

An Optimization Model for the Incorporation of the Cultural Environment in the Aggregate Production Problem

by

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**An Optimization Model for the Incorporation of the Cultural
Environment in the Aggregate Production Problem**

Koç University

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This is to certify that I have examined this copy of a master's thesis by

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and have found that it is complete and satisfactory in all respects,
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I dedicate this thesis to my wife, Ayşegül, who has been a constant source of support and encouragement. I also dedicate this study to my advisor Prof. Metin Türkay, who has guided, supported and trusted me throughout this study.

ABSTRACT

Supply chain management uses different tools in the planning process one of which is the aggregate production planning model. This model determines production rates, inventory levels, and workforce requirements of a production plant on a periodic basis to minimize total costs (or maximize total profit) while fulfilling customer demands in time. The traditional aggregate production planning model is a cost-driven model like other prevalent supply chain management tools. However, the widespread adoption of economic factors while ignoring environmental, social and cultural factors in the planning and management of the supply chain is a flawed approach: the supply chain cannot be expressed apart from environmental, social, and cultural factors as an island isolated from the real world. Therefore, the requirement for a step change to a realistic model leading to sustainability forces the decision makers to be more demanding and sensitive to all four pillars of the sustainability. In this scope, this thesis aims to fill gaps in the current body of knowledge by combining economic, environmental, social, and cultural factors of sustainability within the aggregate production planning model. To do so, firstly we define new parameters, decision variables, and constraints. Then, we expand the formulation scope of the traditional aggregate production planning model within single- and multi-objective models to cover sustainability considerations. Finally, we analyze the modified models with a case study from real life.

Keywords: supply chain sustainability, sustainable aggregate production planning, environmental responsibility, social equity, cultural vitality

ÖZETÇE

Tedarik zinciri yönetimi, planlama sürecinde farklı araçlar kullanır; bunlardan biri bütünleşik üretim planlama modelidir. Bu model, müşteri taleplerini zamanında yerine getirirken toplam maliyeti en aza indirmek için (veya toplam karı en üst düzeye çıkarmak için) bir üretim tesisinin dönemsel bazda üretim hızlarını, stok seviyelerini ve işgücü gereksinimlerini belirler. Geleneksel bütünleşik üretim planlama modeli, diğer birçok tedarik zinciri yönetimi aracı gibi maliyet odaklı bir modeldir. Bununla birlikte, tedarik zincirinin planlanması ve yönetiminde yaygın olarak ekonomik faktörlerin göz önünde bulundurulurken çevresel, sosyal ve kültürel faktörlerin göz ardı edilmesi kusurlu bir yaklaşımdır; tedarik zinciri, gerçek dünyadan izole edilmiş bir ada gibi çevresel, sosyal ve kültürel faktörlerden ayrı ifade edilemez. Dolayısı ile sürdürülebilirliği sağlayacak gerçekçi bir modele adım atılması gereksinimi, karar vericileri sürdürülebilirliğin dört temel unsuruna karşı daha fazla talepkar ve duyarlı olmaya zorlar. Bu kapsamda, bu tez bütünleşik üretim planlama modeli içerisinde sürdürülebilirliğin ekonomik, çevresel, sosyal ve kültürel faktörlerini birleştirerek mevcut bilgi birikimindeki boşlukları doldurmayı amaçlamaktadır. Bunu gerçekleştirmek için ilk olarak yeni parametreler, karar değişkenleri ve kısıtlar tanımlandı. Daha sonra, geleneksel bütünleşik üretim planlama modelinin formülasyon kapsamını, hem tek amaçlı hem çok amaçlı fonksiyona sahip modellerde sürdürülebilirlik konularını kapsayacak şekilde genişlettik. Son olarak, gerçek hayattan alınmış bir vaka çalışmasıyla, düzenlediğimiz modelleri analiz ettik.

Anahtar kelimeler: sürdürülebilir tedarik zinciri, sürdürülebilir bütünleşik üretim planlama, çevresel sorumluluk, sosyal eşitlik, kültürel canlılık

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TABLE OF CONTENTS

List of Tables	ix
List of Figures	x
Chapter 1: Introduction	1
1.1 Background and Problem Definition	1
1.1.1 Supply Chain System and Supply Chain Management	2
1.1.2 Aggregate Production Planning	6
1.1.3 Sustainability	10
1.1.4 Problem Definition	17
1.2 Thesis Statement	18
1.3 Thesis Objective	19
1.4 Contributions of the Thesis	19
1.5 Thesis Outline	20
Chapter 2: Literature Review	22
2.1 Insights from Previous Literature Reviews	22
2.2 Environmentally Conscious Studies	25
2.3 Socially Conscious Studies	28
2.4 Both Environmentally and Socially Conscious Studies	29
2.5 Inferences of the Literature Review	32
Chapter 3: Materials and Methodology	34
3.1 Economic Viability	35
3.2 Environmental Responsibility	37

3.2.1	Energy Consumption Reduction and Renewable Energy Source Integration	38
3.2.2	Greenhouse Gas Emission Reduction	41
3.3	Social Equity	43
3.3.1	Employee Safety Improvement	46
3.3.2	Employee Gender Equity Satisfaction	47
3.3.3	Worst-Case Customer Satisfaction Level Restriction	48
3.3.4	Corporate Social Responsibility Project Implementation	49
3.4	Cultural Vitality	50
3.4.1	Employee Well-being Fulfillment	51
3.4.2	Innovation Performance Improvement	52
3.5	The Sustainable Aggregate Production Planning Models Including the Cultural Environment	53
3.5.1	Parameters of the Models	53
3.5.2	Decision Variables of the Models	56
3.5.3	The Single-Objective Model	57
3.5.4	The Multi-Objective Model	62
3.6	Case Study	66
Chapter 4:	Results and Analysis	68
Chapter 5:	Conclusions	76
Appendix A:	Traditional Aggregate Production Planning Model	81
Appendix B:	Sustainability Framework Aspects	84
Appendix C:	Properties of Used Computer and Version of Fico Xpress Solver	87
Bibliography		88

LIST OF TABLES

2.1	Advantages of sustainable supply chain management	23
2.2	Several sustainable framework aspects	24
2.3	Summary of model-based literature review	33
3.1	Measures for social sustainability performance	45
4.1	Highest and lowest values of objective functions among the investigated solutions	69
4.2	Rates of costs within a total cost	70
B.1	Sustainable framework aspects	86

LIST OF FIGURES

1.1	Supply chain system	3
1.2	Positive impact of effective supply chain management practices	5
1.3	Opportunity of leading supply chain management practices	6
1.4	Supply chain planning levels	7
1.5	Gainings with sustainability	11
1.6	Sustainability as defined by the triple bottom line	14
1.7	Three alternative roles of culture inside the sustainable development .	16
2.1	Distribution of reference papers with respect to the sustainability di- mensions	24
3.1	Used path in this study for sustainable aggregate production planning model	35
3.2	Energy consumption and population growth projection	39
3.3	Discovered oil worldwide	40
3.4	Customer response to stock-out situation	48
4.1	Trade-off between net profit and total revenue	69
4.2	Environmental performance is dominated by production activities . .	71
4.3	Best economic performance solution	73
4.4	Best environmental performance solution	73
4.5	Best social performance solution	74
4.6	Best cultural performance solution	74
4.7	A balanced performance solution	75

Chapter 1

INTRODUCTION

This introductory chapter gives an overview of the main points of the thesis. The first section starts by identifying the problem area, goes on with defining some concepts related to this issue, and finally concludes after specifying the problem in question. Supply chain system and supply chain management, aggregate production planning, and sustainability are the established concepts covered in this section. The second section presents the thesis statement that is prepared under the light of given background in the first section of the chapter. The third section is devoted to the introduction of thesis objectives. Then, we discuss contributions of the thesis to the current literature. Finally, we conclude the first chapter by providing the structure of the remaining chapters.

1.1 Background and Problem Definition

Professionals and academicians all over the world have progressively recognized the importance of the sustainability concept in the recent years. In most cases, refusal of belief in the essence of the idea has returned the pro-activity in sustainability issues day-to-day. Actually, those who think about sustainability have realized that sustainable development is not a short-term temporary target that comes with immediate profits but a long-term evolution that needs to change the mind of each individual and collective behavior patterns all over the world [Bouchery, 2012]. Thus, leading companies have started sustainability projects and have collected long-term acquisitions although they have made a huge amount of initial investments to these projects [Chopra and Meindl, 2016].

Supply chains are the systems that have a significant influence on the implementation of sustainable development strategies. This is because practices, flows, and actions along the supply chains have a strong relationship with the pillars of the sustainability and affect the success of global sustainability targets [Varsei, 2016]. As a result, both literature of sustainability consideration in supply chain and practices in the industry have been growing gradually. Moreover, there exists a strong consensus that sustainability issues will continue to shape supply chains in the future [Berns et al., 2009, PwC, 2013].

Among the many works related to sustainability issues in the supply chain, we observe that optimization models used in supply chain management deserve further attention in order to update them with sustainability criterion. Indeed, some researchers have already mentioned the need for modification of traditional models by considering requirements of sustainability [Turkay, 2008, Benjaafar et al., 2013]. By taking the relevant observation into account, we identify the problem area of the current thesis as the model-based study for satisfying supply chain sustainability by updating traditional optimization models.

There are many different models used in the supply chain optimization process. In this thesis, we study to adjust only one of the most commonly used optimization models of the supply chain with sustainability consideration. However, before specifying the exact problem, we have to define concepts of supply chain system and supply chain management, aggregate production planning, and sustainability.

1.1.1 Supply Chain System and Supply Chain Management

A manufacturing operation occurred at an assembly line, a storage activity started and finished between the four walls of the warehouse, or a single planning process performed by a group of engineers cannot completely define the supply chain. The supply chain comprises all the activities from the point of raw material procurement to the point of final product consumption [Lummus and Vokurka, 1999]. Sourcing and procurement of raw materials, scheduling of production plans, processing of customer

orders, management and control of stocks, transfer of materials and finished goods, warehousing, and providing customer service are some of these activities that can be observed from beginning to the end of the supply chain [Quinn, 1997]. Furthermore, information systems make it possible to monitor all these activities.

Supply chain activities have a linked chain structure of operational stages performed by several parties that may include suppliers, manufacturers, carriers, warehouses, distributors, retailers, and customers. In other words, supply chain connects all of these participants from raw material to the ultimate customer as shown in Figure 1.1. Each organization also has supportive functions, some of which are research and development, finance, marketing, operations planning, information technologies and customer service. Product, information, and fund flowing both directions of the chain provide a connection between stages. As an integral part, customers stand at the final stage of the chain. Together with its all activities, parties and supportive functions, a supply chain is a system that ultimately exists to serve this last stage while generating profit for itself [Chopra and Meindl, 2016].

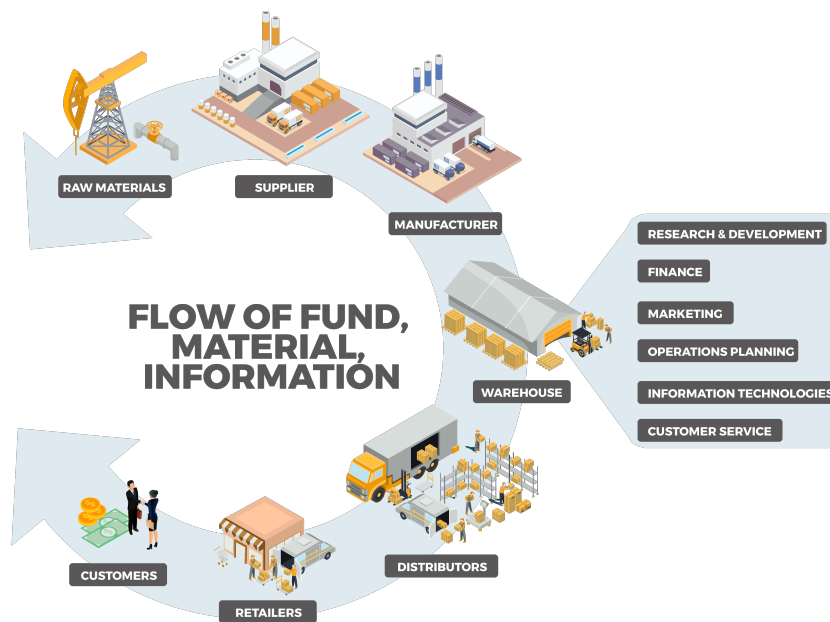


Figure 1.1: Supply chain system

Historical development of the supply chain has progressed systematically over the years; it evolved gradually from transportation dock and warehouse floor planning to management of extraordinarily complex global networks. From the 1950s to the end of the 1990s, transportation, physical distribution (outbound logistics), materials management (inbound logistics), and the business logistics were respectively the focal points of the organizations [Southern, 2011]. The term "supply chain", which covers logistics planning and management activities, first used by Keith Oliver in 1982 [Laseter and Oliver, 2003]. However, logistics management evolved to supply chain management in the first decade of the 21st century with the development of information systems and communication technologies that provide more opportunities for coordinating activities across the supply chain [Robinson, 2015].

Companies concern on supply chain management has increased gradually and in an even and regular way since the 1980s with the observation of advantages and gained profits via growing collaborative interrelation between both in-organization functions and out-organization partners through supply chains. Companies have made an inference that they can no longer compete in an efficient way if they are in isolation from their partners or other entities in their supply chain. At that point, several numbers of different definitions have been proposed for "supply chain management" term in both the academic literature and practice. The Council of Supply Chain Management Professionals (2013) gives the description that

Supply chain management encompasses the planning and management of all activities involved in sourcing and procurement, conversion, and logistics management activities. Importantly, it also includes coordination and collaboration with channel partners, which can be suppliers, intermediaries, third party service providers, and customer. In essence, supply chain management integrates supply and demand management within and across the companies.

In other words, supply chain management plans and manages all the operations in the supply chain, and allocates cooperation and coordination among supply chain stake-

holders by controlling the flows. Definition of it indicates the fact that supply chain management is not standalone processes of stock control, warehouse and inventory management, logistics and transport management, customer or supplier relationship management, shipping, marketing or sales strategy, procurement management or an information technology infrastructure. Thus, with its all parties, functions, and activities, supply chain works as one entity in harmony.

Nowadays, market conditions convert rivalries between companies to the wars of supply chains. Managers start to look beyond their own companies to reform the structure and increase competition power of their whole supply chain instead of engaging in the success of merely their companies. Processes, functions, entities, companies and even industry groups come together and coordinate their activities to catch harmony under the pressure of improving their supply chain processes and accelerating gains via successful implementations. Hence, the process from raw material procurement to consumption is viewed as one single system.

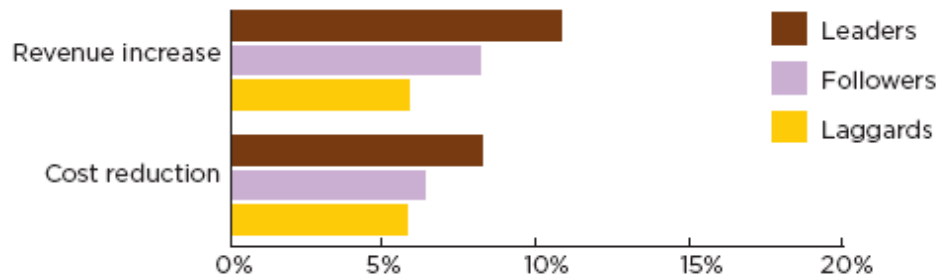


Figure 1.2: Positive impact of effective supply chain management practices [Computer Sciences Corporation, 2012]

Comprehensive application of supply chain management with this perspective can empower the parties in the chain to upturn market shares, minimize expenditures, and improve customer services. Gaining such advantages increases the confidence of supply chain management to be successful in the competition of the global market and networked economy. Companies who successfully performed supply chain integration reports lower inventory levels, reduced cash flow cycle times, shorter inventory cycle

times, declined material acquisition costs, increased employee productivity, and higher customer satisfaction. Supply chain management helps increase revenues and reduce expenses that market leaders can achieve 1.5 to 2 times better experiences in comparison to laggards as can be seen in Figure 1.2 [Computer Sciences Corporation, 2012]. Global Supply Chain Survey of PwC (2013) also demonstrates that companies that recognize supply chain management as a strategic asset accomplish 70% higher financial performance (see Figure 1.3). The difference between success and failure of Walmart and its past primary competitor Kmart results from the difference between excellence and poorness of their supply chain management [Bogenrief, 2012]. Amazon, Apple, Coca-Cola, Dell, Intel, P&G, Walmart, Whirlpool, and Zara are companies that owe at least part of their success to their mastering supply chain management.

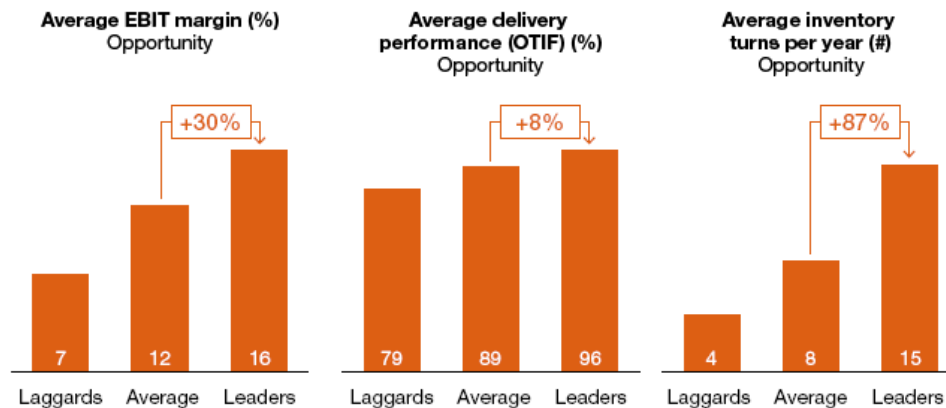


Figure 1.3: Opportunity of leading supply chain management practices [PwC, 2013]

1.1.2 Aggregate Production Planning

Drawing a supply chain strategy that is in the same direction with an overall business strategy of a firm is the first and foremost necessity for success. After that, supply chain management promotes success stories using different tools one of which is aggregate production planning. Aggregate production planning is a mathematical model that determines production rates, inventory levels, and workforce requirements

of a production plant to minimize total costs (or maximize total profit) while fulfilling customer demand in time.

It is a crucial necessity for companies to clearly define their organizational objectives and make supply chain decisions to meet these targets, since clearly defined organizational objectives are imperative to provide guidance and direction to the enterprise. Once the goal is decided, a company must manifest relevant policies to design, plan and operate its supply chain to be successful.

Supply chain planning process is divided into three levels according to decision frequency and affected time distance as can be seen in Figure 1.4. The first and highest level is the strategical level where the supply chain is designed according to organizational objectives. Decisions in these groups affect the next several years and involve a significant amount of investments. The second level is the tactical level where the supply chain is planned to maximize profit and plans cover three to 18 months. The third and lowest level is the operational level where decisions are made to arrange individual customer orders to achieve the highest customer satisfaction. The time horizon in this group of decisions is weekly or daily [Anthony, 1965]. A company must establish and spread a set of detailed objectives for each part of the supply chain from the strategical level to operational level. This cascading technique integrates all the parts of the supply chain with the company objectives.



