Statistical Methods for Sustainability Measurement of Supply Chain Management

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Submitted to the
Institute of Graduate Studies and Research
in partial fulfillment of the requirements for the degree of

Doctor of Philosophy
in
Industrial Engineering

Eastern Mediterranean University
May 2020
Gazimağusa, North Cyprus

Approval of the Institute of Graduate Studies and Research

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ABSTRACT

Sustainability is of essential interest for many organizations and is defined as the ability to maintain existing resources at a certain rate or level when encountered with barriers. Factors affecting sustainability are categorized as enablers (capacities) and barriers (challenges) that have positive and negative effects on sustainability, respectively. To evaluate the status of sustainability, organizations need a measurement method to account for all the aspects of the sustainability classified into social, economic, and environmental tiers. Previously, many researchers have provided indicators for measuring sustainability in specific fields, which is not applicable to organizations operating in other areas.

The main purposes of this research are to investigate how statistical methods are used to improve previous methods of sustainability measurement as well as to propose a new approach to sustainability measurement at organizational and supply chain management (SCM) levels. Emphasis is particularly devoted to determining how the sustainability of supply chains may be measured in the presence of exponentially distributed indicators for both independent and dependent variable cases.

Keywords: Statistical Performance Measurement, Bootstrap Re-sampling, AHP, TBL (Triple Bottom Line), Independent and Dependent Exponentially Distributed Indicators, Supply Chain Stakeholders, Copula Function

ÖZ

Sürdürülebilirlik birçok kuruluş için büyük önem taşımakta ve mevcut kaynakların engellerle karşılaşıldığında belirli bir oranda veya seviyede korunabilmesi becerisi olarak tanımlanmaktadır. Sürdürülebilirliği etkileyen faktörler, sürdürülebilirlik üzerinde olumlu ve olumsuz etkileri olan kolaylaştırıcılar (kapasiteler) ve engeller (zorluklar) olarak sınıflandırılmıştır. Sürdürülebilirliğin durumunu değerlendirebilmek için, kuruluşların, sürdürülebilirliğin sosyal, ekonomik ve çevresel katmanlarda sınıflandırılan tüm yönlerini hesaba katacak bir ölçüm yöntemine ihtiyaçları vardır. Daha önce yapılan çalışmalarda araştırmacılar, her alanda faaliyet gösteren kuruluşlara değil, sadece üzerinde çalışılan alanda uygulanabilecek sürdürülebilirlik göstergeleri önermişlerdir.

Bu araştırmanın temel amaçları, önceki sürdürülebilirlik ölçüm yöntemlerini geliştirmek için istatistiksel yöntemlerin nasıl kullanıldığını araştırmanın yanı sıra, organizasyonel ve tedarik zinciri yönetimi (SCM) düzeylerinde sürdürülebilirlik ölçümüne yeni bir yaklaşım önermektir. Özellikle üzerinde durulan nokta, üstel olarak dağıtılmış göstergelerde bağımsız ve bağımlı değişkenlerin her ikisi için de tedarik zincirlerinin sürdürülebilirliğinin nasıl ölçüleceği ile ilgilidir.

Anahtar Kelimeler: İstatistiksel Performans Ölçümü, Özyükleme Yeniden Örnekleme, AHP, TBL (Üçlü Sonuç), Bağımsız ve Bağımlı Üstel Olarak Dağıtılmış Göstergeler, Tedarik Zinciri Paydaşları, Kopula Fonksiyonu

Along with the fond memories of my dear parents who are no longer in this world, but whose memories continue to shape my life, I dedicate this thesis to my son (Hirbod).

ACKNOWLEDGEMENT

I would like to express my special appreciation and thanks to my advisor Assoc. Prof. Dr. Gökhan İzbirak, you have been a tremendous mentor for me. I would like to thank you for encouraging my research and for allowing me to grow as a research scientist. Your advice on both research as well as on my career has been priceless.

I would also like to thank my committee members, Prof. Dr. Bela Vizvari, Assoc. Prof. Dr. Hüseyin Güden for serving as my committee members even at hardship. I also want to thank you for letting my defense be an enjoyable moment, and for your brilliant comments and suggestions, thanks to you.

And special thanks to the faculty members of IE, Assoc. Prof. Dr. Adham Mackieh, Assoc. Prof. Dr. Orhan Korhan, Assist. Prof. Dr. Sahand Daneshvar, and Assist. Prof. Dr. Emine Atasoylu, and, who was kind and supportive to me.

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Chapter 1

INTRODUCTION

Finally, sustainability has become a real and measurable concept that has helped micro-decision makers and senior policymakers to formulate strategies at all levels of the organization and supply chains for optimal retention and utilization of resources. Gimenez and Tachizawa (2012) had demonstrated how understanding the concept of sustainability and applying its calculation methods has been able to change the traditional thinking of managers about the value of primary resources.

In order to cover the goals that mentioned in the abstract, the following five objectives are considered:

1- Application of bootstrap resampling method to solve difficulty of finding unbiased point estimators of population's parameters. Objective 1 investigates a statistical method to measure the sustainability and the application of the bootstrap re-sampling method in order to overcome the problem with normality assumption when the sample size is not large enough and thus develop a more realistic stochastic model. The Bootstrap re-sampling method enables the unbiased estimation of population parameters such as mean and standard deviation. The proposed method is evaluated by comparing its results with those found in the literature.

2- Application of Analytical Hierarchy Process (AHP) model to find weights of indicators according to expert views. Objective 2 represents a weighted statistical stochastic based Analytical Hierarchy Process (AHP) model for modeling the potential barriers and enablers of sustainability for measuring and assessing sustainability. For context dependent potential barriers and enablers, the proposed model takes basis of the properties of the variables describing the sustainability functions and was developed into a realistic analytical model for sustainable behavior of an organization. Previously, many models, mathematical, statistical and theoretical based AHP methods have been used by researchers, amongst all statistically based methods for measuring sustainability is the of most interest in this study and hence a strong weighted stochastic AHP based procedure that measure sustainability in it real amount was achieved. A case study scenario of a widely reported major Canadian electric utility was adopted to demonstrate the applicability of the developed model and comparatively examined its results with those of equal weighted model method. Variations in the sustainability of a company, as fluctuations were figured out during the time. By obtaining relatively necessary informative measurement indicators, the model can practically and effectively evaluate the sustainability extent of any organization and to determine fluctuations in the organization over time.

3- Developing a Triple Bottom Line (TBL) approach for measuring sustainability performance at the company level. By providing relatively simple and informative measurement, the model developed in Objective 3 presents an exponentially distributed stochastic model for the purpose of measuring the sustainability of .healthcare system. The aim of this study is to provide a sustainability measuring model that is driven by the actual distribution status of the sustainability indicators. In this paper, the notions of the "Triple

Bottom Line" (TBL) are followed in deriving the sustainability challenge and capacity indicators for the environmental, social, and economic indicators. Since basic challenges and capacities depend on the modes of the organization, the study proposes an exponentially distributed stochastic model for measuring sustainability. A numerical illustration of Iranian healthcare is presented to demonstrate the efficiency of the model. In the results obtained, the sustainability index for environmental, economic, and social are 54.40%, 48.80%, and 66.80% respectively. It indicates the healthcare achieved some sustainability through the social aspect; therefore, improving the environmental and economic aspect of the TBL is necessary. The proposed model can be used as a panoramic tool for measurement of the sustainability level of any healthcare system.

4- Developing a stakeholder perspective of the social sustainability performance framework for the broader context of the supply chain with independent exponentially distributed indicators. Furthermore, by providing an original and a straightforward analytical approach, the model developed in Objective 4 is one of the first to explicitly adopt probabilistic approaches for sustainability measurement in the supply chain context. The model can be employed as integrative, multi-dimensional tools for evaluating changes in the sustainability status of a supply chain over time. This study demonstrates a stochastic exponential distribution model for measuring the social sustainability status of a supply chain based on stakeholder theory. Iranian healthcare situated in Tehran is studied to illustrate the applicability of the proposed framework. In the results obtained, the sustainability index for Suppliers, Patients, Patient relatives, Employees, and Government &

Decision makers are 47%, 60%, 59%, 75%, and 56% respectively. The proposed model can be applied as an extensive tool for measurement of the social sustainability level of any supply chain system.

5- Developing a stakeholder perspective of the social sustainability performance framework for the broader context of the supply chain with dependent exponentially distributed indicators. Last objective is in the proposition of a probabilistic model for evaluating corporate social sustainability performance on value creation from among complex-criteria of stakeholders' participation and contribution. The majority of the literature has capitalized on the influence of the stakeholders' decision as sole criteria for adopting social and environmental practices. Previous supply chain sustainability measuring techniques has suggested the Irreplaceable resources at national or regional levels as major factors. Meanwhile, the use of statistical models to earnestly assess the sustainability performance of the supply chain through its dependent indicators is few. This has paved the way for the application of probabilistic techniques. In this article, we assessed and evaluated the dependency of some factors to suggest that stakeholders' decision does not only influence the adoption social practices, it also determines the strict relationship between capacity and challenge factors. In the proposed model, all the variables employed for the performance evaluation are exponentially distributed and correlated with one another, unlike the previous techniques that focus only on the independent variables. In previous studies, factor independence was considered, leading to anemia that was sometimes overestimated or underestimated. To overcome these drawings, a statistical model is constructed for the calculation of sustainability with dependent factors using copula functions.

Chapter 2

LITERATURE REVIEW

2.1 Introduction

Sustainability is most often defined as meeting the needs of the present without compromising the ability of future generations to meet their's (Cassen, 1987).

Sustainability is a concept that incorporates social, economic and environmental Pillars (Govindan, 2015; Wilson *et al*., 2017). The most popular pillar, i.e. the environmental aspect, considers the reduction of carbon footprints, water usage and the effect of developments, productions and technology on the environment while the two other pillars provide social and economic welfare of the present and to subsequent generations (Hansmann *et al*., 2012).

Some claim that as long as the value of total capital is increased or at least not decreased, consumption of natural capital for the production of manufactured capital is justified. In other words, they consider manufactured capital as a substitution natural capital (Gutés, 2009). (Solow, 1993) reasoned that economic capital in the mainstream can replace all-natural capitals apart from distinctive locations including Yosemite National Park and Grand Canyon. On the opposition, some consider natural resources of unique elements vital to human well-being which cannot be substituted with other forms of capital (Ayres, 2008). This group claims that the degradation of one natural resource would expose limitations on available options for future generations. These conflicts of ideas have led to a debate between weak and strong sustainability.

2.2 Weak versus strong sustainability

According to weak sustainability, natural capital and manufactured capital are substitutable and there is no vital difference between the kinds of well-being they generate (Ekins *et al*., 2003; Sinha *et al*., 2007; Neumayer, 2012). From this point of view, the only important issue is that the total value of the aggregate stock of capital should be ideally increased or at least maintained for the sake of future generations (Solow, 1993). In such a perspective: “it does not matter whether the current generation uses up nonrenewable resources or dumps CO2 into the atmosphere as long as enough machinery, roads, and ports are built-in compensation”(Neumayer, 2003). Such a position leads to maximizing monetary compensations for environmental degradation. In addition, from a weak sustainability perspective, technological progress is presumed to solve the environmental problems caused by the increased production of goods and services (Ekins *et al*., 2003).

On the other hand, strong sustainability prohibits the consideration of natural capital as an equivalent to manufactured resources and relies on nature as the sole provider of resources and services vital to human beings ((Ekins *et al*., 2003; De Groot *et al*., 2003; Brand, 2009; Dedeurwaerdere, 2013; Ekin, 2014; Pelenc and Ballet, 2015; Phillips and Whiting, 2016). Since these resources are degradable, they must be maintained beyond a critical level (Ekins *et al*, 2003; Brand, 2009; Chiesura and De Groot, 2003; Dietz and Neumayer, 2007). Thus, it is of great importance to be able to measure the dependence of human well-being on natural capital and thus constructing tools to assess sustainability.

Sustainability assessment methods are crucial to decision-makers in their movement towards sustainability. Developing a comprehensive approach inclusive of all the tiers of sustainability and applicable to all fields has always been a challenge that not many studies have pursued. Developed methods limited their evaluation to a specific industry, used the indicators, and features specific to that particular sector. Following is an abstract review of methods and tools, introduces in literature.

2.3 Triple Bottom Line (TBL)

Sustainability of an organization or a supply chain in terms of the triple bottom line, in researches, relies on the link between increasing profit and environmental protection, and often the social dimension is less attentive. In the early concept, sustainability was the optimal use of resources in the field to preserve the next generation's share; the focus today is on natural resource extraction and production control as well as optimal consumption. The notion that economic sustainability means sustainable profits from planned approaches that are sensitive to social and environmental contexts is a fundamental approach. Businesses and supply chains use different metering systems to establish links between factors and sustainability in the social, economic, and environmental domains that point to the triple bottom line (TBL) approach. (Wikström, 2010). The TBL approach is used to balance different aspects of sustainability in supply chains across different product and service areas. Balance or optimization refers to the access to goals that begin with the targeting and continue with the measurement of indicators and actions. (Allaoui *et al*., 2019).

Table 2.1 summarizes the concept, overall goals, expected results, characteristics, key areas, and related factors of each social, economic, and environmental sustainability perspective.

Table 2.1: Basic concepts related to the social, economic, and environmental sustainability perspectives. ∗

	Social sustainability	**Economic sustainability**	**Environmental sustainability**
Meaning	To what extent should the ability of a system to meet a specific and an acceptable level of social welfare be achieved? In a balanced society, all citizens, while having the right to live with adequate opportunities, must have this right for the benefit of future generations, which means establishing the necessary standards of social welfare and complying with it for access to the present and future generations.	To what extent should the ability of a system to meet a specific and an acceptable level of economic welfare be achieved? Economic prosperity means the optimal use of environmentally friendly natural resources to increase production efficiency, especially sensitive and important resources, such as water and minerals, which are promoted by innovation in the industry.	The ability of a socioeconomic system to optimally utilize raw material resources is focused on avoiding environmental pollution and conserving scarce resources. Concentrated social welfare production and concentrated social welfare must be developed in a way that is not at the expense of destroying environmental ecosystems.
Object-Goals	The humanitarian benefit of a community of their fundamental rights (privacy, social dignity, and cultural requirements) realized by committed leaders and discerning decision-makers	Human societies have access to financial independence and the support of economic systems to ensure that this prosperity is sustained.	Adjusting the economic accessibility of humankind emphasizes maintaining an ecological balance to enable the reconstruction of resources
Expected effects on TBL evaluation criteria	Social factors such as level of individual and social health, access to shelter, social rights, gender equality, individual culture and beliefs, rights of the disabled and deprived, personal and social justice, etc.	Economic factors such as adequate budget allocation, support for jobs and small industries, investment, development, optimal consumption pattern, cost-of-living balance, employment-based education, etc.	Environmental factors, including renewable and non-renewable natural resources, climate quality, greenhouse gas emission alert, industrial waste, environmentally harmful waste, environmental landscape, etc.
Specifications	In a sustainable social system, equal opportunities for all, regardless of gender and humanity, are available, with a particular emphasis on education and health as well as on the importance of public participation in the social sphere.	In a sustainable economic system, special emphasis is placed on the production of goods and services on a continuous and high-quality basis, and there is a trade-off between domestic revenue and losses from imports, with particular attention being paid to the domestic producer.	In an environmentally sustainable system, access to sustainable resources, avoids the unnecessary use of environmentally damaging systems, and special attention is given to replacing non-renewable resources with renewable resources.
Main themes	Proper distribution not only of social facilities and access, but also of educational equality, which are the fundamental	Maintaining and strengthening domestic and foreign investment this underpins the optimal economic	Optimal allocation of resources to deal with production mechanisms that damage environmental

	underpinnings of development.	production and balances the short and long-term investment.	ecosystems.
Type of indicators	Safety, security, health, quality of life, wellness	Income, job creation, development, employment, investment, job stability	Waste, energy, water, air quality, transportation, land use

⁎ Adopted from Lehtonen (2004), Spangenberg (2005), Morelli (2011), Fauzi *et al*. (2010), Eizenberg and Jabareen (2017), Boyer *et al*. (2016), Sridhar and Jones (2013), and Foy (2009).

2.4 Methods of measuring sustainability performance at the organizational level

One of the most well-known methods for evaluating sustainability is Life Cycle Assessment (LCA) which quantifies all the environmental impacts of a product from providing the raw material, through the production and down to its disposal (Gan and Griffin, 2018). One of the benefits of the LCA method is that it avoids the shifting of the impact from one point in the life cycle of the product to another point. Many variations of LCA have evolved through the years such as Life Cycle Costing (LCC) which additionally accounts for costs and Social LCA (SLCA) that also considers the social pillar of sustainability. LCA, mostly based on ISO 14040, is a data-intensive method and the reliability of the results is highly dependent on the collected data, thus it is not so desirable when exact data is not at hand. Another drawback of using LCA is the high complexity and uncertainty of the results that makes it hard for decision-makers to understand it.

Cumulative Energy Demand (CED) is considered as a derivative of LCA that indicates the energy requirements. This method requires less data compared with LCA. CED indicates the energy used during a full life cycle of a product and is easier to use for non-expert users, but with the price of losing detail information (Huijbregts *et al*., 2006).

Energy Life Cycle Assessment (E-LCA) considers energy losses in a process and also accounts for the quality degradation of the resources.

Carbon Footprint (CF) indicates the emissions of greenhouse gases over the full life cycle of a product or process. CF uses ISO 14064 to compute the emissions of greenhouse gases and mostly focuses on climate change impact and as a result, compared to LCA is less data-intensive, easier to understand and the results are more precise. These benefits are the reasons that have caused CF to be widely used in the industry. Water Footprint (WF), first introduced by (Hoekstra, 2017 is another assessment method that evaluates environmental aspects of sustainability. WF presents quantified water-related impacts of a product or process. Although WF only considers the water element, the complete life cycle of the product is considered in its calculations and the vitality of water to human beings makes this method highly important. Since LCA does not thoroughly account for water impact, WF may be used as a complement to LCA.

The Material Input Per Service (MIPS) introduced in 1990, indicates the productivity of the natural resources used to provide a particular product or service and is performed by quantifying the resources. One of the advantages of this method is its simple calculations and results (Ritthoff *et al.*, 2002). MIPS can be used to compare different products based on the quantity of the material used in their production. One of the disadvantages of this method is ignoring quality.

Partial Equilibrium Model (PEM) is used alongside LCA to evaluate the impact of policy changes on the market and the economy. This model is used to scrutinize the effect of substituting a good or a set of goods with other products and the potential consequences regarding the environment. (Freire *et al*., 2001) developed LCAA in the LCA framework which is based on Activity Analysis (AA). LCAA accounts for physical flows between the processes and the environment. Similar to LCA, LCAA is data intensive and requires the cooperation of experts in various fields.

Eco-Efficiency (EE) is a vital criterion for evaluating the green performance of an organization that is recently highlighted by the movement of organizations towards sustainable development. The merit of EE is that it links the environmental impacts directly with some kind of economic performance and it works as a valuable tool towards sustainable development (Caiado *et al*., 2017; Ma *et al*, 2018). Introduced by (European Environment Agency. 1999), Eco-Efficiency Analysis (EEA/EE) aims to deliver products and services and meet the market demand while progressively decreasing ecological impacts, at least to the level of the earth's carrying capacity. The goal of EE is to create more and have less impact. EEA is based on different approaches developed for measuring EE.

Socio-Eco-Efficiency Analysis (SEEBALANCE) is a method developed by BASF that evaluates the environmental and societal impacts and costs of a specific product. SEEBALANCE quantifies and evaluates all three pillars of sustainability in an organization. This method evaluates the social impact in five groups, including employees, the international community, the future generation, consumers and local & national communities. Evaluation of each group is limited to specific indicators.

Product Sustainability Assessment (PROSA) determines changes required to move towards sustainable development. Some applications of this method include strategic planning, product policy, sustainable consumption and product development and marketing. Three pillars of sustainability are considered in this method throughout the life cycle of a product.

(Khan *et al.*, 2004) proposed the Life Cycle Index (LinX), which facilitates the process of selection and design of products. LinX is comprised of factors such as the environment and technology. Each of these factors includes several parameters. LinX does not consider some parts of the life cycle. Sustainable Value (SustV) indicates the monetary value a company has produced during its course of life compared to other companies in the same sector. SustV covers the most common aspects of environmental issues and the basic social and economic aspects of sustainability in the production phase. It also reflects how efficient the company uses its resources. SustV uses only one indicator that facilitates comparison among companies.

To investigate whether remaining stocks of natural capital are adequate to sustain the anticipated load of the human economy into the next century, (Rees and Wackernagel, 1996) introduced Ecological Footprint (EF) to assess capital stocks, physical flows, and corresponding ecosystems areas required to support the economy. The ecological footprint measures how much bio productive area (land or water) a population would require to produce all the resources it consumes and to absorb the waste it generates, using the prevalent technology.

Similar to the ecological footprint metric, the Surplus Biocapacity (SB) measure measures the sustainability of consumption patterns, but accounts the difference between a country's ecological footprint and its domestic production area of the ecologically productive land and water (Giannetti *et al.*, 2010).

Drawing on the above, sustainability measurement methods can be summarized in Table 2.2.

Table 2.2: Sustainability measures. *

Method	Focus on	Tier	Cons	Pros
Life Cycle Assessment (LCA)	Environment and Total Quality Management (TQM)	Environmental	Data-intensive Complexity Uncertainty	Comprehensive evaluation of factors
Life Cycle Costing (LCC)	The distinction between whole life costs and life cycle costs of products and services	Environmental Economic		
Social Life Cycle Assessment (SLCA)	Investigating the social impacts of a product's life cycle	Environmental Social		
Cumulative Energy Demand) CED	Energy Consumption	Environmental	Lost of information	Less data-intensive compared to LCA User-friendly
Exegetic Life Cycle Assessment (E-LCA)	Evaluation of resource consumption	Environmental	Inability to optimize chemical processes	Considers energy + quality
Carbon Footprint (CF)	Effects of production on climate change	Environmental	Ignoring environmental damages like depletion of natural resources	Informed decisions to overcome environmental change
Water Footprint (WF)	Amount of used freshwater for the process of production	Environmental	Limited to water	Reducing production risks
Material Input Per Service unit (MIPS)	Quantity of directly or indirectly resources used for production	Environmental	Ignoring quality	Simplicity
Partial Equilibrium Model (PEM)	Environmental Impacts of Production Policy Changes	Economic	Addressed only by few models and factors	Keeping a balance between supply and demand
Life Cycle Activity Analysis (LCAA)	Effects of optimal resource allocation on the environment	Environmental	Data-intensive and Complicated calculations	Explicit recognition of alternative ways of production and distribution
Eco-Efficiency (EE)	More production, less resource use and less pollution	Environmental Economic	Setting quantitative goals	Compatible with today's economic system
Socio-Eco-Efficiency Analysis (SEEBALANCE	Incorporating social sustainability into environmental analysis	Environmental Economic Social	Compatible with ISO 14040	Limitation of evaluations to some selected criteria

)				
Product Sustainability Assessment (PROSA)	Energy consumption and socio-economic consequences of the product	Economic Social	Little chance to assess future developments	Increasing innovation-reducing complexity
Life Cycle Index (LinX)	Process design	Environmental Social	Is flexible of different impacts	Life Cycle is not accounted for completely
Ecological Footprint (EF)	Ecological Impact	Environmental	Mainly hypothetical land use and resource use are oversimplified	Ease of use at different scales of organization
(Sustainable Brand Index) SBI	Stakeholder priorities	Environmental Social	Improvement of SB being impacted by larger corporations	Synergy in environmental and social responsibilities

* Adopted from (Gan and Griffin, 2018; Huijbregts *et al*., 2006; Hoekstra, 2017; Ritthoff *et al*., 2002; Freire *et al*, 2001; Caiado *et al*., 2017; Ma *et al*., 2018; Khan *et al*., 2004; Rees and Wackernagel, 1996; Giannetti *et al*., 2009)

Sustainability is a multi-dimensional concept, in which economic, social and environmental aspects must be equally considered and integrated (Azimifard *et al*., 2018). For instance, there is no particular quantification of corporate sustainability and every company requires contriving its own description of sustainability that is consistent with its aims, nevertheless they presume that corporate communal responsibility and corporate sustainability are equipollent.

The business case for corporate sustainability has also been broadly investigated in the literature (Soleimani, 2018; Pactwa *et al*., 2018; Fattahi *et al*., 2018). In an endeavor to address sustainability at the company level, plenty of strategies, policies, programs, and other improvisations have been exposed. There is a growing body of research on corporate sustainability reportage (Brown *et al*., 2009), sustainability inspecting (Srivastava *et al*., 2013), codes of behavior (Bondy *et al*., 2008), and standard systems for environmental and socially liable handling (Castka and Balzarova, 2008).

Aside from summarized sustainability measures, there have been many indexes and indicators developed for a particular field which of course are not expandable to other environments. In continuing some of the studies of this kind will be discussed in brief.

(Gómez-Limón and Sanchez-Fernandez, 2010) assessed the sustainability of farms through an assessment method comprising 16 indicators that covered three bottom tiers of sustainability and was proved to improve sustainability and agricultural policies. Using the IDEA method (Bertocchi *et al*., 2016; Zahm *et al*., 2008) integrated 41 sustainability indicators to support the agriculture sector by comparing different production systems in terms of sustainability. (Van Cauwenbergh *et al*., 2007) proposed a framework to select indicators and reference values that are used to assess the sustainability of an agro-ecosystem. (Rasul and Thapa, 2004) used twelve indicators to compare the effects of ecological and conventional agriculture on sustainability. They resulted that ecological agriculture has more tendency towards sustainability. Similarly, (Orlova and Sharabarina, 2015) Proposed an interaction matrix that yields two types of indicators to assess the impact of a specific production system on the environment (Agro-Ecological Indicators) and to investigate the common impact of all production systems on the environment (Indicators of Environmental Impact). These indicators are supposed to help decision-makers in the selection of the farming system in terms of economic and environmental factors. (Oñate *et al*., 2000) illustrated that environmental Regulation can have a positive impact on Agricultural lands by agri-environmental indicators. (Mohamed *et al*., 2016) applied the Farmer Sustainability Index (FSI), which is comprised of 33 production systems, each having a positive or negative score.

Changes in FSI would reflect the changes of ecological sustainability thus enabling farmers to know about their position in their movement towards sustainability.

(Wernick and Ausubel, 1995) highlighted that from a scientific point of view, it is highly unlikely to provide one comprehensive metric or index of sustainability that could satisfy all the requirements posed by different philosophies (e.g., weak and strong sustainability perspectives). Also (Kinnear and Ogden, 2014) states that the sustainability evaluation requires the development of a multidimensional assessment tool that integrates economic, environmental and social issues.

Pearce (1988) noted about the close probabilistic relation between the stability of natural capital and sustainability. Destroying natural resources may decline the amount of sustainability in different aspects. By this view, improving sustainability, especially environmental sustainability must be an important issue of organizations in these years (Kuan *et al*., 2013). This shows the importance of studies on finding methods of measuring sustainability by adopting a strong sense in preferable levels of a supply chain or individual companies.

