship between these two things. For example, if the managers of a manufacturing company would like to apply just-in-time positively to their supply chain model there will be a positive effect due to the positive contribution that is made in the replenishment frequency. N sign means an adverse effect. As a result, when waste minimization (energy, water, raw materials, and non-product output) is used, production lead time increases, implying a negative relationship between this technique (waste minimization) and sub-criteria (production lead time). Among the supply chain

parameters examined were "capacity surplus," "replenishment frequency," "information frequency," "integration level," "inventory level," "production lead time," and "transportation lead time." The values of the properties can be changed by implementing various supply chain concepts. Supply chain attributes are important components of supply chain strategies because they determine the behavior of the entire supply chain, allowing supply chain performance to be measured.

(Kainuma and Tawara, 2006) refer that “there are a lot of metrics for evaluating the performance of supply chains. However, they may be aggregated as lead time, customer service, cost, and quality”.

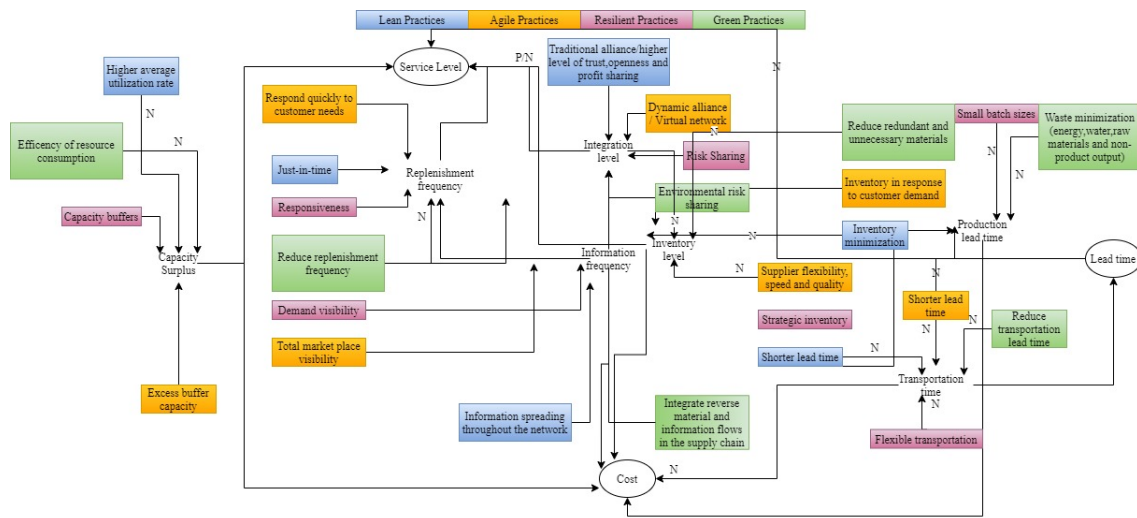


Figure 2. 3 Conceptual model with LARG practices and SC performance (Carvalho and Cruz-Machado, 2011)

3. MULTI-ATTRIBUTE DECISION MAKING

In this thesis, the purpose is to indicate whether these four approaches Lean, Agile, Resilient and Green (LARG) increase supply chain performance or not. That's why the most important thing to do is to get benefit of multi-criteria decision making techniques. Because there are four different broad areas to deal with and all of them will affect our decisions from different perspectives. For example, assuming that quality is an operational performance measurement. It has indicators such as customer reject rate, increment products quality and so on. So, first of the most used multi-criteria decision making techniques, Analytic Network Process (ANP) will be used for prioritization for performance criteria. Furthermore, information will be gathered from a manufacturing company in the industry. Below, there are multi-criteria decision making techniques.

1-) Multi-Attribute Utility Theory (MAUT)

MAUT is a systematic approach identifying and analyzing the single utility functions and their weighting factors to come to a conclusion. It differs in providing an expected utility function taking uncertainty into account.

2-) Analytic Hierarchy Process (AHP)

In this method, there is a goal which is hierarchically influenced by criteria and its sub-criteria. Depending upon some calculated weights alternatives are to be selected. These weights are found by using pairwise comparison matrices and lastly prioritization made amongst alternatives.

3-) Fuzzy Set Theory

The fuzzy theory is based on fuzzy logic. This theory can be used when data are vague. It can quantify the linguistic part of the problem resulting in values between 0 and 1.

4-) Case-Based Reasoning (CBR)

CBR collects similar cases from an existing data set. Then, it suggests a decision by choosing the most similar cases.

5-) Data Envelopment Analysis (DEA)

Data Envelopment Analysis (DEA) is a technique for analyzing data (DEA)

The relative efficiency of alternatives are measured using a linear programming technique

by DEA (Thanassoulis, Kortelainen, and Allen, 2012).

6-) Simple Multi-Attribute Rating Technique (SMART)

MAUT in its simplest form. Ratings of alternatives are assigned directly in the natural scales of the criteria (when available) in the SMART technique (Filho, 2005).

7-) Goal Programming

Goal programming is a method of optimization that allows you to choose from an endless number of options. Obviously, it is capable of dealing with large-scale issues.

8-) ELECTRE

This is a concordance analysis-based outranking approach. It has gone through several revisions. Its benefit is that it accounts for uncertainty.

9-) PROMETHEE

The PROMETHEE is similar to ELECTRE. It is easy to use.

10-) Simple Additive Weighting (SAW)

SAW is a MADM technique in which the value function is determined by adding the scores that signify goal achievement under each criterion. (Qin et al., 2008).

11-) Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS)

TOPSIS has a straightforward procedure. It's both user-friendly and programmable. It provides an alternative answer that is very close to the perfect solution while being the furthest away from the negative ideal option.

Supply Chain Management that incorporates Lean, Agile, Resilient, and Green paradigms at the same time may assist supply chains become more efficient, streamlined, and sustainable. It is vital to examine the performance of a supply chain in order to design one that is efficient and effective.