Figure 1.4: Supply chain planning levels [Mattes, 2015]

Aggregate production planning is a capacity-planning method at the tactical planning level. The name aggregate is given the planning model because it looks the big picture with the pre-determined capacity constraints instead of providing attention to individual products or orders. This is the result of the fact that in the time frame of tactical planning, it is too late to make investments to increase capacity, and it is also early to make plans in a stock-keeping unit base. Moreover, it does not plan whole tactical planning horizon as a single period. Alternatively, the planning horizon is divided into the small extent of times like as weeks, months or quarters.

The model handles cost figures that are:

- Material costs,
- Regular and overtime labor costs,
- Hiring and firing costs,
- Inventory holding costs,
- Subcontracting costs,
- Stock-out costs.

Furthermore, forecasted demands, initial workforce and inventory levels, regular work hours in each period, and required work hours per labor to produce a unit of an item have to be declared to the model. After that, the model restricts the results with respect to constraint such as:

- Workforce balance,
- Upper capacity limit,
- Inventory balance.

Correspondingly, it helps planners meet fluctuating customer demand in a cost-effective manner by offering production amounts, workforce levels, overtimes, hiring and firing requirements, inventory levels, back orders, and subcontracting on a periodic basis. Parameters, decision variables, objective function and constraints of the traditional mathematical model with their explanations are provided in Appendix-A.

The aggregate production planning model not only presents the optimized output levels but also delimits the used source levels to constitute appropriate input mixture. In other words, it allows planners to put usage limitations on one or more source(s) in the production planning process. Moreover, like supply levels, the model is capable of dominating demand levels by optimizing variables such as price, promotions, and product mix [Pan and Kleiner, 1995].

In many contemporary research studies and practices provide pieces of evidence for awareness that solutions to real-life problems of managers, decision-makers, and academicians can be developed by optimization models [Davizon et al., 2015]. Hence, extremely broad modeling options of aggregate production planning make it a powerful tool in the cascading process of organizational objectives. Targets of strategic planning level can be injected into the model of aggregate production planning via new parameters, decision variables, and constraints. Therefore, reformulation of the model will meet the requirements of faced situations and problems in practice [Schroeder and Larson, 1986]. The general model has been arranged to include additional managerial objectives of keeping the low level of inventories, improving labor relations, increasing flexibility to increase future output, and achieving higher customer satisfaction level.

On the other hand, results of the aggregate production planning model also have an important impact on supply chain performance [Schroeder, 1985]. Outputs of the aggregate planning govern roughly all parts of the organization. In this scope, even if the aggregate planning draws a picture for medium-range time horizon, it must support the long-term strategic targets, therefore, reflects objectives of the firm. The "Hierarchical Production Planning" model exactly explains the situation. This model

explains that decisions from higher levels constrain the lower levels, and conversely outputs of the lower levels feedback higher levels [Bitran and Tirupati, 1981]. For this reason, organizational policies of a company must represent itself inside the constraints and the objective function of the aggregate production planning model.

1.1.3 Sustainability

Nowadays, players in the global market are not appraised only with their financial performances. Hence, most of their traditional financial-based business growth and development paths become insufficient for the contemporary business environment that companies may not follow these ways in the future. The challenges may drive companies to change their growth and development strategies because success comes with new thinking, approaches, and infrastructures. The leading practices demonstrate that the solution may be sustainability where World Commission on Environment and Development (1987) presents the most accepted definition of the sustainability as "meeting the needs of the present without compromising the ability of future generations to meet their own needs".

Sustainability has become a new mantra of both practitioners and academics in recent years. A survey conducted by Boston Consulting and MIT with more than 1500 business leaders and more than 400 academician respondents has revealed that sustainability will reshape the actions and thoughts of the entities. More than 92% of the same survey respondents state that their company worked on sustainability issue in some way [Berns et al., 2009]. More than two-thirds of all participants in the Global Supply Chain Survey of PwC, which was conducted with more than 500 supply chain experts, report that in the future, sustainability will return a tremendous driver in the supply chain [PwC, 2013]. 95% of G250 companies -the largest 250 companies in the world- report their activities about sustainability and 62% of them offer sustainable products to the market [KPMG, 2011].

Several factors lead to an increase in the importance of sustainability. Firstly, sustainability dramatically affects the company image as shown in Figure 1.5. All

stakeholders of the supply chain in present-day hyper-communicative social environment pursue sustainability approaches of the companies. Customers measure, compare and rank the sustainability performances of the organizations. Sustainability creates value for customers and a growing tendency to prefer sustainable products [Berns et al., 2009, Melnyk et al., 2010, Bask et al., 2013]. Customers engage companies that create highest sustainability passion perception. Conversely, customers punish products that do not follow the sustainability requirements; a research shows that customers may pay more for sustainable products, but they buy a product with a discount if it is produced in unethical ways [Trudel and Cotte, 2009]. A good company image also attracts the investors to prefer a company to put their funds. Moreover, self-motivation of internal stakeholders are impressed by the sustainability. Being the part of a solution creates value for employees. Hence, employees of modern time put positive and responsible company culture center of their attraction. Sustainability is a trump in hand for the companies to draw the attention of skilled employees that favor working for an organization with strong sustainability commitment.

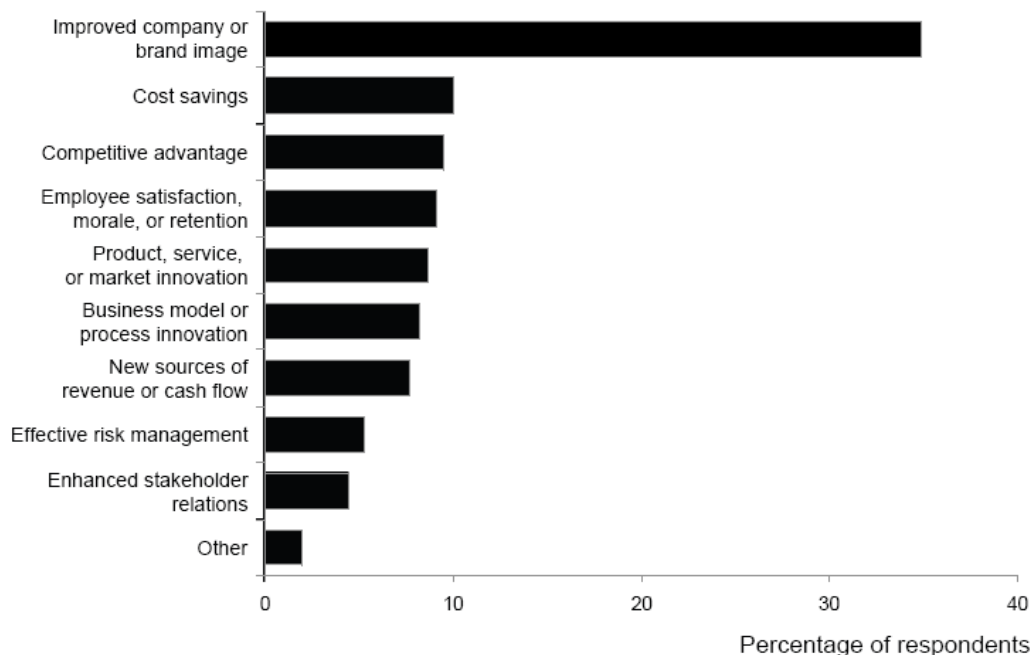


Figure 1.5: Gains with sustainability [Berns et al., 2009]

Secondly, sustainability consideration increases the market, operation, and accounting based performance of the firms. Although supply chain management centralizes cost issues to maximize acquisitions, companies gain an advantage in the market competition with sustainability factors [Pullman et al., 2009, Salmona et al., 2010, Golicic and Smith, 2013]. On the one hand, the number of companies that pay closer attention to sustainability is increasing; however, most of these companies spend an insufficient amount of effort to integrate sustainability applications on their supply chains and fall back at the competition [PwC, 2013]. On the other hand, results show that companies are acting aggressively on sustainability -such as GE, Toyota, IBM, Shell, and Wall-Mart achieve rewards more than their expectations [Berns et al., 2009]. Wal-Mart, for example, announced its sustainability index in July 2009, which positively affected their public relations and increased their cost savings by reducing energy consumption [Blackhurst et al., 2012].

The third, sustainability initiatives are the response to pressure from government regulations [Massaroni et al., 2015, Varsei, 2016]. Companies want to ensure legal and regulatory compliance of their businesses that with their all units and business partners they strive to follow legal arrangements of their operational areas. The Kyoto Protocol, the United Nations Climate Meeting of 2007, the Bali Treaty, the British Climate Change Bill, the Carbon Disclosure Project, the EU Directive on Renewable Energy, and other political actions force industries to find new solutions.

The fourth motivation for the sustainable approach of companies is natural resources depletion risk and other related risks [Chopra and Meindl, 2016]. Resource depletion can disturb businesses in several ways. If a company has a dependency on a resource that is scarce, then the company has huge dangers of speculations, price manipulations, political problems and worst of all facing depletion of the resource that may stop business. To overcome such obstacles, companies conduct studies to reduce their resource requirements, invest funds in environmentally friendly technologies for more independent renewable sources and diversify their current supply sources.

It is predicted that sustainability will become an integral part of business strategies

and operations because sustainability issues are strategic and economic arguments of businesses. Sustainability approaches directly or indirectly affect every single department of companies from research and development, and manufacturing to sales, marketing, and even information technologies. Sustainability decisions potentially modify every value created step of the businesses both in the short- and long-term. At this juncture, supply chains play an increasingly vital role to achieve sustainability targets.

Even if the contributions of supply chains directly determine economic performance of the businesses nowadays, supply chain management may not continue to look world from a single perspective of economic concentration. Therefore, it becomes suitable to mention sustainable supply chain management. Sustainable supply chain management aims to mount up the performance of the supply chain both from the aspect of economic expectations and sustainability considerations, while co-ordinately and efficiently managing flows of the fund, information, and material through the supply chain.

Many of the sustainability approaches are based on the "Triple Bottom Line" concept of the Elkington (1997). The concept puts the sustainability to the intersection point of economic viability, environmental responsibility, and social equity as can be seen in Figure 1.6. Economic dimension focuses on the financial expectations of the customers, employees, suppliers, and investors. Environmental side of the sustainability considers minimizing waste, reducing the carbon emission and other pollution, and protecting natural resources. In order to satisfy environmental sustainability, the consumption rate of the natural resources has to be balanced with replenishment rate of them. Social aspect matters for human rights, diversity, employment quality with opportunities for training and development, and health and safety conditions of workers. This trilateral structure is also called 3P model -people, profit, and planet [Tascioglu, 2015].

Some researchers, on the other hand, explains that three-dimensional model cannot characterize the bottom line of the sustainability completely. Multidimensional

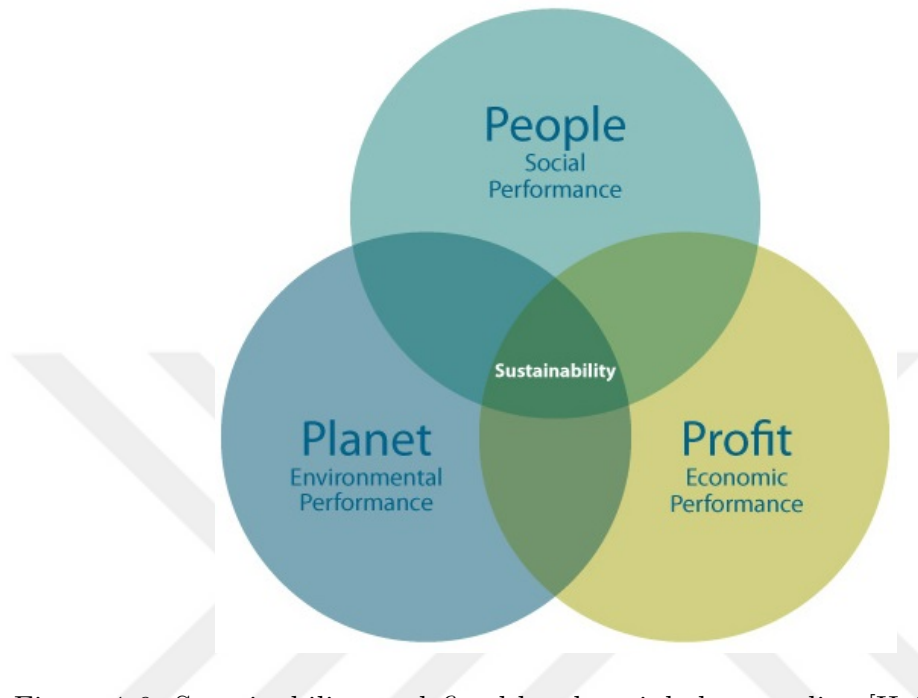


Figure 1.6: Sustainability as defined by the triple bottom line [Heffernan, 2015]

structure of sustainability consists of four pillars that culture takes an essential role in the sustainability. Glossary definition of the term culture is given as "the customs and beliefs, art, the way of life and social organization of a particular country or group" [Oxford Learner's Dictionary, 2017]. Cultural action shapes our feelings and thoughts about our presence and surrounding we live. By the help of culture, one can point out our values and requirements. Hawkes (2001) states that culture is the "bedrock of society" and every other thing in society stands on it because culture manages patterns of human activities. This awareness amends the viewpoint that brings clarity to appraising past, planning future and reviving the present to achieve sustainability. Astara (2014) puts culture among the other three pillars as an essential component and states that as a second role, culture also conduces other commonly accepted pillars for sustainable development. They explain their statement with three examples that point out the contribution of culture to the other three pillars. First, they state that the environmental management of cultural heritage makes it possible to reduce CO₂ emissions. Second, they reveal that investment selections are performed under

cultural influences leading to ensure continuity of activities such as construction, food production, tourism, traditional therapy, and pharmacology. Finally, they assert that conservation of cultural diversity with a fair share of resources increase the respect for others and satisfies the social peace.

The Council of European Union (2014) sees cultural heritage as a valuable asset that plays a crucial role to achieve objectives of the 2020 strategy for a "smart, sustainable, and inclusive growth". Then, the council explains that culture influences social life, economic growth, and environmental sustainability as the fourth pillar. Nurse (2006) states that preservation, advancement, and continuity of cultural diversity comes with universal human rights, fundamental freedom and genetic and ecological diversity. For that reason, sustainability depends on the harmony and adjustment between the targets of cultural diversity and that of social equity, environmental sustainability, and economic viability. Moreover, they declare that the meaning of development and actions of people among the society are shaped by the culture so that culture is not the fourth pillar but also the central one for the sustainable development.

In their book *Resetting the Compass*, Yencken and Wilkinson (2000) point out culture as the fourth aspect of sustainability. After four years research with around 100 researchers from 25 different countries, as the conclusion of European Cooperation in Science and Technology, Dessein et al. (2015) draw three different roles for culture inside the sustainability according to different definitions of it as shown in Figure 1.7. First drawn role is "culture in sustainable development" that culture is a complementary factor that supports other three pillars and promotes itself. This approach expands conventional triple bottom line structure of the sustainable development by giving the role to the culture as a self-standing 4th pillar alongside separate economic, environmental and social pillars. In other words, culture is combined with other three pillars as a fourth pillar. The second alternative is "culture for sustainable development" that culture combines other three pillars as a bridge in this role. However, the culture in this role is a more powerful factor that can act operate beyond itself.

Culture stands into a "framing, contextualizing and mediating mode" so that it can satisfy harmony among all three of the existing pillars and manage sustainable development by balancing pressures and needs of the economic, environmental and social pillars. Third and final alternative role is "culture as sustainable development" that with its ever-changing dynamic structure, culture is the foundation for sustainable development. This role is a more fundamental one that consolidates, coordinates and directs all aspects of the sustainability actions. As a result, all of the three roles consider cultural diversity as a need for sustainable development that culture is mutually intertwined with sustainability.

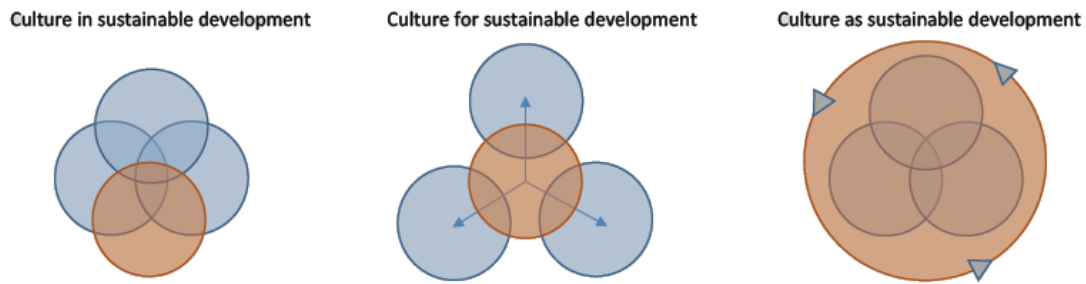


Figure 1.7: Three alternative roles of culture inside the sustainable development [Dessein et al., 2015]

After then UNESCO's "Universal Declaration on Cultural Diversity" in 2001 and "Convention on the Diversity of Cultural Expressions" in 2005, United Cities and Local Governments Committee on Culture and World Secretariat (2010) states that:

The world is not only facing economic, social, or environmental challenges. Creativity, knowledge, diversity, and beauty are the unavoidable bases for dialogue for peace and progress as these values are intrinsically connected to human development and freedoms.

and develops policy statements on culture as the fourth pillar of sustainability.

It is an era in the history of the world that all nations should show higher interest than ever for developing coordinated actions for persuading common goals of sustain-

ability by taking into account of the interrelation between humankind, environment, culture, wealth and development. Within this context, a business should pursue sustainability with the supply chain design, plans, and operations combining all four kinds of drivers of sustainability -economic, environmental, social, and cultural.

1.1.4 Problem Definition

The traditional aggregate production planning model is a cost-driven model like other prevalent supply chain management tools. Nevertheless, the widespread adoption of economic factors while ignoring environmental, social and cultural factors in the planning and management of the supply chain is a flawed approach: the supply chain cannot be expressed apart from environmental, social, and cultural factors as an island isolated from the real world. Each supply chain is a small part of the world. Activities of supply chain start with sourcing and procurement of raw materials from nature, then they follow several production processes to obtain finished goods, and finally, they finish with consumption of products. Along with this path, the supply chain gets all essential material resources for generating raw materials and energy for running operations from nature. Conversely, it releases wastes to nature originating from its activities. Moreover, in different stages of a supply chain, human beings take different roles such as investors, employees, and customers. In these roles, they reflect their social and cultural identity in their actions that interact with supply chain activities. As a result, environmental, social, and cultural factors become influential in every part of a supply chain that companies should investigate and gauge not only economic but also environmental, social and cultural impacts of their activities.