Schaefer *et al.,* (2006) mentioned that there is a competition between nature and human about restoring renewable resources with the ability to replenish or revived and consuming it. Because of more consuming than restoring, mankind always is the winner of this contest. The ecological footprint (EF) refers to the amount of the reproductive area that mankind demands when consuming resources in a sustainable way and conversely, biocapacity (BC) is the quantity of existing reproductive supply within a specific area. EF and BC can be assumed as demand and supply by using an economic perspective. Surplus biocapacity (SB) as reported by Gianetti *et al*., (2010) can be defined as the absolute value of the difference between EF and BC in a mathematical view. Selecting appropriate metrics for measuring and analyzing these concepts is vital. For instance, SB of an area can be obtained from the differences between EF of the area, its indoor production area of land and water ecologically productivity. The difference between the sustainability views (economic, environmental, and social) with various theoretical and practical methods of sustainability assessment and measurement, resulted in a big challenge for organizations and decision makers of supply chains (Dzemydiene., 2008).

According to the most usable description of sustainability as reported by (WCED., 1987), humanity has the ultimate powers of ensuring sustainability by getting their present necessities without jeopardizing the needs of the next descendants. Moreover, impressions of EF and SB failed to fully establish and accounted for the range of environmental problems. This was also opined by Schaefer *et al.*, (2006) that nature seems not to have significant capacity to absorb some important obstacles in the environment and the thereby acts as contaminants and impurities of high-density materials. Nijkamp *et al*., (2004) in their research showed that the biological view of measuring the productivity of an area, may not necessarily consider the resources in the absence of renew-ability of capacity. For instance, in the study of the amount of co_2 emissions from domestic gas consumption, cremated fuel remaining is not considered as a metric. Most of the metrics of EF and SB concepts are obtained according to an analysis of a system in a static situation, in this situation, every individual metric will lose its power to predict future (Rees., 2006).

The development of this model, is therefore based on the fact that there will always be both effective factors of sustainability (barriers and enablers) which are the catalysts for the growth of the organization necessary for its sustainability without hampering its capacity. With this in mind, organizational sustainability can be idealized in terms of its capacity to move progressively to subdue the challenges imposed on it. Consequentially, the capacity of the organization is manipulated by particular exterior or interior situations. Thus purposed model in this paper admits these facts that those catalysts vary between organizations.

It should be noted that not all factors imported in sustainability measurements are relevant therefore possible barriers and enablers to sustainability are usually at the instance of the prevailing conditions at the subjected organization. It is worthy of note that priority assigned to relevant variable changes over time. It becomes more complicated when different variables are given in diverse units or even in quality measures, then the correlation among the variables perhaps uncharted (Marchini *et al.*, 2009). Putz Huber and Hasenauer (2010) corroborated this by applying a probabilistically method of sustainability insulated from probabilistic measures as a pragmatic and feasible approach.

2.5 Methods of measuring sustainability performance at the supply chain level

Supply Chain Sustainability From the perspective of stakeholder requirements, various approaches have been taken, including the discretion of supply chain focal companies to balance social, economic, and environmental goals. Note that there is a significant relationship between these three goals so that disregarding one of them also disrupts others.

Nine models are AHP, BSC, SCOR, DEA, LCA, Equilibrium models, Input-Output analysis, MCDM, Composite Metrics. Before looking at the application of these models, we have a glance at the concept of each model.

2.5.1 AHP

The model, which is used to solve multi-criteria decision-making problems in the manufacturing and service industries, is based on the assumption that such problems can be solved by considering hierarchical relationships between levels. The main objective at the top level and the associated constraints at the intermediate levels and finally at the lower levels of the alternatives is organized and calculated by pairwise comparisons of the positive weight of each factor (Stefanović *et al*., 2016). Based on pairwise comparisons using standard tables, AHP is used to find priorities. The comparisons are made based on the experts' opinions and finally, the overall objective is divided into measurable criteria. Decisions are made based on pairwise comparisons on a numerical scale from one (equality of importance) to nine (a very important activity) (Dos Santos *et al*., 2019). AHP has been used by many researchers in various fields of industry, services and supply chains to support decision making. (Subramanian and Ramanathan, 2012). This model operates on a hierarchical structure such that each decision criterion is subdivided into lower levels. This process results in the weighting of decision-makers by considering the subjective opinions of the experts in the field, and by answering pre- questionnaire questions about the importance of the factors. Due to the inability of the traditional AHP model to fully understand the qualitative factors, recently the AHP fuzzy model has been considered. This approach is one of the most widely used multi-criteria decision-making approaches with qualitative factors (Calabrese *et al*., 2016).

2.5.2 BSC

Managers who only used financial metrics to evaluate the sustainability of their organizations have been criticized until the modified BSC model created in 1992 by Kaplan and Norton came to their attention with a focus on stakeholder satisfaction, internal process integration, social expectations, and reputation for a more accurate presentation on sustainability. According to the BSC concept that was used as a tool to balance short-term activities with long-term goals, there is a causal relationship between the financial and other non-financial aspects with considering qualitative and quantitative information from inside and outside of an organization. Although BSC had recently used a combination of Enterprise Planning Resources (ERP) to align financial and non-financial assets to strategic goals, a new approach called BSC fuzzy network has helped to understand the interdependencies of sustainability factors (Lin *et al*., 2013). The sustainable balanced scorecard (SBSC) model was a derivative of BSC, based on a hierarchical structure that relies on four approaches: financial, customer satisfaction, internal processes, and growth and learning. The SBSC model not only recognizes the environmental goals of the organization, but also enhances the value-added of social factors and later becomes a tool for managers to increase their awareness and understanding of their responsibilities (Zhao and Li., 2015). The financial approach emphasizes the organization's financial concerns and how the organization behaves to ensure continued growth and protection of shareholders' equity and financial balance. The customer perspective refers to understanding the needs and expectations of potential and actual customers to grow and survive the organization in a competitive environment. All internal processes and customer expectations are usually the outcomes of the demands that the organization should necessarily implement their internal processes. The growth and learning dimension is a set of intangible assets of the organization that refers to optimizing the flow of information through the use of related systems. To implement the model, the organization needs highly skilled staff to understand the concept of innovation and to employ strategic tools to meet customer needs that lead to the organization's financial profit. In achieving the organization or supply chain with strategic goals, a variety of methods have been proposed by researchers that the BSC has become a powerful tool for balancing the four equilibrium perspectives (Mendes *et al*., 2015).

2.5.3 SCOR- supply chain operations reference

A model aimed at improving supply chain performance that serves as a link between optimally identifying process elements and finding the best way to mark effective and efficient core activities for measuring sustainability. In short, the model is the interface between the supplier and the customer. SCOR cycle: production planning according to customer's needs, a supply of storage for order maintenance, manufacture and production of order, delivery of goods to the customer, the supply of raw materials for planning (Tramarico *et al*., 2017). Today, the traditional SCOR goes beyond the boundaries of measuring and improving organizational performance with a more realistic approach, considering environmental concerns and playing a role in its new role as Green SCOR. The model in its interactive cycle enables organizations to supply and refine value chain approaches and activities. The model has been rapidly applied in a variety of production field and service-oriented areas, from the automotive industry to the tourism, from the wood industry to information systems consulting, from the oil industry to geographic information systems, and although it has also demonstrated its environmental impact, but has a greater impact on the economy field (Ntabe *et al*., 2015). The cycle steps must be sequenced and reviewed at predetermined time intervals to be used effectively in the organization or supply chain. The quality of implementation of this model is closely related to the level of training and knowledge of staff (Bendul *et al*., 2017).

2.5.4 DEA

DEA is a non-parametric mathematical model for evaluating the performance of a decision-making unit (DMU) with multiple inputs and outputs. Traditional DEA (classic DEA) was introduced by Charnes in the Year 1978. The range of efficiency changes between zero and one, which Values close to one represent the unit with excellent efficiency. The model has been developed in a variety of areas like urban, banking, hospitals and supply chains, one of which is a two-integrated model, which has been used to assess the efficiency of the Chinese road transport service in terms of technical, environmental, and ecological dimensions (Xie *et al*., 2019). The DEA model has recently been applied to a wide range of private and public sectors such as technical evaluation of thermal power plants, evaluation of electricity generation performance, assessment of the sustainability performance of the automotive industry with an emphasis on environmental protection, which sometimes results in the creation of integrated sustainability models. Like other decision-making models, the DEA has its own set of limitations and challenges, one of which is determining the number of decision units. It has been agreed by the researchers that the number of decision units should be at least equal to three times the sum of the model inputs and outputs. In many model applications, the number of decision units is insufficient. Although several solutions have been proposed to overcome this limitation, it should be noted that, in spite of these limitations, the different models developed have different and often unexpected results (Mahmoudi *et al*., 2019). Another challenge was the existence of a large number of highly effective tenants in several areas, including utilities. Recently, DEA-based models have been developed to overcome this challenge, which has made DEA a multi-criteria decision-making approach. In this application, decision-making units are categorized into efficient and inefficient branches that have been used by researchers in various fields of agriculture, energy, environment, and supply chain management (Pozo *et al*., 2019).

2.5.5 LCA

The traditional Life Cycle Assessment model was used as a means of linking organizational plans to achieve a good level of employee satisfaction, but today it is used as a means of achieving stability in production and maintaining value within the supply chain. The main purpose of the developed LCA model is to reduce the environmental impacts by emphasizing the impact of the products (Gestring, 2017).

The following cycle can be considered for a model that examines the relationship between the environmental impacts associated with the product life cycle. LCA cycle: Targeting and setting boundaries of activity, Determining and measuring inputs and outputs, Indexing of environmental factors, Conclusions based on cause and effect relationships among indices. In recent years, a variety of applications of traditional LCA and social life cycle assessment (S-LCA) have been used in various applications including environmental impact assessment of sugarcane industry as well as the use of a computer simulator to evaluate environmental indicators. However, analyzing the outputs of these models that result in, the weighting of different products or scenarios is sometimes difficult to understand for decision-makers. To address this difficulty, assigning equal or stochastic weights to all indicators was proposed and applied, which led to the overriding of preferences as well as the ineffectiveness of multi-criteria decision-making models. The most appropriate solution is based on assigning a random weight of all possible compounds to find the optimal weight (Du *et al*., 2019). Today, LCA is one of the most widely used methods for measuring the environmental impact of products and services used in developed countries as well as booming economies. Other approaches, such as the energy model alongside the LCA model, are used as the Eco-LCA model as a supplement to measuring sustainability in assessing environmental impacts in industrial areas, agricultural productivity, value-added mining, and other areas. This integrated approach is also used to evaluate the effectiveness of strategic planning (Liu *et al*., 2019). Another application of the LCA model has focused on reducing the environmental impacts of food supply chains. (Noya *et al*., 2018). The program has four steps in succession: identifying effective units and defining system boundaries, system input, and storage of output, probing the effects of predefined scenarios and interpreting outputs and outputs (Smol *et al*., 2019). The LCA model can also be used to optimally manage the use of harmful environmental waste (waste incineration to generate energy and generate electricity from landfills) (Ghose *et al*., 2017). Because this model can simultaneously consider the environmental impacts of each stage of the life cycle and introduce an environmentally friendly model. The LCA has also been used as an effective tool for the development of waste management programs, examining different landfills without energy recovery, waste recycling with energy recovery, and model results indicate that waste incineration is a better option (Bartolozzi *et al*., 2018).

2.5.6 Equilibrium models

The equilibrium model is derived from an economic network aimed at balancing production rates and optimal transportation costs. The equilibrium model applies to the overall and partial supply chain sustainability assessment. For example, retailers are looking to balance the maximization of profits and shipping costs, as well as the end consumer interested in balancing optimum consumption and payment costs

(Nagurney *et al.*, 2002). A supply chain generally involves suppliers, manufacturers, distributors, retailers, and end-users who each seek to maximize their needs and requirements, leading to equilibrium. Other measurement models, such as AHP, have also been used occasionally to check for sustainability and achieve equilibrium solutions. The discussion of supply chain sustainability with the help of the equilibrium model refers to balancing all the components involved so that if one component tries to change its behavior to enhance its sustainability, it may reduce the sustainability of the entire supply chain (Hsueh and Chang, 2008).

2.5.7 IOA analysis

This top-down method that Introduced to illustrate the relationship between commodity production and the exchange of materials in economic firms, now considers the protection of resources and the environment at the enterprise production stage. Although this model was not introduced to identify the internal organizational segments, it is nowadays used as a tool for investigating supply chain actions and responses and is very powerful in identifying communications (Wang *et al.*, 2017). The IOA method is closely related to the LCA model and is capable of describing the economic system with the help of the linear equation system:$ax + y$ In this system x and y are the vector of total production and total demand and A is the relationship between input and output of the system. Specifies that each x and y member generates a segment's production efficiency as well as their net consumption efficiency (Tan *et al.*, 2018). In the environmental field, this model illustrates the direct and indirect effects of environmental impacts as well as ecosystem degradation by integrating effective elements within an economic network (Pang *et al.*, 2019). The model also has sufficient rationale for evaluating supply chain sustainability, by analyzing the functional actions and their interactions within each component of the chain (Bappy *et al.*, 2019).

2.5.8 MCDM

The MCDM model has been used to rank existing options and prioritize them and is nowadays used in various areas including waste management. In this program, the model assists decision-makers in assessing the social, economic, and environmental impacts and selecting the appropriate criteria and ultimately what to make. MCDM approaches are separated into two groups, Multi-attribute Decision Making (MADM) consist of value-based methods, outranking methods, and distance-based methods, and Multi-Objective Decision Making (MODM), which evaluate a certain number of alternatives according to criteria (Brookes *et al.*, 2014). In the model, in addition to resource constraints, there is an objective function that must sometimes be maximized (profit) and sometimes minimized (cost). In multi-criteria decision making, different models such as TOPSIS (Remote Axis), PROMETHEE (Priority Based Integration), ELECTRE (Elimination and Choice Translating algorithm), and AHP (Priority Oriented) models are used to evaluate organizational sustainability and supply chain management. But in supply chains with multi-stakeholders, the AHP model is dominant. However, it seems that the combined use of two or more models will lead to more reliable results. Nowadays, MCDM methods are sometimes in fuzzy form, to evaluate the efficiency and sustainability of metropolitan decisions (choice of method and location of landfill or solid waste incineration, environmental pollutant control, sustainable transport system, level of health services) (Coban *et al.*, 2018). Sometimes the vector weighting is based on incomplete, which is a drawback of MDCM models. However, methods such as the maximum deviation model or the use of expert opinions can be helpful (Wang *et al.*, 2018).

2.5.9 Composite metrics

Composite metrics is a centralized application tool for aggregating complex and multi-dimensional problems into a single metric. While model metrics are more subjective than objective, they are used by researchers to evaluate organizational performance and supply chain, given the fact that it uses a good weighting system to combine different factors (Singh *et al*., 2007). The last but not least model used in supply chain sustainability measurement is a model based on composite metrics or criteria. This approach uses composite metrics to summarize multifaceted and complex factors that lead to results based on factor weight. The subjectivity of the model has been criticized by some researchers (Bappy *et al*., 2019). Recently, many studies have been conducted on various organizational or supply chain sustainability assessment models, which, after reviewing the concept of each model, provide a list of each application in Table 2.3.

Table 2.3: List of sustainability measurement models in supply chains with emphasis on key findings.

Method	Authors	Highlights
AHP	How *et al*. (2018)	• Focus on the non-responsiveness of process optimization to improve the biomass product life cycle in the supply chain. • Application of the AHP model to prioritize sustainability dimensions of social, economic, and environmental aspects. • Investigation of three different environmental pollution scenarios in a case study in Malaysia to evaluate the efficiency of the model.
	Govindan *et al*. (2017)	• Investigating and categorizing thirty potential barriers to sustainable consumption in the supply chain. • Apply a fuzzy-based AHP model to prioritize the barriers mentioned, with a view to eliminating or minimizing the factors that influence it. • A case study in the Indian automotive industry to understand the factors.
	Ansari *et al*. (2019)	• Identify and prioritize performance outcomes related to organizational reorganization factors. • Introducing a hybrid AHP model to obtain weights and TOPSIS to prioritize factors. • A case study of the manufacturing industries in India to show step by step the continuous improvement of performance.
	Chand *et al*. (2018)	• Identifying effective factors as business barriers at the global supply chain level. • Using performance measurement models, SAP and LAP and

		combining them with AHP to understand how decision-makers prioritize behavior. • A case study in India to understand the complexities of supply chains with the aim of helping managers understand the role of global decision-makers.
	Luthra *et al.* (2017)	• Emphasis on the importance and role of suppliers in the sustainable supply chain. • Twenty-two criteria for selecting a sustainable supplier in the social, economic, and environmental areas and using AHP to understand the importance of the criteria. • A case study in the automotive industry in India to select five important factors in selecting a sustainable supplier and suggest that this model can also be used to compare and categorize efficient suppliers.
Balanced scorecard based model (BSC)	Callado and Jack (2015)	• Examine the roles of suppliers, manufacturers, distributors, and retailers in the supply chain that have provided a new perspective on the use of performance metrics. • Performance appraisal should be based on the measurement of effective factors for different units. • The results showed that finding a viable and collaborative solution for evaluating the sustainability of different parts of the supply chain is very difficult and other options should be considered.
	Bhagwat and Sharma (2007)	• Classifying different metrics of strategic supply chain management into the financial, customer, internal processes, and growth perspectives that are the main pillars of the BSC model. • Three case studies at the level of SMEs in India to examine supply chain performance.
	Varma *et al.* (2008)	• Emphasizing the complexity of the supply chain in the petroleum industry and using hybrid models to evaluate performance to quantify qualitative data. • Combining AHP to select the influencing factors of the four domains and BSC to find the relative importance of the criteria based on pairwise comparisons across domains. • The results showed that AHP criteria are in descending order of importance for the customer, financial, internal processes, and learning growth, respectively.
	Bigliardi and Bottani (2010)	• Application of Integrated BSC and Delphi to Measure Food Supply Chain Performance in Quadrilateral Areas. • Presenting case study results based on similar perspectives in the areas of customer, finance, internal processes and divergent results in growth and learning. • Emphasize that the findings of the application of the food supply chain model cannot be generalized to other types of supply chains.
	Motevali Haghighi *et al.* (2016)	• Call attention to the choice of a supply chain performance measurement system to maximize the efficiency of manufacturing and service activities. • Using a sustainability model of balancing factors: social (meeting social expectations), economic (maximizing economic) and environment (minimizing environmental damage from productive activities). • Applying multi-stage DEA and BSC model for creating balance between the performance of units and two case studies in production and service.
SCOR	Cai *et al.* (2009)	• Emphasis on a systematic approach to the continuous improvement of supply chain performance indicators based on internal analysis of indicators.

		• Using a process-driven SCOR model to identify important indicators that reinforce them will lead to synergies in supply chain components.
	Tramarico *et al*. (2017)	• Bring attention to the evaluation of training in the chemical supply chain. • The Score model is used for factor selection and the AHP model is used to rank individuals and organizational interest options. • The output of the model emphasizes the incremental effectiveness of individual and organizational learning.
	Daghfous, and Zoubi (2017)	• Exploring the importance of knowledge management as a key role in improving supply chain sustainability in production and service. • Providing combined knowledge management and scoring model as a benchmark for measuring organizations and supply chains in knowledge management deployment. • A functional case study of model performance in the UAE
	Sellito *et al*. (2015)	• A comparative literature review of the SCOR model was performed to evaluate the sustainability of supply chain management. • The application of the SCOR model in the Brazilian shoe industry was examined from a process and functional perspective. The process dimension included source, production, delivery, and efficiency, while the functional dimension included cost, quality, delivery, and flexibility. • The sustainability of a supply chain was evaluated based on four suppliers; two distributors, one return channel, as well as eighty-five operational factors, and constructive suggestions were made to apply this model to other supply chains.
	Kocaoglu *et al*. (2015)	• Conflicts between senior supply chain decision-makers and sustainability evaluators focus on how to implement improvement strategies and emphasize the alignment of strategic and operational goals. • In this regard, the AHP model based on the integrated approach to weighting the criteria as well as a TOPSIS model based on the order of priority separation has been used to analyze the hierarchical criteria.
Data envelopment analysis (DEA)	Wang (2015)	• The emphasis was on ignoring the optimization of the industrial supply chain and paying more attention to economic and environmental developments. • To evaluate the environmental chain efficiency, a DEA model with ecological constraints was used. • The findings showed that the relative efficiency of environmental chains can be increased by continuous optimization and rearrangement of strategic goals.
	Tajbakhsh and Hassini (2015)	• The focus was on measuring the environmental efficiency of a supply chain and examining the number of DMUs in commerce more than others. • The two-step DEA model was used to illustrate how to maximize overall efficiency, focusing on finding optimal solutions for each step. • A case study in China was used to improve productivity that resulted in potentially valuable results for managers in reducing environmental pollutants.
	Yousefi *et al*. (2017)	• The focus was on improving solutions for developing supply chain performance ratings that were used to convert targets into phased values. • In the DIA model, the mean and standard deviation of the units were used as target deviation values, which were intended to

		minimize these values. • Using a case study, the performance of the model was shown to evaluate the ranking of different types of network supply chains.
	Rentizelas *et al*. (2019)	• The survey was on finding alternative paths (compared to efficiency) in the biomass supply chains. • Multiple measures of environmental performance were applied simultaneously to a DEA model and sensitivity analysis was performed. • The field of study was a case study in Latin America that resulted in potential suggestions for improving and supporting short and long term decisions of managers.
	Babazadeh *et al*. (2017)	• The focal point was on finding appropriate solutions to address worrisome phenomena such as global warming, lack of nutrition, and the spread of environmentally damaging human activities. • A two-stage DEA model was applied, which were ranked in the first stage of the crop according to social and climatic factors, and in the second stage, places with high-performance scores were proposed for crop production. • The model was implemented in Iran and resulted in potential suggestions for decision-makers at the macro level.
LCA	Khoo *et al*. (2019)	• The focus was on the hybrid LCA model, supply chain risk factors (production, distribution, end-product sales), as well as geographic information systems (spatial data clarity). • A case study was conducted to investigate the performance of the model in eight different scenarios in China, the United States, Germany, Japan, and Singapore. The results were analyzed using multivariate optimization techniques.
	Ingrao *et al*. (2019)	• Environmental Impact Assessment of Tomato Supply Chain in Planting, Processing, Distribution, and Consumption and Emphasis on LCA Model to Increase Cycle sustainability. • A case study was carried out on the production of tomato puree in Italy to identify environmental factors and to present improvement strategies. • The results of the study were summarized on optimization of soil management, drip irrigation, and finally replacement of damaged packaging materials.
	Skunca *et al*. (2018)	• Performance evaluation of poultry supply chain performance on environmental factors (global warming hazards, environmental acidification, soil erosion, ozone depletion, and energy demand) was investigated using the LCA model. • A case study was carried out on 119 farms and 500 households to investigate the environmental impact of the chain. • The results showed that controlling the protein source of chicken feed and optimizing energy consumption had the greatest impact on preventing environmental degradation.
	Neto *et al*. (2013)	• Environmental Impact of the White Wine Supply Chain in Portugal was investigated to identify factors and provide solutions to mitigate the detrimental effects. • The stages of production were identified (vineyards, wine production, wine distribution, and production) as well as feed units (methods of consuming materials and energy, greenhouse gases, soil and water requirements). • The model LCA applied and output showed that vineyard and wine production were the most damaging factors and wine production and distribution were next. Sensitivity analysis showed that the optimization of dosages and herbal products caused the greatest improvement in yield.

	Gava *et al.* (2018)	• Using the Life Cycle Assessment Model to Achieve Food Security in Agriculture by Identifying, Monitoring, Reducing and Finally Removing Traumatic Factors. • The results showed that the combination of LCA methods with economic evaluations can be used to obtain more exaggerated results.
Equilibrium models	Daultani *et al.* (2015)	• Countering the barriers affecting the performance of supply chain segments plays an important role in ensuring the integrity of the whole chain. • The network equilibrium model was developed based on maximal profit, and minimal risk. • Three simulated case studies were used to find strategic solutions for supply chain decision-makers.
	Han *et al.* (2017)	• Overcoming the challenges of construction companies in their production or outsourcing is critical to measuring the sustainability and productivity of an organization. • A comprehensive equilibrium model was designed and implemented in a simulated study for the supply chain. A large contractor with the capability of producing and outsourcing as well as a small outsourcing contractor was considered. • The results show that the level of sustainability of small contractor's increases as outsourcing increases and large contractors increase with self-producing, and supply chain sustainability depends on factors such as market size, type of consumers, and strategic decisions.
	Zhang *et al.* ⁽2005)	• The focus is on adjusting the supply chain network equilibrium model to examine the competitive behavior of demand-based producers and retailers in the market. • The output of the equilibrium model is used to create the equilibrium conditions and the economic interpretation of the above conditions. The output is obtained using the variables inequality model.
	Meng *et al.* (2007)	• Balancing focus of interurban urban supply chain network with random demand to minimize distances. • A hybrid factor-based equilibrium model with eleven benchmark samples was used to demonstrate the model's performance.
	Xu and Cau (2017)	• The focus is on creating a network equilibrium supply chain model for manufacturers, retailers, and consumer markets for optimal pricing. • The equilibrium model by examining the current and optimal behavior of decision-makers with the approach of change equality has been achieved. • The outputs of the model include suggested solutions for improving the level of production technology used and increasing the share of the product used, which in the sensitivity analysis discusses the effect of some parameters on the equilibrium model.
Input-output analysis (IOA)	Albino *et al.* (2002)	• Emphasis on the localization of supply chain management in a specific geographic area as a network of manufacturing processes. • To evaluate the sustainability of the supply chain localization model, an adequate input and output approach has been used with sufficient interconnections between manufacturing processes and the environment.
	Weinzettel and Wood (2017)	• Application of Input-Output Model to Reduce Damage to Environmental Ecosystem Chains Due to Human Life Cycle and Production Cycle. • A comparative study focusing on the strengths and weaknesses

		of the model of finding sustainable production patterns for export products. • Sensitivity analysis of the case study in China showed that the given model is capable of identifying and segmenting export products whose production chains are less likely to be harmful to the environment.
	Owen *et al.* (2017)	• Using environmental accounting tools to understand the relationships between elements of the food supply chain (energy, water, production). • A case study in the UK using the input-output model to balance attitudes between energy, water, and food as well as understanding the interplay of factors. • The use of sensitivity analysis and structural path analysis showed that optimizing resource efficiency strategies could enhance the sustainability of food supply chain elements.
	Cruz *et al.* (2009)	• The input and output model was presented to simulate the system for measuring the sustainability of the Bioenergy supply chains, assuming that the level of production in the next phase of the chain will be adjusted to the goals of the current time period. • To investigate the model behavior in possible scenarios, a simulated study was performed and the results were compared with the actual biological system. • Model sensitivity analysis reveals the high performance of the model to investigate the dynamic properties of emerging fuel chains.
	Johansen *et al.* (2017)	• Focus on using a combination of macroeconomic research practices and policies to support forest supply chain decision-makers to maintain sustainability. • Combined with different approaches and using the input-output model in a case study of Norway, practical approaches to preserve and increase forest volume and area were achieved.
Multi-criteria decision making (MCDM) models	Tamošaitiene *et al.* (2017)	• Material management is a major challenge for supply chain decision-makers, and choosing the right supplier is one of the most influential factors. • A multi-criteria decision model was used to measure the contradictions of criteria and decision-makers based on eight effective factors (cost, quality, delivery, reliability, validity, level of technology, adaptability, and finally development capability). • The AHP model to find priorities and the Hovanov model was used to normalize the weight values.
	Poh and Liang (2017)	• Paying attention to improving the social, economic and environmental performance of supply chains to maximize productivity and minimize unnecessary environmental damage to compete globally is a concern of today's business owners. • To assist supply chain decision-makers in developing sustainable chain management models, an AHP-based multi-criteria decision-making model and Process Analytical Network Process (ANP) model were introduced to understand interdependence. • Four strategies were used for the evaluation of sustainability, and reverse logistics was selected as the optimal strategy.
	Erol *et al.* (2011)	• The importance of paying attention to the dimensions of sustainability in the social, economic, and environmental aspects of a supply chain and to ensure that all aspects of driving sustainability can be measured with a one-dimensional standard. • To solve this problem, a model based on multi-criteria

		evaluation was introduced. However, even with this model, not all decision-makers' needs can be met. • Using a case study from a food retailer in Turkey, the model's performance was investigated and the proposed framework for real data was tested.
	Sreekumar and Rajmohan (2018)	• Using a Multi-Criteria Decision Making Approach to Prioritizing Sustainability Criteria in Choosing Sustainable Development Strategies in Supply Chains. • The selective model is a combination of HP for weighting, an integrated mental and objective weighting approach, as well as TOPSIS for an ideal solution. • A case study of India's production chains showed that the model enables managers to incorporate the appropriate level of subjectivity into their decisions based on their abilities.
	Banasik *et al*. (2018)	• Emphasis on the effectiveness of multi-criteria decision-making models for designing green (environmentally friendly) supply chains based on measured decision support. • An in-depth comparative study of the multi-criteria decision-making applications that focus mainly on production problems and a new field of research in green chain design is applied. • The results showed that more attention should be paid to compliance with the actual loss criteria, attention to fuzzy data, as well as minimizing environmental damaging factors.
Composite metrics	Ngai *et al*. (2013)	• Study on the design and development of a corporate sustainability-based (composite) model for performance analysis of companies and supply chains that can be supported by modern management theories. • The proposed model, which had no prior record of such models, is the first application of a prototype for CSP analysis that can be extended to industrial applications.
	Böhringer and Jochem (2007)	• Introducing indicators of social, economic, and environmental conditions under the heading of Sustainability Indicators and the need to create a balance between the three indices for measuring sustainability. • Presenting a composite model based on sustainability indicators in the policy domain that can lead to misleading results if the policies adopted are not in line with the strategic goals, which will discredit the indicators.
	Dietz *et al*. (2018)	• The increasing tendency of global markets to create sustainable value-added supply chains has increased the need for new ways of measuring sustainability. • A new methodological model based on composite indexing has been introduced to evaluate and compare the power of standards, and ninety-two topics have been identified and weighted for the sustainability of global coffee production. • Model outputs were computed based on a comparison of sustainability levels across the four social, economic, environmental, and adaptability domains and significant topics were selected.
	Talukder *et al*. (2017)	• Given the multidimensional nature and sometimes the use of indices with different measurement units in measuring the sustainability of agricultural systems, it has been a major challenge. • Fifty indices in the areas of productivity, stability, efficiency, durability, rug rate, and shareholder rights were selected for agricultural sustainability issues and mathematical analysis was used to construct the final composite index. • After a comparative study of the various models and discussion
	Singh *et*	• Steel companies that have recently taken up the issue of

	al. (2007)	sustainability measurement often have a large number of indicators that sometimes interfere with the use of the appropriate approach. • A model based on the integration of key indicators and their conversion into composite indicators is presented that examines sustainability in social, economic, and environmental aspects as well as two aspects of organizational management and technical aspects. • The model was used in a case study of the Indian steel industry. In this model AHP was used for weight allocation.

