Using Six Sigma to Achieve Sustainable Manufacturing:
A Case Study in Aviation Company

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A Thesis
in
The Institute
for
Information Systems Engineering

Presented in Partial Fulfillment of the Requirements
for the Degree of Master of Applied Science (Quality Systems Engineering) at
Concordia University
Montreal, Quebec, Canada

August 2014

CONCORDIA UNIVERSITY

School of Graduate Studies

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Entitled: Using Six Sigma to Achieve Sustainable Manufacturing: A Case Study in Aviation Company

and submitted in partial fulfillment of the requirements for the degree of

Master of Applied Science (Quality Systems Engineering)

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ABSTRACT

Using Six Sigma to Achieve Sustainable Manufacturing

Min Zhang

Sustainability has been widely discussed from different points of view. Manufacturing is contributing a critical part of incompliance to environment and human rights in our modern society. While a lot of companies are seeking strategies to either promote corporation image or stimulate employees' work passion, most of research and guidelines are focusing on how to measure the sustainability based on the cases from big firms. Most of manufacturing firms are medium and small sized, they are searching for a comprehensive and systematical way to implement sustainability practice step by step without using very experienced professionals. This thesis research is supplying a systematic framework for firms to achieve sustainability in manufacturing environment with the widely used problem solving tool Six Sigma. Inexperienced professionals will be able to implement the sustainability practice from defining problems to achieving leadership in sustainability. It has also supplied a case study where it illustrates how to customize the framework content based on individual needs.

Key words: Sustainability, Manufacturing, Six Sigma

Acknowledgements

I would like to dedicate my tremendous appreciation for Dr. Anjali Awasthi because of her dedicated supervision and generous help during my study at Concordia University, especially her efforts to guide me through my thesis research. Whenever I have questions and puzzles, she is more than happy to accommodate her time to help me resolve my difficulties. She is also very considerate for foreign students who are facing immigration, financial and cultural problems in Canada.

Additionally, I want to thank all Concordia University professors who have advanced my knowledge in quality management. Also I want to thank all department, library and administrative staffs who have enriched my life by their amazing job.

I also want to thank my friends from Quebec who give me a lot of support and consultation during my study in Canada. For the completion of this thesis, I also want to thank Mr. John Chan who gave me chance to work with him in order to generate the idea of this thesis.

Nevertheless, I want to thank my family who has given me endless support for my study and life. During my growing up, they have given me tremendous love and care that encourages me to move forward.

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Chapter 1 Introduction

1.1 Forward

Sustainability has been widely discussed from different points of view. As one of the most important parts of Sustainable Supply Chain, Sustainable Manufacturing is inheriting the genes of Sustainable Supply Chain Management. Among all the activities along supply chain, manufacturing has been considered as one of the biggest contributors for environmental pollutants and work related injuries. Especially the work environment of the manufacturing plants in the developing countries is receiving lots of criticism. Besides, companies across the world are facing the increased cost in materials, energy, and compliance coupled with higher expectations of customers, investors and local communities (Wyckoff).

Except the needs to achieve the sustainable manufacturing environment, there are also plenty of benefits that have been observed. For example, a 2010 survey of UK-based manufacturing SMEs shows that 56% are already investing in low-carbon technologies and strategies. The global market for low-carbon products is already estimated to be worth over USD 5 trillion and growing. Also the sustainable manufacturing companies are receiving higher financial benefits and better company reputation than those who are facing profound sustainability problems (Wyckoff).

1.2 Goal of Study

In order to help companies to achieve sustainable manufacturing environment, there should be flexible and comprehensive framework to help companies who are new into this area to understand their current situations and find corresponding solutions while still can be controlled and improved in a continuous behavior. Most of the articles or handbooks are giving emphasize on how to measure

sustainability, while there are rarely comprehensive work routine for a company to start achieving sustainable manufacturing from zero.

Six Sigma as a problem solving tool has been widely used for different sectors to achieve higher performance in an organization. It supplies a comprehensive framework to solve any critical problems, especially there are a lot of tools can be used.

The combination of Six Sigma and Sustainable Manufacturing can give any organization a systematic framework with abundant tools to make changes to current manufacturing environment in order to achieve sustainability goals. Due to the flexibility and various tools that can be used, different organization can customize its own specific execution routine based on their own resources and vision. It won't restrict to any industry, and it can be also applied to others when the detailed industry information is supplied.

This research is contributing to the hot topic related to sustainable manufacturing while it can still be very practical and easy to implement. Additionally, an aerospace company which is based in Montreal, Canada, has been used as a case study to illustrate the way to use this framework. It will help organizations to understand clearly how to customize the framework based on its own situation.

The research and work practice mentioned in these literatures are putting a lot of efforts on the concepts of sustainable manufacturing and the measurement methods that can be used to measure the performance of sustainability.

While for a lot of organizations, it is necessary to understand how to align these separate concepts, tools together to successfully achieve sustainable manufacturing from zero. There needs systematical way to help organizations to execute sustainable manufacturing from understanding to real implementation.

At the same time, a lot of measurement metrics that have been mentioned in different literatures are not feasible for small and medium sized organizations to

really collect the data, such as carbon dioxide emission. It will be helpful to get comprehensive summary and validation of these metrics for more suitable usage.

What's more, sustainability includes broad range of topics and requirements, in reality not everything can be achieved at the same time. The sequence and interaction of these three factors should be fully investigated to understand the work priorities under different circumstances.

The research objectives are summarized below:

- 1. How do organizations be aware of sustainability?
- 2. What are the proper metrics for sustainable manufacturing?
- 3. How can organizations analyze sustainability problems?
- 4. How can organizations improve sustainability performance?
- 5. How can organizations achieve leadership?

The contribution of this study is also categorized as below:

- 1. Build framework for small to medium sized company (In Canada, 99% of companies have fewer than 100 employees) (Daly, 2000)
- 2. Categorize measurement target levels
- 3. Identify specific metrics for sustainability measurement
- 4. Quantitative and qualitative analysis for sustainability performance
- 5. Build continuous improvement cycle

Chapter 2 Literature Review

2.1 Introduction

Articles that are stating sustainable supply chain are ranging from academic journal, business cases, company reports, business journal to organizational (including NGOs and academic institutions) publications. From the database search of "Engineering Village", (the articles classification have been summarized in the Figure 1, 2 and 3) it shows that the academic journals regarding "Sustainable Supply Chain" are emerging from year 2004, just after the publications of UN Millennium Development Goals (United Nations, 2000). And from year 2009, the number of articles is increasing rapidly since a lot of countries and organizations become aware of the impact of environmental change and its reputation regarding the human rights. Besides, from the subject's classification, most of the articles are distributed under the theme of production planning, industrial economics and environmental issues, since they are more related to sustainable supply chain. Interestingly, sustainable supply chain has been also connected with marketing and organizational aspects, which is indicating that sustainable supply chain has interrelationship with marketing. Additionally, from the distribution of geography, most of the sustainable supply chain articles are from the United States, China, and Germany, since supply chain is showing the dynamic of a country's economy. The discussion of sustainable supply chain in these countries is also showing that sustainable supply chain is becoming a hot topic for the current industry. The articles that have been citied in this study have been summarized in Table 1 based on journal names. The articles being reviewed have been summarized based on subthemes in Table 2. The articles have been also summarized based on document type in Table 3.

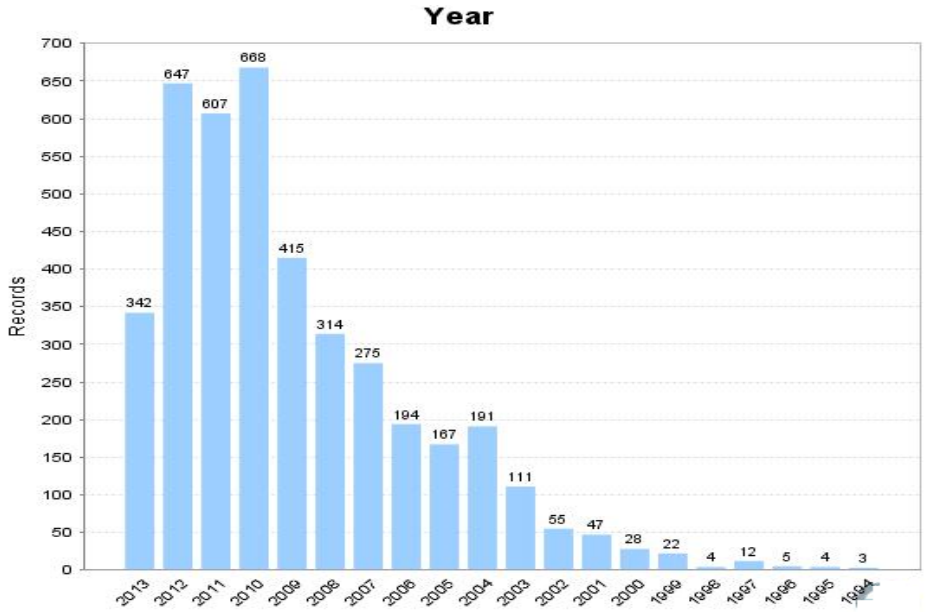

Figure 1 Sustainable Supply Chain Articles based on Year (Eng13)

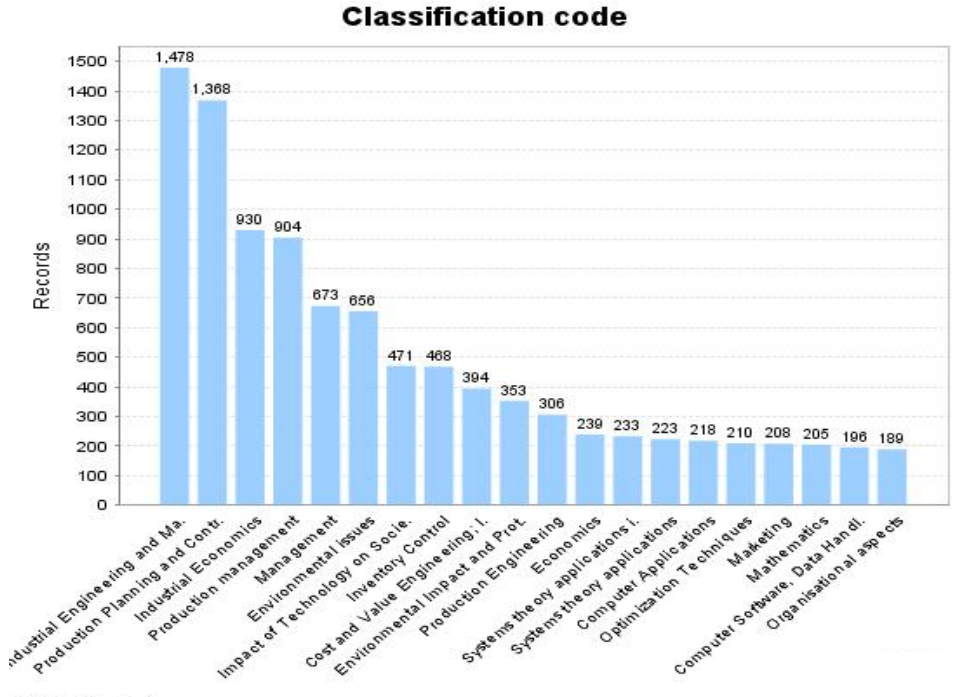

Figure 2 Sustainable Supply Chain Articles based on classification code (Eng13)

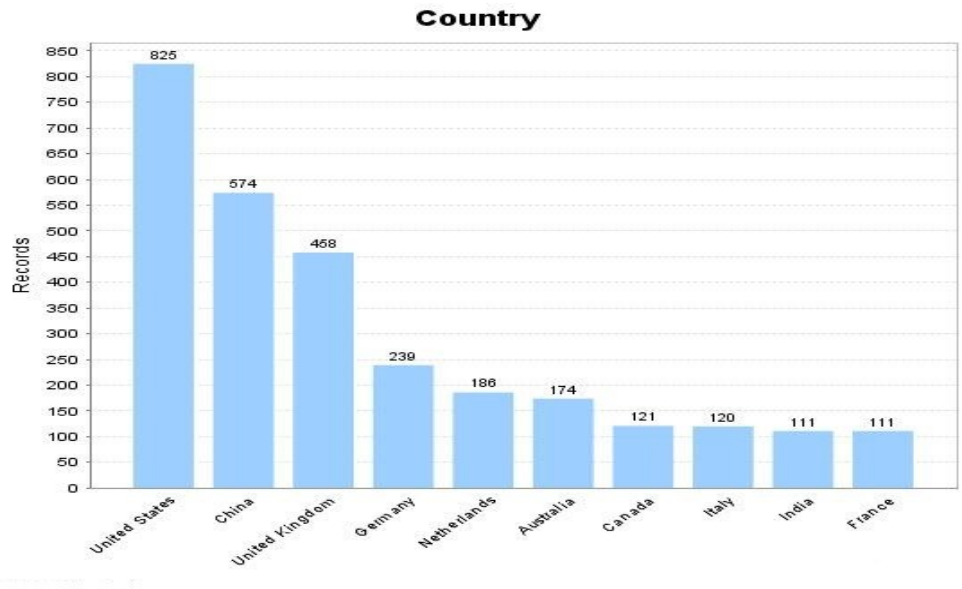

Figure 3 Sustainable Supply Chain Articles based on country (Eng13)

From the Figure 1-3, it is obvious that sustainable supply chain topics have rapidly increased since 2000. Most of the topics belong to industrial engineering, production and planning, etc. The country that has showed most interests in sustainability topics are the United States, China, which are the two biggest economies in the world. It is obvious that most of the articles that are related to sustainability are highly related to economy status of the countries. These high profile countries have been dominating the global supply chain. Thus it has demonstrated high interests in sustainable supply chain.

From Table 1 which has summarized the academic journals that have been cited in this study, the journal that has included most of the articles directly related to sustainable supply chain is Journal of Cleaner Production. Most of the articles that are talking about sustainable supply chain, sustainable manufacturing are in the operations, environment, and economy journals. It has reflected the concepts of sustainability which includes economy, environment and society. A lot of journals are also highly related to business, which has shown the interest of business world.

Table 1 Summary of Academic Journals Citations

Journal Name	Citation Quantity
Annual Review of Environment and Resources	1
Applications of Industrial Ecology	1
Benchmarking: An International Journal	1
British Journal of Management	1
Business and Society Review	1
Business and the Environment	1
Business Ethics: An European Review	1
California Management Review	1
Corporate Social Responsibility & Environmental Management	1
Environment	1
Environment and Planning	1
Environmental Impact Assessment Review	1
Environmental Quality Management	1
Environmental Science and Pollution Research	1
Greener Management International	2
Harvard Business Review	2
Impact Assessment and Project Appraisal	2
Industrial Engineer	1
International Business Research	1
International Journal of Environmentally Conscious Design & Manufacturing	1
International Journal of Logistics Research and Application	1
International Journal of Management Review	1
International Journal of Operations & Production Management	2
International Journal of Physical Distribution & Logistics Management	2
International Journal of Production Economics	1
International Journal of Production Research	5
Journal of Business Ethics	1
Journal of Business Logistics	1
Journal of Change Management	1
Journal of Cleaner Production	8
Journal of Economics Perspectives	1
Journal of Environmental Management	1

Journal of Marketing	1
Journal of Operations Management	6
Journal of Supply Chain Management	3
Logistics Information Management	1
Manufacturing & Service Operations Management	1
Manufacturing Engineer	1
Measuring Business Excellence	2
MIT Sloan Management Review	1
Northeastern Journal of International Human Rights	1
Production and Operations Management	1
Production Planning and Control	1
Progress in Industrial Ecology: An International Journal	1
Quality and Reliability Engineering International	1
Robotics and Computer Integrated Manufacturing	1
SAE Transactions Journal of Aerospace	1
Supply Chain Management: An International Journal	3
Sustainability	1
Technovation	1
The International Journal of Life Cycle Assessment	1
Transportation Research Part E: Logistics and Transportation Review	1
Waste Management	1

Table 2 Summary of Sustainable Supply Chain Articles

Subthemes	**Articles**
Definition of Sustainable Supply Chain	(Fine, 1999) (World Commission on Environment and Development, 1987) (Linton, et al., 2007) (Carter, 2008) (Responsibility, 2010) (John, 1994) (Hall, et al., 2012) (Drumwright, 1994) (Seuring, et al., 2008) (Handfield, et al., 1997) (Kogg, 2003) (Kleindorfer, et al., 2005)

Environmental Concern	(Green, et al., 1996) (Narasimhan, et al., 1998) (Hall, 2000) (Srivastava, 2007) (Lamming, et al., 1996) (Hill, 1997) (Abukhader, et al., 2004) (Zhu, et al., 2004) (Kumar, et al., 2012) (Zhu, et al., 2004) (Srivastava, 2007) (Rao, et al., 2005) (Zhu, et al., 2007) (Porter, et al., 1995) (Lee, 2008) (Green, et al., 1998) (Rao, 2002) (Sarkis, 1995) (Klöpffer, 1997) (Llgin, et al., 2010) (Rusinko, 2007) (Li, et al., 2011) (Morrissey, et al., 2004) (Skjøtt-Larsen, 2008) (Zhu, et al., 2008)
Social Concern	(Hutchins, et al., 2008) (Goleman, 2010) (Chouinard, et al., 2011) (Senate) (United Nations, 2012) (Esteves, et al., 2012) (Wilson, et al., 2011) (Zaklad, et al., 2004) (United Nations, 2007) (Nations, 2011) (Parris, et al., 2003) (Benoit, et al., 2009) (Klöpffer, 2003) (Hauschild, et al., 2008) (Vanclay, 2003a) (Vanclay, 2006) (Benoit-Norris, et al., 2012)
Profitability	(Linton, et al., 2007) (Matos, et al., 2007) (Hutchins, et al., 2008) (Seuring, et al., 2008) (Krause, et al.,

	2009) (Pagell, et al., 2009) (Pullman, et al., 2009) (Kumar, et al., 2012) (Rao, et al., 2005) (Granade, et al., 2008) (Mefford, 2011) (Heskett, et al., 1994) (Hanifan, et al., 2012)

Table 3 Articles Distribution based on type

Documents Type	**Articles**
Academic Journal/Book	(Eng13) (Hutchins, et al., 2008) (RW, et al., 2005) (Carter, et al., 2002) (Kovacs, 2004) (Preuss, 2001) (Graafland, 2002) (Seuring, 2001) (Seuring, et al., 2008) (Beske, et al., 2008) (Fine, 1999) (Linton, et al., 2007) (Carter, 2008) (John, 1994) (Hall, et al., 2012) (Drumwright, 1994) (Seuring, et al., 2008) (Handfield, et al., 1997) (Kogg, 2003) (Kleindorfer, et al., 2005) (Green, et al., 1996) (Narasimhan, et al., 1998) (Hall, 2000) (Srivastava, 2007) (Lamming, et al., 1996) (Hill, 1997) (Abukhader, et al., 2004) (Zhu, et al., 2004) (Kumar, et al., 2012) (Zhu, et al., 2004) (Srivastava, 2007) (Rao, et al., 2005) (Zhu, et al., 2007) (Porter, et al., 1995) (Lee, 2008) (Green, et al., 1998) (Rao, 2002) (Sarkis, 1995) (Klöpffer, 1997) (Llgin, et al., 2010) (Rusinko,

	2007) (Li, et al., 2011) (Morrissey, et al., 2004) (Skjøtt-Larsen, 2008) (Zhu, et al., 2008) (Hutchins, et al., 2008) (Goleman, 2010) (Chouinard, et al., 2011) (Esteves, et al., 2012) (Wilson, et al., 2011) (Zaklad, et al., 2004) (Parris, et al., 2003) (Klöpffer, 2003) (Hauschild, et al., 2008) (Vanclay, 2003a) (Vanclay, 2006) (Benoit-Norris, et al., 2012) (Matos, et al., 2007) (Seuring, et al., 2008) (Krause, et al., 2009) (Pagell, et al., 2009) (Pullman, et al., 2009) (Kumar, et al., 2012) (Rao, et al., 2005) (Mefford, 2011) (Heskett, et al., 1994)
International Organization Reports	(Linton, et al., 2007) (Responsibility, 2010) (Senate) (United Nations, 2012) (United Nations, 2007) (Nations, 2011) (Benoit, et al., 2009)
Company reports	(Granade, et al., 2008) (Hanifan, et al., 2012) (Pricewaterhouse Cooper, 1999)

Globalization and outsourcing have increased the complexity of supply chains (Hutchins, et al., 2008). The World Commission on Environment and Development (WCED) brought the concept of sustainability to global prominence in Our Common Future (World Commission on Environment and Development, 1987) that described sustainable development as meeting 'the needs of the present without compromising the ability of future generations to meet their needs'. The

United Nations has repeatedly demonstrated its commitment to sustainability through efforts such as Agenda 21 (United Nations, 2002) and the Millennium Development Goals (United Nations, 2000). Furthermore, sustainability has been integrated into the mission of numerous organizations and institutions, from local to international in scale (RW, et al., 2005).