The requirement for a step change to a realistic model leading to sustainability forces the decision makers to be more demanding and sensitive to environmental, social and cultural factors as well as the economic factors. Requisitions for sustainability is the result of the fact that economy is six times, energy consumption is two times larger than five decades ago. Globalization accelerates the diffusion of ideas and cultural values. The number of migrants in the world has increased from 77 mil-

lion to 230 million since 1970. Even if the economy grows, some countries experience a financial crisis that leads to social and cultural destruction. Unemployment, for instance, increased 20% between 2007 and 2009, so 83 million young people were unemployed worldwide in 2009. After 1960, the world economy faced a global recession every decade (1975, 1982, 1991, and 2009). Poverty and inequality turned into the chronic illness of society. Climate change has become a dangerous problem of the world; carbon dioxide emission has risen significantly; weather-related natural disasters have ascended to the point that is three times greater than it was in the 1960s [Kose and Ozturk, 2014].

Firms should improve their company image by being the part of the solution of these problems. They also should strengthen their market position in such tough conditions by increasing their performance across all kind of risks threatening their business. However, by traditional financial based approaches, it is more difficult to develop new strategies for achieving these targets. Therefore, the specified problem of the current thesis is "single-dimensional structure of traditional aggregate production planning model that ignores the multi-dimensional structure of the sustainability by paying no attention to environmental, social and cultural considerations".

1.2 Thesis Statement

Changing market conditions continue to modify management of production and operations that stimulates companies to revise their strategies accordingly [Liu et al., 2017]. Nowadays, the sustainability concern is one of the main factors affecting the decisions in supply chains. Hence, the multi-dimensional structure of the sustainability reshapes future strategies in supply chain management, and improvements establish synchronization with the world that makes it possible to see the bigger picture for nature and human beings instead of narrowing it to the financial perspective. Thus, the thesis statement of the current body is as follows:

Supply chain management has started to evolve sustainable supply chain management. To support and strengthen this transformation, traditional

supply chain optimization models require modification with sustainability considerations. In this context, the traditional aggregate production planning model needs to be re-modeled with the consciousness of environmental, social and cultural factors together with economic factors.

1.3 Thesis Objective

The fundamental objective of the current thesis is to illustrate how a methodical approach can be developed for integrating all four pillars of the sustainability inside the aggregate production planning model. We aim to demonstrate how sustainability-related issues could be associated with several decision variables, parameters, and constraints. Moreover, we examine the effects of reformulation. We aspire to provide a series of insights in order to underline the impact of the decision under sustainability concern.

1.4 Contributions of the Thesis

Reformation of supply chain strategies for improving company image, increasing operational performance, satisfying long-term profitability and strengthen competitiveness has encouraged supply chain professionals to put rising interest on sustainability. The significance of sustainability has been realized widely not only by practitioners but also by academicians, so studies about sustainability have increased gradually in recent years. The environmental aspect of the sustainability has taken spotlights of the sustainability studies. However, social factors of sustainability cannot get sufficient attention, and cultural side becomes a niche in the literature. Besides that, most of the works are empirical based that enough consideration has not been given to modification of the traditional models of the supply chain management with sustainability approach.

Turkay et al. (2016) reveal gaps in the current body of knowledge by combining economic, environmental, and social factors of sustainability within a modification of aggregate production planning model. This thesis aims to take a step forward to

expand the scope of sustainable aggregate production planning model by the incorporation of the cultural environment.

1.5 Thesis Outline

This report includes four more chapters. The remaining chapters are the literature review, materials and methodology, results and analysis, and conclusions chapter.

Literature review chapter intends to analyze sustainability based studies in the supply chain management literature. It starts with investigating previous reviews and accordingly derives some useful results. In the next three sections, deeply examined studies are shared with the reader under the headings of environmentally conscious studies, socially conscious studies, and both environmentally and socially conscious studies. Finally, we conclude the chapter by a summary.

Sustainable development requires a multi-dimensional thinking so that new approach to aggregate production planning model includes multiple objectives and restrictions of economic, environmental, social, and cultural pillars. Defining the parameters, decision variables, constraints and objective functions of the modified aggregate production-planning problem is one of the most critical stages of the model development process. The more precise definition of model components means the more reliable solutions to aggregate planning problem and the more closely approach to the sustainability target. Accordingly, in the first four sections of the materials and methodology chapter, we argue our criterion by concerning their impacts on the pillars of sustainability and explain how to modify the traditional aggregate production planning model from the perspectives of economic viability, environmental responsibility, social equity and cultural vitality. Then, we reformulate aggregate production planning problem both as a single- and multi-objective linear model by the help of arguments presented in the first four sections of the chapter. Finally, we share a case study from a real-world situation in the last section of the chapter.

In the results and analysis chapter, we evaluate solutions coming from the multi-objective model. Solutions from the multi-objective model are non-dominated solu-

tions. A non-dominated point in the objective space is a solution that not all of objective function values associated with this non-dominated point can be improved simultaneously. We obtain a number of non-dominated points of the sustainable aggregate production-planning problem, and measure effect of each sustainability consideration accordingly. Therefore, we interpret the trade-off among the non-dominated points.

Finally, in the conclusion part, we summarize our work and findings with presenting our recommendations for future studies.

Chapter 2

LITERATURE REVIEW

Literature review chapter intends to make an analysis of sustainability based studies in the supply chain management literature. In the related literature, sustainability consideration steadily has taken more space in the recent years. Fast consumption and rising contamination of natural resources and unrestrained urbanization return sustainability consideration into a mandatory issue of massive economic growth. Furthermore, the effect of recognized importance of sustainable development on long-term profitability and competitiveness are the other drivers for these academic works. A general review of these studies points out that the related literature can be divided into three groups. The first group focuses solely on environmental sustainability, the second group puts emphasis only on social sustainability, and the third group studies both environmental and social aspects of the sustainability. These three groups shape the outline of the current chapter. We start with investigating previous reviews and accordingly derive some useful results. In the next three sections, we examine studies under the headings of mentioned three groups. Our literature review also demonstrates that there exists no study taking into account the cultural vitality as a fourth pillar of the sustainability in the sustainable supply chain management literature. Finally, we conclude the chapter by a summary.

2.1 Insights from Previous Literature Reviews

Sustainability issue in the supply chain management is one of the attractive topics in the recent years. A significant number of academicians and practitioners contemplate about this subject [Turkay, 2008, Salmona et al., 2010, Pfeffer, 2010, Park et al., 2013, Tascioglu, 2015, Massaroni et al., 2015, Liu et al., 2017]. There are several factors in-

creasing the attraction of the sustainability issue in the supply chain. In their literature review, Salmona et al. (2010) share list of their findings motivating sustainability pursuit as shown in Table 2.1.

Increment of efficiency
Increment of financial profits
Increment of customer satisfaction level
Increment of environmental effectiveness
Increment of employee job satisfaction and social life quality
Reduction of wastes
Reduction of system costs
Reduction of resource usage (i.e., raw materials, work force, and energy)
Reduction of risks and gaining agile characteristic with accelerating innovation
Enabling recycling
Gaining a good public image
Advancing the control mechanism
Joining global markets more easily
Relatively less difficulties in decision-making
Obtaining more power in the market competition
More adaptability through process innovations and continuous improvement

Table 2.1: Advantages of sustainable supply chain management [Salmona et al., 2010]

Each pillar of the sustainability has several sub-issues as shown in Table 2.2. However, publications about the sustainability issues in the supply chain management intensely focus on environmental issues that social aspect of the sustainability gets the relatively small amount of interest so that this context has relatively more gaps [Salmona et al., 2010, Pfeffer, 2010, Brandenburg et al., 2014, Massaroni et al., 2015, Varsei, 2016]. For instance, Liu et al. (2017) examine more than four thousand papers and filter 101 of them that are triple bottom line based studies. Among them, 94% include environmental consideration where only 27% of them touch social aspect as can be seen in Figure 2.1.

Environmental Aspect	Social Aspect
Energy consumption	Employee working conditions
Water consumption	Corporate social responsibility
Closed-loop supply chain	Effects of layoffs
Greenhouse gases emission	Work hours and work-family conflict
Green product development	Inequality
Renewable energy source usage	Training and education
Waste management	Child labor
Biodiversity	Diversity and equal opportunity
Material selection	Occupational health and safety

Table 2.2: Several sustainable framework aspects [Pfeffer, 2010, Tascioglu, 2015, Massaroni et al., 2015, Varsei, 2016]

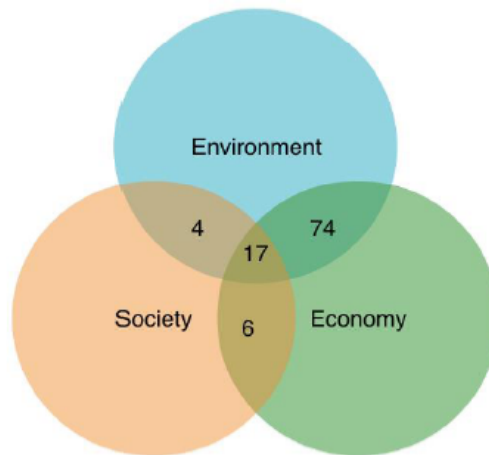


Figure 2.1: Distribution of reference papers with respect to the sustainability dimensions [Liu et al., 2017]

Another finding demonstrated that current literature mostly includes empirical studies, but there is a need for model and network design based studies to inject sustainability targets inside the strategic, tactical and operational level decision-making processes of the supply chain [Salmona et al., 2010, Brandenburg et al., 2014]. On the other hand, Eskandarpour et al. (2015) investigate 87 mathematical model based

studies for the supply chain network design problem. He points out that mixed integer programming is the most used technique in these works. Furthermore, he shares that about two third of proposed models include more than one objective function.

2.2 Environmentally Conscious Studies

Environmental sustainability approaches in the supply chain increase the operational and financial performance. Rao and Holt (2005) investigate the relationship between the green supply chain and supply chain performance with their implemented conceptual model. They find that application of environmentally friendly policies in the different stages of the supply chain leads to a better economic performance and stronger competitiveness. Golcic and Smith (2013) study more than twenty years of the environmentally sustainable supply chain literature and cover more than 4500 papers published between 1990 and 2011. They use an effect-based meta-analyze method and point out that practices positively affect performances of firms. They also divide the problem into four sub-problems and state that the positive effect of environmental sustainability approaches is significant in an application even if they are performed only one of the following: in the supplier side of the chain, in the product design process, in a manufacturing process and also in the customer side of the chain. Moreover, they claim that the most attractive returns are gained in the applications on the supplier side of the supply chain.

Some studies draw a framework for the sustainability of the supply chain. Sarkis and Rasheed (1995) point out the necessity of environmentally conscious manufacturing strategies and give tools and techniques to a successful application of these strategies in the processes and technologies. They call their method "3R"s -reduce, remanufacture and recycle. Noci (1997) identifies metrics to grade the environmental performance of suppliers and suggests a vendor-rating technique for decision-makers to manage supplier selection process. They use water and solid waste, energy consumption and greenhouse gas emission amounts as green performance indicators. Handfield et al. (2005) review some leader companies (some of which are IBM, Sony, BMW, In-

tel) to point out their methodology to develop environmental strategies in the supply chains. They conclude that the way to a greener supply chain passes from five steps: (i) define the strategic and ecological value of the commodity, (ii) make investigation about the commodity, (iii) declare and (iv) implement a strategy, and (v) measure performance. Ferguson and Souza (2010) demonstrate that closed-loop supply chains not only reduce carbon emission of firms but also create new ways of revenue streams for them. In their study, they investigate re-manufacturing, recycling, disassembling of old products for using as spare parts, and reverse logistics activities, and present state of the art in this field. Van Hoek and Johnson (2010) address energy consumption on Wal-Mart and Cisco Systems with the handled case study and call attention to new equilibrium points while still applying current cost-lead time trade-off.

Model-based approaches also attract the attention of the researchers. They do not only adjust traditional models with sustainability concern but also they create new models to increase sustainability performances in the supply chains. Lu et al. (2007) set a multi-objective decision analysis model to measure and evaluate the performance of suppliers. In their innovative model, they use analytical hierarchy process and fuzzy logic process. Furthermore, they examine their model with a case study. Tsoulfas and Pappis (2008) list ecological performance indicators for process/product design and production, packaging, transportation, recycling, and disposal, greening the complete business environment, and other management issues. Using these indicators, they create a multi-criteria decision-making model for supply chain management. Turkay (2008) formulates a multi-objective optimization model that simultaneously reduces greenhouse gas emission and cost in the energy production system. In their model, they add constraints for the use of biofuel, turbines, fuel tanks and mixers. They demonstrate how the model decreases annual carbon dioxide emission amount with an illustrative example.

Lee et al. (2010) form a two-stage stochastic model for designing a sustainable logistics network under uncertain conditions and show efficiency and significance of the model with a performed case study. Aviso et al. (2011) study on water footprint

of industrial activities. They present a multi-regional fuzzy input-output optimization model to constraint water footprint. After that, they set two case studies to demonstrate capabilities of their model. In the first case, they look the issue from the perspective of consumers and optimize water intensity of the activities in the supply chain. In the second case, they investigate production processes of biofuels.

Benjaafar et al. (2013) study to integrate carbon emission consideration into decision-making processes of raw material procurement, production planning, and stock management. They modify the mathematical models of single-stage and multi-stage lot-sizing problems, which are relatively simple, and commonly used optimization models. With respect to different carbon emission reduction policies, they define new parameters for carbon emission and then associate them with parameters of the traditional models. The modified models take into account both the carbon emission consideration and cost reduction expectations. By the help of newly generated models, they investigate the effect of different carbon emission reduction policies. Consequently, they point out that instead of investing lots of money to alternative energy sources or environmentally friendly new technologies, firms can decrease their carbon footprint by merely considering the issue in the operational decision-making phase, respectively adjusting their supply chain operations and satisfying collaboration with all members of the supply chain. With an analytic demonstration, Chen et al. (2013) complete Benjaafar et al. (2013) and support that merely adjusting organizational operations can decrease carbon and other greenhouse gases emission without considerably upturn expenses. They use the EOQ model for their study and try different order amounts to find equilibrium points that lessen the emissions while increasing costs in a relatively small amount. Finally, they examine the relevance of the modified EOQ model under different emission reduction policies like defining a cost figure for a carbon tax, restricting model with a carbon cap.

Validi et al. (2014) focus on the capacitated distribution network design problem for the dairy industry in Ireland. Their multi-objective optimization model considers minimizing carbon emission generated by transportation while remaining economi-

cally competitive with the related transportation cost outcomes. Fareeduddin et al. (2015) define mixed integer linear programming models for the strategic level planning of closed-loop supply chain and logistics operations with (i) mandatory carbon cap policy, (ii) carbon tax policy, and (iii) carbon cap-and-trade policy. Schenker et al. (2015) consider alternative bicycle manufacturing methods that they explain differences between producing a bicycle using aluminum and bamboo. Accordingly, they create a multi-dimensional integer-programming model that accounts both cost and energy consumption reduction concern and gives insights how to produce bicycles via non-dominated solutions. Yamada et al. (2015) conduct a study to select a supplier with both cost and greenhouse gas emission minimization objectives. To do so, first, they determine cost and greenhouse gas emission figures for production of different materials by different Asia countries. Then, they solve a multi-objective mathematical model by using specified data. Hovelaque and Bironneau (2015) also work on EOQ model with carbon emission concern. However, they even consider product price as a variable. They find out that generated EOQ model is more meaningful when used to plan cheaper and environmentally friendly products.

2.3 Socially Conscious Studies

Pfeffer (2010) draws attention to the effects of economic activities on human health and morality, as well as social environment. They question outcomes of health insurances, layoffs, working hours and work-family conflict, work stress and the results of job design, and inequality from the perspective of social sustainability. In the concluding part of their research, they call for the attention of social sustainability and say "we should care as much people as we do about polar bears -or the environmental savings from using better milk jugs". Sarkis et al. (2010) examine the social sustainability indicators in several reverse logistic practices to develop a profile for the social pillar of the sustainability. They divide the problem into four subheadings: social sustainability consideration for (i) internal human resources, (ii) external population, (iii) stakeholder participation, and (iv) macro social issues.

May et al. (2015) claim that current task-centric manufacturing systems will return to worker-centric systems; the importance of socially sustainable workplaces will increase. Hence, they consider worker, factory and context dimensions of the manufacturing system to establish a human-centric factory. Mani et al. (2016) gather responsibilities of suppliers, manufacturers, and customers for social sustainability. Their study demonstrates that social aspect of sustainability has a hexagonal structure with the combination of equity, safety, health and welfare, philanthropy, ethics, and human rights dimensions. Ahmadi et al. (2017) introduce a framework to integrate social sustainability consideration into manufacturing companies. To examine the suitability of their context, they conduct a best worst method analysis (a multi-criteria decision-making method) with 38 experts. Their inquiry shows that the most critical two criterion to reach a goal of social sustainability are the contractual stakeholder influence, and work safety and labor health.

Maloni and Brown (2006) determine eight dimensions of corporate social responsibility in the food supply chain that are animal welfare, biotechnology, environment, community, fair trade, procurement, labor and human rights, and health and safety. They present a framework for decision makers to perform successful corporate social responsibility activities in the strategic and operational levels. Ciliberti et al. (2008) discuss the challenges that the SMEs faced when transferring socially responsible behaviors to suppliers. Zimara and Eidam (2016) focus on corporate social responsibility activities of companies in German chemical industry and point out the gained competitive advantages.

2.4 Both Environmentally and Socially Conscious Studies

The social aspect of sustainability also contributes studies that concern all three pillars of triple bottom line sustainability approach. Dyllick and Hockerts (2002) investigate application methods of triple bottom line structural sustainability approach in a company to achieve sustainable development. They illustrate their extended framework with a triangle where (i) its corners represent aspects of sustainability -economic,

environmental and social; (ii) its edges are formed by arrows of eco-effectiveness, eco-efficiency, socio-efficiency, socio-effectiveness, sufficiency and ecological equity. Pullman et al. (2009) conduct a survey to measure the performance of the food and beverage producers in the U.S. when they expand their sustainability view from the single environmental dimension to both environmental and social aspects. They show that social practices directly, and ecological practices indirectly increase the quality of the products which in turns proves the better cost-saving performance. Moreover, they claim that measuring effects of social and environmental practices via economic performance indicators makes it difficult to recognize their impact on business.

There is also model-based research that considers both environmental pillar and social pillar simultaneously. Zhou et al. (2000) present a model that combines goal programming and analytical hierarchical process to optimize the supply chain. This model is able to solve multi-objective large-scale problems with conflicting constraints of social, environmental and economic factors. They also apply this model to petrochemical entity case study. Dehghanian and Mansour (2009) design a sustainable recovery network that is based on multi-objective mathematical programming model. They use life-cycle analysis to determine environmental effects of different end-of-life policies, and analytical hierarchy process to estimate social impact. Their calculations are combined in a mathematical model having three objective functions. Finally, for the case of scrap tires recovery network, they find Pareto-optimal solutions that maximize economic and social benefits while minimizing environmental destruction by the help of a multi-objective genetic algorithm. Harraz and Galal (2011) design a mathematical model for the network structure of end-of-life vehicles recovery.