2.6 Stakeholder analysis approaches to sustainability measurement of supply chain

An organization or supply chain that meets its needs and considers the rights of future generations to exploit resources is moving towards sustainable development. There are individuals or groups whose presence and understanding of their needs (by defining and measuring appropriate indicators) is a fundamental principle of sustainability that their stakeholders are concerned with (Sardina *et al*., 2011). The stakeholder is someone or group that is affected by the activity of the organization or chain. In the comparative literature, stakeholders are divided into internal (direct involvement in decision making) and external (influenced by actions), while others propose main (essential to organizational survival) and sub-legal (influenced by core group) categories. In general, the indicators involved are classified into general and specific. Stakeholders' general indicators are defined in the three areas of social, economic, environmental, while specific indicators vary by type of organization or chain activities (Poplawska *et al*., 2015). Stakeholder theory, based on the hub-and-spoke model, is part of the strategic management that deals with the direct and interconnected supply chain and stakeholder relationships that today include indirect relationships (Carvalho *et al*., 2019).

Stakeholder theory is used for stakeholder analysis. The performance analysis consists of the following three steps:

- Definition of social and natural phenomena affecting decision or activity.
- Identify the individuals or groups that influence the phenomena or are affected by the activities.
- Prioritize the views of these groups in decision-making that lead to stakeholder alignment decisions.

Adaptive literature is increasingly moving towards sustainable development with an emphasis on stakeholder roles. To this end, the balance between aligning and contrast interests of the stakeholders has been discussed (Castka and Prajogo, 2013). Researchers can explore different approaches to stakeholder management using decision support techniques and a combination of stakeholder perspectives. Recently, the use of fuzzy approaches to assess the social and financial performance of the supply chain has been prioritized by stakeholders in environmental risk management as well as evaluating stakeholders' commitment to the organization. The fuzzy approach also utilizes a three-dimensional graphical model to give stakeholders a prioritization approach (Gil-Lafuente and Barcellos Paula, 2013).

Table 2.4: List of sustainability measurement views in supply chains with a stakeholder approach and key findings.

Reviews	Method &Key findings
Chowdhury *et al.* (2019)	• Emphasizing the dynamic and competitive environment for organizations to adopt sustainable approaches to achieving economic goals, this paper examines how organizational stakeholder changes are facilitated by a case study in the Bangladeshi garment industry. • By using a mixed fuzzy QFD decision support structure for supply chain sustainability identifies and prioritizes optimal and effective strategies in a dynamic environment • The main findings of the research are the use of flexible organizational approaches commensurate with the changes in the priorities of the stakeholders and the positive impacts on empowering efficient managers to balance economic, social and environmental factors.

Silvestre *et al*. (2018)	Supply chain corruption has been discussed as an obstacle to sustainable supply chain performance. The focus is on the factors and consequences of corruption in the Brazilian beef supply chain. The findings of the review are as follows: • The importance of properly understanding management's impact on supply chain management. • Involving supply chain stakeholders sometimes lead to increased corruption. • Understand how the supply chain corruption triangle is integrated. • Training programs to increase managers' awareness of corruption prevention.
Hofmann *et al*. (2014)	• A review of the comparative literature on supply chain risk management revealed that the missing link is the neglect of supply chain stakeholders, which impedes the use of supply chain risk mitigation. • The necessity to apply the views of the stakeholders of the chain that contribute to the sustainability of the supply chain.
Meixell and Luoma (2015)	The importance of influencing supply chain stakeholder demands on supply chain performance was examined. Triple findings include: • Involving chain stakeholders redefines macro goals as well as setting up more stations to make the supply chain more aware of sustainability • Paying attention to stakeholder views in different areas of the supply chain leads to a variety of decisions. • The effects of stakeholder views on environmental sustainability are prominent in social sustainability.
Castillo *et al*. (2018)	• Stakeholders' increasing emphasis on supply chains for environmental and social sustainability and integrated practice has given rise to a new concept of sustainability called supply chain integration. • This concept can help examine how social and environmental decisions depend on supply chain sustainability. • Logistic regression was used to measure the concept of integration and the concept of sustainability of structural and ethical dimensions was measured.
Rezaee (2018)	• Consider the challenges facing supply chains in adapting sustainability strategies in the social, ethical, and environmental areas to create added value for stakeholders. • Emphasize the need to balance financial and non-financial sustainability with the required standards in the areas of design, purchase, production, distribution and... to meet stakeholder requirements for sustainability.
Rebs *et al.* (2017)	• Stakeholders' views on economic, environmental, and social supply chains have been addressed by researchers. • Subject literature to examine stakeholder-related risks has shown that there is a greater emphasis on economic risks than on environmental and social risks. • Studies have shown that qualitative studies focus on multiple stakeholders and quantitative studies focus on operational risks.
Khan *et al.* (2018)	• Social sustainability in the .healthcare supply chain in the United Arab Emirates was assessed using a questionnaire designed and collected by experts in the field. • The five social factors of organizational practices, media and reputation, organizational excellence, technology and innovation, and organizational attitudes were considered based on supply chain stakeholder preferences. The results showed that organizational attitudes and practices have the greatest and the least impact on social sustainability, respectively. • Using a model to compare social sustainability across supply chains in different domains has been suggested as a comprehensive social sustainability tool.
Camilleri (2017)	• Keeping in mind that companies and supply chains in the areas of social performance and sustainable innovation must focus on stakeholder priorities.

	• The result of the model was the adoption of conscious strategies of the organizations called the management of the supply chain of social responsibility that would lead to a sustainable competitive advantage for the organization. • A sustainable responsible supply chain management should strive to develop appropriate relationships with the suppliers and distributors involved in the value chain.
Searcy (2017)	• The need to maintain supply chain sustainability levels with multiple stakeholders and to create a sustainability threshold where the supply chain must operate at that sustainability level. • Identify and utilize the four elements of preparing the learning contexts, formulating standards, formulating executive mechanisms, and issuing labels and certificates, all of which work within a theoretical framework. • The results focused on the involvement of all internal and external stakeholders in the supply chain in the partnership and implementation, as well as the proposal to consider other factors.

Chapter 3

APPLICATION OF BOOTSTRAP RESAMPLING METHOD TO SOLVE DIFFICULTY OF FINDING UNBIASED POINT ESTIMATORS OF POPULATIONS'S PARAMETERS

3.1 Introduction

Excessive consumption of natural resources, global warming, and depletion of the ozone layer, forest degradation and other environmental and socio-economic disasters in the last decades brought the concept of sustainability as a great concern and solution into the minds.

In a study performed in 2010 over 50 percent of participating CEOs marked sustainability as important while in 2017 this percentage increased to 90. Furthermore, 60 percent of participants had invested in sustainability or had planned strategies toward sustainability (Sroufe 2017). The effect of public pressure on governmental organizations has been one of the factors leading to this trend organizations (Atlason and Gerstlberger 2017).

To control sustainability, decision-makers and managers need tools to evaluate and measure its value. There have been many tools devised by researchers. However, the application of these tools is either limited to the specific field of their domain is only limited to some aspects of the sustainability and thus they are not deemed as comprehensive.

In 2014 Ahi and Searcy proposed a stochastic approach based on statistical definitions to measure sustainability in an organization. However, the number of observations is limited, the assumption of normality is endangered, and thus the result of their methods deviates from precision. In this study, the application of the bootstrap resampling method proposes as a remedy to this problem.

The rest of the paper is organized as follows: In the next section definitions, measures and previous works are presented. Section 3.3 describes the proposed method. A problem solved in (Ahi and Searcy 2014) is revisited and solved by the proposed methods in section 3.4. The results are discussed in section 3.5 and finally section 3.6 pertains to conclusions.

3.2 Model structure

In 2014, (Ahi and Searcy 2014) proposed a statistical method for measuring sustainability, which accounts for all the aspects and factors existing in an organization.

In the model presented by (Ahi and Searcy 2014) , population parameters (μ & σ) were used to calculate organizational sustainability. However, in the absence of such data, statistics of a small-size sample ($\bar{x}$ & s) were used which were not unbiased estimators of those parameters and therefore makes the results deviated from reality.

In this chapter, the bootstrap re-sampling method is used to find unbiased point estimators of population parameters and more accurate values of sustainability. The results are compared and discussed.

In spite of previous methods that used a set of indices of various aspects of sustainability, the new method measures sustainability by categorizing all the factors into capacity and challenge factors. Capacity factors are those having a positive effect on sustainability and challenge factors are those reducing sustainability. To be sustainable, an organization should reinforce capacity factors and tackle the challenge ones. For measuring the sustainability of an organization, the first appropriate metrics for capacity and challenge factors are determined. Then sustainability is specified as the probability that capacity factors of the organization surpass or overcome the challenge factors:

$$Sus = P(H < C) \tag{3.1}$$

Where Sus, P, C and H stand for Sustainability, probability, capacity factor and challenge factor, respectively. It's supposed that capacities and challenges are random variables. Thus, one can define a Probability Density Function (PDF) and Cumulative Distribution Function (CDF) of two factors, such that $F(h) = \int_0^\infty f(h)dh$ and $F(c) = \int_0^\infty f(c)dc$. Substituting the probability density functions, equation (1) can be rewritten as $Sus = P(H < C) = \int_0^\infty f(c)\left[\int_0^c f(h)dh\right]dc$. By the assumption of a normal distribution of both types of factors and using a normal probability density function in equations we would have:

$$Sus = \int_0^\infty \frac{1}{\sqrt{2\pi\sigma_c^2}} e^{\frac{-(c-\mu_c)^2}{2\sigma_c^2}} \left[\int_0^c \frac{1}{\sigma_h\sqrt{2\pi\sigma_h^2}} e^{\frac{-(h-\mu_h)^2}{2\sigma_h^2}} dh\right] dc \tag{3.2}$$

In equation (3.2) μ_h and μ_c indicate the mean of the challenge and capacity factors respectively and σ_h^2 and σ_c^2 stand for their variances. A simplified form of the equation (3.2) proposed as illustrated in equation (3.3):

$$Sus = 1 - \varphi\left(-\frac{\mu_c - \mu_h}{(\sigma_c^2 + \sigma_h^2)^{1/2}}\right) \qquad (3.3)$$

Using equation (3.3) and by using the values of the corresponding normal distribution function, one can calculate the numerical value of sustainability in percentage. To acquire equation (3.3) it is supposed that the challenge and capacity populations are normally distributed. For information about the parameters of the population is not available, the point estimators of the parameters are acquired by statistics of the samples taken from the population. According to the central limit theorem, if the sample size is not big enough, unbiased estimators of the population parameters cannot be achieved. In such a case, the bootstrap resampling method proposed by (Efron, 1983) can be used to tackle the problem. Bootstrap is simply defined as taking samples with replacement from the original sample. The bootstrap method was widely recognized as a statistical tool used for approximating standard errors in 1983 after the publication of Efron's monograph. The main purpose of this method is to find unbiased point estimators of the population parameters based on the sample statistics and to evaluate the accuracy of the estimators. Using the bootstrap resampling method, the size of the existing sample is increased such that the population distribution can be extended to sample distribution.

The idea behind the bootstrap method is to use sample distribution instead of population distribution. A sample distribution is a probability distribution that assigns the probability 1/n for each sample properties of the estimator such as its standard error are determined. Assume there is element. Based on sample distribution, a sample of size n based on which a population parameter (θ) is to be estimated ($\hat{\theta}$). The accuracy of $\hat{\theta}$ is determined according to the distribution function F_n which gives a probability 1/n to any member of the sample. Bootstrap distribution is calculated by consecutive samplings with replacement (k times) and acquiring the estimator ($\hat{\theta}$) for each sample. Therefore, the standard deviation of the estimator can be calculated by the standard deviation of the bootstrap distribution for $\hat{\theta} - \theta$. In this way, for any population parameter such as mean, median and standard deviation, an estimator can be found and its accuracy can be validated. The resampling method of bootstrap includes two steps:

1. Taking the samples from the population and determination of the parameter
2. Calculation of the estimator for that parameter based on the existing sample.

These two steps should be repeated k times and according to (Efron, 1983), the k should be at least equal to one hundred in order to decrease the error of estimators. By doing so, a Monte Carlo approximation is obtained for the distribution of θ^*. The standard deviation of this approximation is a good to estimate of estimator's standard deviation. When k is large, the difference between bootstrap estimator and Monte Carlo approximation is negligible. In other words, with the increase of k, the difference between the distribution of bootstrap and Monte Carlo diminishes. It is possible to obtain the bootstrap estimator directly and without Monte Carlo approximation. (Efron, 1983) found a bootstrap estimator for the mean of a variable in population with the standard deviation $\hat{\sigma}_{BOOT} = \left[\frac{n-1}{n}\right]^{1/2}$, where $\hat{\sigma} = \left[\frac{1}{n(n-1)}\sum_{i=1}^{n}(x_i - \bar{x})^2\right]^{1/2}$ and x_i is the value of i^{th} observation and $\bar{x}$ is the sample mean. The other discrimination between the bootstrap sample and the original sample is that in a bootstrap sample an observation may be repeated more than once. In addition, it is possible that observation in the original sample is not present in the bootstrap sample, therefore the values of θ^* is different from one sample to another. The probability of selection of a member of the original sample (x_i) for j times are calculated by multinomial distribution (Chernick and Murthy, 1985). (Efron, 1983) used these probabilities to calculate the ratio of standard deviation and the estimator. The main idea behind the bootstrap is to find the variability of θ^* based on the actual distribution function of the population F around the actual value of the parameterθ. It's obvious that for large values of n, the distribution of the sample (F_n) would be in accordance with the distribution of the population (F). The rule of large numbers for random independently identically distributed variables indicates that with the probability of one, the distribution of the bootstrap samples is identical with that of the population (F). According to a theory proved by Glivenko-Cantelli theorem, the bootstrap estimator is valid when it covers the real parameters of the population.

3.3 Case study

In the case study of this research, the data obtained from Hydro-Quebec Company is used. This data is acquired from the study performed by (Ahi and Searcy, 2014) and the results are compared accordingly. It is noteworthy that in the (Ahi and Searcy, 2014), information on sustainability factors (challenges and capacities) was used in the 2009-2011 interval, while this information was expanded based on Hydro-Quebec sustainability reports by 2018. Clearly, more information has led to a better understanding of how the process of sustainability changes, as well as a better comparison of the results of the original model and the developed model.

3.3.1 Hydro-Quebec

Hydro Quebec is one of the main electric generators and distributors in North America located in Canada owning a nuclear production station and sixty hydroelectric stations. Hydro-Quebec has a sustainable approach to environmental and future priorities pursuing social and economic goals and has organized its activities according to the needs of its stakeholders. It works to generate, transmit, and distribute electricity using renewable sources, especially hydropower in production and wind power in the transmission system (Hydro-Quebec, 2018). From the reports published annually by this company, five capacity factors and five challenge factors are selected from the existing factors.

According to (Ebert and Welsch, 2004) the values reported for sustainability should be mentioned in percentages and thus Table 3.2 reports the sustainability values for selected factors by percentages.

Table 3.1: Sustainability reports acquired from Hydro Quebec

Challenge factors	Year									
	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Area of transmission-line right-of-way treated with herbicides	27.37	29.36	22.05	2.8	0.73	0.4	6.02	2.08	4.75	5.4
Area of dikes and dams treated with herbicides	49.28	26.69	38.48	54.19	42.03	32.02	43.49	49.24	48.16	53.96
GHG emissions (by CO2 only) from thermal electricity generation relative to total GHG emissions (by CO2 only) from all reported sources	86.82	79.03	79.35	80.23	79.26	80.19	79.92	78.99	81.7	81.91
Indirect emissions with power transmission and distribution relative to emissions avoided by exports of electricity	2.17	2.49	0.81	0.2	0.085	0.37	0.19	0.064	0.094	0.0105
Spills due to equipment breakage	45	56	51.5	57	62	60	59	51	53	49
Capacity factors	Year									
	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Renewable energy generated relative to total energy generated	97.58	97.81	97.91	97.56	99.84	99.82	98.45	99.12	99.75	99.18
Energy saved through conservation a efficiency improvement plans	0	19.71	40.26	32.45	36.41	39.15	44.12	38.92	44.16	46.28
Underground hookups on the distribution system	32	36	40	42	41	46	43	46	48	48
Residual hazardous materials (RHMS) diverted from landfill	95	95	94	95	96	93	95	97	94	96
Insulating oil recovered and reused internally	88.4	91	88.8	80.09	81.16	92.22	93.34	87.86	95.84	96.15

Since the sample size is not large enough, even with the assumption of the normal distribution of factor parameters, one cannot use the sample statistics as unbiased point estimators of the population's parameters and subsequently, they cannot be used in the equation (3.3). Therefore, in this study, the bootstrap technique is utilized to obtain the unbiased parameters of the population. To do this, 10000 samples are taken from the challenge factors and capacity factors, by sampling with replacement technique and the unbiased point estimators of parameters are estimated and used to obtain sustainability values.

3.4 Results

Unbiased point estimators acquired from the samples are illustrated in Table 3.3 along with the point estimators used by (Ahi and Searcy, 2014).

Table 3.2: Unbiased point estimators obtained with the bootstrap method compared with those in (Ahi and Searcy, 2014)

Year		2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
$\hat{\mu}_H$	Regular method	0.4213	0.3871	0.3844	0.3888	0.3682	0.3460	0.3772	0.3627	0.3754	0.3806
	Bootstrap method	0.41912	0.38542	0.38221	0.3817	0.36543	0.3422	0.3731	0.3622	0.3719	0.3813
$\hat{\mu}_C$	Regular method	0.6260	0.6790	0.7219	0.6942	0.7088	0.7404	0.7478	0.7378	0.7635	0.7712
	Bootstrap method	0.6229	0.6766	0.7238	0.6915	0.7013	0.7395	0.7398	0.74011	0.7612	0.7723
$\hat{\sigma}_H$	Regular method	0.31110	0.29447	0.29702	0.35604	0.35757	0.35608	0.34207	0.34242	0.34566	0.34676
	Bootstrap method	0.25469	0.25288	0.25490	0.2811	0.28971	0.27115	0.2911	0.29114	0.2942	0.2977
$\hat{\sigma}_C$	Regular method	0.44142	0.37089	0.29448	0.30326	0.30234	0.28975	0.28564	0.29011	0.27744	0.27406
	Bootstrap method	0.36662	0.32393	0.26114	0.2511	0.23115	0.20633	0.21015	0.21095	0.1978	0.2019

The resulting sustainability values calculated by equation (3.3) using the data found in Table 3.2 are illustrated and compared with the previous study in Figure 3.1.

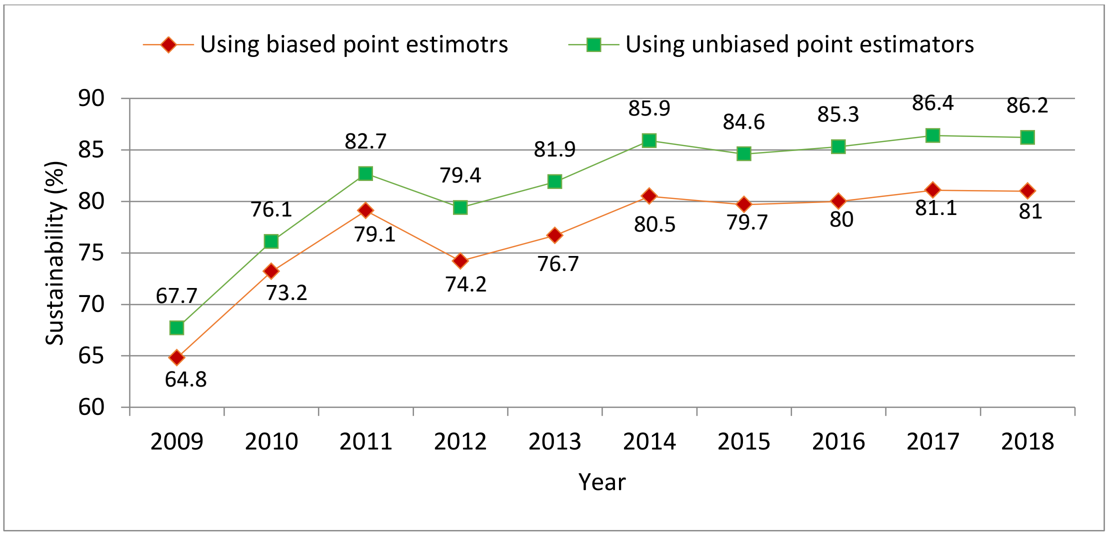


Figure 3.1: Sustainability comparison of Hydro-Quebec Company during the period of 2009-2018

The results indicate that using an unbiased point estimator of parameters acquired by the bootstrap method provides for a more realistic report on sustainability. Using unbiased point estimators in measurement of sustainability makes a significant difference in the results and reflects the precise status for decision-makers.

As shown in Figure 3.1, the sustainability values calculated using the Bootstrap method were higher than values by previous method over all the years studied, illustrating a more realistic sustainability status for decision-makers. Table 3.1 gives further information on the performance differences of the considered methods. In this table the mean values of two methods are very close together while the standard deviations of the bootstrap model (which are population parameters) are lower than the previous method. These smaller values of standard deviation cause smaller values of standard normal random variables in equation 3.3 and, consequently, larger values of probability (sustainability) for the Bootstrap method.

There is a great movement among organizations towards sustainability. To provide their strategic plan to achieve sustainability, organizations need to know their exact sustainability status. Deviated reports would hinder their achievements and as a result, the resources may not be used to their fullest capacity. This study proposes the application of the bootstrap method for calculating the unbiased point estimator of the population parameters that consequently enables the acquisition of more reliable results that would facilitate the process of decision-making and strategic planning to achieve sustainability.

3.5 Conclusion

The concept of sustainability is vital to the survival of both human beings and organizations. To improve sustainability one should be able to determine a method to evaluate and measure it. Previously, many studies proposed methods or indexes that either were designed to a particular field and purpose or simply did not account for all the aspects of sustainability. In the novel approach introduced by Ahi and Searcy, 2014 for measuring organizational sustainability, there is a close relationship between the sample size of the available factors and the accuracy level of estimating the sustainability value. With a large enough sample, the organization's improvement planning based on sustainability value will be more reliable. But with the small sample size, there will be a significant difference between the calculated sustainability and the actual value. To overcome this shortcoming, there is a greater need for statistical approaches such as Bootstrap. To further emphasize the importance of sample size, we observe a difference of 2.9 to 5.4 percent of the sustainability values in successive years. With increasing sample size, the sustainability difference calculated by the two methods will be reduced. Bootstrap method is specifically noticeable when taking large-sized samples is either impossible or costly. By applying the proposed method on the same data used in (Ahi and Searcy, 2014), it is proved that there is a significant difference in the results obtained after applying the bootstrap method and using unbiased estimators acquired from the bootstrap method. Having a clear vision of sustainability status is of paramount importance to organizations seeking improvements in sustainability and this issue highlights the importance of this study.

In this study, it was supposed that the parameters are normally distributed. Future studies can consider other distributions where the nonparametric bootstrap method or other statistical non-parametric methods are applicable where the sample size is not big enough. Furthermore, the factors considered in the case study belong to the environmental tier of sustainability, and the described methods can incorporate other factors in order to account for other aspects of sustainability in case needed. Eventually, the model assumes that each challenge and capacity factors concur in the same way in determining the final sustainability results. However, it seems hard to believe that all elements have the same role in determining the sustainability performance of a specific company. Therefore, maybe a future development of this approach would be to apply specific weights to each factor that gives us more reliable results. Obviously, the main problem would be on how correctly determine such weights. For example, the possibility to explore a multi-non-parametriccriteria analysis following the literature on the Data Envelopment Analysis (DEA) (Charnes *et al*., 1978) and the Preference Ranking Organization method for the Enrichment of Evaluations (PROMETHEE) (Brans and Vincke, 1985 ; Ishizaka and Nemery, 2013; Caravaggio *et al*., 2019) could be an option in future researches.