Reviewing the case for brand-owning companies, as they are likely to come under pressure from stakeholders, e.g., non-governmental organizations (NGOs) (Carter, et al., 2002) (Kovacs, 2004), these companies are asked to consider the environmental and social problems present in their entire supply chain. For example, apparel distributors such as Nike, Disney, Levi Strauss, Benetton, Adidas or C&A have been blamed in recent years for problems occurring during the production of their clothing. Inhumane working conditions (Preuss, 2001) (Graafland, 2002) and contaminations of the (local) environment (Seuring, 2001)were frequently mentioned as problems (Seuring, et al., 2008). Such pressure has triggered the integration of environmental and social issues, including those embedded in related standards (e.g., ISO 14001) into their daily tasks (Beske, et al., 2008). The articles that will be involved in different subthemes discussed in detail are classified as shown in the Table 4.

Table 4 Articles based on subthemes

Definition of Sustainable Supply Chain	(Fine, 1999) (World Commission on Environment and Development, 1987) (Linton, et al., 2007) (Carter, 2008) (Responsibility, 2010) (John, 1994) (Hall, et al., 2012) (Drumwright, 1994) (Seuring, et al., 2008) (Handfield, et al., 1997) (Kogg, 2003) (Kleindorfer, et al., 2005)
Environmental Concern	(Green, et al., 1996) (Narasimhan, et

	al., 1998) (Hall, 2000) (Srivastava, 2007) (Lamming, et al., 1996) (Hill, 1997) (Abukhader, et al., 2004) (Zhu, et al., 2004) (Kumar, et al., 2012) (Zhu, et al., 2004) (Srivastava, 2007) (Rao, et al., 2005) (Zhu, et al., 2007) (Porter, et al., 1995) (Lee, 2008) (Green, et al., 1998) (Rao, 2002) (Sarkis, 1995) (Klöpffer, 1997) (Llgin, et al., 2010) (Rusinko, 2007) (Li, et al., 2011) (Morrissey, et al., 2004) (Skjøtt-Larsen, 2008) (Zhu, et al., 2008)
Social Concern	(Hutchins, et al., 2008) (Goleman, 2010) (Chouinard, et al., 2011) (Senate) (United Nations, 2012) (Esteves, et al., 2012) (Wilson, et al., 2011) (Zaklad, et al., 2004) (United Nations, 2007) (Nations, 2011) (Parris, et al., 2003) (Benoit, et al., 2009) (Klöpffer, 2003) (Hauschild, et al., 2008) (Vanclay, 2003a) (Vanclay, 2006) (Benoit-Norris, et al., 2012)
Profitability	(Linton, et al., 2007) (Matos, et al., 2007) (Hutchins, et al., 2008) (Seuring, et al., 2008) (Krause, et al., 2009) (Pagell, et al., 2009) (Pullman,

	et al., 2009) (Kumar, et al., 2012) (Rao, et al., 2005) (Granade, et al., 2008) (Mefford, 2011) (Heskett, et al., 1994) (Hanifan, et al., 2012)

2.2 Sustainability and Supply Chain

2.2.1 Supply Chain

Before transforming the supply chain into sustainable model, it is important to define what is supply chain and what stakeholders are involved. It is important to understand the process of supply chain activities which can actively influence its sustainability performance.

According to Charles H. Fine, A supply chain is the material, information, and services, typically crossing several different organizations, involved in producing and delivering a product or service to an end user. Supply chain management is a total systems approach to managing the entire flow of information, materials, and services from raw-material suppliers through factories and warehouses to the end customer. In fact, some scholars argue that firm survival in the modern business environment is no longer an issue of one firm competing against another firm but has, instead, become an issue of one supply chain competing against another supply chain (Fine, 1999).

A more complex definition that includes both internal and external supply chain activities is defined by Mentzer, et, al., who state that *Supply chain management is defined as the systemic, strategic coordination of the traditional business functions and the tactics across these business functions within a particular company and across businesses within the supply chain, for the purposes of improving the long-term performance of the individual companies and the supply*

chain as a whole (Mentzer, et al., 2011). The conceptual model of supply chain management is also illustrated in Figure 4.

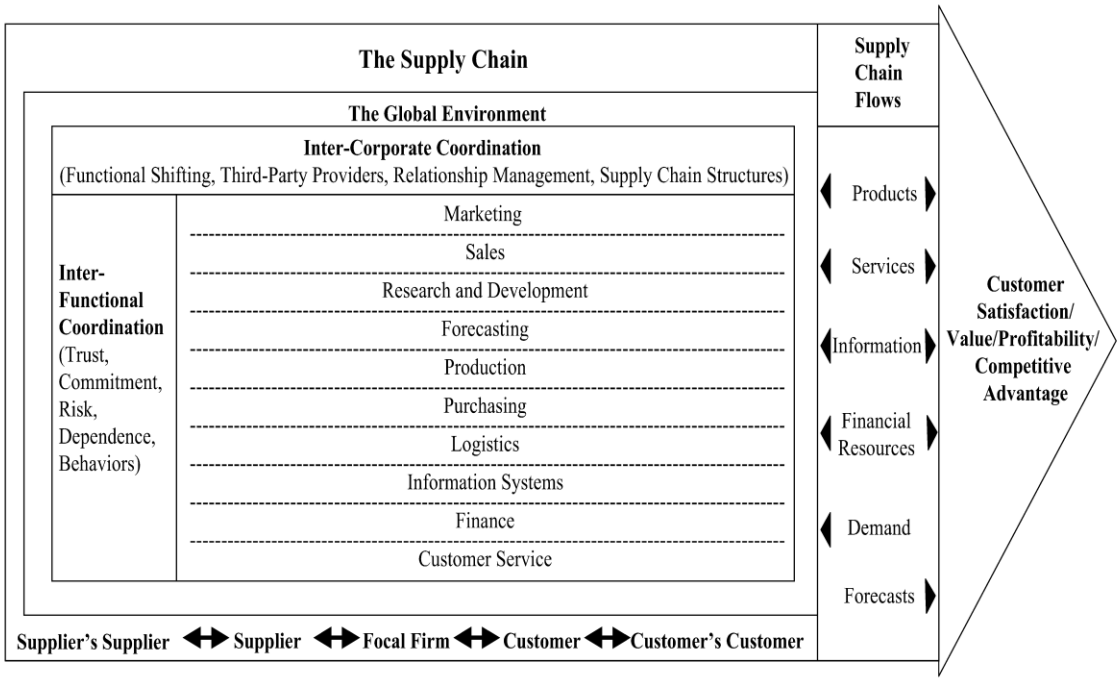

Figure 4 Conceptual Model of Supply Chain Management (Mentzer, et al., 2011)

2.2.2 Definition of Sustainability

Sustainability is increasingly discussed by both policy makers and concerned populations. Sustainability is generally defined as using resources to meet the needs of the present without compromising the ability of future generations to meet their own needs (World Commission on Environment and Development, 1987). Due to the variety of definitions of sustainability, more questions can be proposed to ask for the clear understanding of sustainability, as summarize by Jonathan D. Linton (Linton, et al., 2007), below:

- What resources will future generations require?

- At what levels can pollutants be released without having a negative effect on future generations?
- To what extent will new sources of depletable resources be identified in the future?
- At what level can renewable resources be exploited while ensuring that these resources remain renewable?
- To what extent can technology address sustainable use of resources with continued increases of material wealth?
- To what extent can market forces drive sustainability?
- Do lifestyles need to change and if so how?
- What policies are required to achieve sustainability?

2.2.3 Supply Chain Sustainability

According to the definition and discussion about sustainability, sustainable supply chain is one that includes measures of profit and loss as well as social and environmental dimensions (Linton, et al., 2007) (Carter, 2008).

Another definition of supply chain sustainability by UN Global Compact and Business for Social Responsibility is that Supply chain sustainability is the management of environmental, social and economic impacts, and the encouragement of good governance practices, throughout the lifecycles of goods and services (Responsibility, 2010).

The general concerns related to supply chain sustainability is referred to triple bottom line as environmental, social and economic performance (John, 1994).

Carter and Rogers state that the triple bottom line is the intersection of social, environmental and financial performance, as shown in Figure 5.

Figure 5 Sustainability defined by the triple line (Carter, 2008)

From Jeremy Hall et. al (Hall, et al., 2012), the linkages among sustainability and supply chain management has long been discussed and a few important terminologies regarding sustainability has been displayed in Table 5.

Table 5 Terminologies Regarding Sustainability

Drumwright (1994)	Socially responsible organizational buying is that which attempts to take into account the public consequences of organizational buying or bring about positive social change through organizational buying behavior. (Drumwright, 1994)
Green et al. (1996, p. 188)	Green supply refers to the way in which innovations in supply chain

	management and industrial purchasing may be considered in the context of the environment. (Green, et al., 1996)
Narasimhan and Carter (1998, p. 6)	Environmental supply chain management consists of the purchasing function's involvement in activities that include reduction, recycling, reuse and the substitution of materials. (Narasimhan, et al., 1998)
Hall (2000, p. 456)	ESCD (Environmental supply chain dynamics) are a phenomenon where environmental innovations diffuse from a customer firm to a supplier firm, with environmental innovation defined as being either a product, process, technology or technique developed to reduce environmental impacts. (Hall, 2000)
Srivastava (2007, p. 54 – 55)	GrSCM (Green supply chain management) is defined as 'integrating environmental thinking into supply-chain management, including product design, material sourcing and selection, manufacturing processes, delivery of the final product to the consumers as well as end-of-life management of the product after its useful life' (Srivastava,

	2007).
Seuring et al. (2008, p. 1545)	Sustainable supply chain management 'as the management of material and information flows as well as cooperation among companies along the supply chain while taking goals from all three dimensions of sustainable development, i.e. economic, environmental and social, and stakeholder requirements into account' (Seuring, et al., 2008).

Earlier studies mostly focused on integrating environmental concerns and there continues to be a healthy discourse in this area (Green, et al., 1996) (Lamming, et al., 1996) (Hill, 1997) (Abukhader, et al., 2004) (Zhu, et al., 2004). More recent studies call for integrating the more complex relationships among financial, social and environmental elements to fully understand, and hence manage, the supply chain's social and environmental impacts while maintaining profitability (Linton, et al., 2007) (Matos, et al., 2007) (Hutchins, et al., 2008) (Seuring, et al., 2008) (Krause, et al., 2009) (Pagell, et al., 2009) (Pullman, et al., 2009). In addition to broadening the scope of issues addressed, others call for considering wider parts of the supply chain (Handfield, et al., 1997) (Kogg, 2003) (Kleindorfer, et al., 2005). Pagell and Wu (Pagell, et al., 2009) argue that prior studies primarily examined similarities in sustainable supply chains, but argue that unique approaches of more sustainable companies are more pertinent.

2.3 Environmental Concern

One of the most discussed aspects in regard to sustainable supply chain is environmental impact from product planning to product disposal. The concept that is referring to environmental friendly supply chain is frequently rephrased as Green supply chain. Related management practice is defined as Green supply chain management (GSCM) which is an approach that aims at the overall optimization of material and information flows along the value chain. This affects all areas of an enterprise, but is especially true for emission and waste heavy supply chains (Kumar, et al., 2012).

The definition and scope of GSCM in the literature varies from green purchasing to integrated green supply chains flowing from supplier to manufacturer to customer, and reverse logistics. GSCM is defined as 'integrating environmental thinking into supply-chain management, including product design, material sourcing and selection, manufacturing processes, delivery of the final product to the consumers as well as end-of-life management of the product after its useful life' (Zhu, et al., 2004).

The literatures for green supply chain have been classified mainly into three discussions: importance of green supply chain, green design and green operation (Srivastava, 2007). And its related concepts and techniques that are widely discussed are presented in Figure 6. Some related representative literatures' themes have been presented in Table 6.

Table 6 Green Supply Chain Topics

Importance of GSCM	Discussion of GSCM impact on economic and financial aspect (Rao, et al., 2005)
	Motivation based on Chinese companies (Zhu, et al., 2007)

	Fundamentals of greening as a competitive initiative (Porter, et al., 1995)
	Initiatives for small to medium sized companies to perform GSCM (Lee, 2008)
	Impact from Green purchasing (Green, et al., 1998)
	The insight of green supply chain in South East Asia (Rao, 2002)
Green Design	Environmentally conscious design and manufacturing and Supply Chain Management (Sarkis, 1995)
	Life-cycle assessment (Klöpffer, 1997)
	Environmentally conscious manufacturing and product recovery (Llgin, et al., 2010)
Green Operations	Green Manufacturing and its related competitive outcomes (Rusinko, 2007)
	Reverse Logistics and its added value to enterprise (Li, et al., 2011)
	Waste management and its application to sustainability (Morrissey, et al., 2004)

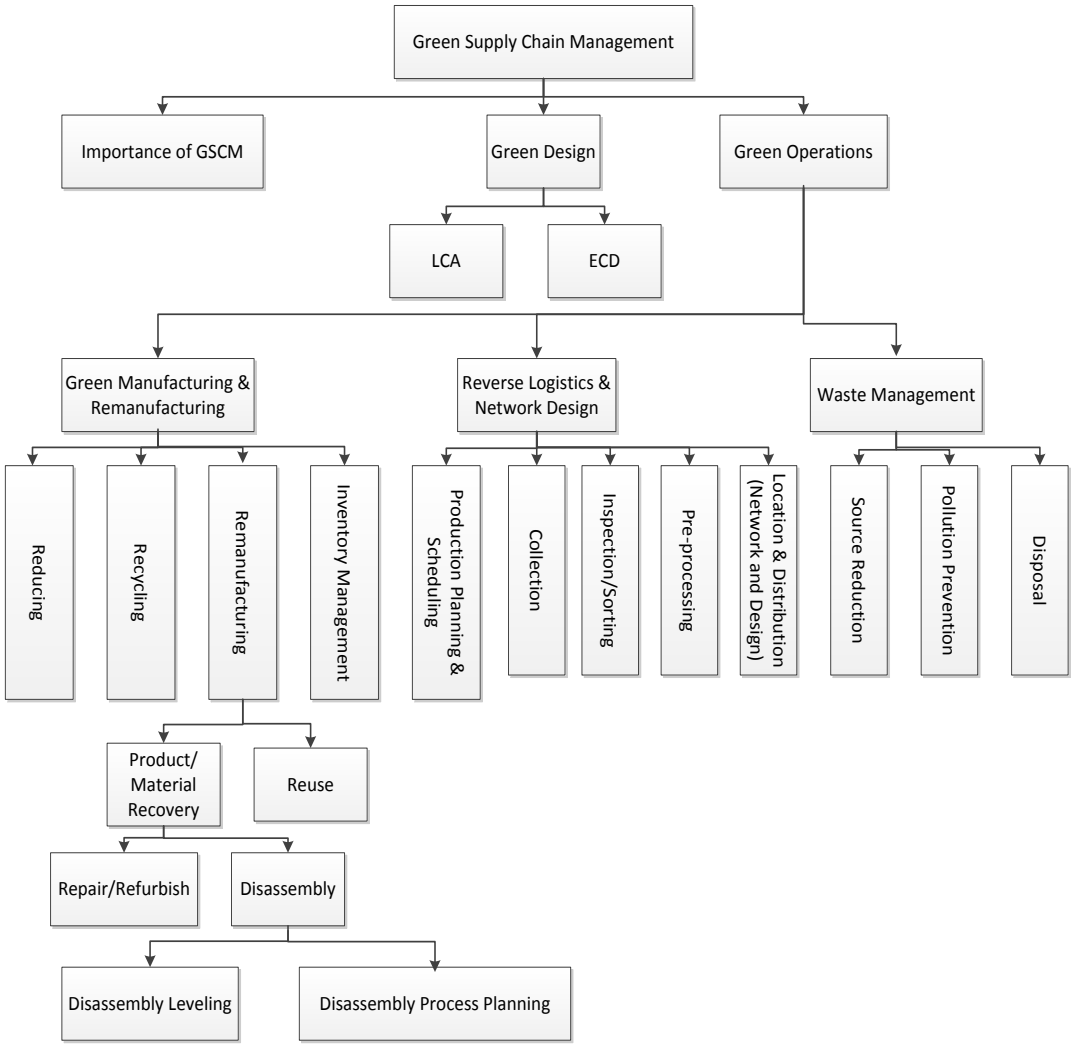

Figure 6 Classification of Green Supply Chain (Srivastava, 2007)

According to the discussion of Skjøtt-Larsen (Skjøtt-Larsen, 2008), the potential for 'green' in supply chain can be demonstrated by (Skjøtt-Larsen, 2008):

- The United Nations (UN) estimates that 20–50 million tons of e-waste is generated worldwide each year and less than 20% of which is captured by recycling programs.