In this thesis, the Analytical Network Process method was used. The Analytic Network Process is a more general and enhanced version of the Analytic Hierarchy Process. ANP prioritizes just like the AHP. ANP takes into account what the AHP does not. It considers all aspects of the relationships between the decisions to be prioritized. In this respect, it meets the decision-making needs of managers in a much better way.

The important thing to consider is that for every problem there may not be a control hierarchy. If there will be a control hierarchy, there has to be a network under this control hierarchy.

For example, the Analytic Network Process includes Goal, Criteria, Sub-Criteria and the

relationships among them. Goal, Criteria and Sub-Criteria are called clusters. These relationships may be either one-way or two-way. There may also be no relationships between some of these clusters. In other words, there may be no dependency, inner dependency or outer dependency and feedback. In the following section, Analytic Network Process steps are given. Firstly, problem is defined. Secondly, criteria and alternatives are specified. After that , decision network is created. Then pairwise comparison matrices are constructed. After that, just like AHP method the weights are calculated. And then, below matrix is constructed. Q matrix is B dimensional weights of clusters. For every C_b cluster, the effects of other clusters to this particular cluster should be specified. In order to get the Q matrix below in equation 3.1, the weights with respect to Goal should be evaluated.

$$Q = \begin{bmatrix} q_{1.1} & \dots & q_{1.j} & \dots & q_{1.B} \\ \dots & \dots & \dots & \dots & \dots \\ q_{i.1} & \dots & q_{i.j} & \dots & q_{i.B} \\ \dots & \dots & \dots & \dots & \dots \\ q_{B.1} & \dots & q_{B.j} & \dots & q_{B.B} \end{bmatrix} \quad (3.1)$$

In figure 3.1 which is shown in the next page ANP steps are indicated. These steps can be separated into two parts. First step, is the completion of the matrices. Second step, is the calculation of the weights of the alternatives.

As the first step, problem is defined. Then criteria and alternatives are determined. Afterwards, we design the decision network suitably. If there are any sub-criteria, they can be specified. These steps are the construction of ANP. In order to solve the problem, pairwise comparison matrices should be constructed. While evaluating the clusters, which are constituted by the criteria and sub-criteria, these two questions are asked. Which criterion is more important than the other one? How much more important is it than the other one? After that, AHP procedure is applied. Calculation of the priority vector matrix is made. Consistency ratio should be checked. It should be less than 0,1.

Subsequently, construction of the cluster weights matrix with respect to our goal is obtained. Then the unweighted supermatrix is constructed. And then, the weighted supermatrix comes ahead. Normalization of the weighted supermatrix has to be made. Next, limit supermatrix is calculated. Then we get the weights of the criteria from this limit supermatrix. It means that we calculated the weights of the alternatives. Finally, alternatives are ranked.

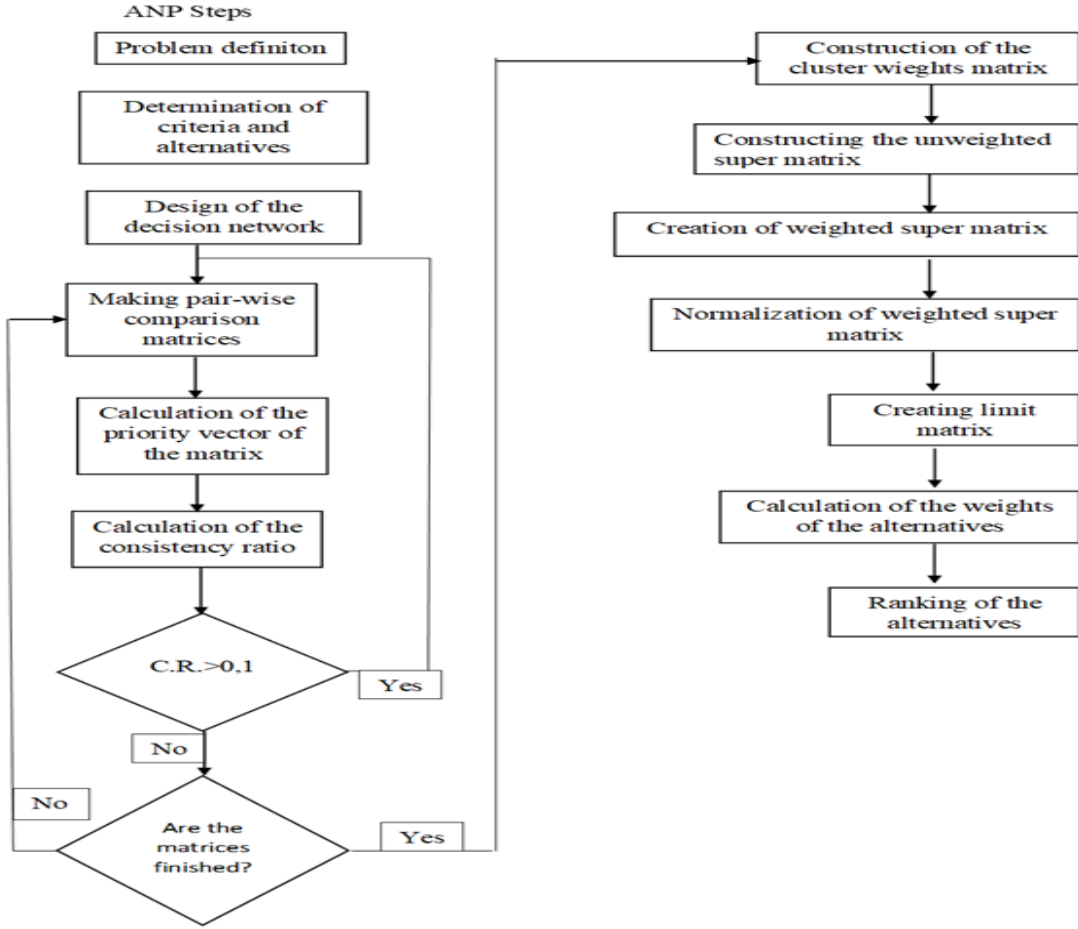


Figure 3. 1 ANP Steps

Afterwards, unweighted supermatrix is constructed. It has priority vectors (W_{ij}). Each W_{ij} block is a matrix which is shown in the below matrix format.