Chapter 4

APPLICATION OF ANALYTICAL HIERARCHY PROCESS (AHP) MODEL TO FIND WEIGHTS OF INDICATORS ACCORDING TO EXPERT VIEWS

4.1 Introduction

Severe and continuous competition globally has provoked the necessity of improving the effectiveness and efficiency of systems, processes and products. This consequentially complicates and expands the range of variables that are usually examined in any improvement initiative. The reflection is seen in the current efforts geared at embedding sustainability principles in the aims, motives, and expectations of the society in all ramifications. Therefore, moving toward sustainability and also measurement methods must be vital for every organization. Nowadays practitioners and decision-makers try to find and design policy for supporting sustainable development (Collins *et al*., 2017) or "meeting the needs of the present without compromising the ability of future generations to meet their own needs" (World Commission on Environment and Development., 1987). For moving toward sustainable development, an organization must define appropriate policies and also methods. But most researchers only tried to define different aspects of sustainability and fewer studies have proposed an evaluation of policy (Collins *et al*., 2017).

Sustainability has two opposing paradigms, could be divided into weak and strong sustainability views. Weak sustainability as defined by the concept of sustainability of man-made for natural capital contains manpower, machine and knowledge (Victor 2005) and Effective and strong sustainability approach according to Neumayer (2012) supposes sustainability concept among natural form of capital (air, water, soil and vital things for living) and another form of capital (social, material, cultural, intellectual) can be measured only in some specific situations. İn these cases, virgin capital must not be ruined or change to other forms of capital. By this view, strong sustainability is seen as keeping the security of mankind. Pelenc (2015).

Recent studies, especially those of Galdeano-Gomez *et al* (2017) have all focused on the evaluation of general sustainability in terms of challenges of modern-day society, which are usually divided into three pillars namely environmental, economic and social terms- the 3Ps. These 3Ps described the importance of sustainability acknowledging social, environmental, and economic. These 3Ps are appraised together in order to identify factors that improves managing and planning for human systems on a long-term basis.

One of the most important methodologies is a sustainability assessment (SA). This method inculcates multidisciplinary (environmental, economic and social) elements with other cultural and value-based elements. It is widely known for its ability to support the broader decision making and policy development. Other concepts the Integrated Assessment and Sustainability Assessment have been utilized to bring in new appraising dimension to impact assessment that is tailored toward planning and decision making for sustainable advancement (Sala *et al*., 2015).

AHP (Analytical Hierarchy Process) applies to model complicated problems where appropriate factor weights are determined based on some criteria. Saaty (1977; 2001) presented criteria and alternatives to aim and motives establishing relationships. AHP on the other hand, consists of stratified puzzlement format, adjudication, pairwise comparisons, a unique method for finding weights, and test of stability (Kasperczyk and Knickel, 2003). There are many variables that either allow or disallow progress towards sustainability. These variables vary according to the organization's inherit situations. To adequately measure improvement in sustainability, enhanced knowledge of the context of the organization prevailing factors are necessary (Ball and Srinivasan., 1994) (Nguyen and Fong. 2010). Because of simplicity, AHP has been widely used by decision-makers in different areas such as Planning, Production, Optimization, and many more (Vaidya and S. Kumar., 2006), (Roy, 2004).

This chapter contributes to this requirement through the consideration of a special case of a weighted base stochastic model for realistic sustainability measurement. The model adopted a weighted stochastic approach to sustainability measurement and assessment, thereafter measures and assesses the sustainability of an organization from the strong sustainability perspective. The additionally to section 4.1, Section 4.2 gave the theoretical considerations where the basic principle underlying the proposed sustainability, actual AHP model structure and the proposed stochastic AHP procedures. Section 4.3 presented a numerical illustration of the proposed approach, comments in section 4.4 conclude the article.

4.2 Model structure

Factors that affect challenge and capacity are firstly determined. Thereafter, the probability distributions of these factors are computed for the sustainability of the organization. Here probability for a sustainable organization is equal that requires to subdue challenges are less than the organization's capacity. This assertion of Ahi and Searcy (2014) by statistical method for measuring sustainability is employed. Therefore:

$$Sus = P(H < C) \tag{4.1}$$

In (4.1) Sus refers to the sustainability of the organization, H is the organizational challenge and C is the capacity of the organization. If $f(h)$ will be the probability density function (PDF) of challenge factors, then the equivalent cumulative distribution function (CDF) could be expressed as:

$$F(h) = \int_0^\infty f(h)dh \tag{4.2}$$

There is the same scenario for capacity factors of organization, so CDF and PDF of capacity factors could be shown below:

$$F(c) = \int_0^\infty f(c)dc \tag{4.3}$$

By these assumptions, sustainability in a simple case (organization) is defined as the probability of inflicting challenge factors do not surpass the organization's capacity. Then sustainability can be expressed as:

$$Sus = P(H < C) = \int_0^\infty f(c)\left[\int_0^\infty f(h)dh\right]dc \tag{4.4}$$

h is the randomized challenge variable, c is the randomized capacity variables.

Sustainability performance when viewed economically can lead to the reduction and controlling of environmental risks (green economics), which is considered to be the preliminary elements that effect challenge and capacity factors of an organization. Another assumption of this study is that both challenge and capacity factors are normally distributed. Therefore, by considering this normality assumption, the sustainability of the organization can be expressed as:

$$Sus = \int_0^{\infty} \frac{1}{\sqrt{2\pi\sigma_c^2}} e^{\frac{-(c-\mu_c)^2}{2\sigma_c^2}} \left[\int_0^{\infty} \frac{1}{\sigma_h\sqrt{2\pi\sigma_h^2}} e^{\frac{-(h-\mu_h)^2}{2\sigma_h^2}} dh \right] dc \tag{4.5}$$

Where μ_h and σ_h^2 are the mean value and variance of challenge factors, μ_c and σ_h^2 are the mean value and variance of capacity factors.

The proposed model is thereby simplified as expressed Eq. (4.6)

$$Sus = \varphi(\frac{\mu_c-\mu_h}{(\sigma_c^2+\sigma_h^2)^{1/2}} \tag{4.6}$$

By Eq. (4.6) with a standard normal table, the sustainability of the organization is hereby estimated.

Khosravi *et al.*, (2019) applied that new look to sustainability in the presence of exponentially challenges and capacity indicators and by using probability density function of joint difference distribution of two exponential variables obtained:

$$Sus = \begin{cases} \frac{e^{y/\lambda_2}}{\lambda_1+\lambda_2} & y < 0 \\ \frac{e^{-y/\lambda_1}}{\lambda_1+\lambda_2} & y > 0 \end{cases} \tag{4.7}$$

Where λ_1 and λ_2 are parameters of challenge and capacity Indicators.

4.3 Analytical hierarchy based weighing procedures

Step 1: Defining the aim and motive of the model:

According to Expert AHP questionnaires, analysis is carried out to establish the weights of the capacity and challenge factors.

Step 2: Selection model variables:

The behaviors in the first hierarchy included challenge variables which are Percentage of transmission-line area fumigated with herbicides, Percentage of range of ditches and clogs fumigated by herbicides, Percentage of green Home Gas emitted compared with those previously reported, Percentage of emissions produced concomitantly along transporting and dispensing power proportionately to those circumvented by net of electricity exported, Percentage of leakage due to device fracture, Percentage of renewable energy produced in accordance with total energy produced, Percentage of energy harvested through thorough supervision and adequate enhancement schedules, Percentage of Sneaky hookups due to the dispensing arrangements, Percentage of remaining dangerous materials transferred from landfill, Percentage of salvaged oil being consumed internally.

Step 3: Questionnaire designing:

The questionnaire is structured to promote pair-wise comparisons among the challenge and capacity variables separately. A popular nine-point scale for an AHP questionnaire as proposed by Saaty (1980) was used and presented in Table 4.1. Table 4.2 shows a simple example of the questionnaire, in which five factors are selected: Factors Ch1, Ch2, Ch3, Ch4, and Ch5. According to Table 4.2, Ch1 is twice important as Ch2 with a ratio of ½. Row 1 corresponds to the ratio of Ch1 to Ch2. Similarly, the importance ratio of Ch1 to Ch3, Ch4, and Ch5 are 6, 5, and 5 respectively. The importance ratio of Ch2 to Ch3, Ch4, and Ch5 are 2, 3, and 2. The importance ratio of Ch3 to Ch4 and Ch5 is ½, and $^{1}/_{3}$, the ratio of Ch4 to Ch5 is 1. The same was repeated for capacity factors and was layout in Table 4.2.

Table 4.1 Saaty's scale for pairwise comparison

The intensity of Relative Importance	Definition
1	Equivalent priority
3	The moderate priority of one factor over another
5	Essential or strong priority
7	Determined priority
9	Absolute priority
2,4,6,8	Intermediate values between the two neighboring scales

Table 4.2: A sample questionnaire (Challenge factors)

Factor	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Factor
Ch1										√								Ch2
Ch1														√				Ch3
Ch1													√					Ch4
Ch1													√					Ch5
Ch2										√								Ch3
Ch2											√							Ch4
Ch2										√								Ch5
Ch3								√										Ch4
Ch3							√											Ch5
Ch4									√									Ch5

Step 4: Using a questionnaire:

After administering the questionnaires, a matrix of outcomes for pair-wise comparisons is constructed and presented in Table 4.3. The matrix is a balanced and double-faced matrix for the pair-wise comparisons among factors.

Table 4.3: A matrix is an example of the importance ratio created by an expert

Challenge Factors

$$\begin{bmatrix} 1 & 2 & 6 & 5 & 5 \\ 1/2 & 1 & 2 & 3 & 2 \\ 1/6 & 1/2 & 1 & 1/2 & 1/3 \\ 1/5 & 1/3 & 2 & 1 & 1 \\ 1/5 & 1/2 & 3 & 1 & 1 \end{bmatrix}$$

Capacity Factors

$$\begin{bmatrix} 1 & 1 & 1/8 & 1/2 & 1/3 \\ 1 & 1 & 1/7 & 1/2 & 1/3 \\ 8 & 7 & 1 & 3 & 2 \\ 2 & 2 & 1/3 & 1 & 1/2 \\ 3 & 3 & 1/2 & 2 & 1 \end{bmatrix}$$

Step 5: Consistency Index Tests:

Consistency Index (CI) was estimated according to Saaty (1980) as given in the expression $CI = \frac{\lambda_{max}-n}{n-1}$.

λ_{max} is the maximum eigenvalue of the matrix, n is the number of factors. Constituency Ratio (CR) as defined Saaty (1980) is: $CR = \frac{CI}{RI}$.

Random Index (RI) is as given in Table 4. Maximum acceptable level of CR (Consistency ratio) is 0.1, otherwise it is rejected.

Table 4.4: Values of Random Index

n	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

4.4 Explanatory case study on the application of the model

Widely reported Hydro-Quebec was used to illustrate the proposed model. The challenge and capacity factors were evaluated based on the environmental indicators reported in Hydro-Quebec sustainability reports (2010-2016). The identified indicators amounting to the challenge and capacity factors are summarized in Tables 4.1 and 4.2 respectively. The sustainability of generating, transmitting and distributing between 2010 and 2016 was estimated separately for each year. The results were presented in Fig. 1 from where the sustainability of Hydro-Quebec in the period of 6 years (2010-2016) was determined. For instance, the outcome explains that with a probability of 80.45 %, Hydro-Quebec successfully prevailed over its inherent challenges, and thus moved towards sustainability in 2016.

For this consistency test, 8 experts passed based on challenge factors while 7 experts passed based on capacity factors and those that failed were excluded from taking part in further estimations. Index values with the weight values were combined to estimate the geometric means for both capacity and challenge factors.

Table 4.5: Notified environmental performance indexes of challenge factors

Challenge factors	Year						
	2010	2011	2012	2013	2014	2015	2016
Area of transmission-line rights-of-way treated with herbicides (%)	0.2936	0.2205	0.028	0.0073	0.0040	0.0602	0.0208
Area of dikes and dams treated with herbicides (%)	0.2669	0.3848	54.19	0.4203	0.3202	0.4349	0.4924
CHG emissions from thermal electricity generation relative to total CHG emissions from all reported sources (%)	0.7903	0.7935	0.8023	0.7926	0.8019	0.7992	0.7899
Indirect emissions associated with power transmission and distribution relative to emissions avoided by next experts of electricity (%)	0.0249	0.0081	0.002	0.00085	0.0037	0.0019	0.00064
Spills due to equipment breakage (%)	0.56	0.515	0.57	0.62	0.60	0.59	0.51

Table 4.6: notified environmental performance indexes of capacity factors

Capacity factors	Year						
	2010	2011	2012	2013	2014	2015	2016
Renewable energy generated relative to total energy generated (%)	0.9781	0.9791	0.9756	0.9984	0.9982	0.9845	0.9912
Energy saved through conservation and/or efficiency improvement plans (%)	0.1971	0.4026	0.3245	0.3641	0.3915	0.4412	0.3892
Underground hookups on the distribution system (%)	0.36	0.40	0.42	0.41	0.46	0.43	0.46
Residual hazardous materials (RHMs) diverted from landfill (%)	0.95	0.94	0.95	0.96	0.93	0.95	0.97
Insulating oil recovered and reused internally (%)	0.91	0.888	0.8009	0.8116	0.9222	0.9334	0.8786

Furthermore, going by Eq. (4.6), in case the challenge and capacity variables are concurrently intensified, little or insignificant progress would be observed towards sustainability. Alternatively, if the factors are moving in the opposite directions, a move towards, or away from sustainability is expected as the case may be. Sustainability data stacked up in Tables 4.5 and 4.6 displays variations in terms of occurrence of fluctuations in the challenge and capacity variables within the duration of operation (2010–2016) studied. Decision-makers may decide to assign different weights to the capacity and challenge factors they dimmed are having specific and significant importance of the factor concerned. Thus Table 4.7 and Figure 4.1 show the real weight for challenge and capacity factors on Hydro-Quebec sustainability over time.

Table 4.7: Summary table combining expert questionnaire with weighted values

Sustainability	Factors	Original weight value	AHP weight value
Challenge factors	Area of transmission-line rights-of-way treated with herbicides (%)	1	0.35
	Area of dikes and dams treated with herbicides (%)	1	0.22
	CHG emissions from thermal electricity generation relative to total CHG emissions from all reported sources (%)	1	0.12
	Indirect emissions associated with power transmission and distribution relative to emissions avoided by the next experts of electricity (%)	1	0.15
	Spills due to equipment breakage (%)	1	0.16
Capacity factors	Renewable energy generated relative to total energy generated (%)	1	0.08
	Energy saved through conservation and/or efficiency improvement plans (%)	1	0.1
	Underground hookups on the distribution system (%)	1	0.35
	Residual hazardous materials (RHMs) diverted from landfill (%)	1	0.19
	Insulating oil recovered and reused internally (%)	1	0.28

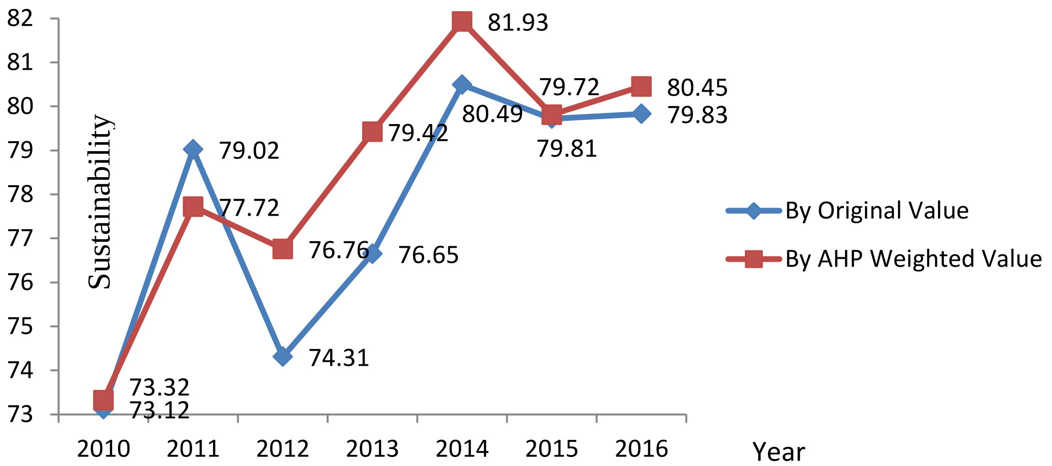


Figure 4.1: Comparative sustainability obtained for Hydro-Quebec Company in the duration of 2010-2016 using the proposed model

Figure 4.1 shows the sustainability progress made each year by Hydro-Quebec. The trend of the challenge and capacity variables utilization is also presented. Similarly, fluctuations in the company’s sustainability were easily evaluated over time. This is one of the strengths of the proposed model. However, large data from the previously reported was highly utilized by the model since on few sustainability data have been previously reported. It should be emphasized that the proposed sustainability model can be well adapted for making comparisons between organizations operating within the same sector. This would, however, necessitate that variable indicators be measured absolutely in the same method. Ahi and Searcy (2014) research also corroborates this assertion.

4.5 Conclusion

The studies show that the model presents a simple and straight-forward approach to evaluating the sustainability performance of an organization. The model explicitly adopted stochastic based AHP procedures that consequently give relatively simple and informative data to sustainability. The model can be used practically for dynamic evaluation of the sustainability, efficiency of any given organization over time thereby making the decision-making process more effective. The proposed sustainability model can adequately provide comparisons between organizations operating in the same sector have the same indicators that are dimensioned in the same way. However, lack of adequate data comparability could make it difficult to perform comparisons between different organizations. Furthermore, given its effective and strong concepts coupled with its stochastic nature, the proposed AHP sustainability model can provide adequate, informative data with uncertainty behaviors that have been previously obtained through the application of probability techniques in most ecological studies.

Chapter 5

DEVELOP A STATISTICAL MODEL FOR TBL SUSTAINABILITY MEASUREMENT OF ORGANIZATION

5.1 Introduction

The concepts of sustainability have gained wider applications within concerted efforts geared toward maintaining the balance between the depletion of resources in such a way that the coming generations can benefit from the resources. Sustainability is a developmental strategy necessary for meeting the needs of the present users without jeopardizing the opportunity of future generations to meet their needs (WCED, 1987). Many studies have been conducted on how to assess, appraise, and evaluate the sustainability of corporations by combining the economic, social, and environmental aspects of human life (Pulselli *et al*., 2006; Distaso, 2007; Floridi, 2011; Salvati and Carlucci, 2014). As it stands today, top managers and researchers are duty-bound to constantly appraise, assess, and evaluate their corporate's sustainability performance. Most times, constant re-appraisal of the sustainability scores would better reposition the corporation strategically so as to contribute immensely and meaningfully to the environmental and social issues of their hosts (Wagner, 2010). The concept of sustainability can also serve as a means of measuring the performance of a country (Wagner, 2010, Siche *et al*., 2008). It may be recalled that sustainability involves finding balance between the depletion and conservation of resources. It is the level of the resources (natural, environment, and capital) the previous generation is bequeathing to the coming generations; however, losses in some natural resources are enviable (Tom and John, 2010). Some researchers have argued on the belief that losses in the natural resources can be compensated for through increased capital. Others maintained the belief that capital cannot be substituted for resources. In this regard, therefore, two major views have surfaced in defense of sustainability as follows: (i) Stock wealth to be inherited by the coming generation cannot be less than the amount inherited by the previous generation, and (ii) Stock of environmental assets bequeathed to the coming generation must be the same proportion inherited by the previous generation (Pearce *et al*., 1989; Daly, 1997). This is the basic concept of weak and strong sustainability, respectively (Ayres *et al*., 1998). It has been reported that it is possible to make a choice between weak sustainability (WS) and strong sustainability (SS) (Elkington, 1994). The four dimensions for finding WS and SS are given as: (i) physical flows of materials, (ii) environmental protection expenditure, (iii) physical and monetary accounting of environmental assets, and lastly (iv) environmentally modified macro-aggregates. These categories are germane for the measurement of WS and SS (Liu *et al*., 2017). Subsequent reports pointed out that the major difference between weak and strong sustainability is the extent at which sustainability between different forms of capital is evaluated (Apte and Sheth, 2017; Kim and Kim 2017).

Sequel to the aforesaid, it is necessary to bear in mind that sustainability assessments often rely on different kinds of indicators which are measured in units pertinent to the particular metric. More so, the same unit of measurement makes the identification and comparison of indicators much more achievable. These indicators can be synthesized analytically, statistically, or graphically (Pires *et al.*, 2016; Wirtenberg *et al.*, 2009). The perspective of an embedded system developed to conceptualize Canada's healthcare sustainability for a novel and productivity solutions for measuring sustainability was found to minimize risk with the health of the populace being optimized (Tsasis and Agrawal, 2019). Hence, to achieve sustainable development, appropriate policies must be strictly followed in arriving at some of these requirements for defining, measuring, designing, and evaluating the objectives. A digital tool adapted for promoting various engagements among the stakeholders in healthcare systems toward attaining sustainability through an online health digital showed that social sustainability of the healthcare was greatly influenced by the online engagement platform (Lo Presti *et al.*, 2019). This study seeks to provide a quantitative assessing methodology which would give insight into the integration of multi-criteria techniques into a procedure for the assessment of the sustainability index of a hospital.

Many assessment methods have been proposed. For the development of sustainable goals in a healthcare system, various emerging algorithms and machine learning techniques have been identified for assessing the sustainability of smart healthcare system for disease diagnosis (Chui *et al.*, 2017). The method proposed in Reference (Russel and Shiang, 2013) only aimed at assessing the degree of sustainability in all dimensions except for those leading to environmental sustainability index and well-being assessment. The appropriate indicators for assessing sustainability are often based on the multidisciplinary nature of the organization, which usually form a basis for quantitative decision making (Epstein and Buhovac, 2014). Some of the newest assessment methods for healthcare sustainability include the Leadership in Energy and Environmental Design (LEED), Building Research Establishment Environmental Assessment Methodology (BREEAM), Comprehensive Assessment System for Built Environment Efficiency (CASBEE), Deutsche Gesellschaft fur Nachhaltiges Bauen (DGNB), Haute Quality Environmental (HQETM), Sustainable Building Tool (SBTool) (Savitz and Weber, 2006), and Healthcare Building Sustainability Assessment (HBSA) (Castro *et al*., 2017).

It is worthy to note that these tools mentioned were used to ascertain the sustainability of the healthcare system based on buildings and other infrastructures. Those tools in Reference (Epstein and Buhovac, 2014) used the environmental impact assessment of buildings, infrastructures, and construction work to measure sustainability. Similarly, HBSA was used to measure the environmental impact of healthcare buildings and assessed healthcare sustainability through a set of benchmarks within the life-cycle efficiency of healthcare buildings and other infrastructures. The benchmarks were defined as the rate of resource depletion, waste generation, overhead costs, and operational environmental impacts of the healthcare buildings. A new sustainability tool for measuring sustainability, Sustainable High-Quality Healthcare (SUST Health) has been widely studied and implemented (Ekins *et al*., 2003; Capolongo., 2015). In summary, SUST Health is based on the submission of the criteria and indicators to scrutiny by a group of experts through specified questionnaires. This group is comprised of selected experts who have been trained to identify and assign relative weight to the indicators and the use of weighing model such as Analytic Network Process (APN). Invariably, SUST Health is structured and applicable to standardized situations in the healthcare system and has been recognized internationally for aligning either directly or indirectly to sustainable development initiatives.

A similar perspective for developing indicators for the sustainability criteria through Specific, Measurable, Assignable, Realistic, and Time-based (SMART) have been applied (Doran, 1981). The selection of sustainability factors for a particular healthcare system must satisfy some conditions, such as: (i) must be homogeneous, (ii) non-dimensional, and (iii) with the tendency to possess equal weight. In addition to these conditions, the indicators must equally be related to sustainability TBL issues surrounding the particular healthcare system. A very important attribute is the reduction of assumptions for the selection of indicators; choice of any indicators is based and justified by appropriate and realistic rationales, fathomable within the prevailing dynamics of the system. This should not be confused with “smart city healthcare system”. The “smart city” attached to the healthcare was merely used to describe a healthcare system where artificial intelligence, big data, decision making, information and communication technology (ICT), and the internet-of-things (IoT) are the hallmark (Chui *et al*., 2017. Furthermore, a smart city would possess the ability to tap various information and communication technology (ICT) techniques available to find solutions to some sundry problems in governance, environment, economy, healthcare, and the society at large. It must also have the propensity to enhance the quality of life of everyone living therein and should be capable of adapting computational intelligence through appropriate mathematical models to deal with real-life problems (Kondepudi *et al*., 2014).

Another similar smart health study was conducted on knowledge management in healthcare sustainability of traditional Chinese diets. A knowledge graph was designed to incorporate healthy diet information on the internet with a semantic retrieval system. This system aided learning and tilted the populace toward having a balanced diet (Chi *et al*., 2018). This study adapted SMART due to the fact that it allows sustainability analysis to be based on the prevailing situations in a particular healthcare system irrespective of their former sustainability status. Mainly, it attempts to leverage on some of the protocols, especially the aspect of utilizing verified indicators. The study advocates the utilization of the prevailing sustainability indicators in a particular healthcare system to determine the sustainability index of that particular healthcare system. The effort now is focused on the utilization of the real statistical distribution of the identified indicators for the analysis. The study proposes an exponential distribution model for measuring the sustainability index of a healthcare system. Unlike the previous methods, where the dimension of the indicators was used, functionality and adequacy of these indicators are employed in this study. Moreover, the focus of this study traverses beyond the healthcare buildings and other construction works. It holistically considers the sustainability of a healthcare system as a way of evaluating the perceptions of the users (patients), medical personnel, infrastructure, and other stakeholders.

Sustainability and sustainable development procedures have been given high priority by most scientists, government, industry, and even the public through to the wide application of the TBL indicators of social, environmental, and economic (Chi *et al*., 2018; Norton and Tom., 2016; Stem, 1997; Böhringer and Jochem, 2007; Bell and Morse, 2008; Heijungs *et al*., 2006). However, little literature is available on how to measure the sustainability of healthcare systems using the actual statistical distribution of the data. For a system to reach its sustainability index, there must be a decrease in the challenge factor and an increase in the capacity factor. In other words, the challenge must not exceed capacity. For measuring sustainability, both capacity and challenge indicators are random variables implying that their respective cumulative density function can be used (Bare *et al*., 2006). By assuming a normal distribution for both capacity and challenge factors, taking μ_c, μ_h as the mean of capacity and challenge factors respectively, σ_c^2, σ_h^2 are the respective variance of capacity and challenge factors, φ is the probability that one normal standard random variable (Z) will be smaller than one specific value (z) of that variable, and sustainability can be expressed as:

$$Sus = \varphi\left(\frac{\mu_c - \mu_h}{(\sigma_c^2 + \sigma_h^2)^{1/2}}\right) \tag{5.1}$$

However, sustainability assessment has been evaluated based other statistical distributions, either in a discrete or continuous mode. These statistical distributions include binomial, Poisson, geometric, negative binomial, exponential, uniform, normal, log-normal, and gamma. Among these distributions, the exponential distribution is of interest to this study due to its many advantages. Some of these unique advantages include: (i) existing within the continuous probability distribution domain with a constant failure rate (lambda) suitable for analyzing real-life situations, and (ii) possessing a constant response time and forming a veritable tool for predicting the mean time of the variables.