- In 2007, about 1.1 billion mobile phones were sold worldwide – 50% of the world's population (6.6 billion)has a mobile phone.
- The European Union (EU) produces 8.7 million tons of e-waste every year. Large amounts are exported to Asia and Africa in spite of the Organization for Economic Co-operation and Development (OECD) and EU ban of export of e-waste.

The potential reasons for implementing green supply chain are (Kumar, et al., 2012):

- Global warming: negative effects on our environment directly or indirectly affect earth's eco-environment.
- International regulation and legislation: the EU forces companies to comply in order to stay in these markets.
- Brand reputation: the lack of environmental policies results in negative publicity.
- Stakeholders' increasing awareness: positive image often is more desirable than pure shareholder value thinking.
- Energy and commodity prices: fluctuations in oil, energy and raw material prices are partially driven through increasing demand in countries like China.
- Potential value creation in green supply chain: seeing opportunities to create value and competitive advantages.
- More integrated and better managed supply chains: supply chain partners have increased visibility to each other's practices through supplier prequalification, environment and social requirements early in the relationship, cross enterprise materials and process optimization and industry standardization.

The Drivers to implement GSCM:

1) External drivers stem mostly from stakeholders and competition. This is particularly due to stricter environmental regulations, increased community and consumer pressures and manufacturers' need to effectively integrate environmental concerns into their supply chain strategy. (Zhu, et al., 2008)
2) Internal drivers for the implementation of GSCM mainly result from top management's insight that tapping potential opportunities leads to reduced emission and to reduced costs when it comes to disposal of waste and energy. (Kumar, et al., 2012)

One case to illustrate the benefits of using green practices to help organizations to generate more revenue and reduce its cost is from Calstone (Scarborough, Ontario, Canada). It has annual revenue USD 7 million (2010) with 28 employees who produce furniture. The company discovered that selling more environmentally sustainable furniture products could provide a valuable competitive advantage and could expand its market for conscious consumers. In 2007, it started implementing several measures to reduce the environmental impact of its manufacturing plant.

To reduce harmful emissions, the company introduced a vapour spray system to decrease the chemicals applied to degrease metal components. Chemical use has since been reduced by 60% compared to 2005 levels. A stainless steel water tank of 7 600 litres (2 000 gallons) was installed to reuse water for cooling the equipment and rainwater is collected for flushing all toilets. Water use for cooling has been reduced by 65% and that for toilets has also been cut by 15% compared to 2004 levels. Skylights have been installed in the plant to bring in natural light, which reduces energy requirement and encourages the growth of nearly 100 foliage plants that purify the indoor air.

The company also installed a heat exchanger made from an old car radiator and automatic heat control units, and hung large pieces of polystyrene foam from the

plant's ceiling to minimise the amount of air space to be heated and cooled. The company buys 10 megawatt hours (MWh) of electricity per month from a hydro and wind power provider and has installed solar panels on the roof. With all the above resource efficiency measures combined, the company is estimated to have reduced operating costs by USD 20 000 annually.

Furthermore, Calstone launched a remanufacturing programme in 2007 that enables it to take back any of their existing furniture and recycle or remanufacture every component. Their furniture is certified by a third-party body for its low volatile organic compound (VOC) emission, helping improve indoor air quality and employees' health. (OECD, 2014)

2.4 Social Concern

Consumers are more frequently questioning where, by whom, and under what conditions their products are being sourced and produced. Transparency, in economic theory, implies providing key information to help stakeholders make decisions, which in turn creates incentives for businesses to align their practices with the public's priorities (Goleman, 2010). A socially responsible company considers the impacts of its products beyond its own sphere of local operation and within its true triple bottom line (including the externalities), with a life cycle perspective (Chouinard, et al., 2011). Corporations, who are somewhat unaware of these social impacts, are now under scrutiny and increased pressure to uncover and divulge this information. The Supply Chain Transparency Act passed in California requires companies to identify the forced and child labor risks of their supply chains (Senate). Moreover, Risk assessment and Due Diligence are some of the first recommended steps of a supply chain social responsibility program (United Nations, 2012).

Increasingly, complex supply chains are demonstrating a sense of shared responsibility by implementing systems and procedures to enforce social

performance standards and provide incentives for good performance by all participants in the chain, and by recognizing differing cultural and contextual requirements. More proponents are collaborating with contractors in early-stage planning and assessments, agreeing on environmental and social obligations and standards, and investing in local capacity building. Proponents are encouraging adoption of social standards in pre-qualification and tender processes; designing contracts to provide incentives for good practice; assisting contractors in developing social management plans; supporting local community liaison officers; and building trust and accountability with external stakeholders through public reporting, engagement, resolution of grievances and oversight by third-party organizations (Esteves, et al., 2012) (Wilson, et al., 2011).

Zaklad et. al suggested that people constitutes of 50% for supply chain performance. Therefore, am integral technical and social system model is built for achieving sustainable supply chain. The so-called "Integrated Intervention Process" has four stages along with the business process, the enabling technologies and the social system (Figure 7) (Zaklad, et al., 2004) .

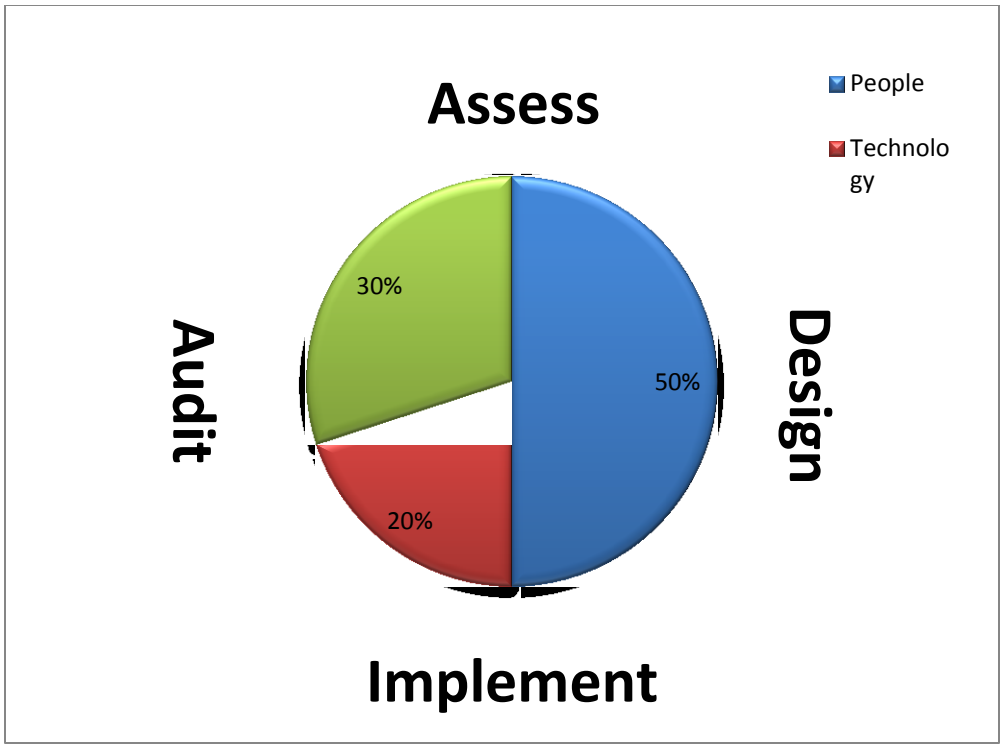

Figure 7 Integrated Intervention Process (Zaklad, et al., 2004)

The first of the frameworks that are evaluating the social sustainability is adopted by the United Nations Division for Sustainable Development (UNDSD), measuring progress toward sustainability via indicators that are tied to the Millennium Development Goals and the other (Hutchins, et al., 2008). The UNDSD theme/sub-theme framework was established to organize and select indicators of sustainable development in Table 7.

Table 7 UNDSD framework for social dimension of sustainability (United Nations, 2007)

Theme	**Sub-theme**	**Indicator**
Equity	Poverty	Percent of population living below poverty line
		Gini index of income

		inequality
		Unemployment rate
	Gender equality	Ratio of average female wage to male wage
Health	Nutritional status	Nutritional status of children
	Mortality	Mortality rate under 5 years old life expectancy at birth
	Sanitation	Percent of population with adequate sewage disposal facilities
	Drinking water	Population with access to safe drinking water
	Healthcare delivery	Percent of population with access to primary healthcare facilities
		Immunization against infectious childhood diseases
		Contraceptive prevalence rate
Education	Education level	Children reaching grade 5 of primary education
		Adult secondary education achievement level

	Literacy	Adult literacy rate
Housing	Living conditions	Floor area per person
Security	Crime	Number of recorded crimes per 100,000 population
Population	Population change	Population growth rate
		Population of urban formal and informal settlements

Besides, according to United Nations Global Compact, the principles that are related to social concerns for sustainable supply chain are (Nations, 2011):

- Principle 1 Businesses should support and respect the protection of internationally proclaimed human rights;
- Principle 2 Make sure that they are not complicit in human rights abuses
- Principle 3 Businesses should uphold the freedom of association and the effective recognition of the right to collective bargaining;
- Principle 4 The elimination of all forms of forced and compulsory labor
- Principle 5 The effective abolition of child labor
- Principle 6 The elimination of discrimination in respect of employment and occupation
- Principle 10 Businesses should work against corruption in all its forms, including extortion and bribery.

Thomas et al. have selected twelve frameworks for sustainability; highlight their similarities and differences in definition of sustainable development, motivation, process, and technical methods. They conclude that there are no indicator sets that

are universally accepted, backed by compelling theory, rigorous data collection and analysis, and influential in policy (Parris, et al., 2003).

Based on the different constructs that have been reviewed, Hutchins et al. have selected four indicators that can be more inclusive of sustainable supply chain, which are Labor equity, Healthcare, Safety and Philanthropy. These indicators are employed in an example to show their interrelationship (Hutchins, et al., 2008).

Regarding the tools that are mostly used for social impact analysis, Social Life Cycle Analysis is a tool that is further developed based on Environmental Life Cycle Analysis. In 2009, after a five-year process with participation from over 70 international experts, the United Nations Environment Program (UNEP) and the Society of Environmental Toxicology and Chemistry (UNEP/SETAC) Life Cycle Initiative published the Guidelines for Social Life Cycle Assessment of Products (The Guidelines) (Benoit, et al., 2009). One of the objectives of the working group was to establish a consensus on how social impacts may be best captured and integrated into the existing life cycle assessment framework in order to move towards the development of Life Cycle Sustainability Assessment (LCSA). Hence, by combining S-LCA with Environmental LCA and Life Cycle Costing—a method that takes into account costs incurred over the entire supply chain, use phase, and end-of-life—a truly holistic representation of the three pillars of sustainability of products can be assessed (Klöpffer, 2003) (Hauschild, et al., 2008).

Also, another tool that is widely used to assess the social impacts of any kind of development is Social Impact Assessment (SIA). Social impact assessment (SIA) is about the processes of managing the social issues associated with planned interventions (Vanclay, 2003a) (Vanclay, 2006). Originally (but now only in its narrowest conceptualization) SIA was regarded as a technique for predicting social impacts as part of an environmental impact assessment (EIA) in the production of an environmental impact statement (EIS), or as a stand-alone

process, usually in the context of national legislation. Now SIA researchers and practitioners are interested in the processes of analyzing, monitoring and managing the social consequences of planned interventions, and by logical extension the social dimensions of development in general (Esteves, et al., 2012). Catherine Benoit-Norris has concluded a table that is indicating social themes that are related to product supply chain and its risks that will have impact on sustainable supply chain in Table 8.

Table 8 Characterized Social Issues (Benoit-Norris, et al., 2012)

Category	Social Theme	Data Indicator	Characterized Issues
Labor Rights and Decent Work	Labor Laws/Conventions	Number of Labor Laws	Risk of country not passing labor laws
		Number of Labor Laws by sector	Risk of Country not passing labor laws by sector
		Number of labor Conventions ratified (out of 81 possible)	Risk of country not adopting labor conventions
		Number of labor Conventions ratified by sector	Risk of country not adopting labor convention by sector
		Year of last Minimum Wage Update	Risk of minimum wage not being updated
	Wage Assessment	Minimum wages(USD)	Risk of country average wage being < minimum wage
		Average Unskilled Wages (USD) in country	
		Non-Poverty Guideline (USD)	Risk of country average wage being <non-poverty guideline
		Average Unskilled Wages (USD) in country	
		Minimum	Risk of sector average

		wages(USD)	wage being<minimum wage
		Average Unskilled Wages (USD) by sector	
		Non-Poverty Guideline (USD)	Risk of sector average wage being<non-poverty guideline
		Average Unskilled Wages (USD) by sector	
	Population living in poverty	Percent of population living on<$2/day	Risk of population living on <$2/day
	Child labor	Child labor % in country	Risk of child labor in country
		Child labor % by sector	Risk of child labor by sector
	Forced labor	Qualitative	Risk of forced labor in country
		Qualitative	Risk of forced labor in by sector
	Excessive working time	Percent working>48 hours/week in country	Risk of population working>48 hours/week in country
		Qualitative	Risk of population working>48 hours/week by sector
	Freedom of Association, Collective Bargaining, Right to Strike	Qualitative	Risk of not having freedom of association rights
		Qualitative	Risk of not having collective bargaining rights
		Qualitative	Risk of not having the rights to strike
	Unemployment	Unemployment Average % in country	Risk of high unemployment in country
		Unemployment % by sector	Risk of high unemployment by

			sector
Governance	Legal System	World Bank Worldwide Governance Indicator-Rule of Law	Risk of Fragility in Legal System
		Bertelsmann Transformation Index-Rule of Law, Independent Judiciary	
		CIRI Human Rights Index-Independent Judiciary	
		Global Integrity Index-Judicial Accountability	
		Global Integrity Index-Rule of Law	
		Global Integrity Index-Law Enforcement	
		World Justice Project-Average	
Human Rights	Indigenous Rights	Presence of indigenous population	
		Indigenous Population, %	Amount of indigenous population
		ILO Convention adopted for Indigenous, Y or N	Risk of country not adopting Indigenous ILO convention and UN Declaration
		UN Declaration for Indigenous, endorsed(Y), abstained(A), against(N)	
		Number of laws enacted to protect indigenous	Risk of conuntry not passing laws to protect Indigenous

		Qualitative	Risk for Indigenous Rights Infringements by Sector
	Gender Equity	Social Institutions and Gender Index	
		Global Gendor Gap	
		World Bank Gender Development Indicator	
		World Bank Gender Empowerment Index	
		CIRI Human Rights Index-Economic	
		CIRI Human Rights Index-Political	
		CIRI Human Rights Index-Social	
		Adolescent fertility rate(births per 1000 women ages 15-19	
		Fertility rate, total(births per woman)	Risk of Gender Inequity
		Share of women' employed in the nonagricultural sector(% of total nonagricultural employment)	
		% Unemployment (% of female labor force unemployed/ % of male labor force unemployed)	
		% of women workers vs. men by sector	Risk of Gender Inequity by sector
	High Conflict Zones	Heidelberg Conflict Barometer-# of conflicts	
		Heidelberg Conflict Barometer-maximum intensity of conflicts (1-5)	
		Heidelberg Conflict Barometer-change in	Risk for High Conflict

		conflicts(positive=worsening)	
		Number of Refugees-UN Refugee Agency (000's)	
		Center for Systemic Peace Indicator	
		Minority Rights Group Indicator	
		Top Risers from last year in Minority	
		Rights Group Indicator, X	
		Qualitative	Risk for high conflic specific to sectors
	Human Health-Communicable Disease & Other Health Risks besides Disease	Life expectancy at birth (years)	Risk of low life expectancy
		Mortality rates for injuries (per 100,000 population)	Risk of high mortality rates due to injury
		Proportion of undernourished % of total population (-)=<5%	Risk of high undernourishment
		Death due to indoor and outdoor air and water pollution, per million	Risk of death due to air and water pollution
		Population affected by natural disaters, ave per year per million	Risk of death due to natural disasters
		Cases of HIV (per 1000 adults 15-49 years)	Risk of HIV
		Cases of Tuberculosis (per 100,000 population)	Risk of Tuberculosis
		Cases of Malaria (per 100,000	Risk of Malaria

		population)	
		Cases of Dengue Fever(per 100,000 population)	Risk of Dengue Fever
		Cases of Cholera	Risk of Cholera
		Mortality rates from commnicable diseases (per 100,000 population)	Risk of mortality from communicable diseases
	Children out of School	Children out of school-male	Risk of children not attending school-male
		Children out of school-female	Risk of children not attending school-female
		Children out of school-total	Risk of children not attending school-total
	Access to Improved Drinking Water	Access to Improved Drinking Water, %-rural	Risk of not having access to Improved Drinking Water-rural
		Access to Improved Drinking Water, %-urban	Risk of not having access to Improved Drinking Water-urban
		Access to Improved Drinking Water, %-total	Risk of not having access to Improved Drinking Water-total
	Access to Improved Sanitation	Access to Improved Sanitation, %-rural	Risk of not having access to Improved Sanitation-rural
		Access to Improved Sanitation, %-urban	Risk of not having access to Improved Sanitation-urban
		Access to Improved Sanitation, %-total	Risk of not having access to Improved Sanitation-total
Community Infrastructure	Access to Hospital Beds	Access to Hospital Beds-# beds/1000 pop	Risk of not having access to Hospital Beds

One example that shows how companies can benefit from implementing health and safety practices is from Otis lift d.o.o. (Slovenia).

Otis lift is part of a multinational company whose core business is manufacturing and selling elevators and escalators as well as maintaining its products on a regular basis. The Otis project aimed at gradually building a complete safety system and culture for all stakeholders (mainly employees, customers, subcontractors and suppliers). (European Agency forSafety and Health at Work, 2011)

Otis implemented various measures with the ultimate goal of creating a safety culture for all. These measures included, among others:

1) Raising awareness of importance of general safety: weekly texts (SMS) messages are sent to every employee in the field on important safety rules and procedures. The employees in the offices receive monthly e-mails instead of texts. In addition, films about the importance of safety were shown to employees, quarterly campaigns on safety issues were carried out and memory cards in the form of checklists were developed for employees.
2) Improvements in safety skills: quarterly safety training and interactive training sessions were carried out, and first aid training was also offered.
3) The employees were more involved in the safety decision-making processes, for example through quarterly meetings on safety; regular offsite activities were organised to decrease stress (weekly sports activities).
4) Field checks by the managers and supervisors to verify if safety rules were correctly implemented.
5) Introduction of new 'job hazard analysis' forms for different groups of employees.
6) The employees are offered rewards for outstanding achievements in the field of safety; rewards are only given for team achievements.
7) Suppliers are selected on the basis of safety records, among other factors.