Perez-Fortes et al. (2012) address to set up and operate biomass energy systems in a sustainable manner by a multi-objective linear program. The model provides support to decision makers for technological capacities, links between system entities, biomass storage periods, transfer of matters and utilization of biomass from the perspective of economic, environmental and social considerations. Bouchery (2012) revises economic order quantity model with sustainability considerations. Arslan and

Turkay (2013) also present an alternative for the economic order quantity model with the consideration of environmental, social and economic aspects. They use greenhouse gas emission consideration as the environmental aspect and employee working hour consideration as the social aspect in order to reformulate economic order quantity model. They find out that sustainability concern affects operating policies and costs. Chen and Andresen (2014) combine three pillars of the sustainability within a multi-objective optimization model that satisfies sustainability requirement of the supply chain system. Their model minimizes cost, carbon emission, and employee injuries. Santibanez-Aguilara et al. (2014) formulate a multi-objective multi-period mixed-integer linear programming model to select locations of biorefinery sites and plan their operations. The model demonstrates attractive results in the case study of Mexico.

Azadnia et al. (2015) develop a multi-objective optimization model that integrates sustainable supplier selection and order allocation problem within a multi-period multi-product lot-sizing problem. In their model, their target is minimizing cost and maximizing economic, environmental and social performance in the same solution. Garbie (2015) not only calculates cost but also considers time criteria with triple bottom line perspective and sets an optimization model for maintaining the sustainability of manufacturing enterprises. Bhinge et al. (2015) generate a decision support model for a global supply chain network. They create input-output diagrams for a manufacturing facility, suppliers, raw materials and transportation, and then they define subheadings for each of the pillars of sustainability. After that, they develop a multi-objective optimization model with the cradle-to-gate approach to optimize the structure of global multi-echelon supply chains. They also analyze the capabilities of their model with a case study. Anvari and Turkay (2017) design a multi-objective decision model for the facility location problem with the sustainability consideration. They take resource consumption, transportation based air pollution, and water and land pollution parameters as environmental metrics. As social metrics, they use demand satisfaction level, resource equity index, job opportunity distribu-

tion, regional development rate, location security indicators, medical facility access level and education level. They illustrate numeric outputs of the model via case study with real data.

There is only a single study in the literature that closely related to our work. It is a recent work by Turkay et al. (2016) which redesigns the aggregate production planning problem with economic viability, environmental responsibility, and social equity concern. In their paper, they consider carbon footprint and energy consumption reduction as environmental targets. Moreover, from the aspect of social equity, they add customer satisfaction level to fulfill demands, overtime reduction consideration to maintain employee health and provide work-family balance, and smoothing limit for improving job security and morale-motivation of the employee.

2.5 Inferences of the Literature Review

In our review, we mostly focus on model-based approaches. Among the investigated papers, we observe that there are several supply chain problems that are modeled with the sustainability consideration. The summary of analyzed model-based studies is given in the Table 2.3. Our findings of the sustainable supply chain management literature show that

- Even if the number of model-based approaches has been increased in the recent years, the social aspect of the sustainability does not attract enough attention of the researchers.
- Sustainable development is restricted with economic, environmental and social pillars. Cultural vitality is never considered as a fourth pillar in the sustainable supply chain literature.

As far as our knowledge there exists only a single article (Turkay et al., 2016) that promotes the traditional aggregate planning problem with sustainability consideration. In this work, we advance the redesigned sustainable aggregate production

planning model with new parameters, decision variables, and constraints via deeply investigating sustainability framework aspects of economic viability, environmental responsibility, and social equity. Moreover, incorporation of cultural vitality in the aggregate production planning model as the fourth pillar of the sustainability makes this paper unique.

Study	Env.	Soc.	Scope
[Zhou et al., 2000]	✓	✓	Supply chain optimization
[Lu et al., 2007]	✓	x	Supplier selection
[Tsoufas and Pappis, 2008]	✓	x	Supply chain optimization
[Turkay, 2008]	✓	x	Energy production system design and operation
[Dehghanian and Mansour, 2009]	✓	✓	Recovery network design
[Lee et al., 2010]	✓	x	Logistics network design
[Aviso et al., 2011]	✓	x	Supply chain optimization
[Harraz and Galal, 2011]	✓	✓	Recovery network design
[Bouchery, 2012]	✓	✓	Economic order quantity
[Perez-Fortes et al., 2012]	✓	✓	Biomass energy system design and operation
[Arslan and Turkay, 2013]	✓	✓	Economic order quantity
[Benjaafar et al., 2013]	✓	x	Lot-sizing
[Chen et al., 2013]	✓	x	Economic order quantity
[Chen and Andresen, 2014]	✓	✓	Supply chain optimization
[Santibanez-Aguilara et al., 2014]	✓	✓	Biorefinery site selection and operations planning
[Validi et al., 2014]	✓	x	Capacitated distribution network design
[Azadnia et al., 2015]	✓	✓	Supplier selection and order allocation
[Bhinge et al., 2015]	✓	✓	Supply chain optimization
[Fareeduddin et al., 2015]	✓	x	Closed-loop supply chain network design
[Garbie, 2015]	✓	✓	Manufacturing enterprises infrastructure installment
[Hovelaque and Bironneau, 2015]	✓	x	Economic order quantity
[Schenker et al., 2015]	✓	x	Manufacturing planning
[Yamada et al., 2015]	✓	x	Supplier selection
[Turkay et al., 2016]	✓	✓	Aggregate production planning
[Anvari and Turkay, 2017]	✓	✓	Facility location planning

Table 2.3: Summary of model-based literature review

Chapter 3

MATERIALS AND METHODOLOGY

Sustainable development requires a multi-dimensional thinking from the strategic planning level to the operational planning level that established detailed objectives for sustainability should be spread each planning level of a supply chain by cascading technique. Herein, aggregate production planning bridges the strategic planning level with the operational planning level. Therefore, a new approach to aggregate production planning model includes considerations of economic, environmental, social, and cultural pillars to support strategic level and guide operational level.

In order to expand the formulation scope of the traditional aggregate production planning problem with the sustainability concern, new parameters, decision variables, constraints and objective functions should be defined to the model. This definition step is one of the most critical steps of the model development process because the more precise definition of model components means the more reliable solutions to sustainable aggregate production planning problem and the more closely approach to the sustainability target. Therefore, in this chapter of the present study, we argue our criterion by concerning their impacts on the pillars of sustainability and explain how to modify the traditional aggregate production planning model from the perspectives of economic viability, environmental responsibility, social equity and cultural vitality as shown in Figure 3.1. In the first part, under the economic viability heading, we discuss the costs and aim to maximize profit. Secondly, in the environmental responsibility part, we focus on reducing greenhouse gas emission and consumed energy generated by non-renewable energy sources while trying to integrate a renewable energy source into the manufacturing system. After that, in the social equity part, we share our targets of increasing employee safety, satisfying employee gender equity, limiting worst-case

customer satisfaction level and implementing corporate social responsibility projects. In the last pillar of the sustainability, the cultural vitality is presented with the objectives of employee well-being fulfillment and innovation performance increment. Then, we reformulate the aggregate production planning problem both as a single- and multi-objective linear model by the help of arguments presented in the first four sections of the chapter. Finally, we share a case study from a real-world situation in the last section of the chapter.

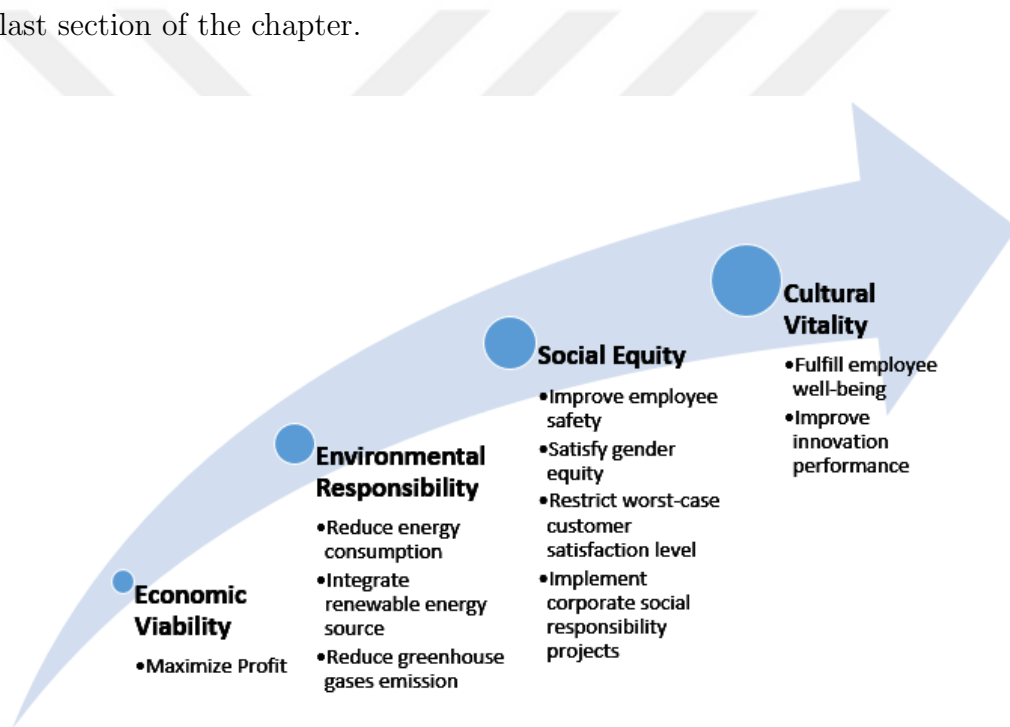


Figure 3.1: Used path in this study for sustainable aggregate production planning model

3.1 *Economic Viability*

Firms have several numbers of different objectives to be fulfilled. These targets are generally profit-oriented goals because making a profit seen as the core and foremost objective for their survival. Most of the projects are evaluated according to their economic performance [Santibanez-Aguilara et al., 2014], most of the decisions are made with the economic objectives [van Hoek and Johnson, 2010].

The economic pillar of the sustainability covers microeconomic targets like as cost reduction and profit maximization [Brandenburg et al., 2014]. Hence, it can be said that the economic viability pillar of the sustainable development follows the requirements of an organization by maintaining a balance between costs and benefits of a business under the pressure of the constraints of sustainability [Elkington, 1997].

The standard aggregate production planning model covers costs of

- raw material,
- regular time and overtime labor costs,
- labor hiring and firing costs,
- inventory carrying cost,
- stock-out cost, and
- subcontracting cost.

This traditional model only inclines to find a cost-optimal solution. However, modestly defined cost values for limiting usage of some resources like as energy and restricting the output of some pollutants like as greenhouse gases are adequate to pursue the sustainability goal because these additional costs make it possible to yield decrease in required inputs and outputs [Benjaafar et al., 2013]. Therefore, for companies aiming to achieve the sustainability, it is very crucial part of the planning process to decide monetary values of their sustainability motivated actions.

Under the sustainability concern, our new modeling approach takes into account five new costs:

- cost of carbon tax (carbon emission tax is calculated only for emission amount generated by production, inventory holding and subcontracting activities),
- cost of used electricity (electricity cost is calculated only for used amount in production, inventory holding and subcontracting activities),

- cost of integrating a new renewable energy source into the system (amortized cost with respect to the useful life of new energy source),
- cost of embracing a corporate social responsibility project, and
- cost of substituting old technology with innovative new one (amortized cost with respect to the useful life of innovation).

These cost components come together on the economic side of the sustainable aggregate production planning problem. Our models aim to maximize profit by minimizing all defined costs within the economic objective function.

3.2 Environmental Responsibility

Supply chains have severe impacts on the environment. Supply chain activities, like as manufacturing and transportation, pollute water and air, emit greenhouse gases, consume a significant amount of energy, damage ecosystems, and cause loss of biodiversity and deforestation [Handfield et al., 2005, Turkay, 2008, Aviso et al., 2011, Bhinge et al., 2015, Anvari and Turkay, 2017]. However, with engaging other members of the supply chain, an organization can improve environmental impacts of its supply chain by applying a precautionary approach. In this manner, environmental responsibility in supply chain sustainability aims to reduce the ecological effects of a supply chain through a reduction in hazardous wastes, resource consumption, greenhouse gas emission and any other kind of pollution [Brandenburg et al., 2014, Chen and Andresen, 2014]. A company is environmentally sustainable if it consumes natural sources at a rate below the reproduction rate of same sources or alternative sources. They do not emit greenhouse gases more than absorption capacity of the natural system. Furthermore, they do not perform actions that destroy and degrade ecological systems [Dyllick and Hockerts, 2002].

Sarkis and Rasheed (1995) offer 3R -reduction, remanufacturing and recycling for greening the manufacturing activities. Remanufacturing and recycling strategies are

not in the scope of aggregate production planning problem. However, by adjusting input and output levels and determining best inventory and subcontracting policy, aggregate production planning model can reduce negative environmental effects of production processes. At that point, Blackhurst et al. (2014) state that a company should reduce usage and production of five metrics

- energy,
- greenhouse gases,
- water,
- materials and,
- waste.

Therefore, to increase the environmental performance of the new sustainable aggregate production planning models, we focus on reduction of energy consumption together with the integration of renewable energy source into a manufacturing system and reduction of greenhouse gas emission.

3.2.1 Energy Consumption Reduction and Renewable Energy Source Integration

Energy is the essential requirement for economic production and, therefore, economic growth. International Energy Outlook 2007 Report projects that the total marketed world energy consumption increases 57% from 2004 to 2030. Omer (2008) relates energy consumption with world population and forecasts that in the year 2100 the energy requirement will be more than four times of consumption amount of 2020 as can be seen in Figure 3.2. Although updated data of International Energy Outlook 2017 Report forecasts deceleration in increase rate of energy demand, the energy requirement still expands by 30% between 2017 and 2040. This equals to adding one more China and India to the current global energy demand. Moreover, the situation gets worse if every community consumes energy as the Western World because at that

time we need four Earth to provide this amount of energy where we have only one [Chen and Andresen, 2014].

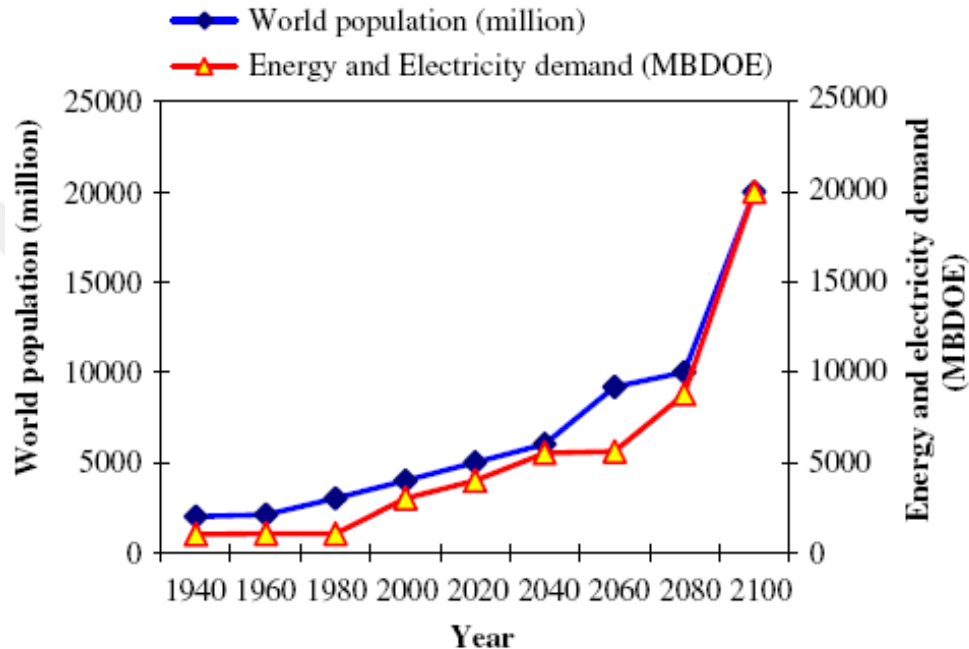


Figure 3.2: Energy consumption and population growth projection (MBDOE: Million of barrels per day of oil equivalent) [Omer, 2008]

Primary energy sources, which are mainly non-renewable such as natural gas, oil, coal, peat and conventional nuclear power, are not infinite sources. Omer (2008), for example, points out that discovered oil worldwide has consistently decreased since the 1980s as shown in Figure 3.3. In addition to the requirement for long-term availability of energy, firms also face the problem of high energy costs [Berns et al., 2009]. Thus, organizations turn their attention to find new ways to reduce both their energy consumption and dependency on non-renewable energy sources. New solutions to achieve this objective are not only supports environmental responsibility consideration but also saves money for a company. Walmart has performed a good example of such a saving. They changed old-fashion lamps with light-emitting diode (LED) lamps that require a huge amount of initial investment to integrate them into all of the Walmart stores. However, in the long-run, they reduced energy consumption and respectively

energy costs [Chopra and Meindl, 2016]. Moreover, Bougain et al. (2015) argue that consumed electrical energy used for production based activities in the manufacturing entities is not accurately concerned in the production planning phase as a planning resource. However, they state that there exists an optimization opportunity for companies to reduce energy consumption and balance energy demand and supply in the manufacturing processes.

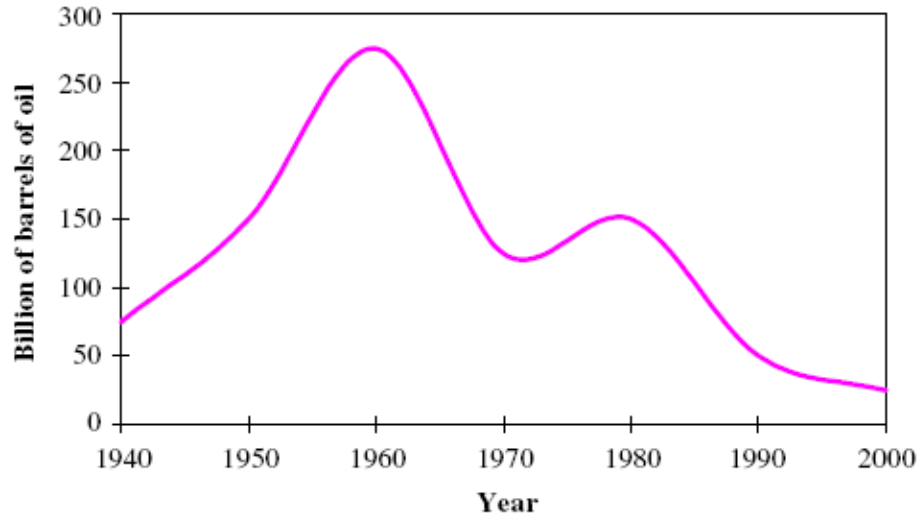


Figure 3.3: Discovered oil worldwide [Omer, 2008]

In the sustainable aggregate production planning models, we take into account amount of consumed energy by manufacturing, inventory holding and subcontracting activities. We set a cap on total non-renewable source generated energy consumption amount. Moreover, in the multi-objective model, we minimize consumed non-renewable source generated energy amount within the environmental objective function in order to maximize environmental performance.