$$W_{i,j} = \begin{bmatrix} w_{i1j1} & w_{i1j2} & \dots & w_{i1jsj} \\ w_{i2j1} & w_{i2j2} & \dots & w_{i2jsj} \\ \dots & \dots & \dots & \dots \\ w_{isij1} & w_{isij2} & \dots & w_{isijsj} \end{bmatrix} \quad (3.2)$$

And below, the unweighted supermatrix format is indicated.

$$\begin{array}{c}
\begin{array}{cccc}
C_1 & C_2 & \dots & C_B \\
d_{1,1} \dots d_{1,s_1} & d_{2,1} \dots d_{2,s_2} & \dots & d_{B,1} \dots d_{B,s_B}
\end{array} \\
\begin{array}{c}
C_1 \\
\dots \\
d_{1,s_1} \\
d_{2,1} \\
C_2 \\
\dots \\
d_{2,s_2} \\
\dots \\
d_{B,1} \\
C_B \\
\dots \\
d_{B,s_B}
\end{array}
\begin{bmatrix}
W_{1,1} & W_{1,2} & \dots & W_{1,B} \\
W_{2,1} & W_{2,2} & \dots & W_{2,B} \\
\dots & \dots & \dots & \dots \\
W_{B,1} & W_{B,2} & \dots & W_{B,B}
\end{bmatrix}
\end{array} \quad (3.3)$$

When the decision network is different from hierarchical structure, weighted supermatrix must be constructed. Because, in a hierarchical structure, unweighted supermatrix and weighted supermatrix is equal ($U = W$) (Saaty, 2003). Below formula is used for calculating the supermatrix.

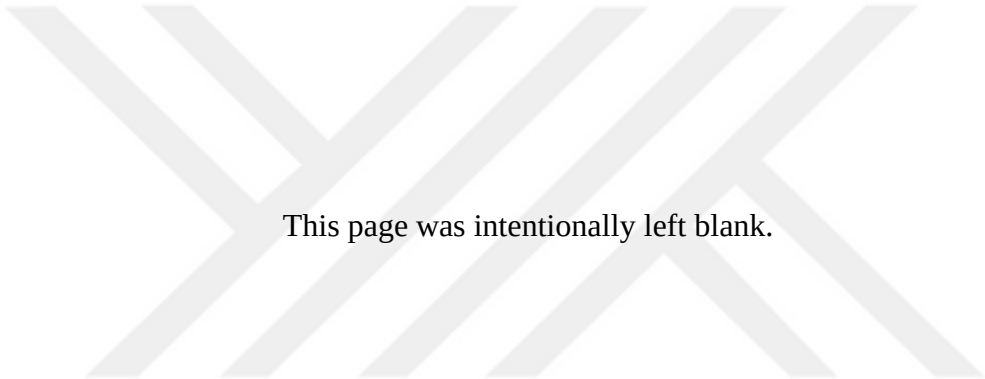
$$W_{i,j} * q_{i,j} \quad i = 1, \dots, B; \quad j = 1, \dots, B \quad (3.4)$$

U^{un} matrix is not normalized but weighted and calculated by B^2 piece of multiplications.

U^{un} matrix should be normalized. Then we get U, Weighted Normalized Supermatrix.

$$U^{un} = \begin{bmatrix}
W_{1,1} * q_{1,1} & W_{1,2} * q_{1,2} & \dots & W_{1,B} * q_{1,B} \\
W_{2,1} * q_{2,1} & W_{2,2} * q_{2,2} & \dots & W_{2,B} * q_{2,B} \\
\dots & \dots & \dots & \dots \\
W_{B,1} * q_{B,1} & W_{B,2} * q_{B,2} & \dots & W_{B,B} * q_{B,B}
\end{bmatrix} \quad (3.5)$$

Limit super matrix is the steady form of the U matrix. The n.power of the U matrix is taken where n is a large number as 79. Step by step, ANP method has been investigated. All these evaluations are indicated as a problem in the Case Study section.



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4. AN APPLICATION IN A CASE STUDY

In this section, in order to indicate whether LARG paradigms are applicable or not within the supply chain in manufacturing industry in Turkey, a case study was undertaken in one of the leading companies in pipe manufacturing industry.

4.1. Getting Experts' Opinions

First of all, a pipe manufacturing firm was visited. Secondly, we had arranged an appointment to make a face to face interview and then recorded it. Afterwards, we were provided with the actual data from the pipe manufacturing company. Below, there is data about sub-criteria which gives specific information about the problem that the company confronts. Quality engineer of the company provided this table. If any of the sub-criteria in the rows are affecting the sub-criteria in the columns, there is a cross sign showing this. Sub-criteria: manufacturing cost e_{11} , inventory cost e_{12} , delivery product to market quickly e_{21} , time to market lower than industry average e_{22} , lead time e_{31} , customer response time e_{32} , process flexibility e_{41} , base of communication e_{42} .