The success of the project is reflected in the following facts:

1) Zero accident or injuries for the employees and subcontractors since 2004;
2) Improved safety skills: the employees are better trained to identify, notice and control or even eliminate hazardous conditions;
3) Better teamwork and communication between the management and employees;
4) Reduced absenteeism among the office workers;
5) Better scores on external safety audit;
6) More frequent near-hit reports.

2.5 Profitability

Managers of today's companies are under significant pressure to meet and exceed quarterly financial goals. Recent changes in investor attitudes, government regulations and consumer sentiment is making that pressure greater. As managers balance spending between driving increased revenue, meeting government regulations required to stay in business like Sarbanes-Oxley, PCI compliance, data privacy laws, etc; as a result of these drivers it is hard for managers to make a tactical decision to spend money on sustainability best practices (Kumar, et al., 2012). However, it will not be long before addressing sustainability will become both a tactical and strategic necessity. In a study conducted by Granade et al. (Granade, et al., 2008), it was found that energy consumption across the US will increase by 1.5% annually in the commercial sector and 0.5% in the industrial sector. Between 1996 and 2006 the price of energy in the US more than doubled. This makes energy costs in the commercial industry have an average increase of close to 10% per year which creates a substantial burden on most companies. The McKinsey study suggests that sustainability efforts could result in a decrease of energy use by 23% over the current 'business as usual' practices. Keeping the cost of energy fixed, the impact of a 2%reduction per year of energy use would

result in nearly 30% lower costs for a company over the next 10 years (Kumar, et al., 2012).

Through structural equation modeling, Rao et al. suggested that sustainable supply chains will not only help firms achieve substantial cost savings, but also enhance sales, market share, and exploit new market opportunities to lead to greater profit margins, all of which contribute to the economic performance of the firm (Rao, et al., 2005).

Many managers pursue sustainable behavior just because they think it is the right thing to do. But some of these managers also think that it benefits their firms in terms of revenue effects. These involve higher sales and strong customer loyalty for firms perceived to be sustainable in their business practices, and the avoidance of buying from those firms they see as not (Mefford, 2011).

A survey of 25,000 consumers in 26 different countries by the consulting firm Pricewaterhouse Coopers in 1999 found that more consumers based their impression of a company on its corporate social responsibility practices than on brand reputation or financial factors (Pricewaterhouse Cooper, 1999). This study indicates that the major CSR issues important to consumers are labor practices, business ethics, environmental practices, and demonstrated responsibility to society at large.

The service profit chain is proposed by Heskett et al. to link customer satisfaction and loyalty in services to market performance. They define market performance to mean higher revenues and market share as well as profitability. Customer loyalty enhances market performance in their model by increased revenues, lower costs to acquire and service customers, and lower customer price sensitivity (Heskett, et al., 1994). Based on the concepts of service profit chain, brand equity, Robert has concluded the channel of the effect on customers of sustainable supply chain practices and the resultant pricing, sales, and revenue effects shown in Figure 8.

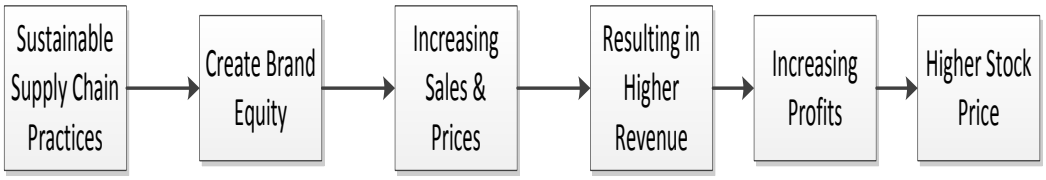

Figure 8 Sustainable Supply Chain Linkages: The Marketing Channel (Heskett, et al., 1994)

Most companies now recognize that a sustainable supply chain is no longer just an optional nice-to-have—it's a business imperative, critical to the success of the organization as a whole in a perilous world. In 2010, when Accenture surveyed more than 700 members of the United Nations Global Compact on sustainable business practices, 96 percent of CEOs said that sustainability should be integrated into all aspects of strategy and operations. And 88 percent of them singled out the supply chain as an area of specific importance. Based on Accenture's analysis, sustainable supply chain will create new business models, which will develop new markets and new services. Also sustainable supply chain will improve energy efficiency, which will lead to cost reduction. Additionally, sustainability will lead to transparency and employee's engagement, which will reflect on company's productivity (Hanifan, et al., 2012).

2.6 Sustainable Manufacturing

2.6.1 In Need of Sustainable Manufacturing

Sustainable Supply Chain Management is including different activities with regard to different levels of decisions, while most of the waste and inhuman activities are directly related to manufacturing operational level. Nearly a third of the world's energy consumption and 36% of carbon dioxide (CO2) emissions are attributable to manufacturing activities (2013 Global Greenhouse Warming, 2013). Manufacturing activities are also integrated in suppliers' activities and distributors' activities, which will have significant impact on the environment.

In addition, manufacturing sectors have been the subject of intense public scrutiny and criticism for their human rights performance abroad. Also, these industrial sectors illustrate challenges of corporate human rights responsibility and implications for corporate policies that are common and applicable to most other sectors (Kaeb, 2008). Sustainable manufacturing helps companies to save money, enhance competitiveness, and reduce environmental, health, and safety impacts. According to a recent survey, two-thirds of nearly 3,000 company officials surveyed responded that "sustainability was critically important to being competitive in today's marketplace." (Haanaes, et al., 2012) In addition, as an indication of company sustainability initiatives and stakeholder interest, 93 of the S&P 100 companies reported sustainability information on their websites in 2008 (Mohan, 2010).

According to the U.S Environmental Protection Agency, Sustainable Manufacturing is referred to as the creation of manufactured products through economically-sound processes that minimize negative environmental impacts while conserving energy and natural resources. Sustainable manufacturing also enhances employee, community, and product safety (U.S Environmental Protection Agency). From this definition, it also indicates that the metrics and/or indicators for Sustainable Supply Chain can be also applied to Sustainable Manufacturing.

As part of Sustainable Supply Chain Management, Sustainable Manufacturing is also inheriting the benefits from Sustainable Supply Chain Management, the key benefits for Sustainable Manufacturing are:

1) Lower Resource and Production Costs
2) Lower Regulatory Compliance Costs
3) Improved Sales and Brand Recognition
4) Greater Access to Financing and Capital
5) Easier Employee Hiring and Retention

2.6.2 Tools for Sustainable Manufacturing

2.6.2.1 Green Manufacturing

Green manufacturing deals with maintaining sustainability's environmental, economic and social objectives in the manufacturing domain. Reducing hazardous emissions, eliminating wasteful resources consumption and recycling are examples of sustainable green manufacturing activities (Deif, 2011).

The importance of Green manufacturing has been discussed by a few articles. Mohnty and Deshmukh (Mohnty, et al., 1998) highlight the importance of green productivity as a competitive edge. They defined green productivity as all activities attempting to decrease wastes. They showed various case studies with different waste elimination practices to highlight the potential green productivity can have on the overall manufacturing performance. Naderi (Naderi, 1996)showed that green manufacturing is highly tied to waste management through the elimination of causal factors. Jovane et al. (Jovane, et al., 2003)presented sustainable and green manufacturing as future paradigm with business model based on designing for environment using new nano/bio/material technologies. They highlighted that the new paradigm will respond to the customer need of more eco-friendly products. Wang and Lin (Wang, et al., 2007) proposed a broad triple bottom line framework to track and categorize sustainability information at the corporate level through a sustainability index system. The framework incorporated environmental and social costs and values into economic activities to support the decisions of the management. Their methodology was suggested to help decision makers to make green manufacturing plans. Burk and Goughran (Burk, et al., 2007) also presented another framework for sustainability to realize green manufacturing. The framework was based on their studies of SME manufacturers who achieved ISO 14001 certification (Deif, 2011).

Various analysis tools and models have also been proposed before. Melnyk et al. (Melnyk, et al., 2001) proposed Green MRP tool. This tool is essentially a conventional Material Requirements Planning system that has been modified to include environmental considerations when converting the Master Production Schedule into the various component schedules. Through this inclusion, Green MRP solves the problem of minimizing environmental impact when managing industrial waste, by flagging potential component planning and environmentally related problems. Fiksel (Fiksel, 1996) gathered different analytical tools that have emerged from product/process design research for green manufacturing. Examples of these tools include Life Cycle Analysis (LCA), Design for the Environment (DFE), screening methods and risk analysis. Hui et al. (Hui, et al., 2002) proposed a model to assess environmental hazards in manufacturing. In their model, the network analytic method was employed to analyze the potential of each impact category created by different kinds of waste in manufacturing processes. Additionally, fuzzy set theory was used to determine a numeric fuzzy weighting factor of each impact category contributing to the overall potential environmental impact on ecosystem. The model was limited to ecological health hazards. For realizing green manufacturing on the machine level, Krishnan et al. (Krishnan, et al., 2004) proposed environmental value systems analysis tool to evaluate the environmental performance of semiconductor processing. The tool develops environmental assessments through a "bottom-up" analysis approach, assembling equipment environmental models to describe a system. Cleanability and burr reduction which are another green manufacturing aspects also on the machine level were studied in various machine tool researches to act as another optimization objectives in their attempts to improve machine tool performance. Example of this type of work was presented by Avila et al. (Avila, et al., 2005) in the aerospace industry.

2.6.2.2 Lean Manufacturing

Together with Green Manufacturing, Lean Manufacturing is also playing an important role in reducing the waste and resource allocation. While Lean Manufacturing is not only considering from the point of the environmental impact, it is mainly based on the point of maximizing the value for end users, which not necessarily includes the reduction of natural resources, but also includes the reduction of human resources.

Lean production is a multi-dimensional approach that encompasses a wide variety of management practices, including just-in-time, quality systems, work teams, cellular manufacturing, supplier management, etc. in an integrated system. The core thrust of lean production is that these practices can work synergistically to create a streamlined, high quality system that produces finished products at the pace of customer demand with little or no waste (Shah, et al., 2003).

The lean thinking can be summarized in five principles "precisely specify value by specific product, identify the value stream for each product, make value flow without interruptions, let the customer pull value from the producer, and pursue perfection". By clearly understanding these principles, and then tying them all together, managers can make full use of lean techniques and maintain a steady course" (Ravet, 2011) (Womack, et al., 2003)

The lean model requires less stock, less space, less movement of materials, less time to set up the machinery, a smaller workforce, fewer computer systems and more frugal technology (Ravet, 2011) (Shahin, et al., 2010) Consequently, lean supply chain strategies focus on waste reduction, helping firms eliminate non-value adding activities related to excess time, labor, equipment, space and inventories across the supply chain (Ravet, 2011) (Corbett, et al., 2006). Such strategies enable firms to improve quality, reduce costs, and improve service to customers (Ravet, 2011) (Larson, et al., 2004).

Lean and green strategies are often seen as compatible initiatives because of their joint focus on waste reduction (Mollenkopf, et al., 2010). Womack (Womack, et al., 2003) underlines that lean thinking must be ‘’green’’ because it reduces the amount of energy and wasted by-products required to produce a given product.

According to Ravet (Ravet, 2011) lean production and sustainable supply chain create their “eco- advantage” in three main ways:

1) Eco-efficiency (cutting out waste, using resources productively, and minimizing the carbon footprint) Lean methods can develop sustainable green practices, particularly in the area of waste reduction.
2) Eco-innovation (improving product and service designs so they’re based on green processes by products and designing for recycling)
3) Eco-transparency: gaining and sharing full visibility into the value chain so that your business can promote its green brand and enhance and protect its overall brand.

2.6.2.3 EHS Development

The violation of human rights in manufacturing sectors has long been criticized, which also leads to difficulty of retention of talented employees. This will directly and indirectly influence the company’s image and its sustainable development. Such as the child labor usage in Apple, it has gained huge public attention and emergent actions are called to protect the labor environment in Apple’s manufacturing environment. Besides, the nuclear power plant leakage in Japan in year 2011 has increased the caution of workplace safety. Thus, more and more companies are implementing the Environment, Health and Safety Initiative in order to reduce the violations of human rights in manufacturing environment and produce an appealing environment for employees. This will also result in higher productivity and better customer satisfaction.

The first formal EHS management approach was introduced in 1985 by the chemical industry as a reaction to several catastrophic accidents (like the Seveso disaster and the Bhopal disaster). This worldwide voluntary initiative called "Responsible Care" is in place in about 50 countries and centrally coordinated by the International Council of Chemical Associations (ICCA). It involves eight fundamental features that ensure plant and product safety, occupational health and environmental protection but also try to demonstrate by image-building campaigns that the chemical industry acts in a responsible manner. Still, this initiative is restricted to the chemical industry.

Since the 1990s, general approaches to EHS management that may fit any type of organization can be found in international standards like ISO 14001 for environmental management and OHSAS 18001 for occupational health and safety management or the European Eco-Management and Audit Scheme (EMAS). In 1998, EHS guidelines were also created by the International Finance Corporation (2013).

2.6.2.4 Corporate Social Responsibility Initiative

Another similar initiative that is widely discussed recently in different sectors, especially in manufacturing sectors, is Corporate Social Responsibility (CSR). The International Organization for Standardization, known as ISO, strategic advisory group on CSR describes it as "a balanced approach for organizations to address economic, social and environmental issues in a way that aims to benefit people, communities and society." (responsibility, 2002). CSR includes consideration of such issues as (Leonard , et al., 2003):

- Human Rights
- Workplace and employee issues, including occupational health and safety
- Unfair business practices
- Organizational governance

- Environmental aspects

As Industry Canada has illustrated, CSR can make companies more innovative, productive, and competitive. CSR helps make Canadian business more competitive by supporting operational efficiency gains; improved risk management; favorable relations with the investment community and improved access to capital; enhanced employee relations; stronger relationships with communities and an enhanced licence to operate; and improved reputation and branding (Industry Canada, 2011).

2.7 Six Sigma in Sustainability

2.7.1 Definition of Six Sigma

Two and a half decades ago, Bill Smith of Motorola started Six Sigma philosophy, principles and methods based on Total Quality Management. Since then, thousands of organizations have been involved in Six Sigma practice (Brady, et al., 2006).

Linderman *et al*. (Linderman, et al., 2003) defines that 'Six Sigma is an organized and systematic method for strategic process improvement and new product and service development that relies on statistical methods and the scientific method to make dramatic reductions in customer defined defect rates.'

Even though Six Sigma is associated with abundant statistics tools, such as factor analysis, statistical control chart, etc. Brady and Allen argues that Practitioners applying Six Sigma can and should benefit from applying statistical methods without the aid of statistical experts (Brady, et al., 2006). Hence Six Sigma is a systematic method to help organizations to investigate critical problems and find out solutions to implement continuously.

There is sufficient consensus within the Six Sigma literature to offer the following additional details about the Six Sigma method in its definition:

The Six Sigma method for completed projects includes as its phases either Define, Measure, Analyze, Improve, and Control (DMAIC) for process improvement or Define, Measure, Analyze, Design, and Verify (DMADV) for new product and service development (Brady, et al., 2006).

The Table 9 summarizes the strategies and tools that are frequently used in the real industry.

Table 9 Six Sigma Strategies and Tools (Antony, et al., 2003)

Six Sigma Business Strategies & Principles	Six Sigma Tools & Techniques
Project management	Statistical process control
Data-based decision making	Process capability analysis
Knowledge discovery	Measurement system analysis
Process control planning	Design of experiments
Data collection tools and techniques	Robust design
Variability reduction	Quality function deployment
Belt system (Master, Black, Green, Yellow)	Failure mode and effects analysis
DMAIC process	Regression analysis
Change management tools	Analysis of means and variances
	Hypothesis testing
	Root cause analysis
	Process mapping

2.7.2 DMAIC

DMAIC is a closed-loop process that eliminates unproductive steps, often focuses on new measurements, and applies technology for continuous improvement (Kwak, et al., 2006). The key processes for each step are summarized in Table 10.

Table 10 DMAIC Key Processes (McClusky, 2000)

Six Sigma Steps	Key processes
Define	Define the requirements and expectations of the customer
	Define the project boundaries
	Define the process by mapping the business flow
Measure	Measure the process to satisfy customer's needs
	Develop a data collection plan
	Collect and compare data to determine issues and shortfalls
Analyze	Analyze the causes of defects and sources of variation
	Determine the variations in the process
	Prioritize opportunities for future improvement
Improve	Improve the process to eliminate variations
	Develop creative alternatives and implement enhanced plan
Control	Control process variations to meet customer requirements
	Develop a strategy to monitor and control the improved process
	Implement the improvements of systems and structures

2.7.3 Benefits of Six Sigma Implementation

2.7.3.1 Six Sigma in Manufacturing

Since the introduction of Six Sigma in Motorola, Six Sigma has been implemented in a wide range of industries. The successful financial returns have encouraged different organizations to take Six Sigma initiative. The Table 11 summarizes the reported benefits from manufacturing sectors.

Table 11 Reported benefits from Six Sigma in manufacturing
(Weiner, 2004) (de Feo, et al., 2002) (Antony, et al., 2002) (Buss, et al., 2001) (McClusky, 2000)

Company/project	Metric/measures	Benefit/savings
Motorola (1992)	In-process defect levels	150 times reduction
Raytheon/aircraft integration systems	Depot maintenance inspection time	Reduced 88% as measured in days
GE/Railcar leasing business	Turnaround time at repair shops	62% reduction
Allied signal (Honeywell)/Iaminates plant in South Carolina	Capacity Cycle time Inventory On-time delivery	Increased to near 100%
Allied signal (Honeywell) /bendix IQ brake pads	Concept-to-shipment cycle time	Reduced from 18 months to 8 months
Hughes aircraft's missiles systems group/wave soldering operations	Quality/productivity	Improved 1,000%/Improved 500%
General electric	Financial	$2 billion in 1999
Motorola (1999)	Financial	$15 billion over 11 years

Dow chemical/rail delivery project	Financial	Savings of $2.45 million in capital expenditures
DuPont/Yerkes plant in New York (2000)	Financial	Savings of more than $25 million
Telefonica de espana (2001)	Financial	Savings and increases in revenue 30 million euro in the first 10 months
Texas instruments	Financial	$600 million
Johnson and Johnson	Financial	$500 million
Honeywell	Financial	$1.2 billion

2.7.3.2 Six Sigma in Sustainability

Many projects that are related to sustainability development have been conducted using Six Sigma approach. As a leading global supplier of high performance specialty chemicals and coatings, Enthone has demonstrated good examples of the applications of Six Sigma in Sustainability development. The project of Reduction of Plastic Packaging has resulted in a 20% reduction in plastic packaging while providing environmental benefits. Additionally, the project of Reduction in Energy Usage resulted in a significant annual cost savings, primarily by consolidating into larger batches being manufactured. This has resulted in less waste treatment and has resulted in a 10% reduction in energy usage (Enthone, 2013). What's more, 3M as a pioneer in corporate pollution prevention, it has implemented sustainability development with the help of Lean Six Sigma. Over the last 31 years, the program has prevented more than 2.6 billion pounds of pollutants and saved more than $1 billion based on aggregated data from the first year of each 3P project (EPA United States Environmental Protection Agency).