There also exist renewable energy sources like water, sun, wind, biomass, geothermal, and hydrogen that can satisfy increasing energy demands of sustainable development in the long-term. These sources are safe and environmentally friendly that they present an efficient and effective solution for sustainable development [Omer, 2008]. Renewable energy sources have the potential to meet a significant amount of global

electricity demand. For example, in 2015, hydropower supplies 71% of all renewable source electricity and has the capacity of 1,209 GW. However, the undeveloped global potential of hydropower is around 10,000 TWh/y that approximately equals to consumed electricity amount in 2015 by the top three electricity consumers -China (4,963 TWh), USA (3,898 TWh) and India (1,007 TWh) [World Energy Council, 2016]. Walmart and P&G aim to be supplied 100% of their energy requirement from renewable energy sources [Blackhurst et al., 2012]. Hence, we add decision variables to our mathematical models to decide whether to integrate a new renewable energy source into the manufacturing system at the beginning of specified periods by paying predefined costs. As a return of renewable energy source integration into the system, a company can reduce electricity cost via generating own electricity which is taken into account within the models. In the multi-objective model, we additionally consider renewable source generated electricity amount in the calculation of the environmental objective function value.

3.2.2 Greenhouse Gas Emission Reduction

It is a reality that the human-made climate change threatens our planet and its residents. The average temperature of the earth has increased, glaciers have shrunk, sea level has risen, and more intense hurricanes have occurred in the past century. Scientists report that climate change will continue and the average temperature of the world will accelerate to increase decades to come, predominantly because of greenhouse gases produced by human activities [Yamada et al., 2015].

Almost all operational activities in the supply chain inevitably generate greenhouse gases. As one of the primary sources of greenhouse gases emission [Turkay, 2008], supply chains emit carbon dioxide, methane, nitrous oxide, sulfur difluoride to nature [Fareeduddin et al., 2015, Yamada et al., 2015]. Therefore, emission of these gases amount is one of the major performance indicators of environmental sustainability in the supply chain [Arslan and Turkay, 2013].

Governments recognize the seriousness of the problem so that they make regu-

lations on the subject to curb carbon emission. Environmentally friendliness is also worth to consider in the product selection process of customers and decision-making process of other shareholders of a company. As a response to both the government legislation and customer expectations with the concern of shareholders, firms undertake initiatives to decrease their greenhouse gas emission [Berns et al., 2009, Chen and Andresen, 2014, Hovelaque and Bironneau, 2015].

Current data entail reducing greenhouse gas emissions by at least 80% up to 2050 in the developed countries to slow down the rapid increment of the average temperature of the Earth [Woods et al., 2010]. This requirement seems to find a response in the industry: in the survey of PwC, 87% of survey participants who agree with the high importance of sustainability, give priority to optimize their internal carbon footprint [PwC, 2013]. Walmart has reported 20 million metrics ton of greenhouse gas reduction in its supply chain [Blackhurst et al., 2012].

There exist different regulation policies to reduce carbon emission including

- Carbon cap: limiting carbon emission amounts of a firm by mandatory caps
- Carbon tax: collecting tax as a penalty of emitted carbon
- Cap-and-trade: limiting carbon emission amounts of a firm by carbon caps but also rewarding/punishing them if they emit less/more amount than the cap. It is possible with permitting different companies to trade for their emission amounts (permission for buying/selling the right of emitting) while total allowed amount of all companies cannot exceed the limit
- Cap-and-offset: investing several projects -like changing old technology machines with new energy efficient ones- that reduce carbon emission amounts [Arslan and Turkay, 2013, Benjaafar et al., 2013].

Furthermore, it is a complicated issue to decide the scope of emission concern. There are three defined scope levels in the emission reduction concentration. Scope 1 refers greenhouse gas emission produced by the entity that is in the center of concern. This

scope is also called direct emission. Scope 2 refers greenhouse gas emission released to nature when other entities produce energy and provide utility services to the entity that is in the center of concern. Scope 3, on the other hand, refers indirect emissions generated by all the related third-party service providers like suppliers and distributors [Chopra and Meindl, 2016].

The new approach to aggregate production planning model engages with carbon-cap and carbon-tax policies and covers Scope 1 and Scope 3 emissions for the greenhouse gas emission reduction target. As separate parameters, released greenhouse gas amounts are estimated for manufacturing (Scope 1 emission), inventory holding (Scope 1 emission) and subcontracting (Scope 3 emission) operations per product. These parameters are then used for calculating total greenhouse gas emission amount and total carbon tax expense during the entire planning horizon. In both single- and multi-objective models, the carbon-cap constraint is mandatory. Furthermore, in the multi-objective model, the environmental objective function includes emitted greenhouse gas amount to maximize environmental performance.

3.3 Social Equity

Although the majority of the studies in the sustainable supply chain literature focus on damages of development on the ecological life, industrialization also destroys human life [Ahmadi et al., 2017]. Social pillar of the sustainable development concerns problems of a society and struggles to present applicable and sustainable solutions to these problems. Social responsibility presents a way to achieve economic improvement while committing to behave ethically and improving the life quality of the employees as well as the society [Dehghanian and Mansour, 2009]. Socially sustainable companies are the organizations that improve the involved society from the perspectives of both individuals and communities [Dyllick and Hockerts, 2002]. As a result, the social pillar of the sustainability focuses on social impacts of development and tries to offer solutions that support the sustainability targets. It underlines the requirement to upturning life standards and strengthening social justice for all citizens by

enhancing material income levels, promoting senior health care services, removing away faced weary and destructive events of the daily life, and satisfying equal access to education, employment, and other resources.

Social pillar of the sustainability handles health, safety and living conditions of individuals, communities, customers and other stakeholders by showing respect to their rights and freedom [Bhinge et al., 2015]. Social sustainability focuses on employee safety and health, working environment conditions, salaries, employment gender ratios, child labor and improvement of human capital [Massaroni et al., 2015]. Brandenburg et al. (2014) relate the social aspect directly with employment gender ratio and customer needs and requirements. In their research, Mani et al. (2016) use six dimensions for social sustainability -equity, philanthropy, safety, health and welfare, ethics, human rights. ISO (2010) publishes Guidance on Social Responsibility that declares seven subheadings for social sustainability: organizational governance, human rights, labor practices, the environment, fair operating practices, consumer issues, community involvement and development. Global Reporting Initiative (2013) divides social dimension of the sustainability into four sub-parts: labor practices and decent work, human rights, society, and product responsibility (together with economic and environmental framework aspects, social framework aspects of Global Reporting Initiative are comprehensively listed in Appendix-B). Bhinge et al. (2015) argue sub-measures and indicators for social sustainability as shown in Table 3.1, and use them to formulate an optimization model.

Inside the sustainable supply chain management, the social pillar of sustainability requires bearing in mind the issues about the workforce, customers, and society [Chopra and Meindl, 2016]. In this study, we consider the safety of employees across work accidents and gender equity among employees as workforce-related issues. Satisfying customer demands with properly informed, reasonably labeled, healthy and confidential products are the customer-related issues [Anvari and Turkay, 2017]. Hence, we focus on customer satisfaction level. Furthermore, the new models consider impacts of corporate social responsibility projects as the society-related issues.

Sub-measure	Indicator	Unit
Delocalization and migration	People resettled	Number
Community engagement	Volunteer hours	Hours
Cultural heritage	Is it preserved?	Binary
Indigenous rights	Is it preserved?	Binary
Access to material sources	Is it restricted?	Binary
Access to immaterial sources	Is it restricted?	Binary
Community security	Number of cases	Number
Public commitment	Do they hold promises?	Binary
Economic development	Revenue increase	\$
Corruption prevention	Number of cases	Number
Technology development	Is it assisted?	Binary
Fair competition	Is it allowed?	Binary
Intellectual property rights	Are they preserved?	Binary
Supplier relationships	Supplier satisfaction	%
Social responsibility	Suppliers audited	%
Social security	Workers with paid time-off	%
Labor equity	Cases of discrimination	Number
Gender equity	Ratio of women employees	%
Child labor	Child labor ratio	%
Community safety	Cases of health effects	Number
Working hours	Amount of over-time work	Hours
Fair salary	Fair salary ratio	%
Freedom of association	Is it encouraged?	Binary
Forced labor	Forced labor ratio	%
Community service	Donation amount	\$ / year
End of life responsibility	Incidents of non-compliance	Number
Local employment	Local employment ratio	%
Prevention of armed conflicts	Are resources which may lead to conflicts used?	Binary

Table 3.1: Measures for social sustainability performance [Bhinge et al., 2015]

3.3.1 Employee Safety Improvement

Accidents occur on industrial business sites that lead to physical or mental harm of the employee are called workplace accidents [European Commission, 2001]. These accidents cause losses and damages for both employees and employers. Employer-side may pay compensations, medical and travel expenses, and lose workforce because of these accidents. Cost of a middle-range workplace accident for an employee may exceed €3.8 million [Hrymak and Perezgonzalez, 2007]. On the other hand, employee-side may lose much more valuable things than money that an accident may cause a permanent disability.

May et al. (2015) explain that the establishment of human-centric factories ensures a healthy working environment and can provide social sustainability in manufacturing facilities. Therefore, to achieve a more sustainable supply chain target, workplace accidents should be avoided.

One of the major causes of the workplace accidents is lack of training and education [Bibowei, 2015]. Employees should have knowledge about the dangers of the machines and the areas of accident proneness. Thereby, the number of such dangerous occurrence can be reduced by giving training to the employees regarding safety measures [Lesonsky, 2016]. As a result, training of newly hired workers is a part of our models. In the first period of hiring, all employees are considered to be trained before they start a task so that they spend some working hours without participating manufacturing activities. Thus, we define a new parameter that holds the average productivity level of a newly hired worker. The value of the parameter may change according to task and work environment.

Even if employees are trained, long working hours is another primary reason for the work accidents. The risk of an accident at 12 working hours is twice the risk at 8 hours [Wagstaff and Lie, 2011]. Overtimes can also be considered for work-family conflict issues [Turkay et al., 2016]. Long work hours can cause the conflict between work and family responsibilities. This conflict can be in the form of stress and negatively affect the mental and physical health of the employee [Pfeffer, 2010]. Therefore, for

the safety of an employee, we define a parameter that holds the permitted maximum amount of overtime hours for a period per each employee. Using this parameter, we set a constraint for the safety of employees, which limits overtime hours of an employee for each period in the models. Furthermore, in the multi-objective model, overtime hours are also minimized within the social objective function to maximize the social performance.

3.3.2 Employee Gender Equity Satisfaction

Diversity is a requirement of a social equity aspect of the sustainable development and inclines organizations to give equal job opportunities to all people regardless of their ethnicity, gender, age, religion, disability, national origin and sexual orientation [Council of Supply Chain Management Professionals, 2013]. Hence, in the workplaces, equity and fairness should reign for socially sustainable development [Dehghanian and Mansour, 2009].

Gender equity defines the situation that both sexes can reach resources, programs and decision making in a fair and reasonable way without any discrimination generated from sex [CAAWS, 2017]. Gender equity closely connects with the sustainability because building a gender equity supports the diversity of workers. Therefore, Committee on Women's Right and Gender Equity of the European Parliament declares requirement of gender equity and empowerment of all women for the sustainable development. They define women empowerment as "gaining more power and control over their own lives" and explain proven synergies between empowerment of women and pillars of the sustainability. They state that this empowerment also includes an economic dimension that women should play a more active role in the economic life [European Parliament, 2016].

In their model, Bhinge et al. (2015) use ratio of women employees as a sub-measures of social sustainability. In our models, we define constraints for the gender difference that the difference between male and female workers cannot exceed the allowed limit. In the multi-objective model, social performance also increases simul-

taneously with the decrement of gender difference within the social objective function. However, depending on a difficulty of a job, average productivity level of female workers may stay below average productivity level of male workers. Therefore, we also define an average productivity level parameter for female workers that is used within the calculation of production capacity. This parameter is calculated with respect to average productivity level of male workers.

3.3.3 Worst-Case Customer Satisfaction Level Restriction

Each day consumers become more demanding and strengthen their position in the supply chain by becoming more active partners who will directly drive product development and replenishment processes. On the one hand, companies should satisfy needs of customers for social sustainability; on the other hand, they continue their operations with a profitable way for economic sustainability [Zhou et al., 2000, Liu et al., 2017].

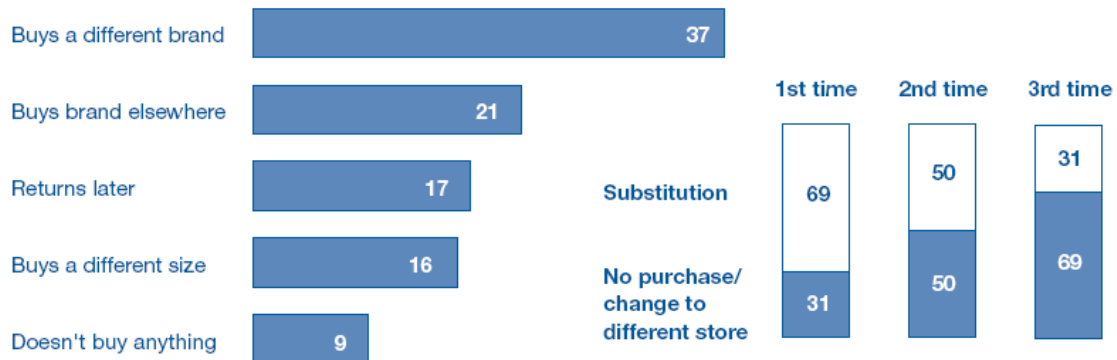


Figure 3.4: Customer response to stock-out situation [ECR, 2017]

If a consumer faces a stock-out situation, he classifies this shopping experience as time, money and energy wasting. Worse than that, they may visit other brands or stores to fulfill their demands or decide not to buy anything. Recent research shows that 37% of all customers will purchase a different brand, 21% will go another store, and 9% will premit to buy something if faces a stock-out situation as shown in figure 3.4 [ECR, 2017]. Thence, the primary social consideration for customers in the

sustainable development of supply chain is the demand satisfaction level. Turkay et al. (2016) and Anvari and Turkay (2017) also measure the customer satisfaction with demand fulfillment rate.

The customer is the primary source of the revenue in the supply chain. On the one hand, the traditional model have no restriction for stock-out situations. On the other hand, stock-out causes customer loss that makes the business unsustainable. As a result, our models include a lower limit for customer satisfaction level. In the multi-objective model, lower stock-out amount increases customer satisfaction level and maximizes the social performance within the social objective function.

3.3.4 Corporate Social Responsibility Project Implementation

Corporate social responsibility projects are not imposed on companies by regulations or laws; instead, the companies perform them voluntarily for adding value to society beyond their economic expectations [Zimara and Eidam, 2015]. These projects reflect organizational attitudes, strategies, and relationships with stakeholders by touching ethical issues and supporting economic prosperity of society. Therefore, corporate social responsibility concentration holds the organization socially accountable in the viewpoint of stakeholders [Maloni and Brown, 2006], and increases the financial performance of organizations [Sarkis et al., 2010].

Corporate social responsibility projects are seen as a tool by which companies fulfill their public moral obligations so at the beginning, managers started to perform these projects compulsorily. However, these projects not only help social aspect of sustainability but also creates a good company image with additional financial returns. With rising number of firm beginning to use different methods to connect with their shareholders, corporate social responsibility projects advance comprehensive communication strategies that build up trust and create value for the company. As a result, reputation of the company with its brand awareness increases. KPMG (2011) reports that 47% all G250 enterprises gain financial returns via increment of market shares and revenues with better cost-saving results because of their social awareness.

Organizations take social and ethical roles to solve problems of society by corporate social responsibility projects. Walmart, for instance, bears a hand to mentally ill children in India, finds places to stay for abandoned children in America, supports education system by building schools after an earthquake in China, and rebuilds homes and drinking water infrastructures [Tascioglu, 2015]. In our models, we consider that the implementation of corporate social responsibility projects increases the social performance and positively affects customer demand.

3.4 Cultural Vitality

Cultural values are the building blocks of which all else is built. Hence, to create a sustainable society, culture has an essential role because plans become more efficient if they include an integrated framework of cultural evaluation. Moreover, intellectual tools are provided by the culture to the society and these leads to build a more developed structure [Hawkes, 2001].

Cultural heritage is an important and unique asset to humanity that is not the renewable source or cannot be replaced. To satisfy continuity of the development, cultural heritage should be protected, improved and inherited to the next generations. Past occurrences have demonstrated that the deterioration of the natural resources, disregarding of backcountry, widespread poverty and ignorance, and degeneration of customs, values, and morality threaten not only cultural heritage but also the existence of communities. On the other hand, well-protected natural resources and traditional knowledge form a strong cultural capital that empowers the resilience of the nations across the demolished risks on the path of development. Astara (2014) concretizes this fact with a real-life practice. They say that in 2005, the tsunami in the Indian Ocean region killed more than 200,000 people. However, people of Andaman and Nicobar survived the disaster. Their survival is the result of their cultural heritage because they conserve mangroves in their countries that provide a buffer across the strike of the tsunami and soften its impact. Moreover, residents of the region preserve their oral traditions generated from past earthquakes that says

huge waves visit the land after a big earthquake. Thus, with this collective memory transferred from generation to generation, they moved towards elevated areas and escape from the killing impact of the tsunami.

Cultural and spiritual heritages strengthen economic activities and life continuity [World Commission on Environment and Development, 1987], thus Bhinge et al. (2015) uses cultural heritage as a measure of social sustainability. The cultural pillar of the sustainability engages in well-being, creativity, diversity, and innovation [Hawkes, 2001]. Therefore, our models cover the welfare of employees and integration of innovations for increasing cultural performance.

3.4.1 Employee Well-being Fulfillment

Sustainable development includes the preservation of cultures that are threatened by globalization and modernization [Navarro, 2010]. One factor that directly related to the cultural pillar of the sustainability is the well-being of society [Hawkes, 2001]. Hence, well-being of the people is the principal step to achieve sustainability target [Santibanez-Aguilara et al., 2014, Ahmadi et al., 2017].

Wellbeing or welfare used to define the condition or state that one copes and satisfies with life. Welfare draws the quality of life. It has several aspects including but not limited to physical, social, mental and spiritual. Life satisfaction comes with the sense of meaning and purpose, which are fundamental for cultural vitality. On the other hand, in spite of the fact that the material wealth of society of today as a whole is more than ever before, many of its members felt weak, unhappy and excluded [Hawkes, 2001]. Layoffs are occurrences triggering these negative feelings. Layoffs are very destructive events that affect the physical and mental health of fired workers. Studies show that tendency to violence and suicide increase with a layoff. Layoffs increase the probability of death so that someone fired lives 1.5 fewer years than someone not fired. Moreover, a dismissal is the predictor of listed symptoms of many physiological disorders [Pfeffer, 2010]. As a result, for the sustainability of the human resource, companies should realize, treasure, and improve the capabilities of

its community and develop policies and practices for well-being [Pullman et al., 2009].

Providing job opportunities to a community can be used as a sustainable performance indicator [Santibanez-Aguilara et al., 2014]. However, in our aggregate production planning models, corruption effects of layoffs on the culture are one of the considerations. The models have a constraint to limit layoffs of each period for reducing such a corruption, and in the multi-objective model, we also put layoff level into the cultural objective function to minimize it for increasing the cultural performance.