Table 4. 1 Sub-Criterions

<i>SUB-CRITERIA</i>	e_{11}	e_{12}	e_{21}	e_{22}	e_{31}	e_{32}	e_{41}	e_{42}
e_{11}	-	X	X	X	X	X	X	-
e_{12}	-	-	X	X	-	X	-	X
e_{21}	X	X	-	X	-	X	-	-
e_{22}	X	X	X	-	-	X	-	-
e_{31}	X	X	X	X	-	X	-	-
e_{32}	-	-	X	X	X	-	-	-
e_{41}	-	-	X	X	X	X	-	-
e_{42}	X	X	X	X	X	X	-	-

The problem that the company confronts were given as follows:

Table 4. 2 Alternatives and the sub-criteria of the problem

<i>SUB-CRITERIA</i>	Manufacturing Cost	Inventory Cost	Delivery product to market quickly	Time to market lower than industry average	Lead time	Customer response time	Process flexibility	Base of communication
	($\text{\$}$)	($\text{\$}$)	(YEAR)	(YEAR)	(YEAR)	(YEAR)	(%)	(MIN)
<i>MIN</i>	MIN	MIN	MIN	MIN	MIN	MIN	MAX	MIN
<i>A1</i>	100.000	1.000.000	0,4167	1,0000	0,5833	0,0385	0,1000	160.000
<i>A2</i>	670.000	350.000	0,5000	1,2500	0,7500	0,0192	0,3000	190.000
<i>A3</i>	380.000	468.000	0,5833	1,4000	0,8333	0,0577	0,2000	220.000
<i>A4</i>	250.000	770.000	0,6666	1,6000	0,9166	0,0769	0,4000	250.000
<i>A1</i>	100.000	1.000.000	5 MONTHS	12 MONTHS	7 MONTHS	2 WEEKS	10,0000	160.000
<i>A2</i>	670.000	350.000	6 MONTHS	15 MONTHS	9 MONTHS	1 WEEK	30,0000	190.000
<i>A3</i>	380.000	468.000	7 MONTHS	17 MONTHS	10 MONTHS	3 WEEKS	20,0000	220.000
<i>A4</i>	250.000	770.000	8 MONTHS	19 MONTHS	11 MONTHS	4 WEEKS	40,0000	250.000

This table illustrates the problem of this study. The managers of the related manufacturing firm were trying to make the best decision among four different alternatives. All of the alternatives included the combinations of different LARG practices so that the performance of the company's supply chain increases. To illustrate, Alternative 1 was such a project that cost 100.000 \$ of manufacturing, inventory of one million \$. Delivery times, lead times and customer response times were given in particular periods of time. And also, the percentage of process flexibility after implementing those practices into firm's supply chain has been provided. Base of communication cost was 160.000 \$. To solve this problem ANP had been chosen to be implemented. As it is one of the most used multi-attribute decision making techniques and fits well to our problem. There is the designation of the decision network in the following section.

4.2. Implementation of ANP

Firstly, the components of the related problem has been explained briefly. The following are the primary clusters:

(1) Goal (SC Performance Improvement) – As the declaration of the reason for LARG SCM techniques implies, this cluster only has one element (i.e. refers to the objective of the SC). To compete in the global market and against other SCs, a SC must be competitive. It is necessary to improve performance in some way.

(2) Enablers (criteria) – The performance of the SC has been assessed using four primary enabling criteria, which have been included as nodes in this cluster: Cost (C1), service level (C4), time to market (C2), and product quality (C3) are all factors to consider (C3). The components in this cluster are critical enablers for SC competitiveness. Each enabler adds to the SC's performance evaluation. These four criteria will be used to evaluate the SC's performance, according to the links to the objective cluster.

(3) Sub-criteria (LARG KPIs) – This cluster offers a list of possible LARG KPIs that can be used to assess each enabler's criterion.

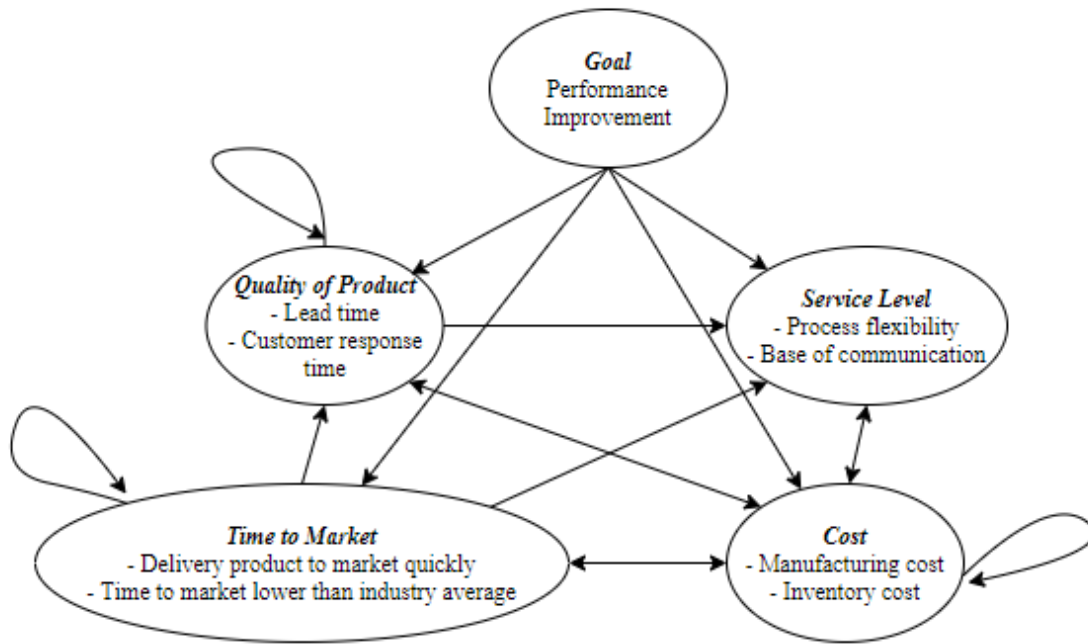


Figure 4. 1 Proposed decision network for performance improvement

First of all, pairwise comparison scales were gathered according to the values in table 4.1.