Another technique that is widely discussed is Lean Six Sigma. It evolves from Six Sigma with DMAIC framework but also involves green concepts (Park, et al., 2008). While it has been implemented in different organizations, the focus of Lean Six Sigma is mostly to reduce waste and environmental impact. It lacks of emphasis on social impact which is becoming more and more crucial in developing countries, especially in Asia and Latin America which is the hubs for production activities.

Chapter 3 Solution Approach

The solution provided for this thesis is evolved from Six Sigma and Achieving Excellence System with the concepts of sustainability. There are five phases to achieve sustainable manufacturing, Define, Sustainability Measurement, Sustainability Analysis, Sustainability Improvement and Achieving Leadership. The tools from quality management are integrated into these five phases. Figure 9 has shown the five phases with the main tools used in each phase.

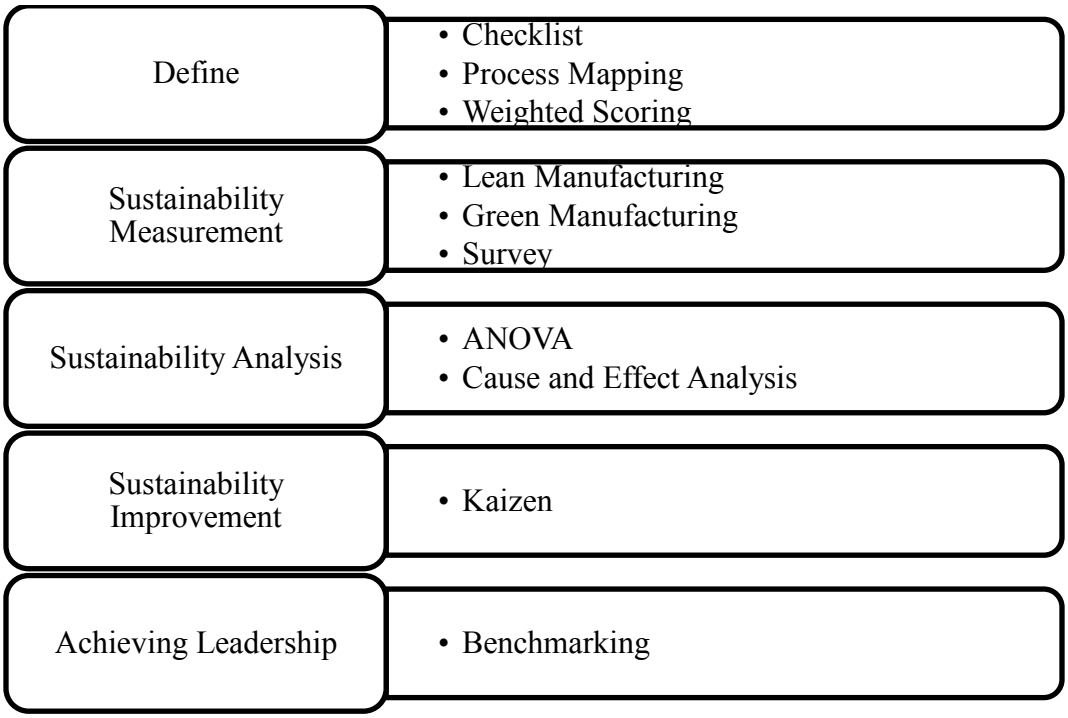

Figure 9 Solution Phases and Main Tools

The link between the remaining research problems and proposed solution framework is showing in Figure 10.

Figure 10 Link between Problems and Solutions

3.1 Define

3.1.1 Preliminary Check

The first question that should be asked is whether the organization has been aware of the sustainability impact. A preliminary checklist shown in Table 12 can be used as a survey to understand the level of implementation of such practices among employees. The checklist will provide an overview of the understanding of sustainability development in a manufacturing environment. The items will be separated for three groups. The first group is for employees who are working under office environment, such as supply chain planner, accountant, etc. This group of employees is aware of the general policies of companies, while they are

not the ones that are experiencing the sustainability initiatives directly and intimately. The second group is for employees who are doing the manual labor work under manufacturing environment, such as assembly workers, transportation drivers, testers, etc. This group of people is directly facing the challenges of sustainability development and witnessing the outcomes of manufacturing activities, such as polluted water, work-related injuries, etc. The third group is targeting the management, who is directing the development of sustainability. This group is reflecting the commitment and awareness of sustainability development for the company.

Table 12 Preliminary Checklist for Understanding of Sustainability

Item	Checklist
For office employees	
1. Do you know sustainability?	Y/N
2. Do you think that XX Company is implementing sustainability initiative?	Y/N
3. Do you expect the implementation of sustainability if it is not implemented?	Y/N
For manual labor workers	
1. Do you have or witness any pollution activities during production?	Y/N
2. Do you have any injuries related to work?	Y/N
3. Are there any practices that are used to recycle the wastes and pollutants?	Y/N
4. Do you feel that the XX Company is making changes to use less polluted components, such as plastics, lead, etc.?	Y/N
For management:	
1. Do you know sustainability development?	Y/N
2. Are you interested in sustainability development?	Y/N/Maybe
3. Is there any policy that is related to sustainability development in XX Company?	Y/N/Not Sure
4. Is XX Company is willing to invest in sustainability development?	Y/N/Maybe
5. Do you know the benefits of sustainability development?	Y/N

From the checklist survey, it gives analysts general view of the understanding of sustainability development. Based on this, analysts are able to develop more specific investigation with regard to the obstacles and futures for sustainability development under the manufacturing environment.

3.1.2 Management Commitment Investigation

As a key factor for implementing sustainability development and Six Sigma, it is crucial to understand the level of commitment from management and its restrains. The following aspects should be investigated:

1) The strategic goals of the current management?
2) What are the current manufacturing benefits?
3) How much of investment XX Company is willing to allocate?
4) What are the obstacles for implementing sustainable strategy under the manufacturing environment?
5) What are the expectations that the management are expecting from the implementation of sustainability development in the manufacturing environment?

It is encouraged that the investigation is under a confidential environment, and it could include the management from different functions, which have different views for the commitment for sustainability development. It is good practice to draw or figure out the organization chart before the investigation, since the right target of interviewees will have better influence for the understanding of current management commitment and its implementation for the future projects. For example, the president should be able to give the long term vision of company's development, while the chief financial officer will give visible economic data to display the current manufacturing status, etc. Additionally, the interview should include the opinions from the middle management who practically give instructions to the front employees.

3.1.3 Current Process Mapping

After the investigation of management attitude for the implementation of sustainability development under manufacturing environment, it is essential to clearly understand the work flow of the manufacturing environment. Especially to understand if there is any practice related to sustainable development for the daily work.

The tool can be used is called Process Mapping, which is a workflow diagram to bring forth a clearer understanding of a process or series of parallel processes. The following steps can be used to complete a clear process diagram (Ahoy, 1999):

1) Determine the boundaries, meaning the begin and end;
2) Use verbs to list all the steps;
3) Sequence the steps;
4) Check the resources and constrains;
5) Draw appropriate symbols;
6) Link the resources and constrains with the steps.

In order to assess the sustainability development, the 5M elements that are widely for lean production can be used to understand clearly the input and output of the process (Wee, et al., 2009):

1) What the materials are involved as input and output?
2) What are the methods that have been used to produce the products?
3) What are the machines used during the production process?
4) What kind of man power is used during the production process?
5) How much money has been invested in different steps?

By asking these 5M questions, it will help the analyst to clearly understand how each step of production activity has been practiced in reality. Besides, it will supply basic ideas for the future measurement and analysis with regards to sustainability development under the manufacturing environment.

3.1.4 Preliminary Project Selection

After understanding the company business vision from management and current manufacturing process, the analyst need to identify the specific sustainability development projects due to the limited resources and wide range of sustainability development feasibility. It is not easy and feasible to implement all the sustainable practices at the same time for all the manufacturing process. There should be some selection criteria to help analyst and management team to identify the project that will mostly address the critical problems relating to sustainable development at the current stage.

Table 13 Preliminary Project Selection Scorecard Illustration

Process	1	2	3
Material Utilization Rate	1	3	3
Labor Working Environment	3	5	1
Pollution Impact	5	1	5
Importance for the manufacturing	1	5	1
Investment	3	1	1
Final Score	**13**	**15**	**11**

From Table 13, an illustration sample, we can see that process 2 has highest score for sustainability improvement. The detailed criteria assessment methods are in details below.

For each process or step that is recognized in the process mapping, it is helpful to do a preliminary assessment of the sustainability development and to determine which process or step should be improved first based on the different criteria:

1) Material Utilization Rate: To assess whether the raw materials have been appropriately transformed into final products. It describes the difference between the raw material weight used to produce a part and the actual weight of the finished part. The higher the percentage of utilization, the

better and more economical the stamping process (FMA Communications Inc.). The following equation can be used as a preliminary assessment for the manufacturing department to understand whether the raw material is under proper usage and if there is huge amount of waste. The criteria will be given by 1, 3 and 5 scheme, where 1 means the material utilization rate is high (MUA is between 75%~100%), and 5 means the utilization rate is very low (MUS is between 0~40%).

Equation 1

$$\mathbf{MUA} = \frac{\textbf{Actual Weight of the Material in the Final Product}}{\textbf{Total Raw Material}} \times \mathbf{100}\%$$

2) Labor Working Environment: It is good practice to form a Environment, Health and Safety department or committee under the manufacturing environment to evaluate the working environment for human labor. The most important elements that should be considered for process improvement are: clear working guidance, natural working environment (i.e. if the labor is exposed to the poisonous chemicals, the water and air consumed is clean and safe, etc.), excessive working time and work related injuries. The scheme for each element is 1, 3 and 5. An evaluation example is showed in Table 14 for illustration.

Table 14 Labor Working Environment Evaluation Illustration

Elements	**Weight**	**Evaluation**	**Weighted Evaluation**
Clear working guidance	25%	1 (meaning good guidance)	0.25
Natural working environment	25%	5 (meaning the labor is exposed to very	1.25

		unhealthy working situation)	
Excessive working time	25%	1 (excessive working time is rare)	0.25
Work related injuries	25%	5 (there are a lot of injuries related to work)	1.25
Total Weighted Evaluation			**3**

3) Pollution Impact: This can be evaluated based on the input and output from the process mapping. Due to various definitions of the pollutants from different organizations, in this article, we put pollutants into three big categories. If the pollutants and/or waste are existing in all three categories, it should be given 5 points as an indicator if improvement, otherwise it can be given 1 point.
    a) Liquid Pollutants (Pol):

acids - hydrochloric, acetic, fumaric, sulphuric, nitric, benzoic

bases - hydroxides of sodium, calcium, magnesium

carboxylic compounds

nitrogenous wastes

    b) Air Pollutants: Ozone, Particulate Matter, Carbon Monoxide, Nitrogen Oxides, Sulfur Dioxide and Lead (US Environmental Protection Agency);
    c) Solid Waste: Biodegradable waste, Recyclable material, Inert waste, Electrical and electronic waste, Composite waste, Hazardous waste, Toxic waste and Medical waste (Wikipedia)
4) Importance for Manufacturing: This is a criteria to help organization to prioritize if the sustainable development should be implemented in this process based on its importance for the whole manufacturing process. This

will vary from different organizations due to its products. For example, if the company is a car manufacturing company, and the process is for engine production, then this process will be given high score for its importance. This process will involve both manufacturing and product management or engineering departments to co-operatively assess its importance for the organization. From this, it is obvious that Six Sigma projects include different levels of employees' involvement. From low to high importance, 1, 3 and 5 points will be allocated accordingly.

5) Investment: As for the improvement of a sustainable manufacturing process, it is also crucial for a company to understand how much investment it can be affordable due to the complexity of the problems that have been demonstrated before. For example, after the evaluation of previous work, the management and analysts will decide if there will be a huge amount of investment for the particular process and if the investment can be affordable for the company. A simple equation will help the organization to give indicator for this criteria. If the calculation is between 0~50%, 5 should be given as it is not big financial burden for the company to improve and continuous improvement is possible for Six Sigma projects, if the calculation is between 51%~100%, 3 should be given, otherwise 1 should be given to indicate that the investment is big financial burden that the company might not be able to continuously improve.

Equation 2

$$\textbf{Invetment Feasibility} = \frac{\textbf{Investment needed}}{\textbf{Invetment affordable}} \times \mathbf{100}\%$$

But this is just a preliminary selection, other elements should be addresses at the same time when the Six Sigma projects are to be selected, for instance, if the

organization is considering that investment has high impact for the successful implementation for the sustainable development, then it should be given high weight when we make the decision. Under this circumstance, the weighted scorecard can be used as a final decision making tool as demonstrated in Table 15.

Table 15 Weighted Scorecards for Project Selection

Item		Process 1	Process 2	Process 3
MUA	Original Score	1	3	3
	Weight	20%	20%	20%
	Weighted Score	*0.2*	*0.6*	*0.6*
Labor Working Environment	Original Score	3	1	5
	Weight	15%	15%	15%
	Weighted Score	*0.45*	*0.15*	*0.75*
Pollution Impact	Original Score	1	3	5
	Weight	10%	10%	10%
	Weighted Score	*0.1*	*0.3*	*0.5*
Importance for the Manufacturing	Original Score	3	3	5
	Weight	5%	5%	5%
	Weighted Score	*0.15*	*0.15*	*0.25*
Investment	Original Score	1	5	3
	Weight	50%	50%	50%
	Weighted Score	*0.5*	*2.5*	*1.5*
Final Weighted Score		**0.95**	**3.7**	**3.6**

The weighted score give us a more comprehensive understanding from current objective situation and subjective opinions from the organization. It shows that Process 2 should be the first project for sustainability development due to the financial accessibility for the continuous improvement.

3.2 Sustainability Measurement

During this phase, organization will need to identify different criteria to measure the sustainability development status in manufacturing environment. Different methods can be used during the measurement phase, for example, internal audit, employee questionnaire, etc. Based on the scale of a company or the products the company is producing, numerous metrics or questions can be formulated for the investigation. While for the modelling purpose of this paper, there is a framework for the measurement, which involves three general steps to conduct the measurement systematically.

Except the general steps listed below, one of the most critical areas in measurement phase is to define the measurement metrics. Reviewing from different articles and industry reports, three categories of sustainability measurement for manufacturing are proposed, Lean measurement, Green Measurement and Social Assessment. They will form a comprehensive roadmap to gather information regarding how the sustainability practices have been implemented in manufacturing environment and they will give clear and detailed picture of the situation and problems the company is facing now. But these categories are not exclusively independent; there will be intersection points among each category, such as measurement of poisonous chemicals will also have impact on green and social assessment. There is no specific step for which category of investigation goes first, but it will be more objective to use external auditing team or temporary team to implement the investigation to keep information accurate.

3.2.1 General Measurement Step

In order to assess the sustainability development status, there are general steps shown in Figure 11 to follow in order to understand the targets and the extent to which the organization is performing.

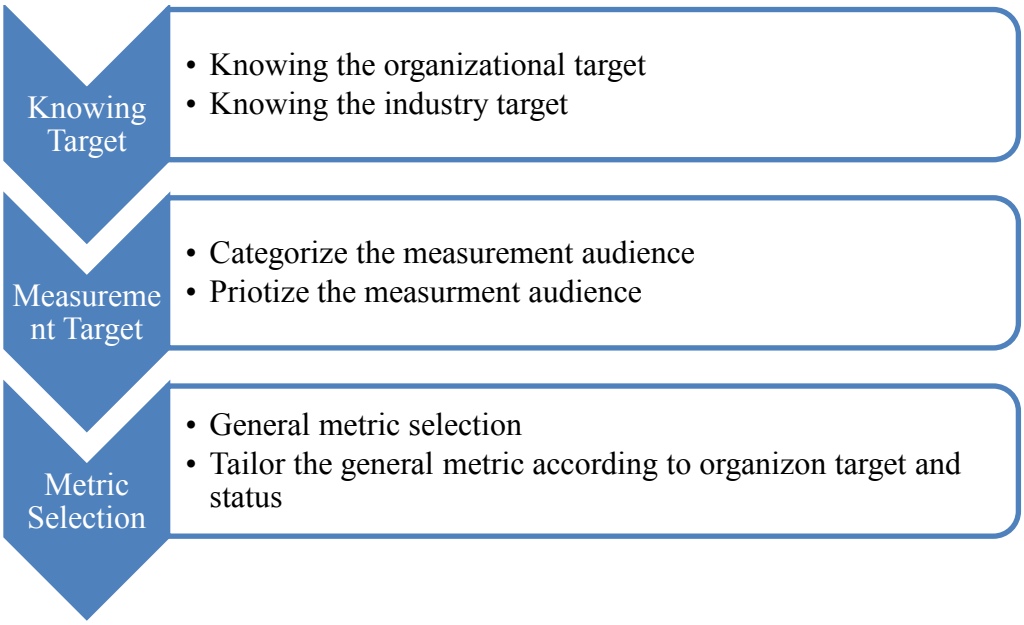

Figure 11 General Manufacturing Sustainability Measurement Steps

The first step is to understand the target of the organization and the industry. It is essential to understand what the organization's expectations and what the industry's requirements and trend in order to be competitive. Different organization and industry have their own characteristics and obstacles in order to achieve the sustainability mission, for example, the ISO 14001:2004 (ISO) has set general targets to achieve environmental friendly management system, and for Canada government, there is Federal Sustainable Development Act (Environment Canada) effective since 2008. There are always different targets, regulations to achieve; it will influence how the organization measures the sustainability.

Second step is to categorize the measurement target, whom the organization will conduct the measurement. For example, if the company is mainly a software R&D center, which mainly performs the design and research activity, then the manufacturing sustainability audience might be the contractors who actually do the production of chips. Besides, since different levels will reflect different

concerns for the company, at what level of the measurement should be done is also an aspect to consider. For instance, do we need to involve the senior management or on-site manual labor workers, do we need to involve all the contractors and so on. If we involve different levels of measurement, the way and content to conduct the measurement will differ from one to another. Additionally, there are different opinions from various backgrounds, as a company, there is need to set priorities for which voice should be emphasized in order to make better use of current resources and align with company's future vision.