The study aims to examine an exponential distribution approach for measuring the sustainability of a service-oriented organization over time from their exponentially distributed indicators. We anticipate contributing to the existing literature as follows: (i) measuring the appropriate and adequate sustainability value of the healthcare system that is based on the actual statistical distribution of its sustainability factors,

(ii) providing a panoramic tool for appraising, assessing, and measuring the sustainability effectiveness of any other organizations with exponentially distributed indicators, (iii) providing leverage for comparing the sustainability issues of different companies functioning in the same or related sector, possessing the same indicators that are measured in the unit, and (iv) within known literature, there are little or no studies on the measurement of the sustainability value of organization using the actual statistical distribution of the indicators. Previous studies (Ahi and Searcy, 2014) were based on the basic assumption of the normal distribution; hence, this chapter will empirically adopt and validate an exponentially distributed probabilistic approach for sustainability measurement. After the introduction presented in Section 5.1, the remainder of this chapter is structured as follows. Section 5.2 presents the materials and methods, where the proposed exponentially distributed sustainability model and the validation are explained. Section 5.3 presents the numerical illustration of the model, while results and discussions are presented in Section 5.4. Section 5.5 concludes the article.

5.2 Methods, theoretical considerations and model development

5.2.1 The proposed exponentially distributed sustainability model

Sustainability is the probability of challenge is less than the healthcare system's capacity. Therefore:

$$Sus = P(H < C) = P(H - C < 0) \tag{5.2}$$

Where Sus is the sustainability of the healthcare system, H is the challenge factor, and C is the capacity factor of the company. Assuming that factors of capacity and challenge are exponentially distributed, then within Equation (5.2) probability density function can be modeled as:

$$f(h, \lambda_1) = \frac{1}{\lambda_1} e^{-h/\lambda_1} \tag{5.3}$$

$$f(c, \lambda_2) = \frac{1}{\lambda_2} e^{-c/\lambda_2} \tag{5.4}$$

Let $Y = H - C$

Thus, the Cumulative Density Function (CDF) of Y, $F_Y(y)$ is piecewise, when $y \leq 0 \; or \; y \geq 0$.

Case (i) $y \leq 0$;

$$F_Y(y) = P(Y \leq y) = P\big((H - C) \leq y\big) = P(C \geq H - y) =$$

$$\int_0^\infty \int_{h-y}^\infty f_{H,C}(h, c) dc dh = \int_0^\infty \int_{h-y}^\infty (\lambda_1 e^{-\lambda_1 h})(\lambda_2 e^{-\lambda_2 c}) dc dh =$$

$$\int_0^\infty \lambda_1 e^{-\lambda_1 h} (e^{-\lambda_2 (h-y)} \Big|_{h-y}^{\infty}) dh = \int_0^\infty \lambda_1 e^{\lambda_2 y} e^{-(\lambda_1 + \lambda_2) h} \, dh =$$

$$\lambda_1 e^{\lambda_2 y} \left(-\frac{1}{\lambda_1 + \lambda_2} e^{-(\lambda_1 + \lambda_2) h} \Big|_0^\infty \right) = \frac{\lambda_1 e^{\lambda_2 y}}{\lambda_1 + \lambda_2} \tag{5.5}$$

Case (ii) $y > 0$;

$$F_Y(y) = P(Y \leq y) = 1 - P(Y > y) = 1 - P\big((H - C) > y\big) = 1 - P(C < H -$$

$$y) = 1 - \int_y^\infty \int_0^{h-y} f_{H,C}(h, c) dc dh = 1 - \int_y^\infty \int_0^{h-y} (\lambda_1 e^{-\lambda_1 h})(\lambda_2 e^{-\lambda_2 c}) dc dh = 1 -$$

$$\int_y^\infty (\lambda_1 e^{-\lambda_1 h})(1 - e^{\lambda_2 c} \Big|_0^{h-y}) = 1 - \int_0^\infty (\lambda_1 e^{-\lambda_1 h})(1 - e^{-\lambda_2 (h-y)}) dh = 1 -$$

$$\left(\lambda_1 e^{-\lambda_1 h} - \frac{\lambda_1}{\lambda_1 + \lambda_2} e^{-(\lambda_1 + \lambda_2) h + \lambda_2 y}\right) dh = 1 - \left(-e^{-\lambda_1 h} - \frac{\lambda_1}{\lambda_1 + \lambda_2} e^{-(\lambda_1 + \lambda_2) h + \lambda_2 y}\right) \Big|_y^\infty =$$

$$1 - \left(-e^{-\lambda_1 y} + \frac{\lambda_1}{\lambda_1 + \lambda_2} e^{-\lambda_1 y}\right) = 1 - \frac{\lambda_2 e^{-\lambda_1 y}}{\lambda_1 + \lambda_2} \tag{5.6}$$

Exponential random variable involves the time of an event and time between two events. In the case of time of an event, sustainability is measured based on "challenge cannot surpass capacity" given in Equation 5.5. Similarly, for the second case, time between two events, sustainability is profiled on "capacity cannot surpass challenge", also given in Equation 5.6. For instance, for the first case time of an event, if the capacity is defined as time of staff training, then the increase in time spent (hours or days of the training) for the training must increase. In this instance, Equation 5.5 is employed to determine the sustainability. Similarly, for the second case, time between two events, if challenge is defined as the time between two complaints, then the decrease in time interval at which at least two complaints are reported must decrease (lower rate of complaint). In this situation, Equation 5.6 is used to measure the sustainability of the system. In this present work, the indicators are measured as the time the particular event took place. Hence, Equation 5.5 is employed to measure the sustainability of the healthcare system. Wherever indicators with time between two events are encountered, the condition of such an indicator is reversed and Equation 5.5 is applied to calculate its sustainability.

By differentiating Equations 5.5 and 5.6 with respect to y,

$$f_Y(y) = \begin{cases} \frac{\lambda_1\lambda_2}{\lambda_1+\lambda_2} e^{\lambda_2 y} & y \leq 0 \\ \frac{\lambda_1\lambda_2}{\lambda_1+\lambda_2} e^{-\lambda_1 y} & y > 0 \end{cases} \tag{5.7}$$

This is the probability density function with parameters λ_1 and λ_2

$$Sus = P(H \leq C) = P(H - C \leq 0) = P(Y \leq 0) = \int_{-\infty}^{0} \frac{\lambda_1\lambda_2}{\lambda_1+\lambda_2} e^{\lambda_2 y}\, dy \tag{5.8}$$

The parameters for determining the exponential distribution are estimated from the number of observation n as follows:

Number of interval, $k = \sqrt{n}$ (5.9)

Range = $Maximum_{value} - Minimum_{value}$ (5.10)

Class interval = $R/\sqrt{n}$ (5.11)

Mean value $\bar{x} = \sum_{i=1}^{k} x_i f_i \Big/ \sum_{i=1}^{k} f_i$ (5.12)

Parameter of exponential distribution , $\lambda = 1/\bar{x}$ (5.13)

Probability density function of exponential distribution, $f(X = x) = \lambda e^{-\lambda x}$ (5.14)

Expected frequency o_i for ith interval $= n \int_{lower\ bound}^{upper\ bound} \frac{1}{\bar{x}} e^{\left(-x/_{\bar{x}}\right)} dx$ (5.15)

5.2.2 Exponential distribution validation (Hypothesis testing procedure)

A well-defined problem is characterized by detailed conditions of its relationship with various terms. Most often, such a detailed and structured problem is not readily defined; therefore, in such cases the assumption of some terms is necessary whenever a solution is anticipated. An explicit assumption, where other experts can ask questions and also contribute comments, is always preferred. This study assumed that both challenge and capacity factors are exponentially distributed. To check the validity of this assumption, the goodness of fit test is adopted. The process of checking and validating has been summarized in five steps (Walpole *et al.*, 2011):

Step 1: State the null H_0, and alternative H_1, hypothesis

Step 2: Choose an appropriate value of the level of significance, α (standard value for α = 0.05)

Step 3: Use the appropriate statistic$\chi^2 = \sum_{i=1}^{k} {(o_i - e_i)^2}/_{e_I}$ (5.16)

Calculate the statistic and show the critical region

Step 4: Reject H_0 if the value of the statistic is in the critical region otherwise fail to reject H_0

Step 5: Draw the conclusion

Hence,

$H_0 = \text{distribution of the value of the indicator is exponential}$

$H_1 = \text{distribution of the value of the indicator is not exponential}$

5.3 Numerical illustration

A numerical illustration of the proposed model is conducted using the TBL indicators of the General Hospital in Tehran. The hospital is the biggest Government hospital located within the heart of the over 10,000,000 populated capital city of Iran. The hospital is organized into various wards, namely male, female, accident and emergency, surgical, children, and maternity. The male and female ward can accommodate 60 patients each, maternity 30 patients, surgical ward 20 patients, children's ward 80, and accident and emergency only 15 patients. The challenge and capacity criteria based on the triple bottom line adapted from the SUST health tool (Capolongo *et al*., 2015) are presented in Table 5.1. Similarly, challenge and capacity indicators with the rationales determined according to SMART logic (Doran, 1981) are presented in Tables 5. 2–5. 4. In this case study, the indicators were measured in a unit of time; therefore, the ability to achieve a specific factor in less time determines the capacity of the hospital and those factors that are achieved with more time constitute the challenge factors. Various data collated for the estimation of these results have been attached as a supplementary file in MS Excel format. Working hours are adopted as the unit of measurement.

Table 5.1: Hospital sustainability evaluation criteria for the existing operative hospital studied, adapted from sustainable healthcare evaluation tool (SUST Health tools).

Macro-Area	Criteria	Indicators
Economic Sustainability	Clinical Performance	Hospital Acquired Infections
		Health technology management
		Build quality
	Managerial Performance	Staff Qualification and Education
		ICT (information and communication technology)
	Technological Performance	Biomedical Technologies Obsolescence
Environmental Sustainability	Envelope Technologies	Maintenance Technologies
	Materials and Resources	Km 0
		Recycled Components
	Saving with Efficiency	Lighting
	Urban Planning	Transportation
		Risks
	Unconventional Source Supply	Electricity
		Heating and Cooling
		Domestic Hot Water
	Waste Care	Hazardous Waste

		Waste generation
	Water Care	Water Consumption
		Water Recycling
	Comfort	Lighting
		Indoor Air Quality
Social Sustainability	Distribution	Space flexibility
		Accesses and Paths
	Humanization	Safety and Security
		Health Promotions

Source: [38].

Having strictly adhered to the conventional guidelines provided by SUST Health as given in Table 5.1, Tables 5.2–5.4 presents the sustainability indicators (challenge and capacity) for the TBL with their rationales coined according to SMART and based on the prevailing situations on the healthcare system.

Table 5.2: Identified Economic indicators and rationales for the Triple Bottom Line (TBL) of the Iranian General hospital determined according to SMART logic.

Sustainability criteria- Economic	**Rationale**
Capacity	
The average time interval between diagnosis and procurement of prescribed medications prior to treatment of the patient.	Temporary pause in the treatment due to the waiting time between purchasing and dispensing of classified drugs or related medications.
The hospital has the capacity to re-strategize in a timely way to reorganize health personnel to brief-up the shortages of personnel in case of industrial action.	The society is prone to infectious or communicable diseases. Timely intervention on the part of the healthcare practitioners in terms of their ability to respond swiftly is sacrosanct.
Average time to take the vital signs of an in-patient.	This is an indication of normalcy in the patient prognosis.
Average time for repairing faults and malfunction information and communication technology (ICT) equipment.	Making all the ICT functional is a way to enhance the efficiency of the health personnel in all areas.
Average time taken to observe quality measure during and after a medical procedure.	Good sanitation to rid tools of spills and contaminates before, during, and after a procedure and proper detailing of all tools are key ways of ensuring quality of service.
Challenge	**Rationale**
Average time taken in extracting facts about the prognosis of an outpatient in an emergency situation.	Most of the time, patient relatives are usually in distress and despair about a case to an extent of withholding adequate information needed to commence treatment.
Average emergency time required to invite a specialist to attend to patients in a special case and time required to refer to another health facility.	The hospital does not have specialists for any classified treatments. Specialists might be engaged or indisposed or reluctant. Most times, other health facilities are occupied, so patients have to queue up.
Average time taken to profile a new patient.	Inability to profile a patient on time could lead to the delay in discharging the treatment.
Average time to take the vital signs of an out-patient.	Out-patients most times do not present themselves for monitoring of vital signs.
Average time for admission and discharge.	Lack of will and financial resources on the part of the patients could influence the admission and discharge times.

Source: [Authors].

Table 5.3: Identified Environmental indicators and rationales for the Triple Bottom Line (TBL) of the Iranian General hospital determined according to Specific, Measurable, Assignable, Realistic and Time-based (SMART) logic.

Sustainability criteria- Environmental	**Rationale**
Capacity	
Average times that the patient can produce some consumables.	Some patients could deliberately delay the purchasing of their treatment essentials while waiting for Government interventions.
Average time for collecting and disposing of hazardous wastes.	Hazardous wastes have high impact on the environment and total wellbeing.
Timely supply of portable water to the hospital facility and the patients.	Constant and timely portable water is necessary for enhancing the general well-being of the patients and for other sundry activities in the hospital.
Timely response for repairs of all faulty electrical gadgets.	Functional gadgets are required for the effective discharge of duties.
Ambulance is capable to bring patient on referral to and fro the health facility within 10 minutes.	Ambulance services are most useful in the movement of patients to and fro their home to the hospital and also from the hospital to any referral center.
Challenge	**Rationale**
Average time required between switching on alternative power supply whenever there is a power outage.	Switching to the alternative power source whenever there is an outage is important for continuous operation and could prevent pausing a procedure unduly.
Average time taken between order and supply of consumables such as cotton wool, spirit, disinfectants, etc.	Hospital management, especially in terms of contracts for supplies most time is prone to strict administrative bureaucracy which usually delay the supply of the mentioned consumables.
Average time required to outsource for bed spaces and bedding materials during an outbreak of diseases.	Getting adequate space and bedding materials to cope with high number of patients during emergency or during outbreak is usually a task for the hospital management.
Average time for maintenance of all alternative power sources.	Bureaucracy within the system could lead to delay of turn-around maintenance and the delivery of some services.
Limited time for producing and delivery hot water to patients.	Cost of electricity and lack of alternative power source could lead to rationing of hot water to the wards for the use of the patients and other stakeholders.

Source: [Authors].

Table 5.4: Identified Social indicators and rationales for the TBL of the Iranian General hospital determined according to SMART logic.

Sustainability criteria- Social	**Rationale**
Capacity	
The hospital has the capacity to receive drugs and material supply from the supplier quarterly	Building confidence between suppliers and the hospital will enhance the relationship between them
Average time for ward-round	Adequate ward round session by the health practitioners will improve patient's confidence
Average time turn-around maintenance on the ceiling fan and air conditioners at the wards for the indoor air quality is conducted.	Functional air conditioners and ceiling fans are necessary for comfort within the Hospital facility.
Timely and routine checks on all the security gadgets to ensure safety and security of the hospital.	Adequate security of people and properties is the most important confidence building measure between patient relatives and the Hospital Management.
Timely seminars, workshops and public enlightenment programs in schools to sensitize the public about their health status.	Adequate security of people and properties is the most important confidence building measure between patients and the Hospital Management.
Challenge	**Rationale**
Average time between prescription from the doctor and dispensing of the drugs/materials at the pharmacy.	Most patients' relatives prefer to purchase their medication outside the hospitals' pharmacy.
Average time taken for an in-patient to receive the prescribed drugs/material at the Pharmacy.	Long queue at the pharmacy could lead to delay in delivery of medications.
Average time taken for an out-patient to receive the prescribed drugs/material at the Pharmacy.	Queuing could be an issue that could lead to discomfort among patients.
Average time required to place an order and to receive supplies of essential drugs for the continuation of the patient's management.	The hospital does not stock any classified medications. Placing orders for them could lead to delay in treatment.
Inadequate time of in-service courier officers to take consignments to and from various remote departments.	Some in-service courier officers could be aggressive in the way they address or attend to the patients' relatives.

Source: [Authors].

5.4 Results and discussion

Exponential distribution validation results are presented in Tables 5. 5–5. 10. Figures 5. 1–5. 6 show the position of the significant χ^2 on the exponential distribution curve for each TBL. The χ^2 obtained for all the indicators did not fall within the critical region, therefore we failed to reject $\mathrm{H_0}$ and accepted that all the indicators are exponentially distributed. For the economic bottom line (Table 5. 5–5. 6), χ^2: 16.9 and 18.3 for both capacity and challenge, respectively, are less than the corresponding critical values: $\chi^2_{0.05,14}$ of 23.685 and $\chi^2_{0.05,16}$ of 26.296; these are outside the rejection region (Fig. 5. 1–5. 2). We failed to reject $\mathrm{H_0}$and concluded that the distribution of the value of the capacity and challenge indicators for economic sustainability bottom line is exponentially distributed. Similarly, for the environmental bottom line, as shown in Table 5. 7-5. 8, χ^2 12.1 and 15.7 for both capacity and challenge, respectively, are less than their corresponding critical values: $\chi^2_{0.05,13}$ of 22.362 and $\chi^2_{0.05,16}$ of 26.296. They are also outside the rejection region (See Fig. 5.3–5.4); thus we failed to reject $\mathrm{H_0}$and agreed that the distribution of value of the capacity and challenge indicators for the environmental sustainability bottom line are exponentially distributed. In a similar way, the social bottom line as presented in Table 5.9 and Table 5.10, χ^2 : 13.8 and 14.3 for both capacity and challenge, respectively, are less than their corresponding critical values: $\chi^2_{0.05,12}$ of 21.026 and $\chi^2_{0.05,13}$ of 22.362. Since the values fall outside the rejection region (See Fig. 5. 5–5. 6), we equally failed to reject $\mathrm{H_0}$ and concluded that the distribution of values of the capacity and challenge indicators for social sustainability bottom line is exponentially distributed. This validation can also be done through the *p-values.* The *p-value* is the smallest amount of probability indicating the rejection of $\mathrm{H_0}$.

Therefore, if *p-value* is greater than α (*p-value* > α), then we shall fail to reject H_o. In this case study, the *p-values* of all the criteria and indicators are greater than α (*p-value* > α), and we hereby conclude that all the indicators are exponentially distributed.

Table 5.5: Exponential distribution statistics of capacity factor for economic pillar

Midpoint	4.0	5.9	7.8	9.7	11.7	13.6	15.5	17.4	19.4	21.3	23.2	25.2	27.1	29.0	30.9
Lower	3.0	4.9	6.9	8.8	10.7	12.6	14.6	16.5	18.4	20.3	22.3	24.2	26.1	28.0	30.0
Upper	4.9	6.9	8.8	10.7	12.6	14.6	16.5	18.4	20.3	22.3	24.2	26.1	28.0	30.0	31.9
Observed frequency o_i	76.0	59.0	32.0	19.0	20.0	8.0	4.0	6.0	5.0	3.0	3.0	1.0	2.0	0.0	1.0
Expected frequency e_i	88.2	58.2	38.4	25.3	16.7	11.0	7.2	4.8	3.2	2.1	1.4	0.9	0.6	0.4	0.3

$\lambda_1 = \frac{1}{8.1}$, $\chi^2 statistics = \sum_{i=1}^{k} {(o_i - e_i)^2}/{e_i} = 16.9$ and $Critical$ $\chi^2_{\alpha,k-1} = \chi^2_{0.05,14} = 23.685$

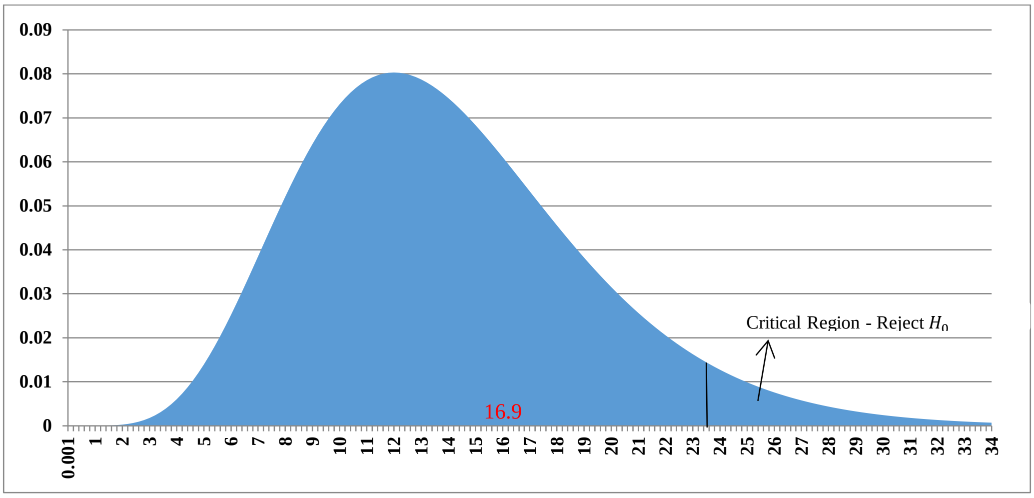


Figure 5.1: $\chi^2_{0.05,14}$ distribution of capacity for economic pillar (*P-value= 0.35)*

Table 5.6: Exponential distribution statistics of challenge factor for economic pillar

Midpoint	5.1	7.4	9.7	12.0	14.3	16.6	18.9	21.2	23.4	25.7	28.0	30.3	32.6	34.9	37.2	39.5
Lower	4.0	6.3	8.6	10.9	13.2	15.4	17.7	20.0	22.3	24.6	26.9	29.2	31.5	33.7	36.0	38.3
Upper	6.3	8.6	10.9	13.2	15.4	17.7	20.0	22.3	24.6	26.9	29.2	31.5	33.7	36.0	38.3	40.6
Observed frequency o_i	62.0	64.0	34.0	25.0	15.0	13.0	8.0	1.0	2.0	4.0	2.0	1.0	1.0	0.0	1.0	1.0
Expected frequency e_i	77.5	51.8	34.7	23.2	15.5	10.4	6.9	4.6	3.1	2.1	1.4	0.9	0.6	0.4	0.3	0.2

$$\lambda_2 = \frac{1}{8.5}, \quad \chi^2 statistics = \sum_{i=1}^{k} {(o_i - e_i)^2}/{e_i} = 18.3 \; and \; Critical \; \chi^2_{\alpha,k-1} = \chi^2_{0.05,15} = 24.996$$

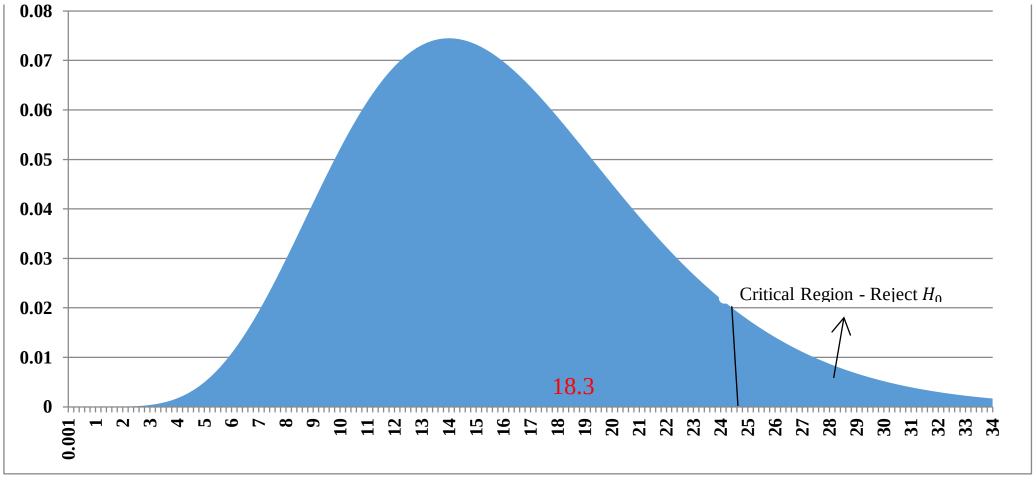


Figure 5.2: $\boldsymbol{\chi^2_{0.05,15}}$ distribution of challenge for economic pillar *(P-value= 0.33)*

Table 5.7: Exponential distribution statistics of capacity factor for environmental pillar

Midpoint	7.0	8.9	10.9	12.8	14.7	16.7	18.6	20.6	22.5	24.4	26.4	28.3	30.3	32.2
Lower	6.0	7.9	9.9	11.8	13.8	15.7	17.6	19.6	21.5	23.5	25.4	27.4	29.3	31.2
Upper	7.9	9.9	11.8	13.8	15.7	17.6	19.6	21.5	23.5	25.4	27.4	29.3	31.2	33.2
Observed frequency o_i	51.0	47.0	22.0	27.0	20.0	9.0	9.0	4.0	5.0	5.0	2.0	3.0	1.0	3.0
Expected frequency e_i	47.6	36.7	28.3	21.8	16.8	13.0	10.0	7.7	6.0	4.6	3.5	2.7	2.1	1.6
$\lambda_1 = \frac{1}{11.7}$, $\chi^2 statistics = \sum_{i=1}^{k} (o_i - e_i)^2 / e_i = 12.1$ and Critical $\chi^2_{\alpha,k-1} = \chi^2_{0.05,13} = 22.362$														

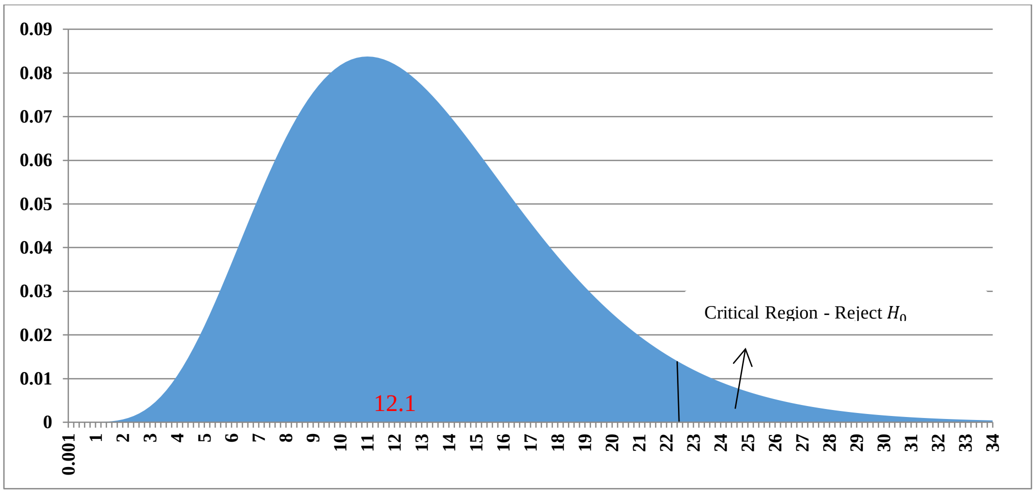


Figure 5.3: $\chi^2_{0.05,13}$ distribution of capacity for Environmental pillar *(P-value= 0.58)*

Table 5.8: Exponential distribution statistics of challenge factor for environmental pillar

Midpoint	5.6	6.8	8.1	9.3	10.5	11.7	13.0	14.2	15.4	16.7	17.9	19.1	20.3	21.6	22.8	24.0	25.2
Lower	5.0	6.2	7.5	8.7	9.9	11.1	12.4	13.6	14.8	16.0	17.3	18.5	19.7	20.9	22.2	23.4	24.6
Upper	6.2	7.5	8.7	9.9	11.1	12.4	13.6	14.8	16.0	17.3	18.5	19.7	20.9	22.2	23.4	24.6	25.8
Observed frequency o_i	60.0	41.0	25.0	17.0	27.0	15.0	12.0	8.0	11.0	2.0	5.0	4.0	5.0	3.0	1.0	2.0	2.0
Expected frequency e_i	50.6	40.0	31.5	24.9	19.6	15.5	12.2	9.6	7.6	6.0	4.7	3.7	2.9	2.3	1.8	1.4	1.1

$$\lambda_2 = \frac{1}{9.8}, \quad \chi^2 statistics = \sum_{i=1}^{k} {(o_i - e_i)^2}/{e_i} = 15.7 \; and \; Critical \; \chi^2_{\alpha,k-1} = \chi^2_{0.05,16} = 26.296$$