Table 4. 3 Pairwise Comparison Scale

Scale of importance	Crisp score	Reciprocal of crisp score
Equal importance	1	1
Moderate	3	0,33
Strong importance	5	0,20
Very strong importance	7	0,14
Extremely preferred	9	0,11

Then, these scales were used as in the below table. After this first phase, sums of the columns were calculated. Then, all of the values in the related cells were divided by their sums. After that, weights were obtained by taking the average of the cells in the same row. Afterwards, the first values (matrix A) gathered from the experts were multiplied by the weights (matrix W) and added. Up to now , we calculated the AxW column in table 4.5. The values in the cells of column D were calculated by dividing the AxW column by the column W. Here is the formula for $\lambda_{\max}$.

$$\lambda_{\max} = \frac{\text{Sum of Column D}}{\text{Size } n} \quad (4.1)$$

Following the calculation of $\lambda_{\max}$, consistency index was found by the below formula.

$$CI = \frac{\lambda_{\max} - n}{n - 1} \quad (4.2)$$

Eigenvectors and eigenvalues will be as follows:

Table 4. 4 Comparison of pair-wise matrix A with respect to criteria C1

C1	QUALITY OF PRODUCT	SERVICE LEVEL	TIME TO MARKET	COST
QUALITY OF PRODUCT	1,0000	3,0000	2,0000	0,5000
SERVICE LEVEL	0,3333	1,0000	0,2500	0,2500
TIME TO MARKET	0,5000	4,0000	1,0000	0,3333
COST	2,0000	4,0000	3,0000	1,0000
SUM	3,8333	12,0000	6,2500	2,0833

Table 4. 5 Weights calculated with respect to criteria C1

C1	QUALITY OF PRODUCT	SERVICE LEVEL	TIME TO MARKET	COST	W	A*W	D
QUALITY OF PRODUCT	0,2609	0,2500	0,3200	0,2400	0,2677	1,1342	4,2366
SERVICE LEVEL	0,0870	0,0833	0,0400	0,1200	0,0826	0,3342	4,0478
TIME TO MARKET	0,1304	0,3333	0,1600	0,1600	0,1959	0,8113	4,1407
COST	0,5217	0,3333	0,4800	0,4800	0,4538	1,9073	4,2033
	$\lambda_{\max}$	4,1571	C.I.	0,0524	C.R.	0,0582	

After all these matrix calculations had been made, consistency ratio was calculated based on the size of the matrix. RCI value has been provided below according to matrix size. Here is the formula for consistency ratio:

$$CR = \frac{CI}{RCI} \quad (4.3)$$

Table 4. 6 Average Random Consistency Index depending on matrix size

S. no	1	2	3	4	5	6	7	8	9	10
RCI	.00	.00	.52	.89	1.11	1.25	1.35	1.40	1.45	1.49

Weights with respect to C2 were calculated as follows:

Table 4. 7 Comparison matrix with respect to C2

C2	COST	TIME TO MARKET	QUALITY	SERVICE LEVEL
COST	1,0000	2,0000	3,0000	4,0000
TIME TO MARKET	0,5000	1,0000	2,0000	3,0000
QUALITY	0,3333	0,5000	1,0000	2,0000
SERVICE LEVEL	0,2500	0,3333	0,5000	1,0000
SUM	2,0833	3,8333	6,5000	10,0000

C2	COST	TIME TO MARKET	QUALITY	SERVICE LEVEL
COST	0,4800	0,5217	0,4615	0,4000
TIME TO MARKET	0,2400	0,2609	0,3077	0,3000
QUALITY	0,1600	0,1304	0,1538	0,2000
SERVICE LEVEL	0,1200	0,0869	0,0769	0,1000

Table 4. 8 Calculations for C₂

W	A*W	D
0,4658	1,8872	4,0513
0,2771	1,1201	4,0416
0,1611	0,6469	4,0159
0,0960	0,3853	4,0152

Weights with respect to C₃ were calculated as follows:

Table 4. 9 Comparison matrix with respect to C₃

C3	QUALITY OF PRODUCT	COST	SERVICE LEVEL
QUALITY OF PRODUCT	1	0,333333333	2
COST	3,0000	1	3,0000
SERVICE LEVEL	0,5000	0,333333333	1
SUM	4,5000	1,6667	6,0000
C3	QUALITY OF PRODUCT	COST	SERVICE LEVEL
QUALITY OF PRODUCT	0,2222	0,2000	0,3333
COST	0,6667	0,6000	0,5000
SERVICE LEVEL	0,1111	0,2000	0,1667

Table 4. 10 Calculations for C3

W	A*W	D
0,2519	0,7667	3,0441
0,5889	1,8222	3,0943
0,1593	0,4815	3,0233

Table 4. 11 Calculations for C3 (continue)

$\lambda_{\max}$	3,0539	CI	0,0270	CR	0,0465
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As Cost (C1) is the only influencing criteria with respect to C4, its weight is assumed to be 1.

Table 4. 12 Comparison matrix and weights with respect to C4

C4	COST
COST	1,0000

Lastly, all of the weights were calculated with respect to Goal as shown in the following table.