After understanding the expectations and measurement target, it is necessary to select the metrics or ways to measure the sustainability status. It can be quantitative and/or qualitative based on the needs and feasibility. There are general metrics can be used as reference. After careful selection, organizations need to tailor the metrics based on their own needs and feasibility. For example, not every company is able to measure the carbon dioxide emission, and then this metric should be adjusted to something easy to measure indirectly, such as how much fuel gas the company is using every month for its trucks.

3.2.2 Lean Measurement

Under the manufacturing environment, lean practice can help to measure if there is any waste which is also a big part as sustainability development. It will help organizations to identify which process has been tremendous contribution for the materials waste. But lean is not necessarily can be fully implemented into sustainability development. Lean is focusing on all waste that will not add direct value to the customer's payment, while it might be harmful to employee's involvement and might violate the human rights. For example, if there the organization identify that one employee should manufacture more products at certain period to add more value to the machine the plant is operating, it might be burden to employee's health if the work load is strengthened. So, when the lean

thinking is applied for measurement of sustainability development, it should be balanced with social impact thoughts.

The typical seven types of waste that should be measured are:

- Transport (moving products that are not actually required to perform the processing)
- Inventory (all components, work in process and finished product not being processed)
- Motion (people or equipment moving or walking more than is required to perform the processing)
- Waiting (waiting for the next production step, interruptions of production during shift change)
- Overproduction (production ahead of demand)
- Over Processing (resulting from poor tool or product design creating activity)
- Defects (the effort involved in inspecting for and fixing defects) (Womack, et al., 2003) (Wikipedia, 2013)

Based on the seven types of waste, the sustainability waste measurement can be developed:

- Internal movement distance: This includes the distance that has been covered by the forklift, conveyer belt etc. It usually shows how much oil, gas and electricity has been consumed by the unnecessary movement of the different transportation equipment inside of the plant. Additionally, it will indirectly indicate the carbon dioxide impact from the internal movement, which is not easy to measure in most of the cases.
- Excessive inventory: This measures the materials that will not be used for the planned production, especially the products and raw materials

that will include the pollutant and poisonous elements mentioned before. Since the need of these materials will drive the production from its suppliers, this will have profound impact through the flow of the supply chain.

- Non-production time for the machine: This inspects the time when the machine is waiting for the next production while still on power. It will demonstrate the waste for electricity, gas and other power resources. Additionally, if the machine is a source of noise and might release non-environmentally friendly chemical or air elements, it will indicate the impact for the environment and employees' working situation.
- Unnecessary production time: This indicates the time that is used to produce the products that are not ordered directly from customer while just for the safe inventory purpose. The excessive production will lead to illegal or unpleasant working environment for employees. In addition, it will drive the unnecessary procurement and supply from its suppliers.
- Amount of chemicals: This measures how much of chemicals we procure and use for the processing of the final products. The amount of chemicals will show the impact it can bring to its processing employees who are exposed to these unhealthy elements. Besides, it will show how much pollution it can bring to the environment when it is disposed.

These measurements are summarized in Table 16 with its indicators:

Table 16 Lean Sustainability Measurement

Measurement	**Indicator**	**Hint**
Internal Movement	Meter	Energy resources consumed
		Air pollutants released

Distance		
Excessive Inventory	per material volume	Excessive energy consumed
		Pollutants and chemicals driven by suppliers
Non-production time	Minute	Excessive energy consumed
		Source for unpleasant noise for employees
		Source for chemicals released
Unnecessary production time	Minute	Excessive energy consumed
		Excessive raw materials consumed
		Illegal working time for employees
Amount of chemicals	Per material volume	Air, solid and liquid pollution

3.2.3 Green Measurement

As there are a lot of different indicators developed by different organizations and individuals, the main questions that should be asked for the environment impact are below in brief:

1) How much raw materials are used?
2) How much renewable resources are used?
3) How much non-renewable recourses are used?
4) How much waste is released to the environment after production?
5) How much waste will be released to the environment after the product life cycle?

There are plenty of indicators that can be used to assess the environment impact under manufacturing environment; it should be based on the company product and company working process. One set of the general and comprehensive green indicators for sustainable manufacturing are developed by the Organisation for

Economic Co-operation and Development (OECD) are illustrated in Table 17 for customized development based on different company's needs and constrains.

Table 17 OECD Green Manufacturing Indicators (OECD)

Inputs	**Operations**	**Products**
Non-renewable materials intensity	Water intensity	Recycled/reused content
Restricted substances intensity	Energy intensity	Recyclability
Recycled/Reused content	Renewable proportion of energy	Renewable materials content
	Greenhouse gas intensity	Non-renewable materials intensity
	Residuals intensity	Restricted substances content
	Air releases intensity	Energy consumption intensity
	Water releases intensity	Greenhouse gas emissions intensity
	Proportion of natural land	

The detailed explanation and formulas regarding the calculations have been listed below as well:

i. Non-renewable materials intensity=Weight of non-renewable resources consumed/Normalization factor

ii. Restricted substances intensity=Weight of restricted substances consumed/Normalization factor

iii. Recycled/reused content of material inputs=(Total weight of recycled material + Total weight of reused material)/Total weight of material inputs x 100

iv. Water intensity=Total water intake/Normalization factor

v. Energy intensity=(Energy consumed in production processes + Energy consumed in overhead)/Normalization factor

vi. Renewable proportion of energy consumed=Renewable energy consumed/Total energy consumed x 100

vii. Greenhouse gas(GHG) intensity=(GHGs released in energy consumption for production + GHGs released in energy consumption for overhead + GHGs released by transport used for business travel + Additional GHGs released from production process)/Normalization factor

viii. Residuals intensity (mass balance) =(Weights of all inputs + Weight of fuel consumed-Weight of all products)/Normalization factor

ix. Or: Residuals Intensity (Waste output) = (Weight of release to air + Weight of releases to surface water + Weight of releases to land + Weight of releases from landfills + Weight of transfers to disposal + Weight of transfers to treatment +Weight of transfers for recycling + Weight of transfers for energy recovery + Weight of transfers to sewage + Weight of additional GHGs produced + Carbon content of direct energy use) / Normalization factor

x. Intensity of pollutant release to air = Weight of releases (from production processes and, if available, overhead) to air/Normalization factor

xi. Intensity of pollutant releases to surface water= Weight of releases (from production processes and, if available, overhead) to surface water/ Normalization factor

xii. Natural cover = Natural cover area/Total land area x100

xiii. Recycled/reused content of products = Sum for each product (Weight of a product unit x Proportion of recycled content x Units produced) + (Weight of a produced unit x Proportion of reused content x Units produced)/ Sum for each product (Weight of a product unit x Units produced) x100

xiv. Recyclability of products =Sum for each product (Weight of a product unit x Proportion of recyclable content x Units produced)/Sum for each product (Weight of a product unit x Units produced) x 100

xv. Renewable materials content of products = Sum for each product (Weight of a product unit x Proportion of renewable materials in product x Units produced)/Sum for each product(Weight of a product unit x Units produced) x 100

xvi. Non-renewable materials intensity over product lifetime = Sum for each product (Weight of a product unit x Proportion of non-renewable content x Units produced)/Expected lifetime of product

xvii. Restricted substances content of products = Sum for each product (Weight of a product unit x Proportion of restricted substances in product x Units produced)/Sum for each product (Weight of a product unit x Units produced)

xviii. Intensity of energy consumption of products =Sum for each product (Average annual energy consumption of a product unit x Units produced) x Normalization factor

xix. Intensity of GHG emissions from products =Sum for each product (Average annual GHG emissions per product unit x Units produced)/Normalization factor

3.2.4 Social Assessment

As an important part of sustainable manufacturing, social responsibility has become more and more crucial for a company's image and its strategy to keep its talents. Besides, a social responsible manufacturing environment will have positive impact on employees' working moral as well as improving working efficiency.

Different organizations have proposed different code of conducts or guidelines for promoting social responsible behaviors, such as International Labor Organization's Conventions, the Universal Declaration of Human Rights, the United National Global Compact Principles (UNGC), and the California Transparency in Supply Chains Act, etc. In addition, different companies have various ways to measure its social responsibilities based on its manufacturing practices. Social responsibility is a comprehensive concept meaning there is no clear boundary to define the right behaviors and unethical behaviors. In order to clearly measure the social responsible actions the manufacturing environment is taking, two audits are designed to comprehensively measure the extent of social responsible actions implemented under the manufacturing environment. One is the objective audit to measure visible actions or accidents that happen due to social responsibility in Table 18. The other is a subjective questionnaire designed for employees to estimate their feeling of company's social responsibilities in Table 19.

Table 18 Social Responsibility Audit under Manufacturing Environment

Audit Items	Audit results
Clear Sign	
There is clear sign indicating different working or non-working area.	Yes/No/Not Complete
There is clear sign indicating the dangers or safety warning in working area.	Yes/No/Not Complete
There is clear instruction or brief warning regarding the machine or materials operation.	Yes/No/Not Complete
Protection Policy	
There is enough and functional fire extinguisher in different working or non-working area.	Yes/No/Not Complete
There is specific protection equipment for different profession, such as mask, protective cover, gloves, etc.	Yes/No/Not Complete
Working Environment	
Working environment is clean without excessive polluted liquid.	Yes/No
Working environment is clean without excessive solid waste.	Yes/No
Working environment is clean without unhealthy air circulating around the plant.	Yes/No
There is clear policy for working environment, regarding temperature, humidity for the sake of comfort.	Yes/No
There are enough and proper working tools.	Yes/No
There is clear policy for cleaning the working environment.	Yes/No
There is clear rule for proper working hour.	Yes/No
There is clear rule for not using child labor or forced labor.	Yes/No
There is clear rule against discrimination with regard to gender, sexuality, race, age, color and physical or mental disability.	Yes/No

There is proper space for employee's rest.	Yes/No
There is proper food plan and/or cooking equipment for employees.	Yes/No
There is clean water for employee.	Yes/No
There is proper accessible bathroom and/or cleaning room for employee.	Yes/No
Health Policy	
There is clear and comprehensive health plan for employees.	Yes/No
There is clear policy for working injuries recovery.	Yes/No
There is clear health plan of pregnancy for both women and men.	Yes/No
There is clear and proper policy for employee's rest, including statutory holidays and other statutory non-working time.	Yes/No
Other Policy	
The wage for employee is meeting legal requirements.	Yes/No
There is clear job responsibility.	Yes/No
Employees are free to make proper suggestions and complain.	Yes/No
There is clear policy against corruption or power abuse.	Yes/No

After the audit, the questionnaire (Table 19) that will complement the results of the audit should be distributed to employees to investigate the social responsibility implementation situation.

Table 19 Social Responsibility Questionnaire

Question	**Answer**
Warning	
1. Do you feel there is enough and proper instructions	Yes/No

regarding how to operate the machine?	
2. Do you get any proper and on-time warning before any accident happens?	Yes/No
Protection	
3. Do you have enough proper protection equipment when you are working?	Yes/No
4. Do you get proper instruction on how to use the protection equipment?	Yes/No
5. Do you always use the protection equipment when it is needed?	Yes/No
Working Environment	
6. Do you feel the working environment is clean?	Yes/No
7. Do you have any difficulty to access proper working tools?	Yes/No
8. Do you feel comfortable when you are working, due to working temperature and humidity?	Yes/No
9. Do you have enough time for rest?	Yes/No
10. Do you always work excessive hours?	Yes/No
11. Do you have difficulty to access bathroom?	Yes/No
12. Do you have difficulty to access clean water during work?	Yes/No
13. Do you have difficulty to eat during work on-site?	Yes/No
14. Do you feel discriminated during work?	Yes/No
Health Policy	
15. Are you able to access proper health plan from your company?	Yes/No
16. Are you able to claim injuries related to work on time?	Yes/No
17. Are you able to get proper health care after injuries related	Yes/No

to work?	
18. Are you able to get statutory leave?	Yes/No
19. Are you able to receive wage and proper health care during parental leave?	Yes/No
Other Policy related	
20. Are you able to make proper suggestions and/or complains to your supervisors or colleagues?	Yes/No
21. Do you witness any corruption and/or power abuse scenario?	
22. Do you feel that you have clear responsibility of your work?	Yes/No

3.3 Sustainability Analysis

After collecting comprehensive information, the analyst should work with management team together to find out the current status and problems the organization is facing. Besides, it is crucial to uncover causes behind.

3.3.1 Statistics Analysis

Based on the information gathered during measurement phase, different statistical tools can be used to analyze the current status of sustainability development in any manufacturing environment. The statistical analysis principles are:

1) Calculate any descriptive measurement and/or any statistical inference
2) Compare the number with standards if it exists
3) Identify the extremes from measurement
4) Figure out any trends included in the statistics

Compared with Six Sigma that is used for products deficiencies resolution, statistics analysis for sustainable manufacturing will be less complicated,

since it involves a lot of subjective and single answer questions. And different size of manufacturing will involve different size of statistics to interpret.

3.3.2 Interpretative Analysis

Due to the nature of sustainable manufacturing, some factors are not directly related to statistics, there is need to interpret the hidden answers or observations that are resulted from incompliance of sustainability practice.

Some tools that are efficient to use are Cause and Effect Diagram and the 7 new Management and Planning tools, which can help to identify the causes for a specific event.

For sustainable manufacturing, there are 6Ms (Wikipedia) used to identify the source of incompliance of sustainable manufacturing:

1) Machine (technology): Machine or technology might be source of incompliance. For example, if the machine consumes a lot of electricity or generate a lot of carbon dioxide.
2) Method (process): The work flow or work sequence might also case issues related to sustainable manufacturing. For instance, raw materials can be destroyed if they are not placed in a proper storage before it will be used.
3) Materials (Includes Raw Material, Consumables and Information): Usually raw materials will consist of some environmental pollutants or some materials are unrenewable. But incorrect information will also result in incompliance of sustainable manufacturing. For example, if there is no clear work guide for people who work in a mining or steel manufacturing environment, there will be high risks that employees will operate in a wrong way to lead to different incidents.
4) Man power (physical and mental power): Man power has played an important role in causing sustainability problems. For example, lack of labor will result in massive overwork. Child labor and women in

manufacturing environment in developing countries get a lot of critics. Besides, mental health is one of the biggest issues that all the employers are dealing with in order to keep employees' efficiency and motivation.

5) Measurement (Inspection): The way to inspect the work environment has direct impact on how do we improve work situation. If the measurement is only focusing on product quality or production rate, then it might lead to heavy work load to employees.
6) Milieu/Mother nature: The natural environment surrounding employees can also have critical impact. For example, if the workers work in under mining situation, there will be health and safety issues remain under cover.

Not every factor will be contributing to the sustainability problem, but these 6 factors cover most of the causes. When organizations think of investigating roots of problems, it's better to have comprehensive investigation of all these factors in order to give suggestions for improvement.

3.4 Sustainability Improvement

Based on analysis results, there is need to set up improvement goals and specific actions to achieve sustainable manufacturing.

3.4.1 Kaizen EHS

Industries are aimed at maximizing profit, though investing in Kaizen EHS will not bring direct income for companies. Accidents and loss of natural resources and human resource will bring constant and hidden side effects for an organization. It is imperative to build EHS committee and have EHS policy to help manufacturing companies to improve production profitability. According to Kaizen principles "Plan-Do-Check-Act", Kaizen EHS framework (Figure 12) can be developed as "EHS Plan-EHS Implementation-EHS Inspection-EHS Correction".

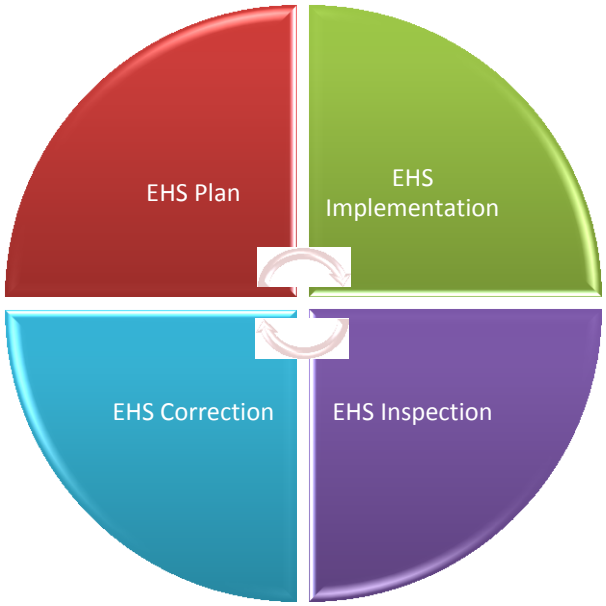

Figure 12 Kaizen EHS Framework

During first phases EHS Plan, organization needs to set targets based on the analysis results which have shown the flaws of insufficiency of EHS policies. At this stage, there should be formation of EHS committee which consists of members from different functions.

For EHS Implementation, EHS committee will draft specific EHS policies based on the targets and any constrain. It should be validated against EHS international standards, such as ISO9001, ISO14000, and/or national or industrial standards. After policy making, there should be formal and continuous training for managers and employees in all departments since EHS target can be only achieved by involvement of all employees.

EHS Inspection is a periodical process to verify the actions that have been taken based on the EHS policy. It is better to have both internal and external auditors to audit the implementation activities. Auditors will do visual inspections with

regard to actions of employees when they perform their work. Besides, auditors will verify actions based on documentation and interviews with employees and managers. At the end, auditors should generate report about the situation of implementation of EHS policy.

EHS Correction is a follow up process to improve what an organization has done and what can be added to correct the current situation. Both auditors and EHS committee members are deemed to join this action to continuously revise actions.

3.4.2 Kaizen Lean

Another important part to achieve sustainable manufacturing is to have Lean production system to reduce waste that will lead to waste of natural resource and accidents of operations due to non-streamlined activities.