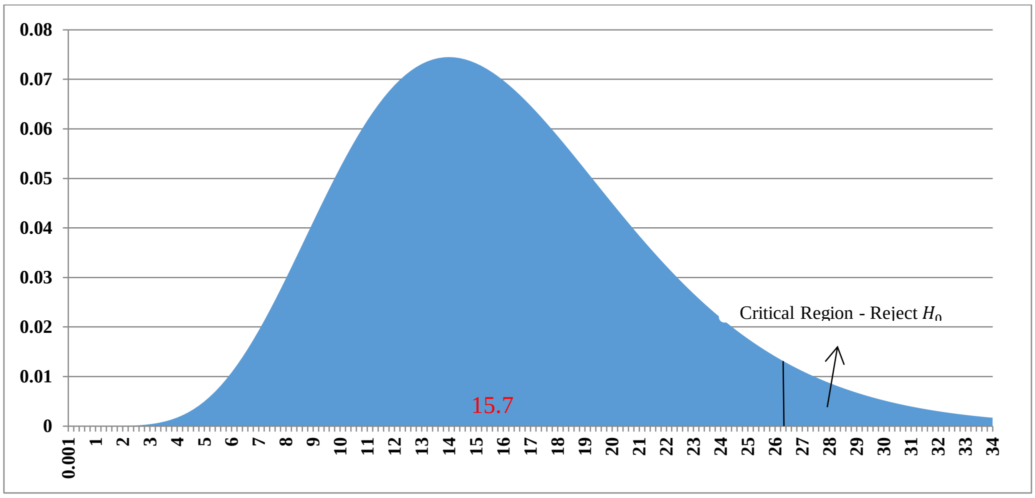


Figure 5.4: $\chi^2_{0.05,16}$ distribution of challenge Environmental pillar *(P-value= 0.54)*

Table 5.9: Exponential distribution statistics of capacity factor for environmental pillar

Midpoint	9.3	11.9	14.4	17.0	19.6	22.1	24.7	27.3	29.8	32.4	35.0	37.6	40.1
Lower	8.0	10.6	13.1	15.7	18.3	20.9	23.4	26.0	28.6	31.1	33.7	36.3	38.8
Upper	10.6	13.1	15.7	18.3	20.9	23.4	26.0	28.6	31.1	33.7	36.3	38.8	41.4
Observed frequency o_i	42.0	35.0	21.0	19.0	9.0	6.0	9.0	5.0	3.0	2.0	1.0	1.0	2.0
Expected frequency e_i	32.5	25.7	20.3	16.0	12.7	10.0	7.9	6.3	4.9	3.9	3.1	2.4	1.9

$$\lambda_1 = \frac{1}{15.3}, \quad \chi^2 statistics = \sum_{i=1}^{k} {(o_i - e_i)^2}/{e_i} = 13.8 \; and \; Critical \; \chi^2_{\alpha,k-1} = \chi^2_{0.05,12} = 21.026$$

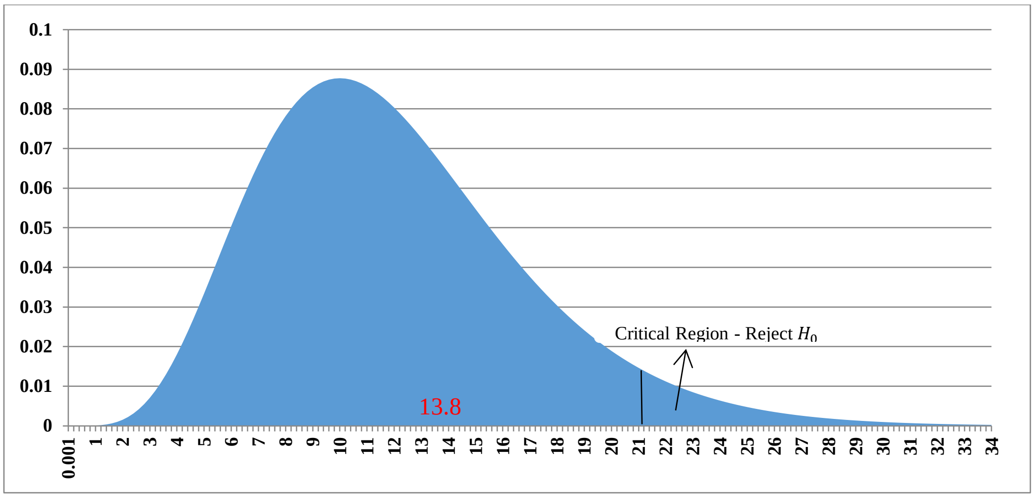


Figure 5.5: $\chi^2_{0.05,12}$ distribution of the capacity for social pillar *(P-value= 0.41)*

Table 5.10: Exponential distribution statistics of challenge factor for social pillar

Midpoint	3.2	5.7	8.1	10.5	13.0	15.4	17.9	20.3	22.8	25.2	27.6	30.1	32.5	35.0
Lower	2.0	4.4	6.9	9.3	11.8	14.2	16.7	19.1	21.5	24.0	26.4	28.9	31.3	33.7
Upper	4.4	6.9	9.3	11.8	14.2	16.7	19.1	21.5	24.0	26.4	28.9	31.3	33.7	36.2
Observed frequency o_i	99.0	52.0	31.0	31.0	12.0	10.0	8.0	4.0	2.0	3.0	0.0	1.0	1.0	1.0
Expected frequency e_i	96.3	59.9	37.3	23.2	14.4	9.0	5.6	3.5	2.2	1.3	0.8	0.5	0.3	0.2
$\lambda_2 = \frac{1}{7.6}$, $\chi^2 statistics = \sum_{i=1}^{k} (o_i - e_i)^2 / e_i = 14.3$ and $Critical$ $\chi^2_{\alpha,k-1} = \chi^2_{0.05,13} = 22.362$														

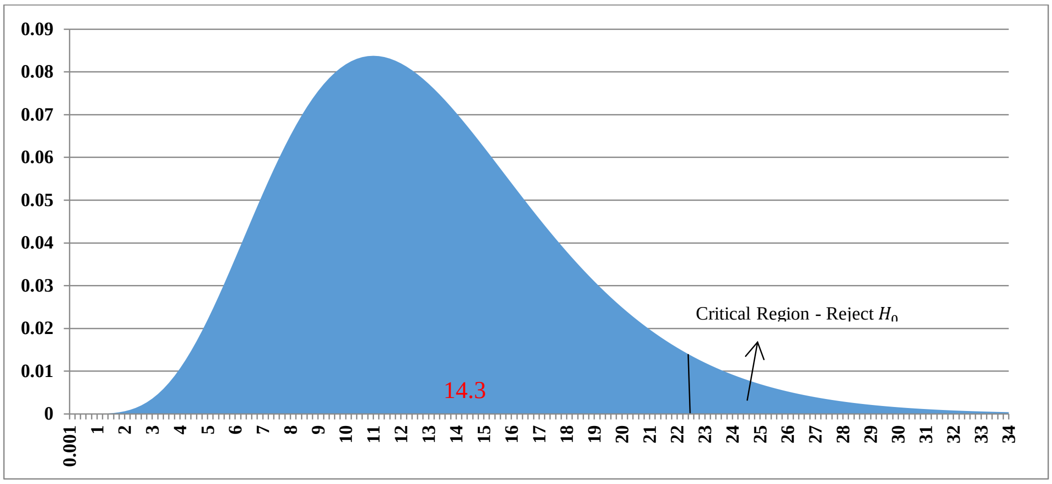


Figure 5.6: $\chi^2_{0.05,13}$ distribution of the challenge for social pillar *(P-value= 0.44)*

Utilizing the indicators in Tables 5. 2–5. 5 and Equation (5. 5), the sustainability of the hospital for one operating year (2016) was obtained according to Equation (5.8) as:

Sustainability = $\int_{-\infty}^{0} \frac{\lambda_1 \lambda_2}{\lambda_1 + \lambda_2} e^{\lambda_2 y} \mathrm{dy}$

For example,

Social sustainability = $\int_{-\infty}^{0} \frac{\left(\frac{1}{15.3}\right)*\left(\frac{1}{7.6}\right)}{\left(\frac{1}{15.3}\right)+\left(\frac{1}{7.6}\right)} e^{\frac{y}{15.3}} dy$ = 0.668=66.80%

Similarly, 54.40% and 48.80% are obtained for environmental and economic sustainability, respectively. This indicates that social sustainability of the hospital is the only macro-area that provided the most acceptable output. This could be as a result of the firm managerial know-how and better policy implementation. These must have been well managed and executed by all the stakeholders against all constraints imposed by the inadequacies of some of the indicators. More so, some other factors that have to do with the delivery, distribution of drugs, services, and some essential products also contributed to the average sustainability scores obtained. The outcome corroborates similar results (Boffoli *et al*., 2013; Buffoli *et al*., 2014; Shannon, 2011). Although the environmental sustainability index of 54.40% is abound the threshold, this is still unacceptable considering the critical nature of the healthcare system. The reason for this unsatisfactory result could be attributed to that fact that the hospital was not established with the aim of enhancing the environmental content of its operations. The concerns of the stakeholders as at the time of designing the hospital focused on rendering social and welfare needs and services to the citizen. Economic sustainability of 48.80% is considered low and unsatisfactory. This low output could be a result of the constraints imposed on the stakeholders in terms of the operational decision making. For instance, stakeholders are constrained within the limit of the current design of the environment and economic situations. For example, incessant power failure without an adequate alternative power source would reduce the public perception of the healthcare unit and also render the medical personnel redundant and ineffective. Also, lack of replacement of the faulty lighting bulbs or lights in some strategic places could reduce the public confidence. The inadequacies of the healthcare practitioners could be a result of malfunctioning essential equipment, poor environmental issues (poor office space, facility, etc.), and lack of adequate and state of the art equipment that could ease some operational services. Figure 5.7 revealed the magnitude of each of the TBL within the healthcare unit. For the healthcare to achieve adequate sustainability status, efforts should be made to improve the economic aspect of the hospital on a macro-scale.

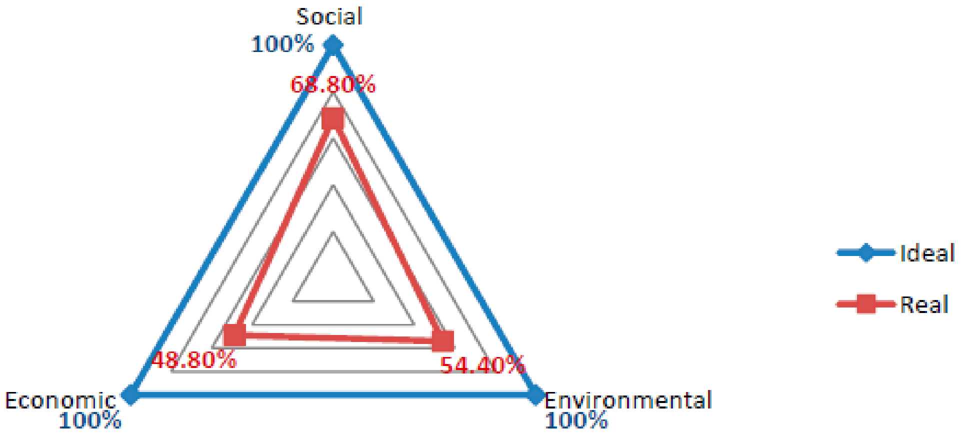


Figure 5.7: Radar plot of economic, environmental and social sustainability of the healthcare unit studied

Generally, the healthcare unit can improve the sustainability score if efforts toward reducing the challenges or by increasing the capacity are intensified. Even just a slight change in any of these factors, as the case may be, could improve the score greatly, thereby enhancing the evaluation of all other possible strategies including a cost–benefit analysis.

5.5 Conclusion

The implementation of the concept of sustainability has been widely recognized to be cumbersome in real time. This includes difficulties experienced in measuring and monitoring the sustainability level of a healthcare system. For measuring empirically the sustainability of healthcare system, an exponentially distributed stochastic model is proposed in this study. In order to illustrate the effectiveness of the proposed model, a numerical case study of real data collated from an Iranian healthcare center is employed. The study, therefore, provides these contributions to the literature:

- A simple and specific statistical distribution validation framework for assessing and measuring sustainability. This study explicitly adopted an exponential distributed probabilistic approach to sustainability measurement.
- The proposed model could be used as a panoramic tool for measuring sustainability, effectiveness in any other organizations with exponentially distributed indicators.
- Provided criteria and indicators are related and measured in the same unit, the proposed sustainability model would offer more opportunities and avenues for comparing the sustainability of different companies functioning in the same or related sectors.

For emphasis, the study did not address the impact of the environmental aspect of sustainability on the system or its surroundings, as advocated in other previously used models. Rather, it strongly recommends and emphasizes the need to always drive the measurement of a sustainability index of healthcare with the actual statistical distribution of the sustainability indicators. However, since the study is premised on the positive and adequate perception of the users (patients and personnel) there is the need to further study how the indicated sustainability index would influence various business practices within the healthcare system. In another way, further works could be on the application of multivariate regression techniques to determine how each indicator contributes to variations in the sustainability index.

Chapter 6

DEVELOP A STATISTICAL MODEL FOR SOCIAL SUSTAINABILITY MEASUREMENT OF A SUPPLY CHAIN MANAGEMENT WITH INDEPENDENT EXPONENTIALLY DISTRIBUTED INDICATORS

6.1 Introduction

The Sustainable Development Goals (SDG), founded by the United Nations for defining targets and indicators for the UN 2030 Agenda, attracted global attention (Reis Monteiro *et al*., 2019). However, lack of appropriate indicators was a major criticism, as well as a model for measuring sustainability (Kapera, 2018). Currently, the definition of sustainable development is dealing with old theories and developing new methods for evaluating the interdependence between economic and social development to considering the environment (Everard and Longhurst, 2017). The issues surrounding sustainability are now becoming more germane than it was in the past years. The Millennium Development Goals (MDG) as reported by Bird & Rowlands (2017) made it incumbent on all the countries of the world to ameliorate some damages that fulfilled in terms of economies and people. It has become necessary for everyone, either as a business owner, Government, and/or as major stakeholders to ensure improvement in all facets. Therefore, based on the studies of Wilcox *et al*. (2016) and Dimond and Webb (2017), various concepts of sustainability based on three independent perspectives on economic, environmental and social point of views have surfaced. However, it has been discovered that significant efforts on the application of economic and the environmental dimensions in sustainability assessment have been abandoned, while the social aspect had been mostly ignored (Ehrgott *et al*., 2011; Pfeffer, 2010). Emphasis has been laid on the assessment of environmental business sustainability (Moreno, 2013). Meanwhile, the study of Ameer and Othman (2012) had reported additional challenges due to the emergence of the new business strategies; and this has necessitated corporate sustainability and sustainable management researches in all facets of sustainability. Although the majority of research questions have been associated with financial objectives of organizations, studies of Carroll and Shabana (2010), Epstein and Roy (2014), Salzmann *et al*. (2005), Schaltegger and Burritt (2018), have been conducted to ascertain how a company could build-up linkages throughout environmental management and social features in a manner that fosters corporate economic efficiency.

Rasouli and Kumarasuriyar, 2017 liken social sustainability to the capability to find reasons in creating and experiencing the value of existence intellectually, emotionally, spiritually, and physically. This, if achieved would be a true reflection of how people are responsive toward the societies business-wise or in another facet of the society (Reis Monteiro *et al*., 2019). Invariably, it is absolutely proper to adopt the theory discussed in Villeneuve *et al*. (2017), that social sustainability is the only tool for assessing the quality of life and could help in decision-making. This study will painstakingly and concisely expose how stakeholder theory can be used to appraise the social sustainability of a healthcare system. Huge legitimacy has been given to social sustainability in the past decade due to a significant change in perception that surfaced in both public and private settings. This is a result of various degrees of responsibilities that have placed on them with the growing economy as well as an increase in the utility requirements of both human and the society. These have grabbed the attention of stakeholders and business owners and showed them the need to redesign the current clumsy-like configurations in order to ensure optimal delivery, even in the face of the dwindling economic and social preferences (Xian *et al*., 2018; Singh *et al*., 2019; Lamberton and Zhou, 2019; Soma and Polman, 2018).

We propose the social sustainability of a healthcare due to its strategic influence on the quality of life, as we know the popular saying that “health is wealth”. The central focus of the healthcare supply chain is the patients; however, this objective will be difficult to achieve if the social roles of other stakeholders are ignored. Synergy surrounded by clients and providers must be put first above the mind of how to treat the patients. According to Eizenberg and Jabareen (2017), researches in the social facet of sustainability are scanty and grossly lacking, theoretical and empirical outputs.

The enablers and barriers of various stakeholders within the healthcare system are yet to be deciphered technically and analytically despite different views to adopt and emphasize social sustainability (Maruthappu *et al*. 2015; Ajmal *et al*., 2018; Karamat *et al*., 2019). According to the studies of Mani *et al.* (2015), it could be said that the nonchalant attitude of the developing countries toward healthcare social sustainability is evidently shown in the high rate of maternal mortality, gender inequality and general health problems that have been ravaging the quality of healthcare delivery in those countries. Most of these problems are due to the ignorance and lip-service paying to the issues of social sustainability in the logistics supply chain of drugs and other areas. Therefore, stakeholder theory found its way among prominent and commonly used theoretical techniques by many researchers and this theory led to important hedges in dimensioning sustainability (see Clark *et al*. 2014; Baric, 2017; Alves and Rodrigues, 2018; Carrol and Brown, 2018).

The field of .healthcare services has much potential for further studies on the interactions between the environment and the human factor. For this reason, the need to pay attention to this vital connection has been of interest to scientists and researchers (Daughton, C. G., 2014).

This chapter has some original and new points. In fact, there are several investigations related to the analysis of sustainability. Some of them are related to statistical methods, but little focus has been made on the effect of statistical distributions on sustainability value. This paper has tried to fill this gap by developing a novel model for measuring the social sustainability of involved stakeholders in a supply chain. Different from the previous studies, the application and extension of this model will allow to focus on the fit ability of statistically meaningful distributions to challenge and capacity indicators. Furthermore, this new vision (involving statistical distribution to sustainability measurement) makes this methodology flexible and applicable to different contexts.

The remainder of this chapter after the introduction in Section 6.1 is structured as follows. Section 6.2 presents a brief literature review. Section 6.3 addresses the research methodology where the conceptual framework for the proposed the exponential distributed sustainability model with the rationales for the selection of enablers and barriers, the exponential model for the social sustainability of the healthcare system, and the validation procedure for the exponential distribution is exposed. The numerical illustration of the model is presented in Section 6.4. Results and discussion are given in Section 6.5. Section 6.6 presents the conclusion.

In the last few decades, the concept of sustainability has been discussed in managing resources in different areas including economic, environmental, and social. (Ashby *et al*., 2012). Sing *et al*. (2019) have added the fourth dimension as stakeholders in those three areas and applied hierarchical pathway trading for finding vitality and magnitude of factors. Social sustainability is considered less important in supply chain management; (Klassen and Vereecke 2012) presented the three levels of social supply chain as (I) who – stakeholders, (II) which issues – social concerns influencing the organization and (III) how – the responsiveness of the management to these concerns in terms of manipulating the attendant risks and enhancing the value added to the customers. Mani *et al*. (2016) reported dimensions such as equity, safety, health and welfare, philanthropy, ethics, and human rights as those highly germane for assessing the social sustainability supply chain. More so, Mani *et al*. (2015), Sodhi and Tang (2018) all opined that this will be followed by customers' needs, liquidity, and the social awareness level of the organization. Incorrect application of these social features could lead to colossal losses for the organization (Mani *et al*., 2016). Puska *et al*. (2018) have noticed the importance of sharing information for developing organizational learning inside a supply chain. With the recent submission of Mani *et al*. (2018) that social sustainability has a high propensity to increase the efficiency of the supply chain, managers have deemed it necessary to integrate several dimensions to the issues of sustainability in a supply chain (Marshall *et al*., 2015). Business requires reporting some of their corporate social sustainability as suggested in Tate *et al*. (2010). Unfortunately, few studies have been conducted to report social sustainable supply chain (Pfeffer, 2010; Ehrgott *et al*., 2011; Badri Ahmadi *et al*., 2017) and this has called for proactive steps to further explore the supply chain in the social content perspective (Morais and Silvestre., 2018).

Over the last decade, the healthcare system has witnessed stiffest competitions due to the huge influence of the patients and the quest to provide quality healthcare services (Samuel *et al*., 2010; Castro *et al*., 2017). Presently, the system is faced with the emerging and evolving challenges of new circumstances related to risks and twists in the known disease. It can be noted that the human element is sacrosanct at managing the healthcare process (Santilli and Vogenberg, 2015). Roy *et al*. (2018) have developed a new model for measuring hospital service quality for finding priorities of internal and external factors; they realized that in this area, medical staff with professional abilities is the most important one. Previous studies (Griffith *et al*., 2006; Huibin SHI, 2014; Grembowski *et al*., 2002) have proven beyond doubt that interactions with external suppliers, inter-organizational, physicians, and their patients, as well as intro-organizational interactions, team members' relationships, supervisor-member relationships, and employee-organization relationships, are all necessary factors. No research has fully exposed or examined how these relationships are linked together in the framework of the service supply chain. Additionally, past research has also failed to examine the influence of enablers and barriers on social sustainability. Ajmal *et al*. (2018) suggested that to implement social sustainability across any supply chain, both the enablers and barriers of the social aspect of the specific organization must be thoroughly considered. We propose to employ this strategy in measuring the social sustainability supply chain of a healthcare system.

As earlier stated, the stakeholder theory is the most formidable framework of sustainability measurements. The majority of researchers supported the assertion that social sustainability and the stakeholder theory are consistent (Perrini and Tencati. 2006; Collier *et al*., 2014; Bellantuono *et al*., 2016; Herazo and Lizarralde, 2016). Therein are the criteria for identifying which of the stakeholders to be engaged in a particular organization. (Veralg, 2018) opined that the legal tendency, power, and relevance to the issues pertaining to sustainability features of the stakeholders could be the criteria for selecting appropriate stakeholders. Many other strategies, normative frameworks, guidelines and standards for choosing stakeholders have been proposed by various authors (see Roloff, 2008; Molteni and Pedrini, 2010; Konrad *et al*. 2006). Recently, some authors (O'Higgins, 2010; Gomes *et al*., 2015) gave a vivid and clear description of some frameworks by explaining what the organizations do to reach the social sustainability.

In some frantic efforts made to achieve healthcare organizational goals, rapt attention and strict priority are given to stakeholders (Bulgacov, 2015). It is believed that proper cognizance to the social exchange within the system is capable of reducing the barriers toward attaining overall sustainability. Huge benefits are availed healthcare practitioners through imbibing social interactions within the others is the ability to gain peoples' trust and credence and to extend and deepen internal and external cooperation (Fawcett *et al*., 2008). The stakeholder theory; Agudo-Valiente (2017) and Schaltegger (2017) argued that contraction to the economic and other resources are the bane and fundamental barriers to attendant risks and enhancing the customers' worth the sustainability. For Pagell and Wu (2009), the misalignment of those resources is the major reason for the inadequate execution of social issues and techniques. The aforementioned drawbacks, prompted most organizations to force suppliers to reduce prices, for instance, as put by Wong *et al*. (2017), in spite of the huge financial burdens of the healthcare system in China, the government still keeps reducing its financial obligations to the system and consequently, the citizens are made to pay more. Ludlow *et al*. (2017) presented another dimension to the barriers; the workplace culture as a serious hindrance to healthcare sustainability. Therefore, misalignment in codes of conduct and other sundry local culture, as well as disagreements among the suppliers as a barrier to social issues toward sustainability has been reported (Walker and Jones 2012).

Two dimensions to social sustainability have been utilized in literature, both internal and external. Ahmad and Thaheem (2017), Gollan (2007), Kaminsky and Javernick (2014), Pfeffer (2010) all described, internal social sustainability as an intention to manage and prioritize human resource, organizational design, and change management processes. In this sense, social sustainability refers to safeguarding and developing internal organization in terms of human and social capital. External aspects of the social sustainability deal with the issues related mainly to strategic management processes and to public perception report (Popovic and Kraslawski, 2018). These two techniques have further explained social sustainability as a means to give back to society rather than just exploiting the available resources (Docherty *et al*., 2009). Summarizing the concepts, internal aspects significantly deals in defining the possibility and finding ways to secure and reproduce human and social capital within the organization. External aspects see the relationships across organizational lines where social resources and regeneration could be exchanged seamlessly and effortlessly.

To assess and measure the sustainability of an organization (manufacturer or service oriented) or to move towards sustainability, there is a common concern about using measurable indicators among scientists, decision makers, institutional and industrial managers (Peixoto *et al.*, 2016). Indicators must be capable of focusing on the targets. Coincidentally, for applicability of indicators, finding the appropriate number of related indicators is a vital pattern in sustainability measurement methods (Atanda, 2019). The importance of the need to define the appropriate indicators that can be measured at intervals is not superficial. The areas that are to be covered by these indicators have been discussed by practitioners and researchers (Fang *et al.*,2018). Involving stakeholders in finding indicators and choosing the method of sustainability assessment will increase the reliability of results (Collier *et al*.,2014).

The contribution of this chapter is to facilitate the measurement of the social sustainability in a healthcare system based on the stakeholder theory and perspectives by establishing the statistical distribution of those sustainability factors, against the previous studies where the assumption of a particular statistical distribution have been continuously used and reported.

6.2 Research methodology

6.2.1 Conceptual framework

This study averred its concept on the social sustainability aggregation in each area of healthcare as highlight previously. Donaldson and Preston (1995), Lambooij (2013), and Leviton and Melichar (2016) have described stakeholder as an entity that can greatly influence or can be affected by the output of the common organizational objectives. The recent report of Varsei *et al*. (2014) opined that despite of many existing social and environmental sustainability pieces of research based on the stakeholders have been restricted to the supply chain manufacturing sectors. The current study proposes Figure 6.1 as the conceptual framework on the basis of four mutually related stakeholders to evaluate the sustainability of a healthcare supply chain of Suppliers, Employees, Community/Patients, and Owners/ Government as reported by Khan *et al.* (2018) and one more element as Patient relatives. Stakeholder theory as advocated by Donaldson and Preston (1995), Carter and Easton (2011) is employed with the view of exploring, evaluating, and measuring the healthcare social sustainability from the dimension of the participating stakeholders. These key areas of healthcare should be considered is driving decision with the process according to previous studies: stakeholders/customers as discussed by Phillips (2013), employees explained by Sarkis *et al.* (2010). So far, stakeholder theory has not been applied to analyze healthcare social sustainability on the basis of all the stakeholders. This study seeks to integrate the social sustainability perspective of all the stakeholders involved. A survey-based empirical data collection method is adopted to analyze the proposed framework.