Table 4. 13 Weights with respect to Goal

G	C1	C2	C3	C4
C1	0,4538	0,4658	0,5889	1,0000
C2	0,1959	0,2771	0,0000	0,0000
C3	0,2677	0,1611	0,2519	0,0000
C4	0,0826	0,0960	0,1593	0,0000

Weights of sub-criteria with regard to each sub-criterion were determined in the tables below. Firstly, sums of the columns were found. Then, pairwise comparison scales were divided by the sums. Afterwards, the average of these divisions provided the weights. Eigenvectors are as follows:

Table 4. 14 Weights with respect to e11

e ₁₁	e ₂₁	e ₂₂		e ₁₁	e ₂₁	e ₂₂	W
e ₂₁	1,0000	3,0000		e ₂₁	0,7500	0,7500	0,7500
e ₂₂	0,3333	1,0000		e ₂₂	0,2500	0,2500	0,2500
SUM	1,3333	4,0000					

Table 4. 15 Weights with respect to e12

e ₁₂	e ₂₁	e ₂₂		e ₁₂	e ₂₁	e ₂₂	W
e ₂₁	1,0000	0,3333		e ₂₁	0,2500	0,2500	0,2500
e ₂₂	3,0000	1,0000		e ₂₂	0,7500	0,7500	0,7500
SUM	4,0000	1,3333					

Table 4. 16 Weights of e11 and e12 with respect to e21

e ₂₁	e ₁₁	e ₁₂		e ₂₁	e ₁₁	e ₁₂	W
e ₁₁	1,0000	5,0000		e ₁₁	0,8333	0,8333	0,8333
e ₁₂	0,2000	1,0000		e ₁₂	0,1667	0,1667	0,1667
SUM	1,2000	6,0000					

Table 4. 17 Weights of e31 and e32 with respect to e21

e ₂₁	e ₃₁	e ₃₂		e ₂₁	e ₃₁	e ₃₂	W
e ₃₁	1,0000	6,0000		e ₃₁	0,8571	0,8571	0,8571
e ₃₂	0,1667	1,0000		e ₃₂	0,1429	0,1429	0,1429
SUM	1,1667	7,0000					

Table 4. 18 Weights of e41 and e42 with respect to e21

e ₂₁	e ₄₁	e ₄₂		e ₂₁	e ₄₁	e ₄₂	W
e ₄₁	1,0000	4,0000		e ₄₁	0,8000	0,8000	0,8000
e ₄₂	0,2500	1,0000		e ₄₂	0,2000	0,2000	0,2000
SUM	1,2500	5,0000					

Table 4. 19 Weights of e11 and e12 with respect to e22

e ₂₂	e ₁₁	e ₁₂		e ₂₁	e ₁₁	e ₁₂	W
e ₁₁	1,0000	0,2500		e ₁₁	0,2000	0,2000	0,2000
e ₁₂	4,0000	1,0000		e ₁₂	0,8000	0,8000	0,8000
SUM	5,0000	1,2500					

Table 4. 20 Weights of e31 and e32 with respect to e22

e ₂₂	e ₃₁	e ₃₂		e ₂₂	e ₃₁	e ₃₂	W
e ₃₁	1,0000	7,0000		e ₃₁	0,8750	0,8750	0,8750
e ₃₂	0,1429	1,0000		e ₃₂	0,1250	0,1250	0,1250
SUM	1,1429	8,0000					

Table 4. 21 Weights of e41 and e42 with respect to e22

e ₂₂	e ₄₁	e ₄₂		e ₂₂	e ₄₁	e ₄₂	W
e ₄₁	1,0000	6,0000		e ₄₁	0,8571	0,8571	0,8571
e ₄₂	0,1667	1,0000		e ₄₂	0,1429	0,1429	0,1429
SUM	1,1667	7,0000					

Table 4. 22 Weights with respect to e31

e ₃₁	e ₄₁	e ₄₂		e ₃₁	e ₄₁	e ₄₂	W
e ₄₁	1,0000	0,5000		e ₄₁	0,3333	0,3333	0,3333
e ₄₂	2,0000	1,0000		e ₄₂	0,6667	0,6667	0,6667
SUM	3,0000	1,5000					

Table 4. 23 Weights of e11 and e12 with respect to e32

e ₃₂	e ₁₁	e ₁₂		e ₃₂	e ₁₁	e ₁₂	W
e ₁₁	1,0000	2,0000		e ₁₁	0,6667	0,6667	0,6667
e ₁₂	0,5000	1,0000		e ₁₂	0,3333	0,3333	0,3333
SUM	1,5000	3,0000					

Table 4. 24 Weights of e21 and e22 with respect to e32

e ₃₂	e ₂₁	e ₂₂		e ₃₂	e ₂₁	e ₂₂	W
e ₂₁	1,0000	0,3333		e ₂₁	0,2500	0,2500	0,2500
e ₂₂	3,0000	1,0000		e ₂₂	0,7500	0,7500	0,7500
SUM	4,0000	1,3333					

Table 4. 25 Weights of e41 and e42 with respect to e32

e ₃₂	e ₄₁	e ₄₂		e ₃₂	e ₄₁	e ₄₂	W
e ₄₁	1,0000	0,3333		e ₄₁	0,2500	0,2500	0,2500
e ₄₂	3,0000	1,0000		e ₄₂	0,7500	0,7500	0,7500
SUM	4,0000	1,3333					

In the following table, weights that had been found by exploiting the Eigenvectors of each elements were shown. Weights were placed to the related blocks. There are $4 \times 4 = 16$ blocks, since the number of clusters are 4.

Table 4. 26 Unweighted Super Matrix

		C1		C2		C3		C4	
		e ₁₁	e ₁₂	e ₂₁	e ₂₂	e ₃₁	e ₃₂	e ₄₁	e ₄₂
C1	e ₁₁	0	1	0,8333	0,2000	1	0,6667	1	0
	e ₁₂	1	0	0,1667	0,8000	0	0,3333	0	0
C2	e ₂₁	0,7500	0,2500	0	1	0	0,2500	0	0
	e ₂₂	0,2500	0,7500	1	0	0	0,7500	0	0
C3	e ₃₁	1	1	0,8571	0,8750	0	1	0	0
	e ₃₂	0	0	0,1429	0,1250	1	0	0	0
C4	e ₄₁	0	0	0,8000	0,8571	0,3333	0,2500	0	0
	e ₄₂	1	1	0,2000	0,1429	0,6667	0,7500	0	0

Weights in table 4.26 and the values found in table 4.13 were multiplied accordingly.