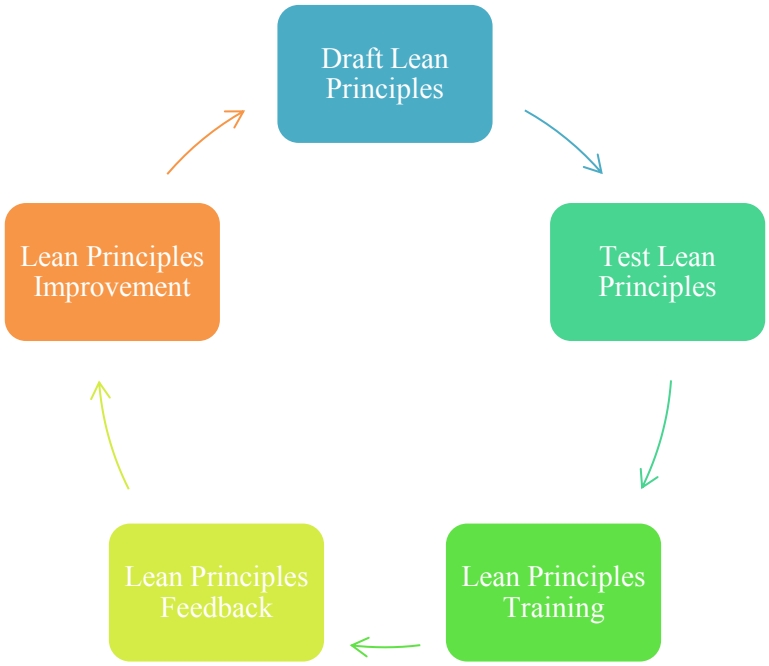

Figure 13 Kaizen Lean Cycle

Through Kaizen Lean cycle (Figure 13), organizations will draft their own lean principles that will meet their needs based on the analysis results. The principles cannot be applied directly before it is tested in a small range of production activities. The reason to test the principles is to validate and improve the drafted principles to reflect its values on developing a sustainable manufacturing environment. After the validation and approval, there is need of training for all levels of employees to undertake these principles. Sustainability should be implemented as culture for the company, so the necessary training will give employees of all levels clear understanding of what the actions and reasons to implement the change. It is crucial to manage the changes and risks during the implementation phases. After the Lean principles are implemented, internal auditors are responsible for continuous auditing to get feedback of what has been done well and what needs to be improved. The feedback should be also from employees of all levels regarding their opinions of how comfortable and how valuable they feel for this new change. As essence of Kaizen, continuous improvement is always core of the changes; organizations should keep a dynamic mindset to adjust the Lean principles as it will appeal to the organizations' needs and status.

3.5 Achieving Leadership

As a way to continuously improve and learn from other organizations, there is need to compare current sustainability programs in plant with other competitors and industry leaders. It will help organizations to advance its practices and develop innovative programs to keep its leadership. There are a few steps (Figure 14) to shape its leadership by creating innovative sustainable practices. First, organizations need to list all the sustainability requirements and related actions taken right now. Second, organizations should analyze what the leading organizations' actions regarding to sustainability. Based on the analysis,

organizations could make recommendations to close the gap between actions taken and target achieved among different organizations. While the recommendation should not be sitting only on desk, it should be tested before widely implemented. It is promising future for organizations to achieve leadership in sustainability. The House of Sustainability can be used as a tool to do such benchmarking.

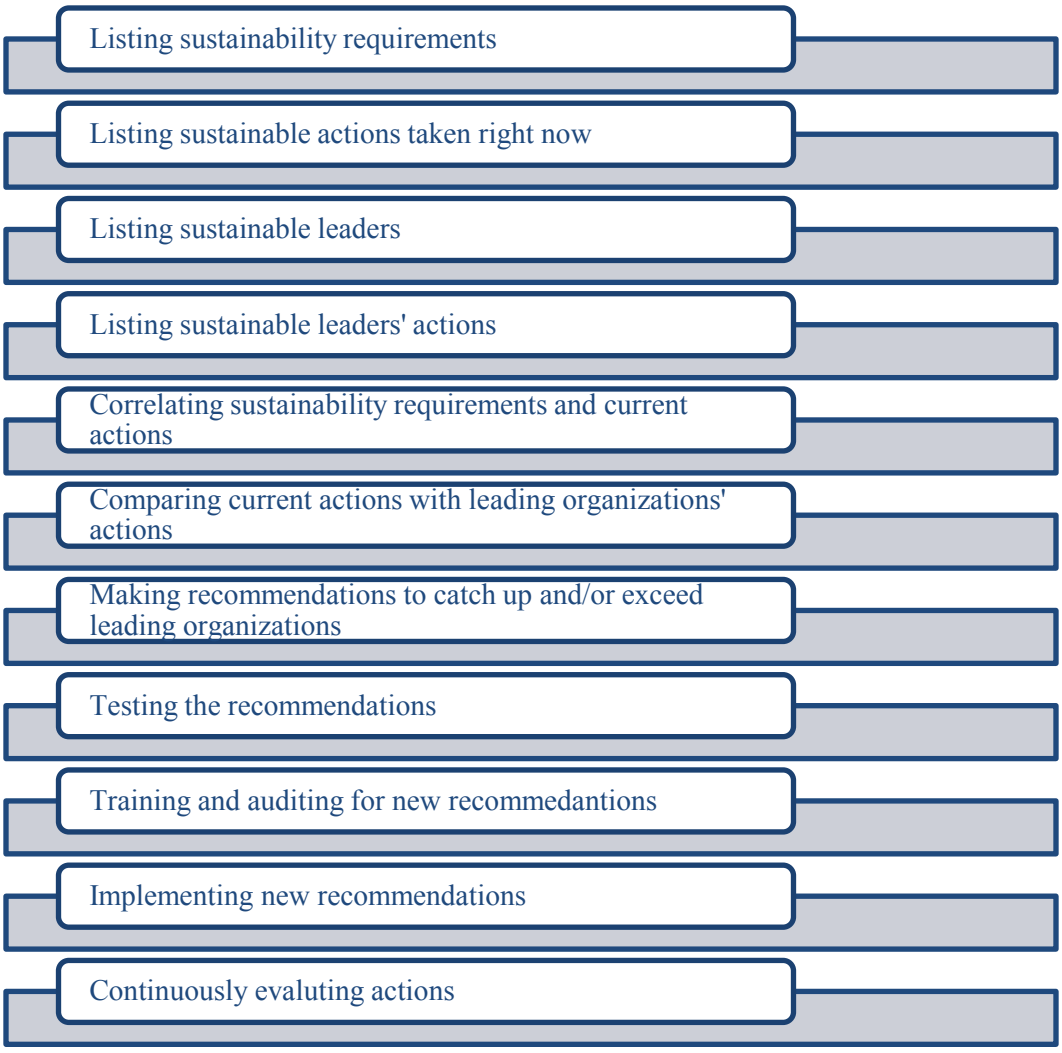

Figure 14 Sustainability Leadership Achievement Roadmap

The way to use the House of Sustainability is based on current situation and industry leaders' actions gap analysis (Table 20). Organizations will list sustainable manufacturing requirements, and the related actions taken in plant and its leading industry's actions. There will be score from 1-5 allocated to these actions to make rating based on advancement of this action. After understanding the gap, specific recommendations will be made for achieving leadership in sustainable manufacturing.

Table 20 Achieving sustainable Manufacturing Leadership Benchmarking

Gap Analysis	Sustainable Manufacturing requirement #1			
Gap #1	Sustainable action #1	Current Score #1	Leading Action #1	Leading Score #1
Recommendation #1				

Chapter 4 Case Study

4.1 Case Study Background

In order to test the framework and illustrate how the framework can be customized in different situations, a private aerospace company in Montreal, Canada, has been contacted for case study.

This company is a design and manufacturing company mainly for civil flight simulators. It has short history in the same industry, but it's been known for its cost effective products. The company is still under new technology and new customers' accumulation phase, which is focusing on developing new customers and selling more products in order to grow into a stronger player in the industry. There are some quality management systems that have been developed. But the system is still in its developing phase. Sustainability as part of their lean production vision starts to get credits from senior management and direct labour workers, though the understanding of sustainability and lean production is still not very clear for the company.

One of the most important parts as production in this company is the electronic lab which is producing a lot of avionics equipment. It is also the only few parts in this company that are actually doing manual production. As a pilot project, the company is willing to join the case study to achieve sustainability goals. The electronic lab is the focus of this case study, since it has produced 60% of its own design, while are including the most critical technology the company has developed.

The electronic lab has 1 general manager, 1 planner, 25 manual labour workers. Additionally, it has close interaction with other departments, such as engineering, procurement, inventory, configuration, etc. The products produced are mainly for final assembly, some are for customers' support.

After discussing with project managers who are focusing on product on-time delivery and financial returns, there is strong interest to improve on-time delivery rate which has been caused by a few reasons:

1) Lack of systematic link guidelines among different departments
2) Lack of motivation for production employees
3) Lack of operation efficiency

Sustainability is agreed as a good practice to generate better work environment which can raise employees' motivation. The increasing motivation will also have good operation efficiency. Besides, adopting sustainability will create better customer values as product is more eco and social friendly for end users.

While the real sustainability implementation is a time consuming process, the visible results and benefits cannot be shown immediately due to the thesis research time limitation. Only part of the framework is conducted, especially the implement and control phase cannot be fully illustrated.

4.2 Define

Under this phase, the company is investigated generally for the current status of company's understanding of sustainable manufacturing.

4.2.1 Preliminary Check

For the preliminary check, 7 office employees from engineering, procurement and inventory are chosen along with 5 employees from electronic lab and 1 general manager and 4 senior managers. The summary of the answers is in Table 21.

Table 21 Preliminary Check Response Summary

Item	Response 1		Response 2	
For office employees (7)				
1. Do you know sustainability?	Y	6	N	1
2. Do you think that XX Company is implementing sustainability initiative?	Y	2	N	5
3. Do you expect the implementation of	Y	5	N	2

sustainability if it is not implemented?				
For manual labor workers (5)				
4. Do you have or witness any pollution activities during production?	Y	2	N	3
5. Do you have any injuries related to work?	Y	1	N	4
6. Are there any practices that are used to recycle the wastes and pollutants?	Y	4	N	1
7. Do you feel that the XX Company is making changes to use less polluted components, such as plastics, lead, etc.?	Y	5	N	0
For management (5)				
8. Do you know sustainability development?	Y	4	N	1
9. Are you interested in sustainability development?	Y	4	N	1
10. Is there any policy that is related to sustainability development in XX Company?	Y	5	N	0
11. Is XX Company is willing to invest in sustainability development?	Y	3	N	2
12. Do you know the benefits of sustainability development?	Y	4	N	1

From the preliminary check, most office employees who have higher education are aware of sustainability concept in general, but 70% of them think that the company is not really implementing sustainability practice. If it is implemented, 70% of them will accept the changes.

Comparing with manual labour workers who acquire less university education, most of them already feels that there is rarely severe environment or work related issues. But they don't feel that there are changes for current situation since they start their work. It has indicated that no continuous improvement related to work situation has been conducted seriously.

From managers, most of them are aware of sustainability concepts in general, and are willing to invest on this trend as part of the company's new strategy. But most of them also think that the company already has sustainability policies, such as recycling.

4.2.2 Management Commitment Investigation

In order to implement the sustainability practice in the company, there must be strong management support since it will cause financial and human resource cost. One senior manager who is responsible for operations, one senior manager who is responsible for accounting, another lab general manager has been interviewed. The brief answers are listed in Table 22.

Table 22 Management Commitment Investigation Summary

Manager / Items	Senior Manager for Operations	Senior Manager for Accounting	Lab General Manager
Strategic Goal	High Quality of Production	More margin benefits	Less re-do work, clear job orders from different projects, better work flow
Current Manufacturing Benefits	Less lead time than outsourcing	Lower logistics fees	Less dependence on any suppliers
Investment for Sustainability Manufacturing	Board of directors are willing to make investment and improve company's reputation	Limited investment due to the focus on sales and its balance on debt	Currently there is partial investment going on for lean production.

Obstacles	Lack of experience, change for current employees.	Limited investment, long lead time to show the financial returns	Less experience, changes for employees
Expectations	The sustainability practice can help stimulate employees' work passion, improve company's reputation for its products.	Quick financial return, expansion of sales due to new changes	Better understanding for employees regarding the changes

Through the one on one face interview, there is clear information that management is willing to invest limited resources at the beginning stage mostly for improving products and work efficiency. Especially there is need to promote company's image to win more market shares. But most of them already noticed that there will be unwillingness from current employees since they have worked here for a long time and already get used to the current work style. This is one problem that should be considered when the sustainability practices are implemented. What's more, due to limited investment and the urge to promote company's image, there is need to select the easiest and most obvious part of changes to conduct at this beginning stage.

4.2.3 Current Process Mapping

After knowing the subjective views from management, it is also beneficial to draw process mapping to understand how the lab is working systematically. It will help company to find out the procedures or practices that are not compatible with sustainability. The lab work process flow has been drawn in Figure 15.

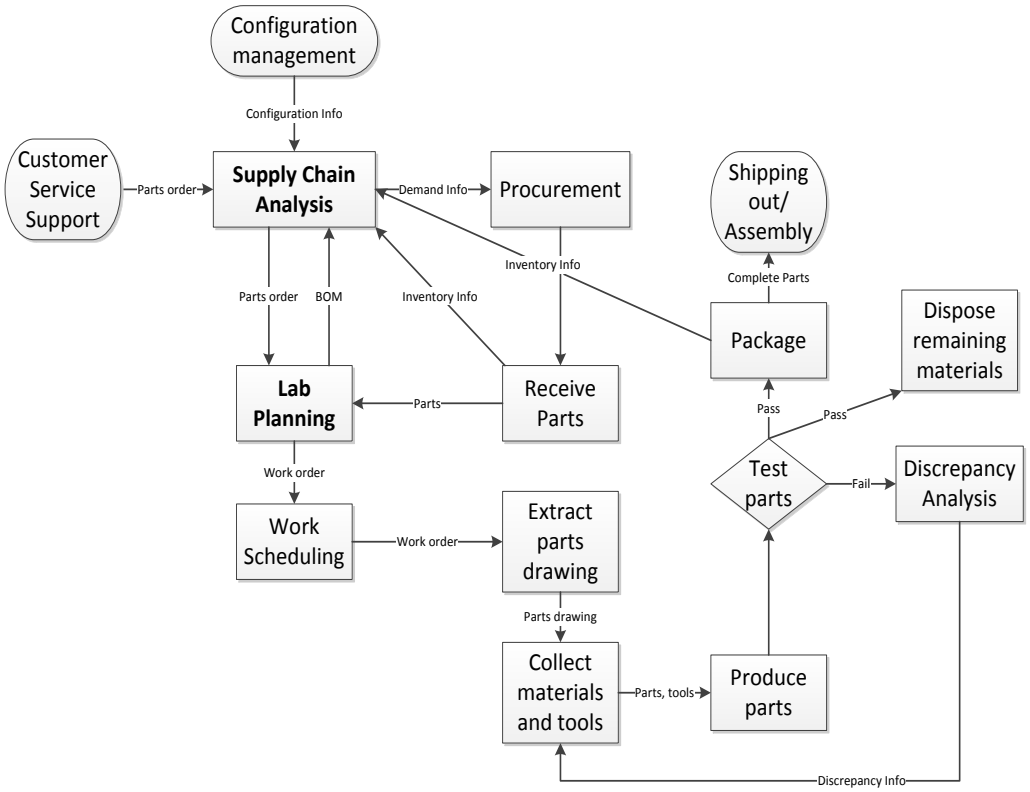

Figure 15 Lab Work Flow

Lab work flow shows that there are two sources of work order for lab work, one is from project orders, which consist of complete parts orders needed from electronic lab. The other source is from customer service support, which includes components needed for maintenance and upgrade after sales. Once the project teams or service support teams receive the order, they will transform either to configuration management or directly to supply chain management to analyze

how many components are needed and how much inventory we already have. After supply chain management has analyzed the needs, it will also confirm the work order with lab planner about inventory and BOM. When the accurate BOM is generated from lab, the demand information will be transformed to procurement departments to buy parts based on priorities and lead time. Upon the delivery of parts from suppliers, lab will schedule assignments among employees and deliver the materials and tools needed to specific employees. When the parts are finished, they will be tested before going to package. If they fail, it needs to go back to rework before it can be tested again. All the remaining materials will be collected and disposed once a week.

From the work flow, we can see supply chain management has played a key input for lab work. But there is no sustainability regulation when the supply chain management is doing the sustainability analysis and it is not clear if the lab planner is considering the usage of materials and work schedule for employees. These will go to investigation in measurement phase to fully understand its circumstance.

4.2.4 Preliminary Project Selection

There are a few aspects of sustainability and process in the lab work, due to limited resources, the priority needs to be set. One way to choose which process and aspects in sustainability is to use weighted matrix. The work process has been divided into three big steps that happen in lab, which are lab work planning, production and packaging. They are contributing most of the energy consumption, waste disposal and human resources consumption.

Table 23, Table 24 and Table 25 are the calculation of preliminary work environment and weighted process scoring to choose which process to pay more attention.

Table 23 Lab Planning Work Environment Preliminary Assessment

Elements	Weight	Evaluation	Weighted Evaluation
Clear working guidance	25%	3	0.75
Natural working environment	25%	3	0.75
Excessive working time	25%	3	0.75
Work related injuries	25%	1	0.25
Total Weighted Evaluation			**2.5**

Table 24 Production Work Environment Preliminary Assessment

Elements	Weight	Evaluation	Weighted Evaluation
Clear working guidance	25%	5	1.25
Natural working environment	25%	5	1.25
Excessive working time	25%	3	0.75
Work related injuries	25%	1	0.25
Total Weighted Evaluation			**3.5**

Table 25 Packaging Work Environment Preliminary Assessment

Elements	Weight	Evaluation	Weighted Evaluation
Clear working guidance	25%	1	0.25
Natural working environment	25%	1	0.25
Excessive working time	25%	3	0.75
Work related injuries	25%	1	0.25
Total Weighted Evaluation			**1.5**

From the work environment preliminary assessment based on opinions from lab general manager, one senior work labor, lab planning plays a key input with regard to the usage of materials and employees' work schedule. Production is the most direct activity that will contribute to materials consumption and lead to employees' wellbeing problems. So this process has been given high priority to improve.

Table 26 Weighted Scoring for Manufacturing Process Selection

Item		Lab Planning	Production	Packaging
MUA	**Original Score**	1	5	3
	Weight	20%	20%	20%
	Weighted Score	*0.2*	*1*	*0.6*
Labor Working Environment	**Original Score**	2.5	3.5	1.5
	Weight	15%	15%	15%
	Weighted Score	*0.375*	*0.525*	*0.225*
Pollution Impact	**Original Score**	5	5	1
	Weight	10%	10%	10%
	Weighted Score	*0.5*	*0.5*	*0.1*
Importance for the Manufacturing	**Original Score**	5	5	1
	Weight	5%	5%	5%
	Weighted Score	*0.25*	*0.25*	*0.05*
Investment	**Original Score**	1	5	1
	Weight	50%	50%	50%
	Weighted Score	*0.5*	*2.5*	*0.5*
Final Weighted Score		**1.825**	**4.775**	**1.475**

From other criteria, production directly generates pollutants, and it involves the most direct investment. Additionally, it will have direct and obvious changes according to sustainability. The weighted score from Table 26 has shown that production is the main focus for sustainability improvement at this stage.