3.4.2 Innovation Performance Improvement

Traditional supply chains suggest that low prices, fast delivery, and high quality are enough to create value to attract people. However, these figures are not enough to engage with the customer. Melnyk et al. (2010) declare innovation as a driver for customers to buy. This is because problems and requirement of the humanity regularly change. Thus, to fascinate customers, companies make innovations in every possible point of their supply chain. World Commission on Environment and Development (1987) reports that

Technology will continue to change the social, cultural, and economic fabric of nations and the world community. With careful management, new and emerging technologies offer enormous opportunities for raising productivity and living standards, for improving health, and for conserving the natural resource base.

To proceed in this civilization path, intellectual wealth has to be protected and enriched with new insertions. An intellectual wealth of any group is a part of their culture, and as a result, development requires cultural vitality. Culture is the combination of material and spiritual outputs that a society produces in its historical process and transfers from generation to generation. Any change in material outputs revise the spiritual ones and vice versa. Innovations and creativity are the reflections of protection and development of intellectual property in the change process

of the culture. Change is inevitable, and innovations are crucial to the survival of businesses [Hawkes, 2001]. Thus, there is a connection between sustainability and innovation ability [Bouchery, 2012]. The innovation of product, service, and market are important factors related to the sustainable development [Berns et al., 2009].

In the recent years, many companies have started to see their supply chains as a source of new innovative products and processes. Moreover, Garbie (2015) takes innovation as a supply chain sustainability indicator so that they calculate cost and time for innovation within their model. Accordingly, in our models, we put a lower limit for the number of performed innovation projects within a specified time by paying predefined costs and consuming stated resources. In return, innovations may save from costs, increase production capacity and improve environmental performance of the manufacturing processes. Therefore, we reflect these effects of innovations in our models. Additionally, within the cultural objective function of the multi-objective model, we investigate optimal ways of carrying out a maximum number of innovation projects as early in the planning horizon as possible.

3.5 The Sustainable Aggregate Production Planning Models Including the Cultural Environment

In this section, we formalize our sustainability considerations via both single-objective and multi-objective linear programming models. However, before setting our models, we define our parameters and decision variables that are used within both formalized models.

3.5.1 Parameters of the Models

Let T be the set of periods in the planning horizon, J be the set of corporate social responsibility projects, and K be the set of innovation projects. Therefore, our parameters are:

sp	Selling price of one item (money unit/item)
c_L	Cost of a worker per hour (money unit/(worker*hour))
c_H	Cost of hiring a worker (money unit/worker)
c_F	Cost of firing a worker (money unit/worker)
c_M	Cost of used material to produce one item (money unit/item)
c_O	Cost of one-hour overtime for a worker (money unit/(worker*hour))
c_I	Cost of holding one item of stock for one period (money unit/(item*period))
c_{SU}	Cost of subcontracting one item (money unit/item)
c_{SO}	Cost of stock-out for one item (money unit/item)
c_{CT}	Cost of carbon tax per unit of volume (money unit/volume)
c_E	Cost of electricity per unit of energy (money unit/ energy unit)
c_t^{RE}	Cost of integrating new renewable energy resource into the system in period t , $t \in T$ (money unit)
c_{tj}^{CSR}	Cost of implementing a corporate social responsibility project j in period t , $j \in J$ and $t \in T$ (money unit)
c_{tk}^{IN}	Cost of carrying out an innovation project k in period t , $k \in K$ and $t \in T$ (money unit) (expected cost saving for the remaining periods after innovation is reduced thus, it is a net cost)
g_I	Amount of greenhouse gas emissions per item hold in the inventory per period (volume/(item*period))
g_P	Amount of greenhouse gas emissions per item produced (volume/item)
g_{SU}	Amount of greenhouse gas emissions per item subcontracted (volume/item)
e_I	Amount of electricity used per item hold in the inventory per period (energy unit/(item*period))
e_P	Amount of electricity used per item produced (energy unit/item)

e_{SU}	Amount of electricity used per item subcontracted (energy unit/item)
e_t^{RE}	Amount of total generated energy from renewable energy source, if it is integrated in period t , $t \in T$ (energy unit)
g_{tk}^-	Total reduction in greenhouse gas emission in period t if innovation project k has already been made in period t , $k \in K$ and $t \in T$ (volume)
e_{tk}^-	Total reduction in consumed electricity in period t if innovation project k has already been made in period t , $k \in K$ and $t \in T$ (energy unit)
ξ_g	Allowed maximum amount of greenhouse gas emissions during the planning horizon (volume)
ξ_e	Allowed maximum amount of consumed electricity originated from non-renewable energy sources during the planning horizon (energy unit)
l_{Lim}	Allowed maximum layoff rate per period (%/period)
o_{Lim}	Overtime limit per worker per period (hour/(worker*period))
cst_{Lim}	Desired minimum amount of implemented corporate social responsibility project during the planning horizon (corporate social responsibility project)
in_{Lim}	Desired minimum number of carried out innovation projects during the planning horizon (innovation project)
su_{Lim}	Subcontracted products amount limit per period (item/period)
fm	Allowed maximum difference rate between female and male workers per period (%/period)
α	Allowed worst customer satisfaction level per period (%/period)
d_t	Forecasted demand for period t , $t \in T$ (item)
d_{tj}^+	Demand increase rate in period t if corporate social responsibility project j is implemented in period t , $j \in J$ and $t \in T$ (%)

h	Regular time working hours per day (hour/day)
n_t	Number of working days in period t , $t \in T$ (day)
p_M	Average number of items produced in one day by one experienced male worker (item/(worker*day))
ph	Average productivity rate of a new hired worker (%)
pf	Average productivity rate of a female worker (%)
ca_{tk}^-	Total capacity loss in period t if innovation project k is made in t , $k \in K$ and $t \in T$ (item)
ca_{tk}^+	Total capacity increment in period t if innovation project k has already been made in period t , $k \in K$ and $t \in T$ (item)
MW_0	Initial male workforce level (worker)
FW_0	Initial female workforce level (worker)
I_0	Initial inventory level (item)

3.5.2 Decision Variables of the Models

In our new models, decision variables are as follow.

FW_t	Number of female workers in period t , $t \in T$ (worker)
MW_t	Number of male workers in period t , $t \in T$ (worker)
FH_t	Number of hired female workers at the beginning of period t , $t \in T$ (worker)
MH_t	Number of hired male workers at the beginning of period t , $t \in T$ (worker)
FF_t	Number of fired female workers at the beginning of period t , $t \in T$ (worker)
MF_t	Number of fired male workers at the beginning of period t , $t \in T$ (worker)
P_t	Number of produced item in period t , $t \in T$ (item)

O_t	Number of used overtime worker hours in period t , $t \in T$ (worker*hour)
I_t	Number of stocks in warehouse at the end of period t , $t \in T$ (item)
S_t	Number of sold items in period t , $t \in T$ (item)
SU_t	Number of items subcontracted in period t , $t \in T$ (item)
SO_t	Number of items stock-out in period t , $t \in T$ (item)
X_t^{RE}	1 if renewable energy source integrated in period t , 0 otherwise, $t \in T$
CSR_{tj}	1 if corporate social responsibility project j implemented in pe- riod t , 0 otherwise, $j \in J$ and $t \in T$
Y_{tk}	1 if innovation project k made in period t , 0 otherwise, $k \in K$ and $t \in T$
Y_{tk}^A	1 if innovation project k has already been made in period t , 0 otherwise, $k \in K$ and $t \in T$

3.5.3 The Single-Objective Model

In the single-objective model, our aim is to maximize profit within the economic objective function. As income, economic objective function includes revenue resulted by sales.

$$\max \quad z = \sum_{t \in T} sp \times S_t \quad (3.1)$$

On the other hand, as expenses, we calculate salaries of workers for normal time,

$$- \sum_{t \in T} c_L \times h \times n_t \times (MW_t + FW_t) \quad (3.2)$$

labor hiring and firing costs,

$$- \sum_{t \in T} (c_H \times (MH_t + FH_t) + c_F \times (MF_t + FF_t)) \quad (3.3)$$

overtime costs,

$$- \sum_{t \in T} c_O \times O_t \quad (3.4)$$

material cost,

$$- \sum_{t \in T} c_M \times P_t \quad (3.5)$$

inventory holding cost,

$$- \sum_{t \in T} c_I \times I_t \quad (3.6)$$

subcontracting cost and stock-out cost,

$$- \sum_{t \in T} (c_{SU} \times SU_t + c_{SO} \times SO_t) \quad (3.7)$$

energy cost of inventory holding, production and subcontracting activities with a saving from renewable energy source,

$$- \sum_{t \in T} c_E \times (e_I \times I_t + e_P \times P_t + e_{SU} \times SU_t - e_t^{RE} \times X_t^{RE}) \quad (3.8)$$

carbon tax cost of inventory holding, production and subcontracting activities,

$$- \sum_{t \in T} c_{CT} \times (g_I \times I_t + g_P \times P_t + g_{SU} \times SU_t) \quad (3.9)$$

cost of integrating a renewable energy source into the system,

$$- \sum_{t \in T} c_t^{RE} \times X_t^{RE} \quad (3.10)$$

cost of implementing corporate social responsibility projects,

$$- \sum_{t \in T} \sum_{j \in J} c_{tj}^{CSR} \times CSR_{tj} \quad (3.11)$$

and finally, cost of making innovation projects.

$$- \sum_{t \in T} \sum_{k \in K} c_{tk}^{IN} \times Y_{tk} \quad (3.12)$$

Our model has several constraints. We put two constraints into the model for the environmental aspect of the sustainability. As the first constraint, we put a cap to restrict greenhouse gas emission amount. Within the constraint, we also reflect the positive effect of making innovation project.

$$\sum_{t \in T} (g_I \times I_t + g_P \times P_t + g_{SU} \times SU_t) - \sum_{t \in T} \sum_{k \in K} (g_{tk}^- \times Y_{tk}) \leq \xi_g \quad (3.13)$$

Secondly, we restrict consumed non-renewable energy source generated electricity amount. At that point, we also consider effects of renewable energy source and innovation projects.

$$\sum_{t \in T} (e_I \times I_t + e_P \times P_t + e_{SU} \times SU_t - e_t^{RE} \times X_t^{RE}) - \sum_{t \in T} \sum_{k \in K} (e_{tk}^- \times Y_{tk}) \leq \xi_e \quad (3.14)$$

For the social aspect, we have four set of constraints. First, we put an upper-limit that restricts overtime hours of each worker in each period.

$$O_t \leq o_{Lim} \times (MW_t + FW_t) \quad \forall t \in T \quad (3.15)$$

Next inequalities satisfy balance between genders of workers in each period.

$$fm \times (MW_t + FW_t) \leq FW_t \quad \forall t \in T \quad (3.16)$$

$$fm \times (MW_t + FW_t) \leq MW_t \quad \forall t \in T \quad (3.17)$$

As the third social consideration, we put a lower-limit for the worst-case customer satisfaction level of each period. However, we also take into account demand change because of corporate social responsibility project implementation.

$$S_t \geq \alpha \times d_t \times (1 + \sum_{j \in J} d_{tj}^+ \times CSR_{tj}) \quad \forall t \in T \quad (3.18)$$

Final social consideration ensures implementing a minimum allowed number of corporate social responsibility projects during the planning horizon.

$$\sum_{t \in T} \sum_{j \in J} CSR_{tj} \geq csr_{Lim} \quad (3.19)$$

As a cultural consideration, the model has a restriction for layoffs of each period. Thus, a number of fired workers at the beginning of each period cannot exceed allowed rate of all workers of the previous period.

$$l_{Lim} \times (FW_{t-1} + MW_{t-1}) \geq FF_t + MF_t \quad \forall t \in T \quad (3.20)$$

Moreover, for the cultural vitality, next constraint ensures making a minimum allowed number of innovation projects during the planning horizon.

$$\sum_{t \in T} \sum_{j \in J} Y_{tk} \geq in_{Lim} \quad (3.21)$$

We also have considerations coming from the traditional model. We have to satisfy workforce balance of each period for both genders.

$$MW_t = MW_{t-1} + MH_t - MF_t \quad \forall t \in T \quad (3.22)$$

$$FW_t = FW_{t-1} + FH_t - FF_t \quad \forall t \in T \quad (3.23)$$

Next constraint is the inventory balance equation for each period.

$$I_t = I_{t-1} + P_t + SU_t - S_t \quad \forall t \in T \quad (3.24)$$

Model also determines stock-out amount according to sales amount and demand amount by calculating effects of corporate social responsibility projects.

$$S_t + SO_t = d_t \times (1 + \sum_{j \in J} d_{tj}^+ \times CSR_{tj}) \quad \forall t \in T \quad (3.25)$$

Next constraint is capacity constraint. It considers productivity level of genders, training of new hired workers, and overtimes. We also assume that if we make a innovation project in any period, we lose some amount of capacity to carry out this project at that period. On the other hand, it is assumed that after making innovation project, the capacity increases in the next periods.

$$\begin{aligned} P_t \leq & p_M \times n_t \times (MW_t - (1 - ph) \times MH_t + FW_t \times pf - (pf - ph) \times FH_t) \\ & + p_M \div h \times O_t + \sum_{k \in K} (ca_{tk}^+ \times Y_{tk}^A - ca_{tk}^- \times Y_{tk}) \quad \forall t \in T \end{aligned} \quad (3.26)$$

There is a limit for subcontracting amount of each period.

$$SU_t \leq su_{Lim} \quad \forall t \in T \quad (3.27)$$

We assume that each innovation project can be made and renewable energy source can be integrated at most once time during the planning horizon.

$$\sum_{t \in T} Y_{tk} \leq 1 \quad \forall k \in K \quad (3.28)$$

$$\sum_{t \in T} X_t^{RE} \leq 1 \quad \forall t \in T \quad (3.29)$$

We formulate an equation to decide whether innovation project has already been made.

$$Y_{1k}^A = 0 \quad \forall k \in K \quad (3.30)$$

$$Y_{tk}^A = \sum_{t' \in (1, 2, \dots, t-1)} Y_{t'k} \quad \forall k \in K, \forall t \in T - \{1\} \quad (3.31)$$

Finally, we have constraints for integer and binary variables with non-negativity.

$$FW_t, MW_t, FH_t, MH_t, FF_t, MF_t, P_t, I_t, S_t, SU_t, SO_t \geq 0 \quad \forall t \in T \quad (3.32)$$

$$FW_t, MW_t, FH_t, MH_t, FF_t, MF_t, P_t, I_t, S_t, SU_t, SO_t \text{ integer} \quad \forall t \in T \quad (3.33)$$

$$O_t \geq 0 \quad \forall t \in T \quad (3.34)$$

$$X_t^{RE} \text{ is binary} \quad \forall t \in T \quad (3.35)$$

$$CSR_{tj} \text{ is binary} \quad \forall j \in J, \forall t \in T \quad (3.36)$$

$$Y_{tk}, Y_{tk}^A \text{ are binary} \quad \forall k \in K, \forall t \in T \quad (3.37)$$

3.5.4 The Multi-Objective Model

In the multi-objective model, we do not only use constraints but also formulate our sustainability considerations within the environmental, social and cultural objective functions together with economic objective function. However, a unit of each consideration is different. Thus, we normalize each consideration by multiplying it by a coefficient. In this part of the study, first, we share our sustainability considerations and put them into the objective functions. Then, we demonstrate our method for calculating normalization coefficients.

The first consideration is related to the economic aspect that maximizes the total profit.

$$\max \quad \text{Consideration}_1 = \text{Total profit calculated in (3.1) to (3.12)} \quad (3.38)$$

Second and third considerations are related to the environmental aspect. They respectively minimize total greenhouse gas emission amount and total consumed non-renewable source generated energy amount during the planning horizon. Both emission and consumed amounts depends on inventory level, production amount, and subcontracting amount of each period. Integrating renewable energy source into the system decreases consumed non-renewable source generated energy amount. Further, making innovation projects decrease greenhouse gas emission amount and consumed energy amount.

$$\begin{aligned} \min \quad \text{Consideration}_2 = & \sum_{t \in T} (g_I \times I_t + g_P \times P_t + g_{SU} \times SU_t) \\ & - \sum_{t \in T} \sum_{k \in K} (g_{tk}^- \times Y_{tk}) \end{aligned} \quad (3.39)$$

$$\begin{aligned} \min \quad \text{Consideration}_3 = & \sum_{t \in T} (e_I \times I_t + e_P \times P_t + e_{SU} \times SU_t) \\ & - \sum_{t \in T} (e_t^{RE} \times X_t^{RE}) \\ & - \sum_{t \in T} \sum_{k \in K} (e_{tk}^- \times Y_{tk}) \end{aligned} \quad (3.40)$$

We have four considerations that are related to the social aspect. First one minimizes total overtimes during the planning horizon for the safety of the employee. Next consideration minimizes the number of male workers to increase female workforce level to satisfy gender equity. After that, we minimize total stock-out amount during the planning horizon to increase customer satisfaction level. Final social consideration maximizes the number of implemented corporate social responsibility projects. However, the first three social considerations are minimization considerations. Therefore, we multiply our fourth social consideration by (-1) and minimize it.

$$\min \quad Consideration_4 = \sum_{t \in T} O_t \quad (3.41)$$

$$\min \quad Consideration_5 = \sum_{t \in T} (MW_t - FW_t) \quad (3.42)$$

$$\min \quad Consideration_6 = \sum_{t \in T} SO_t \quad (3.43)$$

$$\min \quad Consideration_7 = \sum_{t \in T} \sum_{j \in J} -(CSR_{tj}) \quad (3.44)$$

As cultural aspect, we have two more considerations. First, we minimize total layoffs during the planning horizon for the employee well-being. Second, we maximize innovation performance. This performance not only increases by making innovation project but making project in the early periods of the planning horizon also increases the performance. To make both of them maximization consideration, we multiply consideration eight by (-1) and maximize it.

$$\max \quad Consideration_8 = \sum_{t \in T} -(MF_t + FF_t) \quad (3.45)$$

$$\max \quad Consideration_9 = \sum_{t \in T} \sum_{k \in K} Y_{tk}^A \quad (3.46)$$

As a result, our economic, environmental, social and cultural objective functions are respectively:

$$\max \quad z_{ECO} = Coef_1 \times Consideration_1 \quad (3.47)$$

$$\begin{aligned} \min \quad z_{ENV} = & Coef_2 \times Consideration_2 \\ & + Coef_3 \times Consideration_3 \end{aligned} \quad (3.48)$$

$$\begin{aligned} \min \quad z_{SOC} = & Coef_4 \times Consideration_4 \\ & + Coef_5 \times Consideration_5 \\ & + Coef_6 \times Consideration_6 \\ & + Coef_7 \times Consideration_7 \end{aligned} \quad (3.49)$$

$$\begin{aligned} \max \quad z_{CUL} = & Coef_8 \times Consideration_8 \\ & + Coef_9 \times Consideration_9 \end{aligned} \quad (3.50)$$

Our multi-objective model includes all of these considerations in its objective functions. As constraints of the model, it uses all constraints of the single-objective model. Hence, the complete multi-objective model is as follow.

$$\max \quad z_{ECO} \quad \min \quad z_{ENV} \quad \min \quad z_{SOC} \quad \max \quad z_{CUL} \quad (3.51)$$

(s.t.)

All constraints from (3.13) to (3.37).