Then, we get the weighted supermatrix. Sums of the columns were also shown in table 4.27.

Table 4. 27 Weighted Super Matrix

		C1		C2		C3		C4	
		e ₁₁	e ₁₂	e ₂₁	e ₂₂	e ₃₁	e ₃₂	e ₄₁	e ₄₂
C1	e ₁₁	0,0000	0,4538	0,3882	0,0932	0,5889	0,3926	1,0000	0,0000
	e ₁₂	0,4538	0,0000	0,0777	0,3727	0,0000	0,1963	0,0000	1,0000
C2	e ₂₁	0,1470	0,0490	0,0000	0,2771	0,0000	0,0000	0,0000	0,0000
	e ₂₂	0,1959	0,1470	0,2771	0,0000	0,0000	0,0000	0,0000	0,0000
C3	e ₃₁	0,2677	0,2677	0,1381	0,1409	0,0000	0,2519	0,0000	0,0000
	e ₃₂	0,0000	0,0000	0,0230	0,0201	0,2519	0,0000	0,0000	0,0000
C4	e ₄₁	0,0000	0,0000	0,0768	0,0823	0,0531	0,0398	0,0000	0,0000
	e ₄₂	0,0826	0,0826	0,0192	0,0137	0,1062	0,1194	0,0000	0,0000
	SUM	1,1470	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000

The column sums should be stochastic which means that the sums of columns should be 1. That is why the values in the weighted super matrix are normalized. In other words, they are divided by the column sums of which values are not 1.

Table 4. 28 Normalized Super Matrix

NORMALIZED SUPERMATRIX							
0,0000	0,4538	0,3882	0,0932	0,5889	0,3926	1,0000	0,0000
0,3956	0,0000	0,0777	0,3727	0,0000	0,1963	0,0000	1,0000
0,1281	0,0490	0,0000	0,2771	0,0000	0,0000	0,0000	0,0000
0,1708	0,1470	0,2771	0,0000	0,0000	0,0000	0,0000	0,0000
0,2334	0,2677	0,1381	0,1409	0,0000	0,2519	0,0000	0,0000
0,0000	0,0000	0,0230	0,0201	0,2519	0,0000	0,0000	0,0000
0,0000	0,0000	0,0768	0,0823	0,0531	0,0398	0,0000	0,0000
0,0720	0,0826	0,0192	0,0137	0,1062	0,1194	0,0000	0,0000
1	1	1	1	1	1	1	1

Within the normalized supermatrix, instead of indirect influences only the direct influences are taken into consideration. Therefore, until the column values of the same row gets stable, in other words, they become equal for the same row at each column. Because of this, the power of supermatrix has been calculated. The power does not have to be 79. It should be a big number. 79th power of normalized super matrix is as follows:

Table 4. 29 Limit Super Matrix

LIMIT SUPERMATRIX							
0,2856	0,2856	0,2856	0,2856	0,2856	0,2856	0,2856	0,2856
0,2325	0,2325	0,2325	0,2325	0,2325	0,2325	0,2325	0,2325
0,0768	0,0768	0,0768	0,0768	0,0768	0,0768	0,0768	0,0768
0,1042	0,1042	0,1042	0,1042	0,1042	0,1042	0,1042	0,1042
0,1657	0,1657	0,1657	0,1657	0,1657	0,1657	0,1657	0,1657
0,0456	0,0456	0,0456	0,0456	0,0456	0,0456	0,0456	0,0456
0,0250	0,0250	0,0250	0,0250	0,0250	0,0250	0,0250	0,0250
0,0657	0,0657	0,0657	0,0657	0,0657	0,0657	0,0657	0,0657

Finally, we found the weights of each criteria.

4.3. The Significance for the Firm

We are going to decide if these approaches are applicable within manufacturing industry

and how crucial these approaches are when we want to optimize the performance or the gainings of our supply chains. These philosophies, majorly leading the management of supply chains, aim to help managers give decisions on different aspects so as to come up with an improvement in the relevant fields of competitive market.

Based on these criteria , these four approaches (LARG) are taken into consideration by the Project management department in the related company. Criteria are listed in order of importance taking knowledge and experiences of the department into account.

Since the raw data that had been gathered from the firm is qualitative, we will alter the data into a simplified quantitative one. Company executives will benefit from Analytic Network Process regarding their intuition in such a way that ANP providing them the priorities of those alternatives.

4.4. Results and Discussion

At the below table, alternatives were provided. Alternatives were gathered from the pipe manufacturing firm according to the criteria. Criteria weights were found in table 4.29. Almost all criteria values are minimization of cost and time which means that they are non-beneficial values. Among those criteria, process flexibility is the only beneficial value. Therefore, process flexibility is of an issue of maximization. Table 4.30 displays the performance values of the decision options in relation to each criterion.

Table 4. 30 The performance values of alternatives

SUB-CRITERIA	e_{11}	e_{12}	e_{21}	e_{22}	e_{31}	e_{32}	e_{41}	e_{42}
CRITERIA WEIGHTS	0,2856	0,2325	0,0768	0,1042	0,1657	0,0456	0,0250	0,0657
A1	0,00001	0,000001	2,3998	1,000000	1,714384	25,974026	0,1	0,000006
A2	0,000001	0,000003	2,0000	0,800000	1,333333	52,083333	0,3	0,000005
A3	0,000003	0,000002	1,7143	0,714286	1,200048	17,331023	0,2	0,000005
A4	0,000004	0,000001	1,5001	0,625000	1,090988	13,003901	0,4	0,000004
SUM	0,000018	0,000007	7,6143	3,139286	5,338753	108,392283	1	0,000020

This decision matrix is standardized by using these two formulas.

$$\bar{x}_{ij} = \frac{x_{ij}}{\sum_{i=0}^m x_{ij}} \quad (4.4)$$

$$x_{ij} = \frac{1}{x_{ij}^*}; \quad \bar{x}_{ij} = \frac{x_{ij}}{\sum_{i=0}^m x_{ij}} \quad (4.5)$$

First formula is used when the criteria are to be maximized. Second formula is used when the criteria is a non-beneficial criteria. All of the values should be normalized because of the fact that the dimensions of each of the criterions are made up of different units. Normalized values are given in table 4.31.