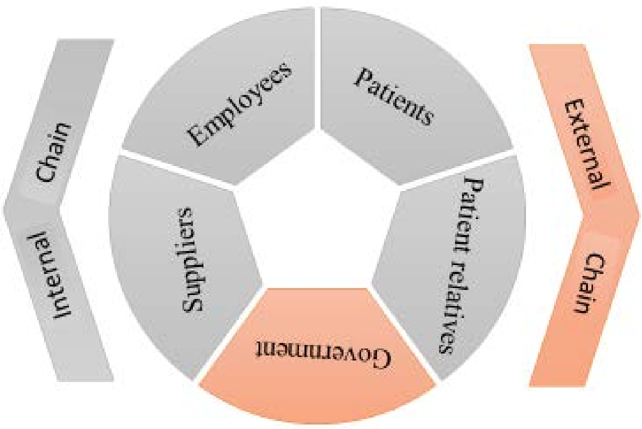


Figure 6.1: Research conceptual framework

6.2.2 Rationales for enablers and barriers selection for the social sustainability evaluation

Table 6.1 presents various rationales for selecting enablers and barriers for appraising and measuring the social sustainability of a healthcare system guided by its identified supply chain elements of suppliers, customers, employees, and government/owners.

6.2.3 Model for exponential distribution of healthcare supply chain

Sequel to the submission of Khosravi *et al*. (2019) that system's factors can enable and also inhibit its progress, this study imbibing this concept poses enablers as those that improve the capacity of the healthcare system toward sustainability while its struggle over some challenges and barriers as those negating the attainment of social sustainability. The proposed exponentially distributed healthcare sustainability model is built of the basic capacity; C is greater than the attendant challenges H, with the view of moving the healthcare system toward sustainability.

Table 6.1: Rationales for enablers and barriers selection for the social sustainability evaluation of a healthcare system

S/N	Supplier	Patients	Patient relatives	Employee	Government
1	Understanding of the cultural values and integrity of the hospital and its surrounding	Ability to assess and decide on the activities of the healthcare providers	Availability of a healthy workplace	Availability of adequate resources, equipment, and technology-driven healthcare gadgets	The commitment of the leadership to the healthcare of the populace
2	The rate performance of the supplier balance sheets and demand uncertainty	Available resources at their disposal for healthcare	Ensuring effectiveness of comments	Poor working conditions and terms of service	Poor management of socio-economic policies and regulations
3	Ability to liaise with classified service providers and partners	High resistance to change	Satisfaction with the behavior of medical staff with patients	Poor management and unreliable leadership support	Diversity of the populace culturally and ethically
4	Level of training and experience to cope with pressure from manufacturer and customers	Healthcare quality and reliability concern	Access to easy payment system during treatment and patient clearance	Ambiguous rules of engagement and empowerment	Incoherent healthcare plans and structure on the basis of lack of consensus and agreement among various arms
5	Capability to foster sustainability issues	Patient-healthcare provider relationship	Availability and easy access to facilities (entrance, lobby, staff assistance, and services)	Work monotonous and capable conflict of interests	The level of commitment to the Green supply chain culture
6	Adequate coordination, Collaboration, and management of its systems	Level of health Education and awareness	Accessibility to meaningful information	General organizational management	Perceived image and reputation of the head of leadership
7	Adequate facilities for promoting healthy Communication and up-to-date information and Feedback	Ethno religion and cultural values –ego and beliefs	Easy access to technological components, including internet, television, computer	Capable of offering services that can enhance customers' Satisfaction	Inadequate budgetary provisions to appropriate various healthcare incentives
8	Sense of humor toward corporate social obligations	Inadequate communication between and within various organs of the healthcare providers	Promoting caring connections between patients and relatives	The flexibility of the workplace, equal opportunity, and fairness	Bad implementation of policies and regulations
9	The propensity for total quality management	High concerns for safety and security of life	The behavior of staff to reduce anxiety and stress of patient relatives	Reward in consonant with productivity and output	Sponsoring of various health education and awareness programs
10	Awareness of the needs of the community and the ability to measure success yet	Issues related cost pressure and constraints	Easy access to the patient in emergency cases	Proper dispensation of policies and regulations	Perception, beliefs, and commitment to issues relating to social sustainability

Hence, from the aforementioned assertion, the probability of capacity greater than the company's challenges. Therefore, Equation 6.1 is used to express sustainability as follows:

$$\mathrm{Sus} = P(H < C) = P(H - C < 0) = P(Y < 0) \quad (6.1)$$

The model further obtains the probability in Equation 1 through a probability density function for capacity and challenge factors as in Equation 2, where λ_1 *and* λ_2 as the exponential parameters:

$$\mathrm{pdf} = \begin{cases} f(h, \lambda_1) = \frac{1}{\lambda_1} e^{-h/\lambda_1} \\ f(c, \lambda_2) = \frac{1}{\lambda_2} e^{-c/\lambda_2} \end{cases} \quad (6.2)$$

Thus, Equation 3 the Cumulative Density Function (CDF) of Y, $F_Y(y)$ Is piecewise, when $y \leq 0$ or $y > 0$

$$F_Y(y) = P(Y \leq y) =$$

$$\begin{cases} \int_0^{\infty} \int_{h-y}^{\infty} f_{H,C}(h, c)dcdh = \int_0^{\infty} \int_{h-y}^{\infty} (\lambda_1 e^{-\lambda_1 h})(\lambda_2 e^{-\lambda_2 c})dcdh = \frac{\lambda_1 e^{\lambda_2 y}}{\lambda_1 + \lambda_2} & y \leq 0 \\ 1 - \int_y^{\infty} \int_0^{h-y} f_{H,C}(h, c)dcdh = 1 - \int_y^{\infty} \int_0^{h-y} (\lambda_1 e^{-\lambda_1 h})(\lambda_2 e^{-\lambda_2 c})dcdh = 1 - \frac{\lambda_2}{\lambda_1 + \lambda_2} e^{-\lambda_1 y} & y > 0 \end{cases} \quad (6.3)$$

By differentiating Equation 3 with respect to y, probability density function is achieved as:

$$f_Y(y) = \begin{cases} \frac{\lambda_1 \lambda_2}{\lambda_1 + \lambda_2} e^{\lambda_2 y} & y < 0 \\ \frac{\lambda_1 \lambda_2}{\lambda_1 + \lambda_2} e^{-\lambda_1 y} & y > 0 \end{cases} \quad (6.4)$$

Finally, Equation 6.5 can be used for finding the exact value of sustainability:

$$\mathrm{Sus} = P(H < C) = \begin{cases} \int_{-\infty}^{0} \frac{\lambda_1 \lambda_2}{\lambda_1 + \lambda_2} e^{\lambda_2 y} dy \\ \int_0^{+\infty} \frac{\lambda_1 \lambda_2}{\lambda_1 + \lambda_2} e^{-\lambda_1 y} dy \end{cases} \quad (6.5)$$

An exponentially distributed variable deals with the time of an event or time between two events. Sustainability is defined as the probability that challenge factors cannot surpass capacity factors and In Equation 6.1, we assumed variable Y is the difference between challenge and capacity factors, so for calculating the value of sustainability we should use the negative side of Y in Equation 6.5.

6.2.4 Chi-square goodness of fit test for checking the fit ability of statistical distributions to data

In many statistical models, we are interested in the testing capability of fitting one of the statistical distributions to the data related to a process, which is extracted from the historical data of that process. The goodness of fit test is a non-parametric method that shows the ability to perform this task well and accurately. We perform a Chi-square goodness of fit test for checking the fit ability of exponential distribution to challenge and capacity indicators corresponding Chi-square values.

This test is well-suited for continuous and categorized data. To find the number of intervals from the square root of observations and also to find class interval, the range of data divided by the number of intervals has been used.

The goodness of fit test requires the analyst to state a null hypothesis H_0, and an alternative hypothesis H_1, the hypothesis is based in a way that they are mutually exclusive. It means that accepting one of hypothesis, makes it impossible to accept another; and conversely.

Step 1: The first step is to state the null and alternative hypothesis to be tested clearly. Hypotheses are:

$H_0 = \text{Distribution of indicators is exponential}$

$H_1 = \text{Distribution of indicators is not exponential}$

Step 2: After establishing the hypothesis, the decision about choosing a level of significance must be taken. Confidence level with which the null hypothesis is accepted or fail to accept. The standard value for α is 0.05.

Step 3: After the hypothesis are constructed, and the significance level is decided upon, the next step is to specify an appropriate test statistic and its distribution and also finding the p-value (Asymp. Sig.).

Step 4: Making a decision about rejecting H_0 or fail to reject H_0 considering the p-value (Asymp. Sig.). According to the definition, the p-value (Asymp. Sig.) is the smallest amount of probability that leads us to reject H_0, it means that the null hypothesis H_0 will be accepted for all values of α less than the p-value(Asymp. Sig.).

Step 5: Once all the steps are performed, the statistical conclusions can be drawn, and we can make our decision. If the result of the test, fails to reject H_0, this conveys that specific statistical distribution is fit able to our data.

6.3 Numerical illustration

To demonstrate the proposed model, general hospital in Tehran is considered. This is the largest government hospital located within the municipality of Tehran with an average population of 10,000,000. Various wards of the hospital, which are male, female, accident and emergency, surgical, children and maternity can accommodate 60, 60, 15, 20 and 80 patients respectively. The five (5) elements of the proposed healthcare supply chain are shown in Figure 2. The challenge and capacity factors based on the social enablers and barriers evaluated for each element are presented in Table 6, 2. The value of each capacity and challenge factor per element is determined and measured in time.

Table 6.2: Challenge and capacity factors of the elements of the healthcare system from stakeholders' perspectives.

S/N	Supplier	Patients	Patient relatives	Employee	Government & Decision Makers
Enablers	1- Time between two complaints from patients about the quality of drugs	1- Time between two complaints from fellows of patients about the long queue at the pharmacy	1- Time between two complaints from relatives about the availability of internet	1- Time between two wrong perceptions	1- Time between two orders of category A drugs (in ABC analysis)
	2- Time between two recalled products	2- Time between two complaints from patients about the long lead time	2- Time between two complaints from relatives about the behavior of staff	2- Time between two complaints from patients about employee's conducts	2- Time between two complaints from employees about working conditions
	3- Time between two complaints from customers about the packaging of drugs	3- Time between two complaints from patients about cleaning and hygiene	3- Time between two complaints from relatives about healthy workplace	3- Time between two lost working days, due to occupational accidents, injuries and illness	3- Time between two complaints from patients or fellows about expensive healthcare
Challenges	1- Response delay, which reflects the difference between the requested delivery day and the negotiated day	1- Waiting time for clinic appointments or specialist treatment	1- Waiting time in payment system during the patient clearance	1- Time between request and receipt of a loan or advance payment of a portion of the salary	1- Average time between invoice to stock sale`s money
	2- Delay, which reflects the difference between the actual delivery day and confirmed delivery day	2- Waiting time for inpatient services (radiology, lab reports, and medication)	2- Waiting time for taking an appointment in emergency cases	2- Time is taken for acceptance sampling of each batch with consideration of quality	2- Time is taken for each checkout
	3- Time is taken between two deliveries on the agreed day	3- Waiting time for operation in case of emergency	3- Waiting time to visit doctors and nurses, according to preferences	3- Time is taken for sorting & shelving of each batch with consideration of quality	3- Time between converting an unsatisfied employee to satisfy employee

The SPSS results of the determination and validation of the exponential distribution are presented in Tables 6.3-6.7.

Table 6.3: Exponential distribution determination and validation of Supplier

Capacity- Supplier

	Observed N	Expected N	Residual
1	28	27.6	0.4
2	20	17.5	2.5
3	8	10.9	-2.9
4	8	6.5	1.5
5	2	4.4	-2.4
6	2	2.2	-0.2
7	2	1.5	0.5
8	1	0.7	0.3
9	1	0.7	0.3
Total	72		

Challenge- Supplier

	Observed N	Expected N	Residual
1	49	41.6	7.4
2	23	23.8	-0.8
3	11	13.9	-2.9
4	6	7.9	-1.9
5	5	5.0	0.0
6	1	3.0	-2.0
7	1	2.0	-1.0
8	2	1.0	1.0
9	1	1.0	0.0
10	1	1.0	0.0
Total	100		

Test Statistics

	Capacity- Supplier
Chi-Square	3.180
df	8
Asymp. Sig.	0.923

Test Statistics

	Challenge- Supplier
Chi-Square	5.226
df	9
Asymp. Sig.	0.814

Table 6.4: Exponential distribution determination and validation of Patient

Capacity-Patient

	Observed N	Expected N	Residual
1	30	31.3	-1.3
2	27	21.1	5.9
3	13	13.8	-0.8
4	4	9.2	-5.2
5	8	5.5	2.5
6	2	3.7	-1.7
7	2	2.8	-0.8
8	2	1.8	0.2
9	1	0.9	0.1
10	2	0.9	1.1
Total	91		

Challenge-Patient

	Observed N	Expected N	Residual
1	32	27.0	5.0
2	17	20.0	-3.0
3	10	14.0	-4.0
4	8	11.0	-3.0
5	12	8.0	4.0
6	4	6.0	-2.0
7	3	4.0	-1.0
8	4	3.0	1.0
9	5	2.0	3.0
10	2	2.0	0.0
Total	97		

Test Statistics

	Capacity-Patient
Chi-Square	8.036
df	9
Asymp. Sig.	0.531

Test Statistics

	Challenge-Patient
Chi-Square	11.087
df	9
Asymp. Sig.	0.270

Table 6.5: Exponential distribution determination and validation of Patient relatives

Capacity-Patient relatives

	Observed N	Expected N	Residual
1	31	29.7	1.3
2	18	20.1	-2.1
3	15	13.6	1.4
4	10	9.2	0.8
5	3	6.2	-3.2
6	7	4.2	2.8
7	1	2.8	-1.8
8	2	1.9	0.1
9	2	1.3	0.7
10	1	0.9	0.1
Total	90		

Challenge-Patient relatives

	Observed N	Expected N	Residual
1	37	29.6	7.4
2	25	21.7	3.3
3	10	15.9	-5.9
4	8	11.7	-3.7
5	9	8.6	0.4
6	3	6.3	-3.3
7	3	4.6	-1.6
8	5	3.4	1.6
9	4	2.5	1.5
10	2	1.8	0.2
Total	106		

Test Statistics

	Capacity-Patient relatives
Chi-Square	3.180
df	8
Asymp. Sig.	0.923

Test Statistics

	Challenge-Patient relatives
Chi-Square	5.226
df	9
Asymp. Sig.	0.814

Table 6.6: Exponential distribution determination and validation of Employees

Capacity- Employees

	Observed N	Expected N	Residual
1	30	26.9	3.1
2	14	17.2	-3.2
3	10	11.2	-1.2
4	8	6.7	1.3
5	7	4.5	2,5
6	1	3.0	-2,0
7	1	1.5	-0.5
8	1	1.5	-0.5
9	2	1.5	0.5
Total	74		

Challenge- Employees

	Observed N	Expected N	Residual
1	27	33.8	-6.8
2	26	22.9	3.1
3	19	15.5	3.5
4	11	10.5	0.5
5	7	7.1	0.1
6	3	4.8	-1.8
7	2	3.2	-1.2
8	3	2.2	0.8
9	1	1.5	-0.5
10	2	1.0	1.0

Test Statistics

	Capacity- Employees
Chi-Square	4.553
df	8
Asymp. Sig.	0.804

Test Statistics

	Challenge- Employees
Chi-Square	7.845
df	10
Asymp. Sig.	0.644

Table 6.7: Exponential distribution determination and validation of Government & Decision Makers

Capacity- Government

	Observed N	Expected N	Residual
1	35	36.0	-1.0
2	24	24.4	-0.4
3	22	15.9	6.1
4	12	10.6	1.4
5	4	6.4	-2.4
6	1	4.2	-3.2
7	1	3.2	-2.2
8	3	2.1	0.9
9	2	1.1	0.9
10	1	1.1	-0.1
11	1	1.1	-0.1
Total	106		

Challenge- Government

	Observed N	Expected N	Residual
1	58	54.1	3.9
2	35	30.9	4.1
3	13	17.7	-4.7
4	8	10.1	-2.1
5	4	5.8	-1.8
6	1	3.3	-2.3
7	2	1.9	0.1
8	1	1.1	-0.1
9	1	0.6	0.4
10	1	0.4	0.6
11	1	0.2	0.8
12	1	0.1	0.9
Total	126		

Test Statistics

	Capacity-Government
Chi-Square	8.613
df	10
Asymp. Sig.	0.569

Test Statistics

	Challenge-Government
Chi-Square	16.087
df	11
Asymp. Sig.	0.138

Worthy of note is the significant level obtained for the capacity and challenging factors for each element. The output reveals that the significance values of both factors of all stakeholders are greater than the level of significance ($\alpha = 0.05$); at 0.923, 0.814, 0.531, 0.270, 0.799, 0.372, 0.804, 0.644, 0.569 and 0.138 for Suppliers, Patients, Patient relatives, Employees, and Government & Decision Makers respectively. It says that we fail to reject the null hypothesis to all factors and exponential distribution is fit able. Therefore, Equation 6.5 can be used to measure the social sustainability of the healthcare supply chain system. Applying the mean values of the factors as given in Table 8, the sustainability values of the healthcare system, according to the perception of each stakeholders is calculated by using Equation 5 as 47%, 60%, 59%, 75% and 56% for Suppliers, Patients, Patient relatives, Employees, and Government &Decision Makers respectively.

Utilizing the indicators in table 6.8 and Equation 6.4, the sustainability of the supply chain stakeholders was obtained according to Equation 6.5 as:

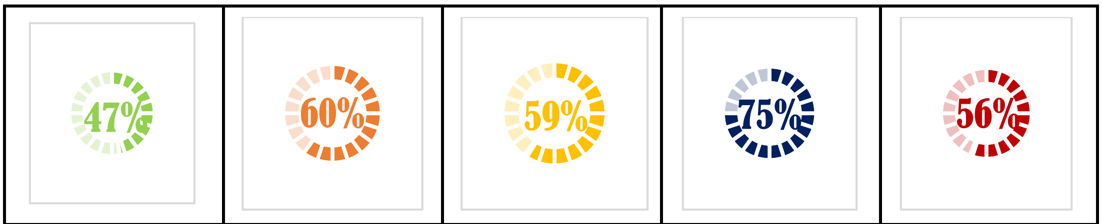
Sustainability= $\int_{-\infty}^{0} \frac{\lambda_1 \lambda_2}{\lambda_1+\lambda_2} e^{\lambda_2 y} dy$

For example, Social sustainability of supplier can= $\int_{-\infty}^{0} \frac{\left(\frac{1}{21.47}\right)\left(\frac{1}{18.93}\right)}{\left(\frac{1}{21.47}\right)+\left(\frac{1}{18.93}\right)} e^{18.93y} dy = 47\%$

Quantifying the contributions of each stakeholder toward the sustainability of the healthcare supply chain studied as advocated through the stakeholder theory, a progress chart in Figure 6.2 is presented.

Table 6.8: Mean value of capacity and challenging factors for measuring social sustainability of a healthcare provider (Hospital) in Tehran, Iran

	Mean value of variables		
Stakeholders	Capacity	Challenge	Social Sustainability Value
Supplier	18.93	21.47	0.47
patients	17.29	11.49	0.60
Patient relatives	15.29	10.33	0.59
Employee	22.62	7.71	0.75
Government	20.72	16.25	0.56



Supplier	Patients	Patient Relatives	Employee	Government

Figure 6.2: Progress charts of social sustainability values in stakeholders of the supply chain

6.4 Results and discussion

In sustainability measurement, there are two type of opposing factors: Capacity and Challenge.

Each organization by empowering capacities to overcome challenges can increase the value of sustainability. From Table 6.8 and Figure 6.2, the sustainability of the stakeholders varies with the employee having the highest value. This means the hospital under investigation is socially sustainable according to the perception of the employees. Overall the hospital is meeting the social yearnings of the employees. For the patients, a higher value equally indicates how patients, Patient relatives and other visitors appreciate the level of the social incentives and various supports provided to the patients and their relatives. The government assumed the fourth higher level of social sustainability. This necessities the evaluation of the same governmental interventions or incentives toward the hospital physicians, patients and the employees. Certainly, these values scored by the Government might be elusive if environmental and economic issues have been sacrificed for the development of social facet in a hospital. Obviously, the yearnings of both the employees and patients must have met by the Government to a reasonable extent. Intuitively, Governmental allocations must have been dissipated and influence the social ability of these two stakeholders.

On the aspect of the supplier, a lower sustainability value is obtained. Reasons not limited to bottlenecks from the hospital, Government and even the suppliers' staff could be a bane hindering the perceptions and low social traits within the supplier circle. Hindrances like bureaucracy within the Government functionaries toward appraising and selecting the adequate supplier, logistics issues from the supplier's side and delay in securing Local Purchase Order (LPO) from financial institution are capable of lowering the way the other two stakeholders perceived the supplier. Therefore, an unsatisfactory social incentive and supports from other stakeholders, especially the Government could be a serious clog in the wheel of the suppliers toward attaining social sustainability goals. It could be deduced that the huge impact of social activities cut across all the participating parties (stakeholders) irrespective of the projected sustainability value obtained for each of them. This implies adjusting just a factor from any stakeholder would produce a ripple impact on all other factors, thereby shifting the sustainability value of all the system. Therefore, holistic maneuvering or improvement of the overall sustainability index of the system is necessary. Another inference could be deducted a positive perception of all and sundry in the issues related to sustainability and also should learn to integrate social sustainability objectives within their mission and value statements. Depending on the prevailing conditions, it could be that mere scrutiny of a factor would lead to the reduction in the challenge loads resulting in an enhanced social sustainability trait.

6.5 Conclusion

The proposed conceptual framework is designed based on properties of exponential distribution and applied to measure the social sustainability for the majority of the stakeholders involved in a healthcare supply chain. In this way, challenge and capacity factors that summarized in table 6.2 selected and measured based on efficiency and the importance of the factors.

This is the first model to measure the social sustainability of a supply chain in the presence of exponentially distributed factors that can be applied in measuring the sustainability of supply chains in various domains. Hence, areas of priorities as identified by all stakeholders can be well focused. The onus is now on individual hospitals to rejuvenate their strategies in order to decipher which factors to be included and those that should be jettisoned. This will go a long way toward attaining high effectiveness of the model.

6.5.1 Implications

This proposed social sustainability exponentially distributed model is flexible, which could form a rigid framework for appraising and measuring the sustainability of today's organizations from different backgrounds. The special and easiest way to enhance the social ability and inclination of all stakeholders within the healthcare supply chain is to present them for training and restraining at all times. No doubt this study will assist the manager in taking an informed decision in accordance with the provisions of the prevailing supply chain. Another way to go is the advocate and foster diligent, equity, fairness and good cultural values among all the participating stakeholders with a view to better assist them to coordinate efficiently. The scope of the capacity and challenge of those areas could be expanded as:

- Planning for cutting-edge standards to care for the patient, diagnosis and surgical procedures, medicine-management and hygienic food supply.
- Using strict social criteria to firstly select suppliers.
- Reducing the ethical decadent and pushing for more transparent and all-inclusive governance that will make the Government be more accountable to their stakeholders.
- Encouraging the employee to freely express how they should be engaged in training that could enhance innovative thinking.

In future studies, issues such as the following should be investigated.

- Developing a model for indicators with other types of meaningful statistical distributions.
- The applicability of the identified capacity and challenge factors should be tested with applying methods of finding indicators priority.
- Various dimensions to compare and contrast with respect to the identified factors with other healthcare centers (hospital) in other localities is essential to generalize the applicability of the proposed framework.

Chapter 7

DEVELOP A STATISTICAL MODEL FOR SOCIAL SUSTAINABILITY MEASUREMTN OF A SUPPLY CHAIN MANAGEMENT WITH DEPENDENT EXPONENTIALLY DISTRIBUTED INDICATORS

7.1 Introduction

Decades ago, attention has been drawn to the issue of sustainability and many types of research on the studies of sustainability have been reported. Many pioneers of development, both in the industry, economic and corporate world have emphasized sustainability as the unique winning technique on competitive advantage between firms. It has become the hallmark of sustainable development of organizations through the firm's economic, environmental, and social dimensions (Lee and Jung, 2019). Sustainability performance measurement, assessment, and management have been addressed and reported in the literature; whilst many focused on the triple-bottom-line perspective of corporate sustainability- environmental, social, and economic. The other corporate sustainability technique includes psychological sustainability, which tends to incorporate social responsibility with corporate sustainability; it also, emphasizes the interrelationships among various sustainability perspectives. So many sustainability perceptions have been reported; this paper employs a wider perspective of stakeholders' expectations for sustainability assessment and measurement. It is of utmost importance to assess, measure and evaluate the sustainability performance of the company based on the multitude of stakeholders, chief executive officers, consumers and other prevalent factors such as the previous and current international organizations, regulators, and non-profit organizations just to mention a few. For the avoidance of doubt, sustainability performance measurement and assessment (SPMA) has been positioned as a vehicle for transporting relevant ethical behaviors of a company and is capable of promoting value creation for stakeholders through requisite information. In this way, therefore, many sustainability performance measurement techniques and tools have been deployed and applied in the last two decades (Silva *et al*., 2019).

Existing literature on sustainability issues in the supply chain management (SCM) has rendered other concepts such as sustainable supply chains, green supply chains, social supply chains, circular supply chain management (CSCM), and closed-loop supply chains either as a single or incorporated models to adequately express sustainability concepts in SCM. However, none of them these concepts systematically considered stakeholders' participation-integrated circular thinking (Farooque *et al*., 2019).

Researches in supply chain management (SCM) have been adjudged the most productive areas in management sciences. Mind-blowing results have been achieved from some cutting-edge supply chain (SC) researches ranging from natural resources, manufacturing goods, to the delivery to the consumers. There is no gainsaying that sustainable supply chain management (SSCM) has recorded an increasingly large number of research outputs. Traditionally, it was based on the environmental and economic aspects; however, social dimensions have been brought into the concept in 1994 through Elkington's introduced Triple Bottom Line (TBL) (Martins and Pato, 2019). In another instance, Silva *et al*. (2019) reported a situation whereby stakeholders seem dissatisfied with the status of sustainability despite the positive trends noticeable in various techniques for measuring and assessing sustainability performance.

In general, social values such as meeting basic needs, equal working conditions for all employees, fair pay, attention to cultural diversity, are the focus of social sustainability. Social sustainability could be assessed and measured in organizations based on a fair distribution of opportunities, assimilation of cultural diversity, development of communication within and outside of society, upgrading of living standards, revision of structures and their re-formulated to ensure equal opportunity allocation. In spite of the increasing popularity in all facets (academia and industry inclusive), there has not been found a suitable definition that could adequately describe the social sustainability. It is also worth noting that social sustainability is an aspect of sustainability that has received less attention among the TBL. More so, it has often been difficult to find the social determinants of sustainability for researchers in most cases. These lapses have hindered decision-makers in finding an accepted agreement of the technique and to expand its outlook (Lee and Jung, 2019). The role of stakeholder participation in sustainability managerial systems incorporation from the organizational points of view-both internal and extended has been thoroughly studied. According to stakeholder theory, a wider set of interests above shareholders' expectations encompasses organizations making satisfying stakeholders' demands to sustain a firm's legitimacy, resource availability, and competitive success so critical to attaining (Ferro-Soto *et al*., 2018).