After formulating multi-objective model, coefficients of the considerations can be calculated. The considerations within the objective functions have different scales and units, so they are not addable. The problem can be solved by normalization coefficients [Kim and de Weck, 2005]. Normalization coefficient for *Consideration_i*, $i \in \{1,2,...,9\}$, can be calculated in three steps [Augusto et al., 2012].

1. Solve the multi-objective mathematical model as a single-objective model and call the optimal value $Consideration_i^{max}$ where the objective function is

$$\max \quad Consideration_i \quad (3.52)$$

2. Solve the multi-objective mathematical model as a single-objective model and call the optimal value $Consideration_i^{min}$ where the objective function is

$$\min \quad Consideration_i \quad (3.53)$$

3. Calculate $Coef_i$ with the following formula.

$$Coef_i = \frac{1}{Consideration_i^{max} - Consideration_i^{min}} \quad (3.54)$$

After normalization by the given steps, the difference between the maximum and minimum value of each consideration becomes one. On the other hand, in order to clearly observe objective function changes in the solutions, we scale objective function value of each consideration into the zero-thousand interval by multiplying each calculated coefficient by thousand. To find optimal solutions to considerations, we use FICO® Xpress Solver that uses the approach of linear programming based branch and bound technique with cutting planes method for solving mixed integer programming problems. The version of the program and the properties of the used computer are given in Appendix-C.

Multi-objective sustainable aggregate production planning problem is a quad-objective mixed-integer model. This multi-objective optimization problem consists of two maximization objective functions that are associated with economic and cultural issues and two minimization objective functions correspond to social and environmental issues. Multi-dimensional structure of such models makes it impossible to limit the solution set with a single optimal solution. Instead, a multi-objective optimization problem has a set of non-dominated solutions in the objective space and a set of efficient solutions in the decision space.

A non-dominated solution results in objective function values - in the objective space - that cannot be improved simultaneously. If we obtain a number of non-dominated solutions for the sustainable aggregate production planning problem, we can interpret the trade-offs among objective function values. Let d_{max}^{ECO} be the vector of objective function values where the economic objective function is maximized. Then, assume that $d_{max}^{ECO} = \{z_{ECO}^*, z_{ENV}, z_{SOC}, z_{CUL}\}$ is a non-dominated solution. Similarly, we obtain other non-dominated solutions associated with the optimal objective function values of environmental, social, and cultural issues.

To solve multi-objective sustainable aggregate production planning problem, we use the Generator of Non-Dominated and Efficient Frontier (GoNDEF) method that ensures finding a number of non-dominated solutions for multi-objective mixed-integer linear problems [Rasmi and Turkay, 2018]. Assume that there exists a finite number of feasible integer solutions of a mixed-integer linear problem. For each feasible integer solution, there may exist feasible values for continuous variables that result in non-dominated solutions. These solutions are defined as efficient integer solutions. The GoNDEF method finds an efficient integer solution at each iteration. Then, it fixes integer variables to the values of the found efficient integer solution. Hence, the quad-objective mixed-integer linear problem changes to a quad-objective linear problem. There are algorithms for finding all non-dominated solutions of quad-objective linear problems [Yu, 1973, Zeleny, 1974]. Then, the GoNDEF finds the non-dominated solutions of the obtained linear problem and filters out the regions that are dominated by the mixed-integer linear problem. Note that at each iteration, this method uses no-good constraints and some constraints to exclude the dominated cone of the previously found non-dominated solutions. Therefore, these constraints avoid finding repeating solutions at each iteration.

3.6 Case Study

Data of the case study comes from a company that is one the manufacturer of consumer durables. They export their products many countries all around the world.

They also has several production plants worldwide. They are conscious their responsibilities. They strive to leave a better world for next generations. Their vision, culture, values and ethical principles lead their way towards meeting these responsibilities. Accordingly, managers of the company would like to prepare master plan of next year for its refrigerator plant in Turkey with a sustainability approach.

In addition to formulized constraints of our models, they have two more concern.

- They need to hold inventory at the end of each month that is equal or above to the specified amount.
- They have to put lower and upper limits for the number of workers performing manufacturing operations.

Sustainable aggregate production planning models are used to solve this case study together with these two concerns.

Chapter 4

RESULTS AND ANALYSIS

In the methodology part, we develop both single-objective and multi-objective models for the sustainable aggregate production planning problem. As a multi-objective model, we formulate a quad-objective mixed-integer linear programming problem. This model includes four objective functions for each pillar of the sustainability -economic, environmental, social, and cultural. In the current part of the report, we evaluate solutions coming from the multi-objective model. Solutions from the multi-objective model are non-dominated solutions. A non-dominated point in the objective space is a solution that not all of the objective function values associated with this non-dominated point can be improved simultaneously. We obtain a number of non-dominated points of the sustainable aggregate production-planning problem and measure the effect of each sustainability consideration accordingly. Therefore, we interpret the trade-off among the non-dominated points.

We get 447 different non-dominated solutions from GoNDEF algorithm. Among the non-dominated solutions, the lowest profit solution is only 1.05% lower than the highest profit solution and there is an opportunity to improve environmental performance with a rate of 3.37%. On the other hand, social and cultural performances dramatically change by the given decisions; social performance can change 80.69% and cultural performance can change 25.35% according to decisions. Achieved highest and lowest values of each objective function is given in Table 4.1.

Although maximized company profit decreases 1.05%, in return, they have the opportunity to increase their sales amount at a rate of 2.72% as can be seen in Figure 4.1. This is the result of implementing corporate social responsibility projects. Hence, these projects positively affect buying decisions of a customer, increase the

Objective	Highest Value	Lowest Value	Change Rate
zECO	3,263.16	3,228.94	1.05%
zENV	4.876.90	4,712.42	3.37%
zSOC	-260.94	-1,351.10	80.69%
zCUL	990.00	739.75	25.35%

Table 4.1: Highest and lowest values of objective functions among the investigated solutions

sales amount and correspondingly market share of the company. Moreover, the social performance of the company increases by the implementation of corporate social projects. The number of implemented corporate social responsibility projects increase more than two times of its lowest value while the company revenue increases. However, the company pays a cost to implement these projects that decreases the profit. As a result, by paying the 1.05% of the total profit as a cost, the company can both increase annual sales amount 2.72% and approximately doubles up corporate social responsibility project implementation performance.

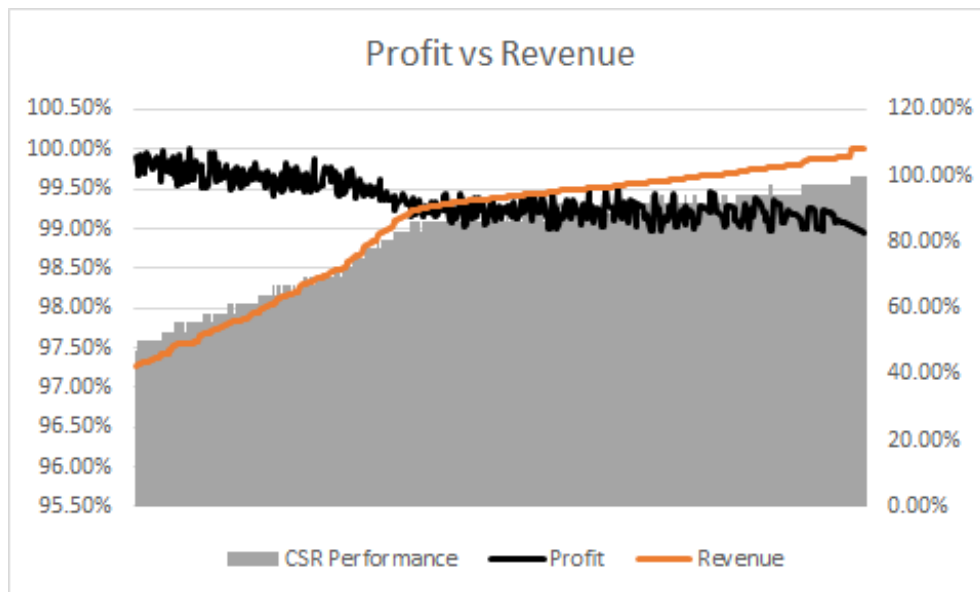


Figure 4.1: Trade-off between net profit and total revenue

Cost	Maximum	Minimum	Average
Workforce related costs	4.14%	3.83%	3.98%
Inventory holding cost	0.63%	0.58%	0.61%
Material cost	92.25%	89.93%	90.78%
Stock-out cost	0.00%	0.00%	0.00%
Renewable energy source cost	0.08%	0.02%	0.07%
CSR project cost	4.55%	2.03%	3.66%
Innovation project cost	0.93%	0.88%	0.90%
Total cost			100.00%

Table 4.2: Rates of costs within a total cost

If we group cost figures as seen in Table 4.2, we observe that considering all solutions, averagely 90.78% of all costs are material cost. On the other hand, number of stock-out situations are insignificantly rare that the average stock-out cost is zero. The cost of renewable energy source includes savings from electricity costs, and cost of innovation projects is calculated by considering expected cost savings. The increment of revenue because of corporate social responsibility projects is not reduced from the costs of these projects. These rates show us that company should focus on reducing material cost instead of focusing on costs of integrating renewable energy source, implementing corporate social responsibility projects and making innovation projects. Actually, 1% saving from material costs approximately equals to the average required amount of investment for integrating renewable energy source into the system together with making innovation projects. Moreover, these investments increase overall sustainability performance of the company.

Production-based greenhouse gas emission and electricity usage amounts directly dominate the overall environmental performance as can be seen in Figure 4.2. Considering all non-dominated solutions, averagely 98.29% of all electricity consumption is occurred during the production operations. The situation roughly same for greenhouse gas emission amount that averagely 95.04% of all greenhouse gas emission

amount is emitted during the production processes. Therefore, changes in production amounts affects the environmental performance.

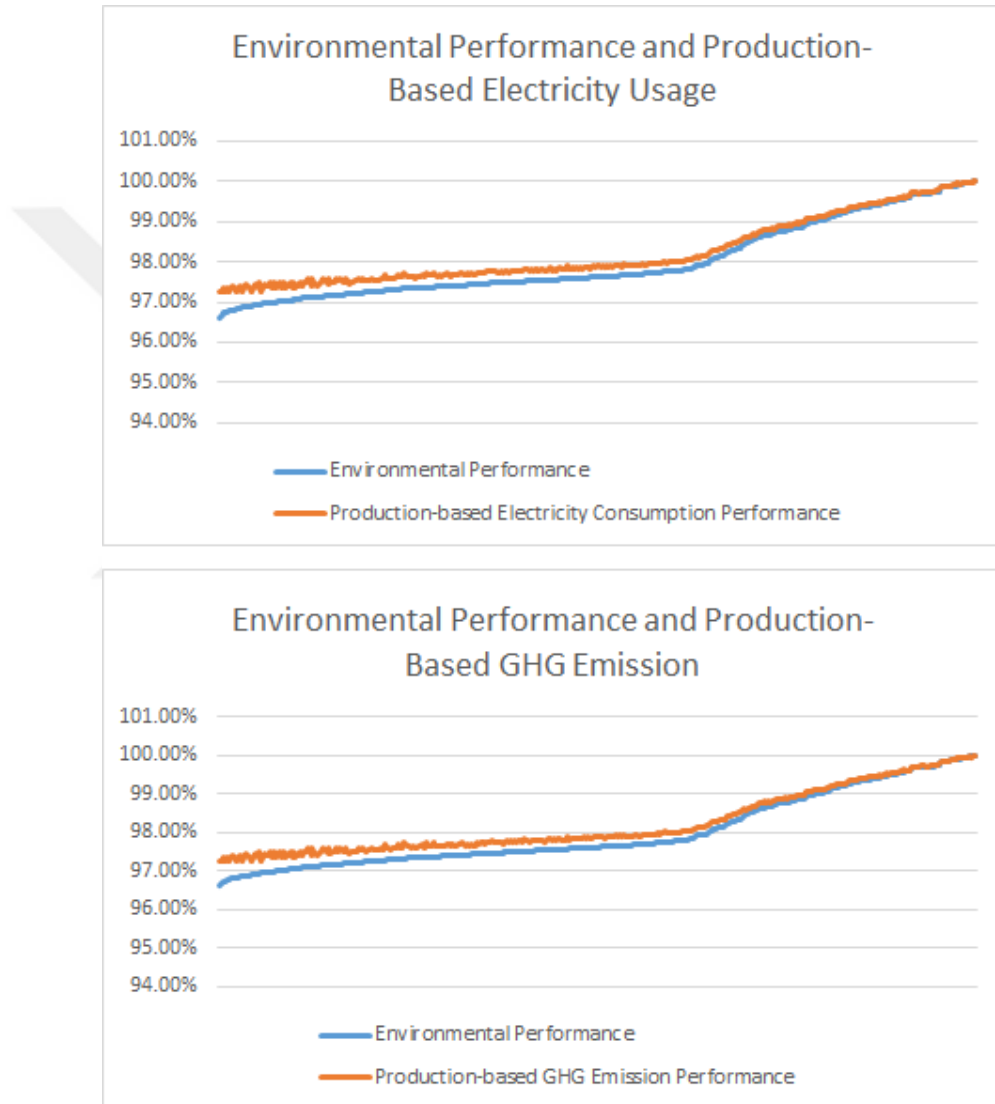


Figure 4.2: Environmental performance is dominated by production activities

However, all non-dominated solutions of the problem decide to make all innovation projects at the beginning of the planning horizon. Hence innovations not only maximize the cultural performance but also the incorporation of cultural consideration into the aggregate production planning can empower environmental performance. By making innovations, average total energy usage and greenhouse gas emission amounts

can be reduced 3.19% and 3.85% respectively. Environmental performance can also be increased by reducing annual production and inventory holding amounts; considering all solutions, according reduction rate for energy usage is 2.9% and 3.19% for greenhouse gas emission amount. The model, on the other hand, has a restriction for the worst demand satisfaction and end of month inventory level that force model to plan production and stock holding. Therefore, the model does not allow to reduce production and stock quantities after a certain level. Moreover, reducing production and inventory amount for increasing environmental performance can causes to face stock-out situations. As a result, the model finds more sustainable ways to improve environmental performance by the incorporation of the cultural environment into the model.

It is not possible to find a solution that simultaneously ensures best performance for all four objective functions because there is conflict among them. Best economic objective performance solution shows lower social performance that corporate social responsibility project implementation and gender equity satisfaction considerations are weak sides of the solution as can be seen in Figure 4.3. Best environmental solution can be achieved by reducing total profit 0.22%. However, social performance of the solution is lower and cultural performance also decreases according to best economic performance solution. This solution shows lower performance according to considerations of employee security, gender equality, corporate social responsibility project implementation and employee well-being as shown in Figure 4.4. In the best social performance solution, cultural performance decreases, economic and environmental performances approach their lowest performance values as can be seen in Figure 4.5. To achieve best cultural performance, the profit decrement is only 0.25%. The environmental performance of the solution is above the average. On the other hand, the social performance of the solution is weak because of low performances of gender equality, customer satisfaction and corporate social responsibility project implementation considerations as can be seen in Figure 4.6.