Table 4. 31 Normalized performance values

A1	0,55175	0,13713	0,31517	0,31854	0,32112	0,23963	0,10000	0,31159
A2	0,08235	0,39179	0,26266	0,25484	0,24975	0,48051	0,30000	0,26239
A3	0,14520	0,29300	0,22515	0,22753	0,22478	0,15989	0,20000	0,22661
A4	0,22070	0,17808	0,19702	0,19909	0,20435	0,11997	0,40000	0,19942

In table 4.32, the normalized performance values of the alternatives were multiplied by the weight values of the criteria.

Table 4. 32 Weighted normalized performance values

A1	0,15758	0,03188	0,02421	0,03319	0,05321	0,01093	0,00250	0,02047
A2	0,02352	0,09109	0,02017	0,02655	0,04138	0,02191	0,00750	0,01724
A3	0,04147	0,06812	0,01729	0,02371	0,03725	0,00729	0,00500	0,01489
A4	0,06303	0,04140	0,01513	0,02075	0,03386	0,00547	0,01000	0,01310

Now, for each of the rows, the weights should be added to eachother. After the calculation had been made, the scores were obtained and the values are as follows:

Table 4. 33 Scores and rankings

SCORE	RANKING	ALTERNATIVES
0,33397	1	1
0,24937	2	2
0,21502	3	3
0,20275	4	4
1		

In this case study, operational and economical performances were evaluated by implementing ANP method. Criterion and sub-criterion weights have been found. Up to

this point, it can be claimed that $e_{11} > e_{12} > e_{31} > e_{22} > e_{21} > e_{42} > e_{32} > e_{41}$ have this priority order in the company's decision-making process. Criteria weights have been provided in table 13.

After all the values have been calculated and related normalizations are done, firm can facilitate its decisions regarding the sequence of the alternatives. As it can be inferred from table, $A1 > A2 > A3 > A4$, this sequence constitutes of the firm's priorities among the projects. While selecting one from the alternatives, the one with the lowest score implies that it is the most non-beneficial alternative. Alternative 1 should be selected first to have a better performance since it has the highest ranking.

In a vast amount of the articles that were reviewed, ANP studies were limited. However, there were papers in which ANP methodology was used. Among these studies, Cabral et al., 2011 studies were the closest compared to this thesis in terms of objective.

In my opinion, the limitation is due to its taking a lot of time and the difficulty of modelling the decision network. In fact, number of managers was adequate, but it would be better to work collaboratively with a team instead of two or three people.

5. CONCLUSION AND FURTHER STUDIES

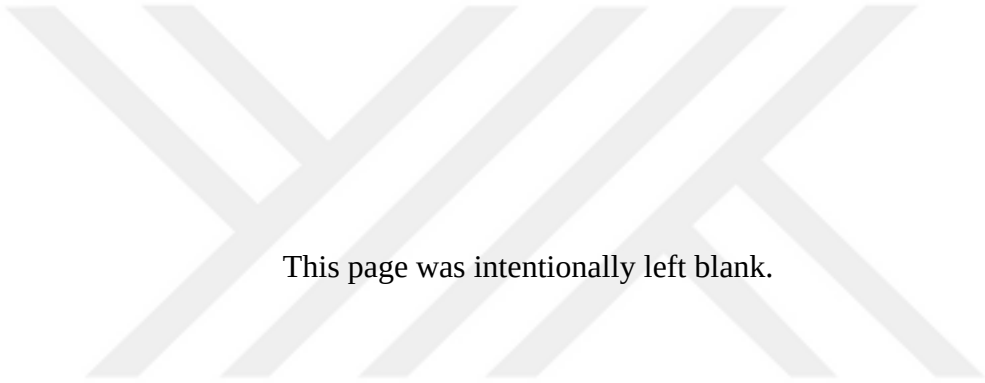
5.1. Conclusion

As a result, LARG approaches and the ANP method are discussed together. The LARG approaches are four different management strategies that optimize supply chain performance with the right practices. The ANP method, on the other hand, is a tool that enables selection among different alternatives by evaluating the effects of certain criteria on each other. This study has been undertaken so as to make contribution to the literature. Although, the significance of the topic is high, it is underestimated by the practitioners. And also, the future prospects were positive about the outcome of this dissertation. For all these reasons, the need to write this paper has arisen. The integration of the managers of the aforementioned firm was perfect in spite of their limited time. And also, the firm was in another city. However, pandemic facilitated the study due to the fact that everyone was able to be online more often. The present study exploits MS Excel. All the works were shown briefly and in a compact style. Considering all the above, this thesis aimed to specify whether lean, agile, resilient and green paradigms are applicable within manufacturing industry in Turkey or not. Based on both quantitative and qualitative analysis made, it can be concluded that there is no inconsistency in our method and the results are highly compatible with the prospects of the managers of the related firm.

5.2. Further Studies

In this thesis, the ANP methodology is solved using MS Excel. This has been a very complex solution. There is some computer software related to the ANP method. This software can be detailed in the future. Templates adapted from real life can be added to this software. This method further facilitates the decision-making mechanism of managers working in the supply chain. Going forward, these approaches will have an even greater impact on the supply chain area.

In future works, this topic can be deeply studied by using artificial intelligence as industry 4.0 integrates into manufacturing. For example, an artificial neural network problem or a genetic algorithm problem can be a new and breathtaking study for this area.



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