Therefore, a proper understanding of stakeholders' expectations and knowledge of how they can be integrated into the management systems is essential to propel organization sustainability performances. Greenwood (2007) opined that the managerial role of stakeholder participation is a pointer to the responsibility to the society, and also an activity that strengthens a firm’s relationship with the stakeholders to develop corporate objectives. In a similar vein, other scholars (Heikkurinen and Bonnedahl, 2013; Matos and Silvestre, 2013) that have worked on the strategic value of stakeholders’ participation in the stakeholder management field have revealed that stakeholder participation and practices could also be motivated by adequate risk management, gain in competitive edge, adequate response to stakeholders' expectations, and improved managerial control. Ferri *et al*. (2016) gave an account of how these practices have been used to examine “how” and “why” supply chain managers could effectively process sustainable development; unfortunately, models for the determination of sustainable development techniques are absent.

This chapter focuses on a measurable model of social sustainability in the supply chain in the company of dependent variables considering the chain stakeholders. Khosravi *et al*. (2019) introduced a statistical model to measure bottom-line sustainability at the organizational level while challenge and capacity variables adhere to an exponential distribution, and the model by Khosravi and Izbirak (2019) was developed to calculate the sustainability of a .healthcare supply chain with Stakeholder approach. This study is, however, an extension of these previous works to embrace common sense schemes that were not kept in mind previously.

One of the basic assumptions in the model introduced by Khosravi *et al*. (2019) was that there is no dependency between the factors affecting sustainability (challenges and capacities) and these factors are independently affecting the amount of sustainability. Many modeling applications have assumed the independence of variables for ease of operation (Brandenburg *et al*., 2014). However, to make decisions in more realistic situations, it may sometimes be necessary to consider the interdependence between the various factors affecting sustainability and to consider them in the calculations. Therefore, the need to introduce models assuming variable dependence should be taken into account. In response to this need, the proposed model addresses how the dependent variables affect the value of social sustainability in a supply chain, a topic that has not been considered in previous studies, including in Khosravi *et al*. (2019). It is worth noting that in measuring different aspects of sustainability, and in particular social sustainability, we often come across variables that act as dependencies. Limited attention has been paid to the importance of considering this correlation. (Hansen *et al*., 2018, Tantau *et al*., 2018). The key weakness in some of the previous measuring techniques is the interrelationships between sustainability measurement schemes that are usually ignored. Besides, sustainability measurement models based on statistical distribution rules at the organizational and supply chain levels have received much less attention. (Khosravi *et al*., 2019).

At this juncture, it expedient to be reminded that Stakeholder participation is an integral part of corporate social responsibility (CSR) with a tendency for improving decision making and accountability. Involving stakeholder views in assessing social, economic, and environmental sustainability are among the requirements that have been strongly recommended by the Global Reporting Initiative (GRI), which is responsible for defining and developing sustainability guidelines (Global Reporting Initiatives, 2013). Currently, the organization would require changing their objectives as well as their mode of operations due to the inclusive Stakeholder participation (Midin *et al.*, 2017). A stochastic sustainability measurement approach is introduced in this paper to answer the stated needs, which is the first model to measure the social sustainability of a supply chain in the sense of stakeholders in the presence of dependent and exponential variables. The model ultimately incorporates the issue of variable dependency on social sustainability factors. Also, this model can be used as a tool for comparing sustainability trends in supply chain management across many organizations. Provided the data necessary for applying the model is sourced, appropriated and published in the same manner for each company under investigation.

A summary of what is presented in the next sections is as follows. While reviewing the basic concepts is discussed in section 7.2. In section 7.3, some basic notions about copula function and how to use these functions to model extraction are discussed. A case study is used to compare sustainability values in independent and dependent cases in Section 7.4. Section 7.5 discusses the comparative results of applying the statistical model. Finally, Section 7.6 begins with a review of the main findings and concludes with a discussion of some of the possible improvements in future researches.

7.2 Motivations for research

Given the lack of replacement of a large portion of the resources consumed, social and economic activities must be undertaken to protect the environment as much as possible, implying the concept of comprehensive sustainability, although the social dimension has been less concerned with economic and environmental dimensions. For this reason, special attention is being paid to social goals and methods of measuring social sustainability (Tang and Zhou, 2012). Recently, potential models have been used by researchers as a reasonable approach to measuring sustainability (Brandenburg and Rebs, 2015).

The model presented in the previous work of Khosravi *et al.*, 2019 is one of the last probabilistic models for evaluating firm sustainability assessment of the Triple Bottom Line sustainability position. The model also distinguishes specific requirements for maintaining and enhancing the sustainability level, depending on the extent to which the indicators have improved or regressed. Khosravi and Izbirak 2019 in their study of social sustainability measurement of the .healthcare supply chain based on a stakeholder perspective theory assumed that the enabler and barrier factors were independent. Considering the requirements of supply chain stakeholders, they applied their model to assess the social sustainability of a .healthcare supply chain through a case study. The assumption of independence of the factors is violated in some real applications. Therefore, a probabilistic model of supply chain social sustainability that explicitly addresses the dependence of factors is developed in this paper and the results are compared. As mentioned in the introductory section, the statistical method under study in this article is another approach of the model introduced by Khosravi and Izbirak, 2019. The two models differ in terms of the relationship between capacity factors and challenges. As in the original model, the assumption of factor independence was accepted, whereas in the current model the assumption was violated and the dependence of factors was taken into account. Considering the potential dependencies of the factors involved in measuring sustainability is the unique feature of the proposed model that leads to a more realistic approach to the sustainability performance of organizations and supply chains in the real world.

7.3 Proposed sustainability model

Sustainability measurement is vital to organizations and supply chain owners. In simple terms, it considers challenge and capacity factors, which are subjected to H and C. If H and C are regarded as random variables, then the probability of challenges will be smaller than capacities is given by P (H < C) gives us sustainability. Statistical independence is usually assumed between the two random variables H and C: in this case, the literature on this topic is particularly rich. This strong assumption makes the calculation and estimation of the sustainability value more tractable. However, this hypothesis is not always verified in practice, and this translates into an over- or under-estimation of sustainability. To avoid this drawback, statistical dependence can be introduced and modeled between H and C, for example resorting to copulas. In some recent works, the problem of computing and estimating sustainability is considered when the challenge and capacity factors, belonging to the same parametric family of distributions, are linked by a specific copula.

The case when (H, C) follows an exponential distribution has been investigated by Khosravi *et al*., 2019 and Khosravi and Izbirak, 2019. In this study, a sustainability model is investigated with marginally exponential distributed and their dependence described by a Frank copula function. The problem of estimation of the sustainability parameter is considered when the Farlie-Gumbel-Morgenstern copula is used to link capacity and challenge factors, whose marginal distributions both belong to the exponential distribution. In this chapter, we further consider the computational issues related to this copula approach applied to the sustainability measurement model, when other families of copulas are selected.

7.3.1 Copulas

In probability terms, a multivariate distribution function, called Copula, can be used to find the joint difference distribution function of variables, assuming marginal distributions to be apparent as well as dependencies between variables. Describing the dependence between discrete or continuous variables is the ultimate goal of applying the Copula functions. The Sklar theorem states that a multivariate distribution function can be considered as a combination of marginal distributions and a copula. The general model is as follows:

$$F(x_1, \dots, x_n) = C(u_1, \dots, u_n)(F_1(x_1), \dots, F_n(x_n)) \tag{7.1}$$

In formula (1), $F(x_1, \dots, x_n)$, is joint cumulative distribution function of n variables, $F_1(x_1), \dots, F_n(x_n)$ are cumulative distribution functions of each variable, while $C(u_1, \dots, u_n)$ is referring to the n-dimensional copula.

If the involved variables following the continuous distribution functions (such as the exponential distribution that is the case in this study), then the unique Copula function can be calculated by the following (Yew Low *et al*., 2016).

$$C(u_1, \dots, u_n) = F(x_1, \dots, x_n)\left(F_1{}^{-1}(x_1), \dots, F_n{}^{-1}(x_n)\right) \tag{7.2}$$

Since this chapter focuses on the sustainability of a supply chain based on two variables (capacity and challenge), the n-dimensional space is reduced to 2-dimensional and so we have:

$$C(u_1, u_2) = F(x_1, x_n)\left(F_1{}^{-1}(x_1), F_1{}^{-1}(x_2)\right) \tag{7.3}$$

Different types of copula functions have been presented and studied by researchers in which elliptic copulas have been used to calculate the dependency parameter of the variables. The general form of the elliptical copulas is as follows:

$$C_\rho^{Ga} = \Phi_\rho\left(\Phi^{-1}(u), \Phi^{-1}(v)\right) \quad (7.4)$$

Which Φ^{-1} is an inverse function of the bivariate cumulative standard normal distribution with the coefficient (ρ) of dependence (Cameron *et al*., 2013).

The Frank, Clayton, and Gamble copulas are one of the most used copulas that are classified in Archimedean copulas. These models are explicitly used to represent the parameter of the correlation coefficient. Frank, Clayton, and Gamble copulas contain special and important types of copulas including independence copula $\prod(u, v) = uv$, comonotonicity copula $M(u, v) = \min(u, v)$, and countermonotonicity copula $W(u, v) = \max(u + v - 1, 0)$.

The following inequality can be shown for such a C (u, v) copulas (Tran *et al*., 2017):

$$\mathrm{W}(u, v) \leq C(u, v) \leq \mathrm{M}(u, v) \quad (7.5)$$

In the case of continuous random variables, the comontonicity copula for the two random variables have a perfectly positive correlation $\rho \rightarrow +1$, the countermonotonicity copula for the two random variables have the perfectly negative correlation $\rho \rightarrow -1$, and the independent copula is also defined for the fully independent random variables $\rho = 0$.

7.3.2 Joint difference distribution of dependent variables

If F and G are considered to be marginal distribution functions of challenge and capacity factors, then the sustainability value associated with a copula C is as follows:

$$\mathrm{P(H - C < 0)} = 1 - \int_0^1 C_1 \left(1 - w, G\left(F^{-1}(1 - w)\right)\right) dw \qquad (7.6)$$

Being $C_1 = \frac{\partial C(h,c)}{\partial h} = P(C \leq c|H = h)$

Dolati *et al*., (2016) showed that with an application of formula (6), the expressions of the joint difference distribution function have been explicitly or numerically found for some possible choices of F and G (namely, exponential) and the linking copulas (Farlie-Gumbel-Morgenstern, Frank, Clayton, and Gumbel).

In the next subsection, we examine the other kind of copulas and compute the sustainability parameter when challenge and capacity follow an exponential distribution.

7.3.3 Developed Farlie-Gumbel-Morgenstern copula for measuring sustainability

The Farlie-Gumbel-Morgenstern Copula function simply calculates the distribution of the capacity and challenge variables with respect to the correlation coefficient (Cossette *et al* 2013).

$$C(c, h) = ch\big(1 + \theta(1 - c)(1 - h)\big), -1 \leq \theta \leq +1 \qquad (7.7)$$

The following equation can be shown for the copulas in continuous form. Given the domain of θ, it will be the correlation coefficient (ρ) changes between $-\frac{1}{3}$ and $\frac{1}{3}$ that actually limits the use of the function to find the joint distribution in other boundaries of ρ. To overcome this limitation, the copula has been developed into various forms, one of which is as follows:

$$C(c,h) = ch + \theta c^a h^b (1-c)^a (1-h)^a, a, b \geq 1 \quad (7.8)$$

The extended cupola is covered by placing $a = 2$ and $b = 1$ larger ranges of θ variations between -1 and $+3$, making Copula's application of the correlation coefficient variations between $-\frac{1}{3}$ and $+1$ possible.

$$C(c,h) = ch + \theta c^1 h^2 (1-c)^1 (1-h)^2, a = 1, b = 2 \quad (7.9)$$

Conditional probability density distribution C_1 is easily obtained:

$$C_1 = \frac{\partial C(c,h)}{\partial c} = h + \theta h (1-h)^2 (1 + 3c^2 - 4c) \quad (7.10)$$

If the challenge and capacity factors comply with the exponential distribution with parameters λ_h and λ_c, and considering the following equations:

$$F^{-1}(w) = -\log(1-w)/\lambda_h$$

$$G(F^{-1}(1-w)) = 1 - w^{\lambda_c/\lambda_h}$$

The formula for the calculation of the sustainability parameter will be calculated according to Equation (7.6) and as follows:

$$\text{Sustainability} = 1 - \int_0^1 \left(1 - w^{\lambda_c/\lambda_h}\right) + \theta \left(1 - w^{\lambda_c/\lambda_h}\right) w^{2\lambda_c/\lambda_h} [1 + 3(1-w)^2 - 4(1-w)] dw =$$

$$1 - \int_0^1 \left(1 - w^{\lambda_c/\lambda_h}\right) + \theta \left(3w^{2(\lambda_c/\lambda_h)+2} - 2w^{2(\lambda_c/\lambda_h)+1} - 3w^{3(\lambda_c/\lambda_h)+2} + 2w^{3(\lambda_c/\lambda_c)+1}\right) dw = 1 -$$

$$\left[w - \frac{w^{(\lambda_c/\lambda_h)+1}}{(\lambda_c/\lambda_h)+1} + \theta \left(\frac{3w^{2(\lambda_c/\lambda_h)+3}}{2(\lambda_c/\lambda_h)+3} - \frac{2w^{2(\lambda_c/\lambda_h)+2}}{2(\lambda_c/\lambda_h)+2} - \frac{3w^{3(\lambda_c/\lambda_h)+3}}{3(\lambda_c/\lambda_h)+3} + \frac{2w^{3(\lambda_c/\lambda_h)+2}}{3(\lambda_c/\lambda_h)+2}\right)\right] \Big|_0^1 = \frac{1}{(\lambda_c/\lambda_h)+1} -$$

$$\theta \left(\frac{3}{2(\lambda_c/\lambda_h)+3} + \frac{2}{3(\lambda_c/\lambda_h)+2} - \frac{2}{(\lambda_c/\lambda_h)+1}\right) = \frac{1}{(\lambda_c/\lambda_h)+1} - \theta \left(\frac{(\lambda_c/\lambda_h)\left((\lambda_c/\lambda_h)-1\right)}{\left((\lambda_c/\lambda_h)+1\right)\left(2(\lambda_c/\lambda_h)+3\right)\left(3(\lambda_c/\lambda_h)+2\right)}\right) \quad (7.11)$$

For $\lambda_c/\lambda_h > 1$, i.e., if the expected value of C is smaller than the expected value of H, Sustainability is a decreasing linear function of θ; for $\lambda_c/\lambda_c < 1$, i.e., Sustainability is an increasing linear function of θ. When $\lambda_c/\lambda_h = 1$, Sustainability is constant and equal to 0.5. The range allowed to Sus is quite narrow; for example, when ${}^{\lambda_c}\!/_{\lambda_h} = {}^{1}\!/_{3}$, Sustainability goes from 0.73 to 0.79. If $\theta = 0$, Equation (11) comes down to the usual formula for two independent exponential distributions: Sustainability= $\frac{1}{{}^{\lambda_c}\!/_{\lambda_h}+1} = \frac{\lambda_h}{\lambda_c+\lambda_h}$.

The sustainability calculation model presented in the current study is the developmental model of previous work by Khosravi *et al.*, 2019 and follows the applicable definitions of the model. For example, the concept of sustainability in the organizational or supply chain application is: meeting the needs of the present generation, taking into account the right of the next generation to use those resources to meet their needs.

The assumed model focuses on the extent to which each of the supply chain stakeholders' approaches or departs from absolute sustainability. Thus, relying on the arguments presented in Khosravi *et al.*, 2019, homogenizing and considering potential supply chain stakeholders can provide a more realistic analysis of how supply chain sustainability behaves. Sustainability as a whole, as well as in any of the aspects of the supply chain, is affected by the challenges and capacity factors. Challenges reduce sustainability while capacities have an incremental effect, and the result is sustainability defined as the probability that the challenges cannot be larger than capacities. Because of the ability to assign different values to enablers and barriers, random variables and, consequently, probability density functions can be assigned to challenges and capacities, and finally, sustainability can be shown as follows. (Khosravi *et al*, 2019).

$$Sus = P_r(H < C) = \int_0^{+\infty} f_h(h) \left[\int_{h-y}^{+\infty} f_c(h) d_c \right] d_h \tag{7.12}$$

Assuming that the exponential distribution can be fit able to the challenges and capacities, it can be claimed that:

$$Sus = P_r(H < C) = \int_0^{+\infty} \lambda_1 e^{-\lambda_1 h} \left[\int_{h-y}^{+\infty} \lambda_2 e^{-\lambda_2 c} \right] d_h \tag{7.13}$$

In Equation (7.13) and also considering the correlation between the challenges and capacities inverters and concerning to Equation (7.11), the value of the sustainability in each of the Supply Chain Stakeholders is that the Supply Chain is likely to be strengthened by two. Overcome is:

$$Sus = P_r(H < C) = \frac{1}{(^{\lambda_c}/_{\lambda_h})+1} - 3\rho \left(\frac{\left(^{\lambda_c}/_{\lambda_h}\right)\left(\left(^{\lambda_c}/_{\lambda_h}\right)-1\right)}{\left(\left(^{\lambda_c}/_{\lambda_h}\right)+1\right)\left(2\left(^{\lambda_c}/_{\lambda_h}\right)+3\right)\left(3\left(^{\lambda_c}/_{\lambda_h}\right)+2\right)} \right) \tag{7.14}$$

Whereas ρ is the Pearson correlation coefficient between the variables affecting efficiency, namely capacity (c) and challenge (h).

These focal points derived from the previous approach introduced by Khosravi *et al*. (2019). In the previous model, the assumption of the independence of the variables is considered, while in the current model the effect of correlation between factors is taken into account. As noted earlier, in some applications of sustainability, there is a correlation between the factors (positive or negative) that were neglected in previous models, but need to be addressed. Therefore, this paper presents a model that is well-suited for calculating sustainability in the organization or supply chain in either the presence or absence of correlation between mines and capacitors. The model was used in a case study to measure the social sustainability of the supply chain with the stakeholder approach in the presence of dependent factors and the results were compared.

7.4 Rational utilization of the model

In the sequence of illustrating the applicability of the proposed model, data related to the case study of Khosravi and Izbirak, 2019 are used in this section and the correlation coefficient of each of the supply chain stakeholders was calculated from the relevant data.

Table 7.1: The calculated values of the parameters taking into account the dependent variables

Parameter	Stakeholders of supply chain				
	Supplier	Patients	Patient relatives	Employee	Government
$\mu_c = \frac{1}{\lambda_c}$	18.93	17.29	15.29	22.62	20.72
$\mu_h = \frac{1}{\lambda_h}$	21.47	11.49	10.33	7.71	16.25
ρ_{ch}	-0.0809	-0.2964	0.2082	0.6567	0.5390

By taking the values of table 7.1 in formula 7.3, the values of social sustainability can be calculated for each supply chain stakeholder in the presence of dependent variables. The comparative results are reflected in Fig.7.1.

As can be seen in Figure 7.1, neglecting negative dependencies leads to overestimation of the true value of sustainability, while less than the true values occur in positive dependencies. It is noteworthy that the increasing or decreasing amount of these correlations increases or decreases the magnitude of this difference (sustainability in independent and dependent states). For example, in Figure 7.1, ignoring the negative correlation between the challenges and the capacities of the suppliers and the patients leads to an estimate of less than the actual value, while ignoring the positive correlation between the factors of the patient relatives, employee, and government leads to an estimate of less than. The maximum difference is in the employee's face, which is the sum of the coefficients and the capacities more closely correlated with the other factors.

Consideration of sustainability differences (even minor differences such as 0.06% for Supplier) is very important in any aspect of the supply chain stakeholders, as these very small changes can affect the supply chain decision-makers' tactics. Therefore, a sustainability measurement model should be based on considering the correlations between factors.

Using factor values as well as the relationship between the factors in Table 7.4 and Equation (7.14), the sustainability of each stakeholder in the supply chain is obtained and is illustrated in Figure 7.1. For example, calculating the social sustainability of the supplier is as follows:

$$\frac{1}{\left({\lambda_c}/{\lambda_h}\right)+1} - 3\rho\left(\frac{\left({\lambda_c}/{\lambda_h}\right)\left(\left({\lambda_c}/{\lambda_h}\right)-1\right)}{\left(\left({\lambda_c}/{\lambda_h}\right)+1\right)\left(2\left({\lambda_c}/{\lambda_h}\right)+3\right)\left(3\left({\lambda_c}/{\lambda_h}\right)+2\right)}\right)$$

$$= \frac{1}{({21.47}/{18.93})+1}$$

$$- 3(-0.0809)\left(\frac{({21.47}/{18.93})\left(({21.47}/{18.93})-1\right)}{\left(({21.47}/{18.93})+1\right)(2({21.47}/{18.93})+3)(3({21.47}/{18.93})+2)}\right)$$

$$= 0.4692 = 46.92\%$$

Moreover, it should be re-emphasized that given the dependence between many social factors in the real world, such dependence mustn't be overlooked when assessing the sustainability performance of supply chains under the social sustainability perspective. Accordingly, the proposed model explicitly recognizes the potential dependencies between the social factors used to measure sustainability performance, and hence, can be used as a practical tool for more realistic assessments of real-world performance. The next section provides a supportive discussion.

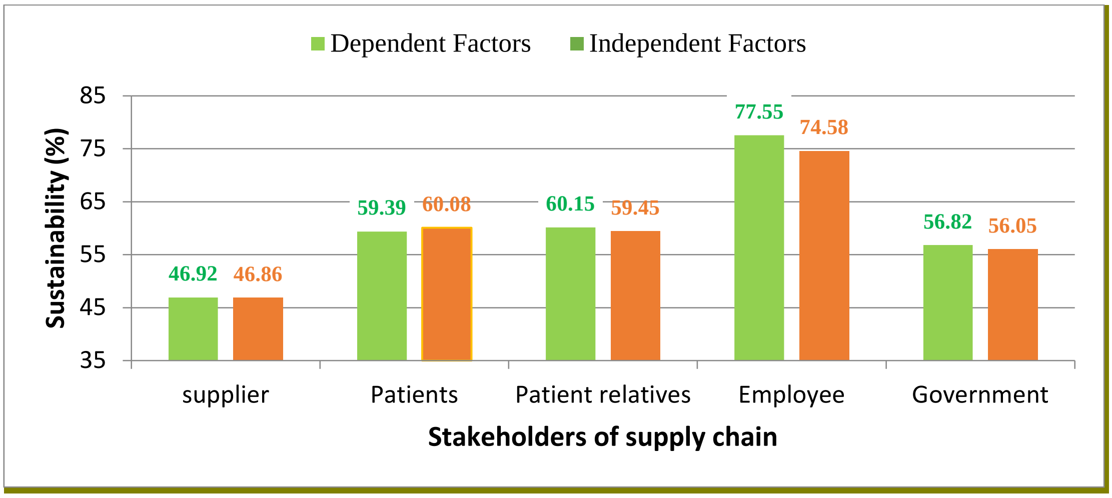


Figure 7.1: Comparative results of social sustainability in the supply chain understudy in two states of independence and correlation between challenges and capacities involved.

7.5 Discussion

The model used in this study is an extended form of the previous model presented by Khosravi *et al*., 2019. The previous model was based on the assumption of independence between challenge and capacity factors. Given that the variability in the variables affecting sustainability is sometimes influenced by their interaction, it makes the need to include the type and extent of dependence in the calculation of sustainability (in many social cases). Recently, research into the dependence between variables of challenge and capacity variables has been the focus of researchers (Eizenberg and Jabareen, 2017).

The exponential distribution is usually easily fitted to models that represent variables related to the time a variable occurs or the time between two occurrences (Khosravi *et al.*, 2019).

It is noteworthy that the focus of both models is to calculate the social sustainability of the supply chain from the perspective of stakeholder theory. Therefore, the challenge and capacity of related social indicators are considered as influencing factors on sustainability.

Both models are based on common principles, but take different approaches to the factors that influence sustainability. In the model of Khosravi *et al.*, 2019 it is assumed that the factors that are independent of each other influence sustainability, whereas in the present study the importance of considering direct or indirect dependence among the factors is considered as a negligible factor.

Figure 7.1 shows the comparative results of social sustainability in each of the two stakeholder groups on the presence and absence of correlation between factors. The analysis of the results reveals that higher sustainability in negative dependencies and lower stability in negative correlations have occurred, highlighting the perception of the type and extent of the dependence.

As supply chain owners have limited and valuable resources and capacities to overcome the challenges ahead and further enhance capacity, pay attention to the type of correlation (positive or negative) that results in a more realistic calculation of sustainability, It will be of particular importance. Given the aforementioned, there is a need to use and introduce methods of calculating the organization's sustainability and supply chain in a more realistic approach, namely the correlation between challenging factors and capacity. This article is moving towards meeting this need. Using this model, sustainability can be measured practically and effectively in all aspects, types of organizations and supply chains. It adopted more effective recovery strategies that had not been anticipated in previous models.

The model is presented to measure the social sustainability of a supply chain with a stakeholder approach. Accordingly, when the Challenging and Capacity factors are independent, the value of the correlation coefficient will be zero ($\rho = 0$), while the negative ($-1 \leq \rho < 0$)and positive ($0 < \rho \leq 1$) values of the correlation coefficient, respectively, indicate an inverse or direct correlation between the factors. There is also a point to the importance of having reliable available data, as well as a list of relevant indicators (factors and related data extracted from Khosravi and Izbirak's earlier work) in each of the domains. Although various organizations have published lists of factors in the social, economic, environmental and other fields, and given that there is still no force to use such lists, it seems that more work in this area is needed.

Another point is that the availability of required data as well as the quality of data may vary between supply chains operating in a common area. Assuming this challenge is overcome, the proposed model can be used to compare the sustainability performance of different aspects of a centralized supply chain in an operational area, especially since the proposed model pays particular attention to the factor correlations that rarely exist in previous models.

7.6 Conclusion

In this paper, a probabilistic model derived from the copula function is presented that can be used to measure the social sustainability of the supply chain in the presence of challenge and capacity dependent factors. The emphasis on holding correlations surrounded by challenge and capacity indicators affecting sustainability is undeniable because a variety of positive and negative dependencies are evident among the factors in practice. Also, it is based on stakeholder requirements to measure the sustainability of a supply chain. Calculating the amount of dependence of the challenge and capacity factors and incorporating them into the resulting model will yield a more realistic value of sustainability.

The main purpose of using different models of sustainability measurement is to create the basis for effective decision making and prioritize the policies facing the organization and supply chain (Tang and Zhou, 2012). The model proposed in this study can be used by supply chain decision-makers to assess how the chain moves in the social sustainability approach and based on stakeholder requirements. It also highlights the importance of taking into account the dependence between the challenge and capacity factors. In the proposed model, for the sake of simplicity in operation, the same weights are assigned to all the factors affecting sustainability that may vary according to the needs of stakeholders or supply chain decision-makers. A further model is recommended for future studies in order to assign weights proportional to the capacity and challenge factors. Approaches such as the Analytic hierarchy process (Saati, 1990), Conjoint analysis (Ülengin *et al*., 2001), Unobserved component models (Thomas, 2010), Composite Indices (Greco *et al*, 2019) are applicable. However, allocating the appropriate weight to the factors will also affect the amount and type of correlation between the factors. Since the correlation between the underlying factors has shaped the proposed model, the choice of model and how weights are assigned will be of particular importance. Not paying enough attention to the amount and type of correlation between the factors sometimes leads to less and sometimes more to the estimation of the sustainability value. In this regard, it is recommended that the study of factor weights be given due to the correlation, although the present study is capable of assessing the social performance of supply chain from the perspective of stakeholders.

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