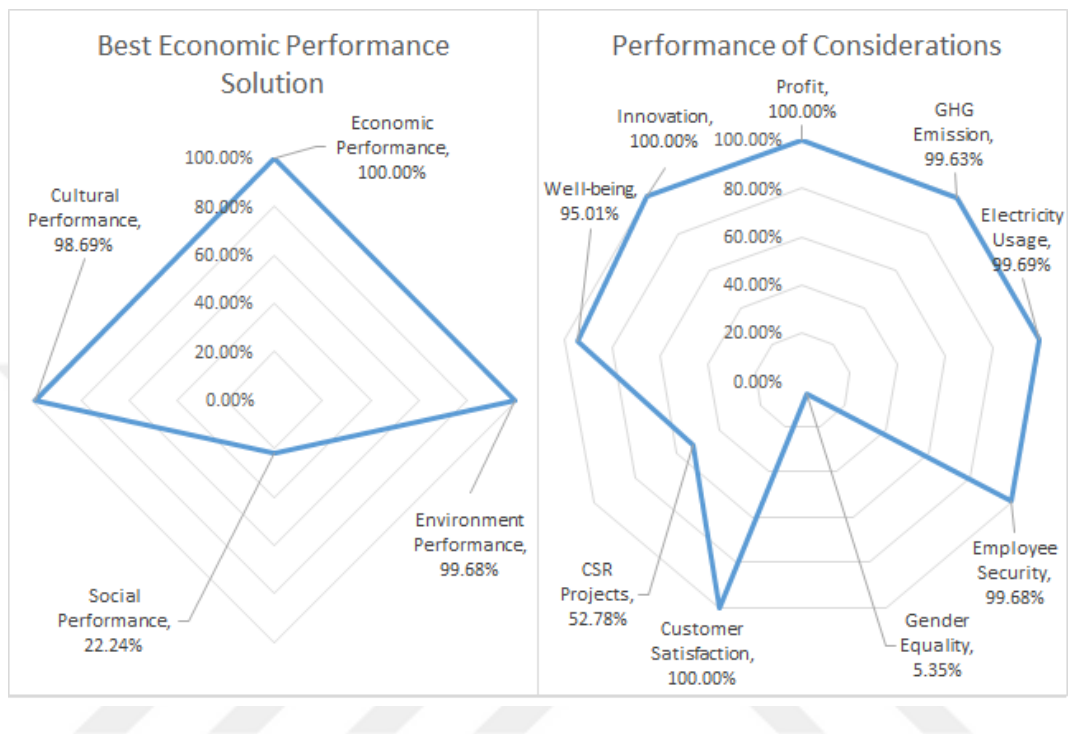


Figure 4.3: Best economic performance solution

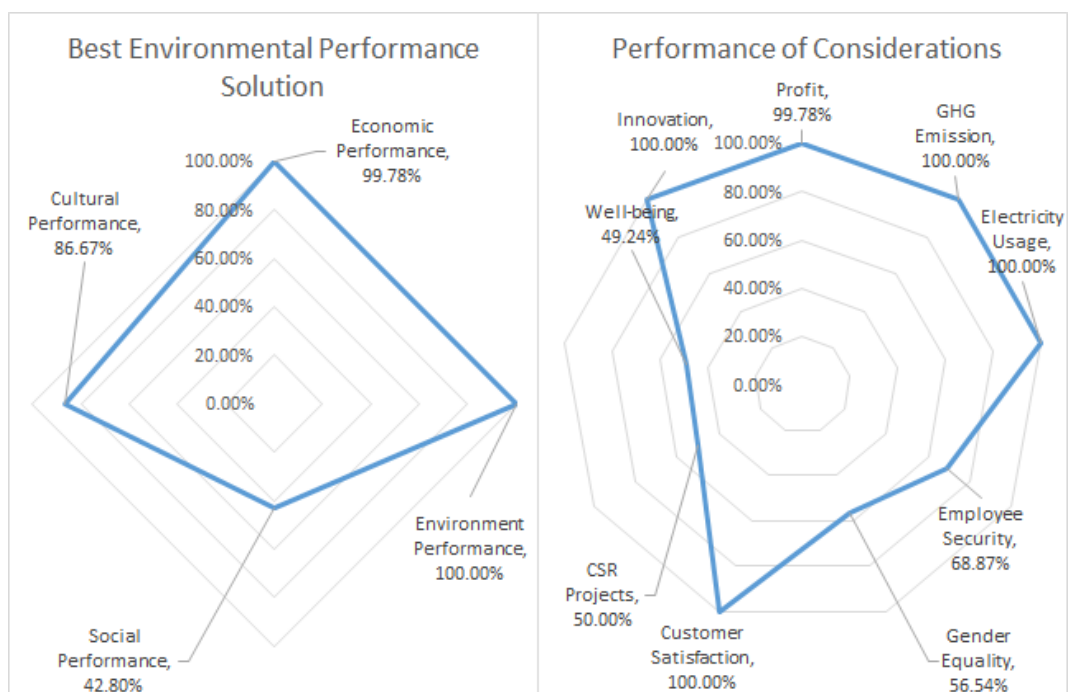


Figure 4.4: Best environmental performance solution

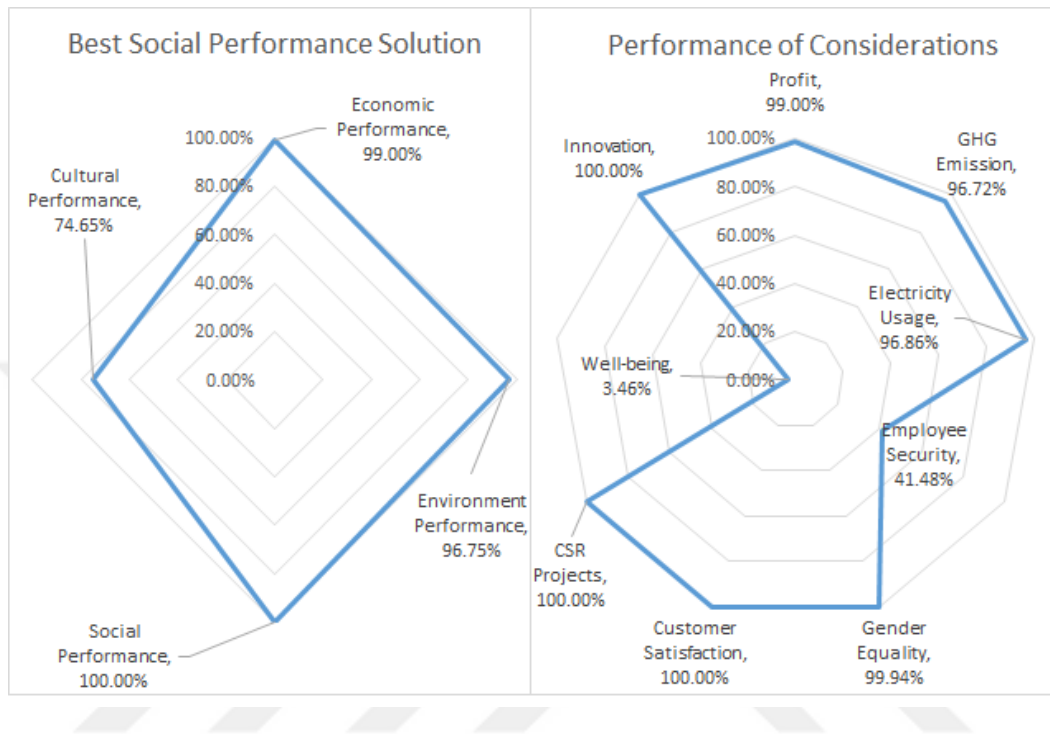


Figure 4.5: Best social performance solution

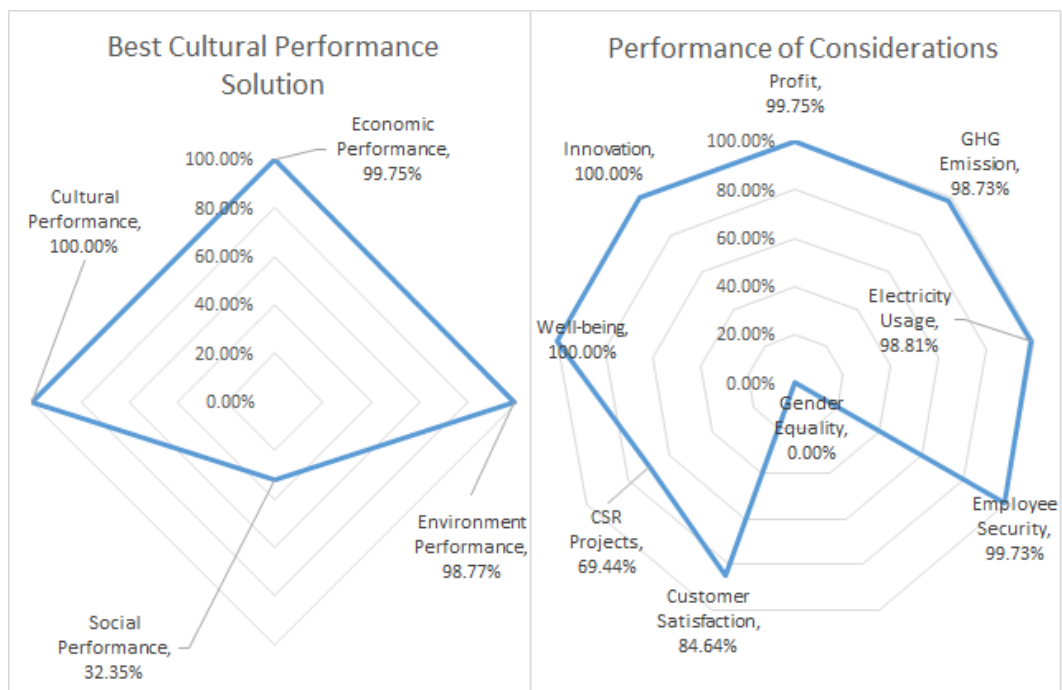


Figure 4.6: Best cultural performance solution

There is also balanced performance solutions among the investigated non-dominated solutions. One which can be achieved by sacrificing 0.63% of the total profit. Economic, environmental and social performances are above their average performance values. Cultural performance, on the other hand, only 3.46% lower than its average. The solution is only weak according to employee well-being consideration as shown in Figure 4.7.

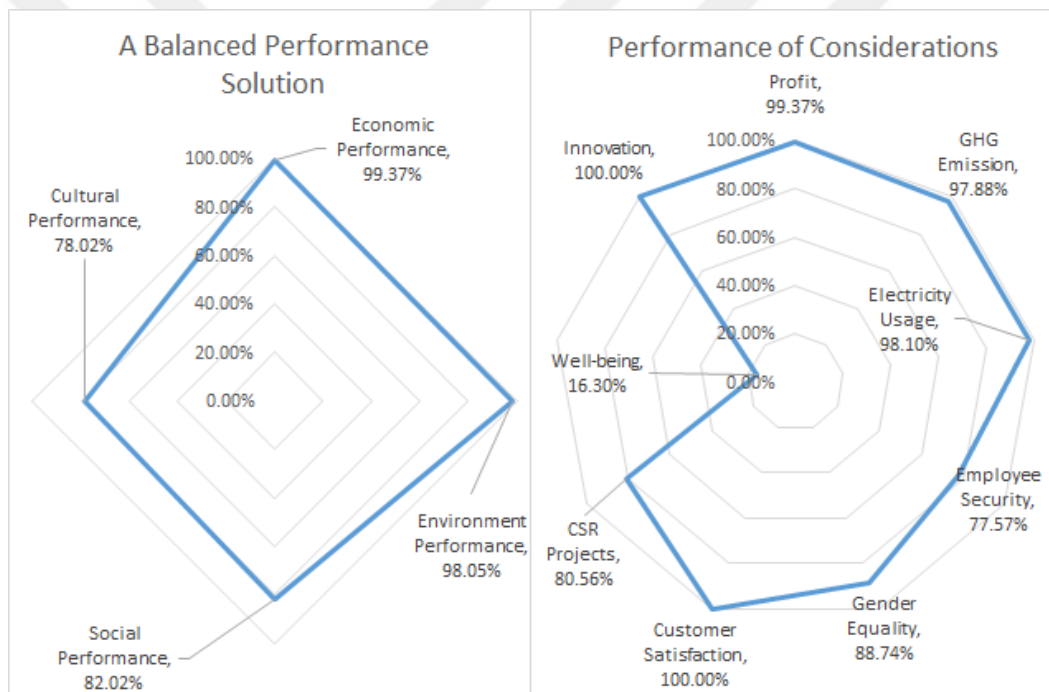


Figure 4.7: A balanced performance solution

Chapter 5

CONCLUSIONS

The known history of the supply chain has started before its first usage as a term. Initial consideration of transportation planning in the 1950s has expanded its field by covering all the activities, and parties from the source of supply to the customer that forms the supply chain system. Nowadays, the term supply chain reflects sophisticated global networks. At that point, observed high profits, share increments of old markets with access to new markets and other advantages of proper supply chain management practices has attracted the attention of companies. Hence, they use the supply chain management as a weapon to triumph over their competitors.

Although contemporary supply chain designs aim to reduce costs and support sound financial figures, the financial performance alone may not ensure engagement with inner and outer stakeholders and empowerment in the market competition. Financial based growth and development paths of businesses ignore environmental, social and cultural pillars of the sustainable development. However, any supply chain is not isolated from the rest of the world. Environmental, social and cultural factors are in a close and prominent relationship with supply chains, therefore companies should investigate and gauge the impacts of their decisions on environment, society, and culture.

The challenges have forced the historical development of the supply chain management to continue its expansion in order to cover environmental, social and cultural issues into consideration. Both practitioners and academicians present their studies and practices about the issue in recent years. Sustainability has returned a new mantra of the supply chain literature. However, the environmental aspect of the sustainability has taken a great interest in the sustainability studies, researches do not

sufficiently touch the social side of the sustainable development, and cultural side becomes a niche in the literature. Moreover, there are gaps in the literature one of which is a modification of the traditional models of the supply chain management with sustainability approach.

One of these traditional models is aggregate production planning problem. This study aims to reveal gaps in the current body of knowledge by incorporating cultural environment together with economic, environmental and social factors of the sustainability within a reformulation of aggregate production planning model. Aggregate production planning is a capacity-planning method at the tactical planning level. It helps planners meet fluctuating customer demands in a cost-effective manner by offering production amounts, workforce levels, overtimes, hiring and firing requirements, inventory levels, back orders, and subcontracting on a periodic basis. In our new approach, we present new parameters, constraints, decision variables and objective functions to pursue sustainability in the supply chain.

The economic side of the new model designate to maximize profit. Energy consumption reduction, renewable energy source integration into the system and greenhouse gas emission reduction are the considerations under the environmental side of the sustainability. The social side of our new model concerns employee safety improvement, employee gender equity satisfaction, worst-case customer satisfaction level restriction and corporate social responsibility project implementation. Finally, cultural side concentrates on employee well-being fulfillment and innovation performance improvement.

Formulated multi-objective model is solved by using parameter values of the case study from the real world situation. Obtained outputs show that

- In the worst case for profit, the decrement is at most 1.05% for the company. However, social and cultural performances change dramatically according to given decisions.
- Though the profit decreases 1.05%, there is an opportunity to increase sales

and correspondingly market shares at a rate of 2.72% by implementing new corporate social responsibility projects.

- Among all cost figures, more than 90% of all costs is material cost that 1% decrement in material cost can satisfy required investment amount for investment for integrating renewable energy source into the system together with making all innovation projects.
- Production level directly determines the greenhouse gas emission and energy consumption amounts. Hence, to increase environmental performance, the model finds lower production levels. However, after a certain amount of reduction, the model crashes worst customer satisfaction level constraint that puts a lower limit on production amount.
- The model finds more sustainable ways to improve environmental performance by the incorporation of the cultural environment into the model.
- There is not any solution that simultaneously ensures best performance for all four objective functions. However, there are solutions where performances of all sustainability pillars are in balance.

This is a critical and special time for the humanity to form a permanent and effective consensus for the sustainable development instead of measuring the success by the financial performance. All nations should show higher interest than ever for developing coordinated actions for persuading common goals of sustainability by taking into account of the interrelation between humankind, environment, culture, wealth and development. We may seize an opportunity to reverse conditions of environmental deterioration, social destruction, and cultural erosion, only if we balance out all pillars of the sustainable development.

As Dierk Peters (the former International Marketing Manager of Unilever) states that the only way to achieve benefits of the sustainability passes from the dealing with

the problem on the supply chain level; otherwise, it is greenwashing [Berns et al., 2009]. Thus, sustainable development goal should be injected into the every cell of the supply chain system. In the next decades, sustainability consideration can carry on reforming supply chain systems. The multi-dimensional structure of the sustainability reshapes future strategies in supply chain management, and improvements establish synchronization with the world that makes it possible to see the bigger picture of nature and human beings instead of narrowing it to the financial perspective. All stakeholders in the supply chain will need to play their part to accomplish this change. Consumer awareness and demand for sustainable products and services will also accelerate the adoption of new practices. Trends, laws, and requirements that will impact and drive future supply chain scenarios make clear that there are critical changes organizations will need to make in order to survive.

To support and strengthen this transformation, new studies should be conducted to arrange other commonly used traditional operations management optimization models under the sustainability considerations. This study can provide a promising template for such studies. Moreover, achieving the vision of the sustainability requires new performance measurement approaches. In the future, the industry must address additional key performance indicators like carbon emissions, energy consumption, employee safety across work accidents, gender equity, customer satisfaction level, layoffs, social responsibility projects and innovations. Supply chain strategy needs to look ahead and give priority to these indicators.

In conclusion, current consumption-based fast-growing economic system ascends on fast environmental depletion, and social and cultural destruction. On the other hand, the earth is a body being healthy only if all its parts are in good condition. It is the time for breaking out of past habits. We have to collectively attempt to renovate environmental, social and cultural collapse of the world. Satisfying stable development of civilization, we should create new approaches instead of watching the world from the perspective of economic expectations. Common and mutually supportive targets should consider interrelationships between people, planet, profit,

and culture. In a broader sense, the strategy of re-evaluating supply chains from the comprehensive perspective of economic, environmental, social and cultural pillars of the sustainability promotes harmony among our civilization, development, and nature. Hence, the world is not an asset that is inherited from us by our forefathers, but it is an entrusted capital taken by our children that we have to protect it.



Appendix A

TRADITIONAL AGGREGATE PRODUCTION PLANNING MODEL

Set of the Model

T set of periods in planning horizon

Parameters of the Model

d_t Forecasted demand for period t , $t \in T$ (item)
 n_t Number of working days in period t , $t \in T$ (day)
 h Regular time working hours per day (hour/day)
 p Number of produced item per day by one worker (item/(day*worker))
 W_0 Initial workforce level (worker)
 I_0 Initial inventory level (item)
 c_L Cost of a labor per hour (money unit/(worker*hour))
 c_H Cost of hiring a labor (money unit/worker)
 c_F Cost of firing a labor (money unit/worker)
 c_M Cost of used material to produce one item (money unit/item)
 c_I Cost of holding one item of stock per period (money unit/(period*item))
 c_O Cost of one-hour overtime for a worker (money unit/(hour*worker))
 c_{SU} Cost of subcontracting one item (money unit/item)
 c_{SO} Cost of stock-out for one item (money unit/item)
 sp Selling price of one item (money unit/item)

Decision Variables of the Model

W_t	Number of workers in period t , $t \in T$ (worker)
H_t	Number of hired workers at the beginning of period t , $t \in T$ (worker)
F_t	Number of fired workers at the beginning of period t , $t \in T$ (worker)
P_t	Number of produced item in period t , $t \in T$ (item)
O_t	Number of used overtime worker hours in period t , $t \in T$ (hour*worker)
I_t	Number of stocks in warehouse at the end of period t , $t \in T$ (item)
S_t	Number of sold items in period t , $t \in T$ (item)
SU_t	Number of items subcontracted in period t , $t \in T$ (item)
SO_t	Number of items stock-out in period t , $t \in T$ (item)

Mathematical Model: Objective Function and Constraints

$$\begin{aligned} \max \quad & \sum_{t \in T} (sp \times S_t - c_L \times h \times n_t \times W_t - c_H \times H_t - c_F \times F_t - c_M \times P_t \\ & - c_O \times O_t - c_I \times I_t - c_{SU} \times SU_t - c_{SO} \times SO_t) \end{aligned} \quad (\text{A.1})$$

(s.t.)

$$W_t = W_{t-1} + H_t - F_t \quad \forall t \in T \quad (\text{A.2})$$

$$I_t = I_{t-1} + P_t + SU_t - S_t \quad \forall t \in T \quad (\text{A.3})$$

$$S_t + SO_t = d_t \quad \forall t \in T \quad (\text{A.4})$$

$$P_t \leq W_t \times p_M \times n_t + O_t \times p_M \div h \quad \forall t \in T \quad (\text{A.5})$$

$$W_t, H_t, F_t, P_t, O_t, I_t, S_t, SU_t, SO_t \geq 0 \quad \forall t \in T \quad (\text{A.6})$$

In the objective function (A.1), the model optimizes profit. To do so, it decides total revenue and then reduce costs of labor wages, labor hiring and firing, material, overtime, inventory holding, subcontracting and stock-out respectively. Constraint (A.2) satisfies workforce balance. Constraint (A.3) strikes balance of inventory between periods. Constraint (A.4) determines stock-out amount. Constraint (A.5) is

the capacity constraint. Finally, constraint (A.6) satisfies non-negativity of the decision variables. The model investigates feasible region drawn by the constraints to find maximum profit.



Appendix B

SUSTAINABILITY FRAMEWORK ASPECTS

Category	Economic
Aspects	Economic Performance Market Presence Indirect Economic Impacts Procurement Practices
Category	Environmental
Aspects	Materials Energy Water Biodiversity Emissions Effluents and Waste Products and Services Compliance Transport Overall Supplier Environmental Assessment Environmental Grievance Mechanisms

Category	Social
Sub-category	Labour Practices and Decent Work
Aspects	Employment Labour/Management Relations Occupational Health and Safety Training and Education Diversity and Equal Opportunity Equal Remuneration for Women and Men Supplier Assessment for Labour Practices Labour Practices Grievance Mechanisms
Sub-category	Human Rights
Aspects	Investment Non-discrimination Freedom of Association and Collective Bargaining Child labour Forced or Compulsory Labour Security Practices Indigenous Rights Assessment Supplier Human Rights Assessment Human Rights Grievance Mechanisms
Sub-category	Society
Aspects	Local Communities Anti-corruption Public Policy Anti-competitive Behaviour Compliance Supplier Assessment for Impacts on Society Grievance Mechanisms for Impacts on Society

Sub-category	Product Responsibility
Aspects	Customer Health and Safety Product and Service Labelling Marketing Communications Customer Privacy Compliance

Table B.1: Sustainable framework aspects [International Energy Agency, 2017]

Appendix C

PROPERTIES OF USED COMPUTER AND VERSION OF FICO XPRESS SOLVER



Windows edition

Windows 10 Pro

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System

Processor: Intel(R) Core(TM) i5-2430M CPU @ 2.40GHz 2.40 GHz

Installed memory (RAM): 6.00 GB

System type: 64-bit Operating System, x64-based processor

Pen and Touch: No Pen or Touch Input is available for this Display

FICO® Xpress Workbench
Version 2.1.2

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