4.3 Sustainability Measurement

4.3.1 Knowing Target

As a part of the manufacturing environment, electronics manufacturing lab is the key part in this company due to the critical functions the electronics have played in this aerospace company. There are some international standards for sustainability or environmental friendly management system, such as ISO14001 on Environmental Management System, and ISO50001 on Energy Management. Though there are no specific regulations regarding electronics manufacturing industry yet, some general framework still exists for sustainable electronic manufacturing, the below framework has shown the current most popular framework in electronics manufacturing industry. Currently, most of the companies are focusing on the end-of life cycle management or supplier management since most of electronics products are containing valuable components which can be reused, if not there will be heavy pollution when they are disposed in the landfills.

As for this company investigated, there are limited production volumes and limited labor force compared with other companies who are only focusing on electronics manufacturing. As for the expectations, 6 points are mentioned by the management team:

1) Less excessive raw materials ordered
2) On time demand supply
3) Cleaning working environment

4) Comfortable working environment for the sake of health of employees
5) Better quality of the electronics
6) New system of remanufacturing and recycling

All the above expectations are suggested by the senior management according to the budget and critical problems the projects are facing for a long time period.

4.3.2 Measurement Target

In order to collect ideas from different backgrounds,

1) Senior management (2): Get strategic insight of the sustainability vision;
2) Lab manager (2): Get tactical insight of the sustainability development practices;
3) Employees' Wellbeing Committee (2): There are several people from different functions to form such committee to ensure the employees' benefits, not only people working in the electronic lab, but also people who are working in different functions, such as HR, Engineering. On this survey, one HR manager and one electronic design engineer is chosen as part of external observer;
4) Manual labor workers (20): People who are directly manufacturing electronic components with hand and/or machine;
5) Inventory clerk (2): People who are responsible to send the raw materials to the lab, and get the final products to store on the shelves;
6) Inspectors (2): People who are performing the quality inspection at the end of the manufacturing.

There are 30 people who are surveyed in this measurement phase with other quantitative metrics. Among all these people, Lab manager and Manual labor workers are the most important people to get the direct opinions regarding how the sustainability practices are performed. Others will supplement the information as how the performance will be viewed from different angles. Additionally, there

will be objective data collection, for example, the water and electricity that has been consumed.

4.3.3 Metric Selection

First, the lean objective measurement is conducted based on the data availability and measurement feasibility. The production efficiency inspection details are shown in table 27.

Table 27 Production Efficiency Inspection

Inspection Item	Unit	Amount
Forklift Movement Per Week	Meter	300
Back-up Display Indicators Production Per Week	Piece	3
Back-up Adapters Production Per Week	Piece	20
Back-up Indicator Lights Production Per Week	Piece	5
Non-production Time for Laser Printer Per Week	Hour	140
Non-production Time for Electric Welder	Hour	130
Amount of iron per flight simulator from lab	Kg	200
Amount of Plastics and other poly materials per flight simulator from lab	Kg	300
Amount of Electricity used per week	Watt	3000
Amount of Water used per week	Gallon	500
Amount of Letter Sized Paper consumption per week	Piece	150
Amount of Electric welding rod consumption per week	Bar	50

Based on the materials used and the most critical materials that can be measured in the lab, 5 green objective measurement metrics are selected:

i. Water Intensity=Water consumed in lab/Total amount of water consumed
ii. Heavy Metal Intensity=Heavy metal consumed in lab per simulator/Total heavy metal consumed per simulator

iii. Electricity Intensity=Electricity consumed in lab/Total electricity consumed
iv. Recyclable Intensity=Recyclable weight per simulator from lab/Total weight per simulator from lab
v. Residuals Intensity=Residuals weight per week from lab/Total residuals weight per week in plant

At the end, three objective assessments (Table 28, Table 29 and Table 30) in the plant have been done based on social, environmental and economic criteria with observation of the author. These objective assessments are completed by the help of the production manager and human resource manager. The quantitative information in Table 29 is given by the production manager. The answers with No are highlighted with underline.

Table 28 Objective Sustainability Social Assessment

Audit Item	Result
Clear Sign	
There is clear sign indicating different working or non-working area.	No
There is clear sign indicating the dangers or safety warning in working area.	No
There is clear instruction or brief warning regarding the machine or materials operation.	No
Protection Policy	
There is enough and functional fire extinguisher in different working or non-working area.	Yes
There is specific protection equipment for different profession, such as mask, glove, glass, protection coat.	Yes
Human Resource	
There are enough and proper working tools.	Yes
There is clear rule for proper working hour.	No

There is clear rule for not using child labor or forced labor.	Yes
There is clear rule against discrimination with regard to gender, sexuality, race, age, color and physical or mental disability.	Yes
There is proper space for employee's rest.	No
There is proper food plan and/or cooking equipment for employees.	No
There is clean water for employee.	Yes
There is proper accessible bathroom and/or cleaning room for employee.	Yes
There is clear and comprehensive health plan for employees.	Yes
There is clear policy for working injuries recovery.	No
There is clear health plan of pregnancy for both women and men.	Yes
There is clear and proper policy for employee's rest, including statutory holidays and other statutory non-working time.	Yes
Administration Policy	
The wage for employee is meeting legal requirements.	Yes
There is clear job responsibility.	No
Employees are free to make proper suggestions and complain.	Yes

Table 29 Objective Sustainability Environmental Assessment

Audit Item	Result
Working environment is clean without excessive polluted liquid.	No
Working environment is clean without excessive solid waste.	No
Working environment is clean without unhealthy air circulating around the plant.	No
There is clear policy for working environment, regarding temperature, humidity for the sake of comfort.	No
There is clear policy for cleaning the working environment.	No

Water Intensity	13%
Heavy Metal Intensity	5%
Electricity Intensity	15%
Recyclable Intensity	1%
Residuals Intensity	4%

Table 30 Objective Sustainability Economical Assessment

Audit Item	Result
There is incentive plan based on employees' performance.	Yes
There is stable investment on Research and Development activities.	Yes
There is cost savings for manufacturing compared with previous fiscal year.	No
There is steady growth of revenues compared with previous fiscal year.	No
There are more jobs created compared with previous fiscal year.	No
There is steady investment on working infrasture.	No
There is investment for local community.	No
There is clear policy against corruption or power abuse.	No

Table 31 is used to assess the subjective feeling of employees from different levels with regards to their working environment. The response is rated as Yes or No scale. Most of manual labor workers don't have high education background; it is not very feasible to create a complicated survey with complicated numerical range scale answers for them. Additionally, considering the working time for manual labor workers, simplicity is very important to have their interest to answer the survey instead of consuming a lot of time to answer one question. That's why the Yes and No scale is applied in this survey.

Table 31 Subjective Sustainability Social Assessment

Question	Answer
Warning	
1. Do you feel there is enough and proper instructions regarding how to operate the machine?	Yes/No
2. Do you think there is any proper and on-time warning before any accident happens?	Yes/No
Protection	
3. Do think there is enough proper protection equipment during work?	Yes/No
4. Do you think there is proper instruction on how to use the protection equipment?	Yes/No
5. Do you always use the protection equipment when it is needed?	Yes/No
Working Environment	
6. Do you feel the working environment is clean?	Yes/No
7. Do you have any difficulty to access proper working tools?	Yes/No
8. Do you feel comfortable when you are working, due to working temperature and humidity?	Yes/No
9. Do you have enough time for rest?	Yes/No
10. Do you always work excessive hours?	Yes/No
11. Do you have difficulty to access bathroom?	Yes/No
12. Do you have difficulty to access clean water during work?	Yes/No
13. Do you have difficulty to eat during work on-site?	Yes/No
14. Do you feel discriminated during work?	Yes/No
Health Policy	

15. Are you able to access proper health plan from your company?	Yes/No
16. Are you able to claim injuries related to work on time?	Yes/No
17. Are you able to get proper health care after injuries related to work?	Yes/No
18. Are you able to get statutory leave?	Yes/No
19. Are you able to receive wage and proper health care during parental leave?	Yes/No
Administration	
20. Are you able to make proper suggestions and/or complains to your supervisors or colleagues?	Yes/No
21. Do you witness any corruption and/or power abuse scenario?	
22. Do you feel that you have clear responsibility of your work?	Yes/No

4.4 Sustainability Analysis

4.4.1 Statistical Analysis

Subjective questions from Table 31 have been asked, answers have been illustrated in Table 32. And Figure 14 has presented the answers in a histogram.

Table 32 Answers for Lab Work

Question	**Answer**					
	Yes			**No**		
Warning	**Manager**	**Direct Employees**	**Indirect Employees**	**Manager**	**Direct Employees**	**Indirect Employees**
1. Do you feel there is enough and proper instructions regarding how to operate the	4	5	3	0	15	3

	machine?						
2.	Do you think there is any proper and on-time warning before any accident happens?	3	3	2	1	17	4
Protection							
3.	Do think there is enough proper protection equipment during work?	2	9	1	2	11	5
4.	Do you think there is proper instruction on how to use the protection equipment?	1	0	1	3	20	5
5.	Do you always use the protection equipment when it is needed?	2	18	4	2	2	2
Working Environment							
6.	Do you feel the working environment is clean?	3	13	5	1	7	1
7.	Do you have any difficulty to access proper working tools?	0	8	3	4	12	3
8.	Do you feel comfortable when you are working, due to working temperature and humidity?	3	4	5	1	16	1
9.	Do you have enough time for rest?	2	12	4	2	8	2
10.	Do you always work excessive hours?	4	10	5	10	0	1
11.	Do you have difficulty to access bathroom?	0	2	0	4	18	6
12.	Do you have difficulty to access clean water during work?	0	0	0	4	20	6

13.	Do you have difficulty to eat during work on-site?	0	14	2	4	6	4
14.	Do you feel discriminated during work?	0	4	1	4	16	5
Health Policy							
15.	Are you able to access proper health plan from your company?	0	16	6	4	4	0
16.	Are you able to claim injuries related to work on time?	4	12	6	0	8	0
17.	Are you able to get proper health care after injuries related to work?	4	12	6	0	8	0
18.	Are you able to get statutory leave?	2	10	4	2	10	2
19.	Are you able to receive wage and proper health care during parental leave?	4	12	4	0	8	2
Administration							
20.	Are you able to make proper suggestions and/or complains to your supervisors or colleagues?	4	15	3	0	5	1
21.	Do you witness any corruption and/or power abuse scenario?	4	5	2	0	15	4
22.	Do you feel that you have clear responsibility of your work?	2	4	2	2	16	4

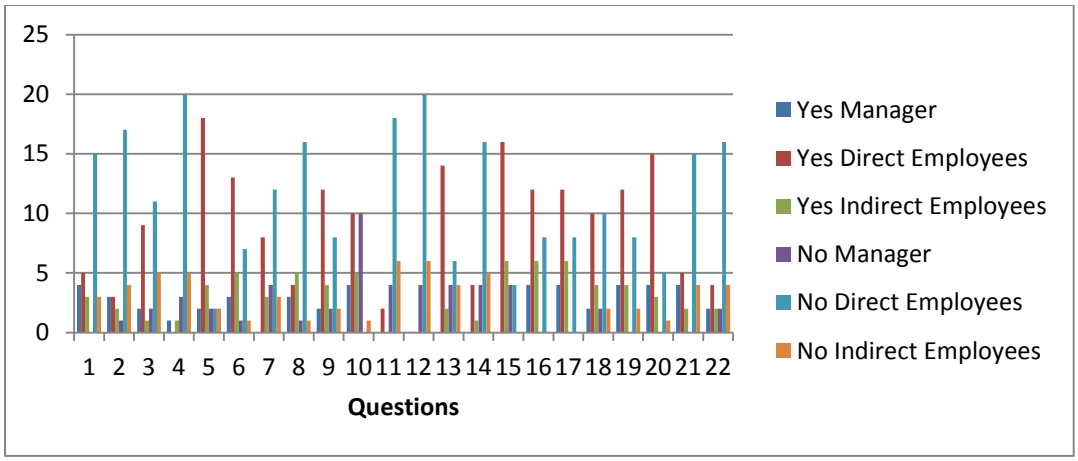

Figure 16 Subjective Sustainability Questionnaire Result

From the statistics in Table 32, there are main problems rising in the following area:

1) There is no clear instruction of how to perform work properly;
2) There is not enough protection equipment;
3) Natural environment in lab is a little bit harsh, meaning coldness;
4) There is not enough dining facility and plan for employees;
5) There is not enough health care plan for all employees;
6) There is no clear boundary of responsibility.

In order to see if the answers among different groups are different significantly, there will be hypothesis testing with the help of ANOVA (Analysis of Variance), which is a methodology for drawing conclusions about equality of means of multiple populations.

In order to compare the means of different groups, meaning Manager, Direct Employee, Indirect Employee, the answer for 'Yes' gets numerical score '1' and the answer for 'No' gets numerical score '-1'. The score for each group will be added within the same group for each question, and it is divided by the total

number of employees in each group. Table 33 shows the normalized mean score for each question. The hypothesis will be:

H_0: There is no difference between answers of each group;

H_1: There is significant difference between answers of each group.

Table 33 Normalized Mean Score for Each Question

Question	**Answer**						**Normalized Score**		
	Yes (1)			No (-1)					
Warning	Manager	Direct Employee	Indirect Employee	Manager	Direct Employees	Indirect Employees	Manager	Direct Employee	Indirect Employee
1.	4	5	3	0	15	3	100%	-50%	0%
2.	3	3	2	1	17	4	50%	-70%	-33%
3.	2	9	1	2	11	5	0%	-10%	-67%
4.	1	0	1	3	20	5	-50%	-100%	-67%
5.	2	18	4	2	2	2	0%	80%	33%
6.	3	13	5	1	7	1	50%	30%	67%
7.	0	8	3	4	12	3	-100%	-20%	0%

8.	3	4	5	1	16	1	50%	-60%	67%
9.	2	12	4	2	8	2	0%	20%	33%
10.	4	10	5	10	0	1	-150%	50%	67%
11.	0	2	0	4	18	6	-100%	-80%	-100%
12.	0	0	0	4	20	6	-100%	-100%	-100%
13.	0	14	2	4	6	4	-100%	40%	-33%
14.	0	4	1	4	16	5	-100%	-60%	-67%
15.	0	16	6	4	4	0	-100%	60%	100%
16.	4	12	6	0	8	0	100%	20%	100%
17.	4	12	6	0	8	0	100%	20%	100%
18.	2	10	4	2	10	2	0%	0%	33%
19.	4	12	4	0	8	2	100%	20%	33%
20.	4	15	3	0	5	1	100%	50%	33%

21.	4	5	2	0	15	4	100 %	-50%	-33%
22.	2	4	2	2	16	4	0%	-60%	-33%

In order to test the hypothesis, ANOVA will be used with a 0.05 level of significance. From ANOVA analysis (Table 34), the *F* value (0.387172) is smaller than the critical *F* value (3.142809), for 2 and 63 degrees of freedom at a 0.05 level of significance; we can accept the hypothesis that the answers for the three employees group are the same. In fact, *F*=0.387172 is smaller than 3.142809, that we have a 0.680578 probability (the *p*-value in the output) that we could be right.

Based on the ANOVA Analysis (Table 34), we could say that generally employees and managers have similar perspectives about the sustainability development in this plant, which is fit with the reality, since sustainability is not applied systematically yet in this plant.

Table 34 ANOVA Analysis

SUMMARY						
Groups	*Count*		*Sum*		*Average*	*Variance*
Manager	22		-0.5		-0.02273	0.72565
Direct Employees	22		-2.7		-0.12273	0.30184
Indirect Employees	22		1.333333		0.06061	0.40885
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.37074	2	0.18537	0.387172	0.680578	3.142809
Within Groups	30.1631	63	0.47878			
Total	30.5339	65				

4.4.2 Interpretative Analysis

Combining production efficiency and objective environmental assessment forms, a few questions are raised below:

1) Working environment is not clean and not comfortable for employees;
2) There is overproduction;
3) Electricity and water is over consumed;
4) There is no mature recyclable plan.

From the objective and subjective social assessment items, a few questions are raised below, and these items have been highlighted with underlines.

1) There is no proper instruction of work;
2) There is no clear responsibility of work;
3) Not everyone has full access to company's health plan;
4) There is not enough proper food facility or plan for employees.

From the objective economic assessment, a few questions are raised below:

1) There is no stable revenue growth;
2) There is no investment for local community;
3) Manufacturing operations cost is increasing.

Based on these questions, cause and effect diagram and 6M can be used to analyze the reasons behind these problems. A few main problems have been selected for analysis based on its complexity and importance to production. Unclean working environment, overproduction, not enough health plans and no stable revenue growth are selected as illustrations from Figure 17 to Figure 20.

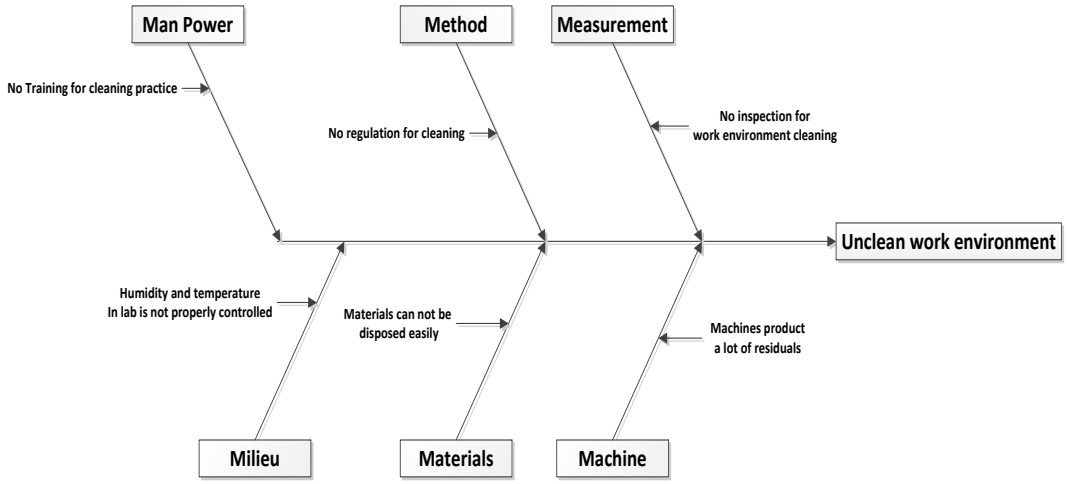

Figure 17 Cause and Effect Analysis for Unclean Work Environment

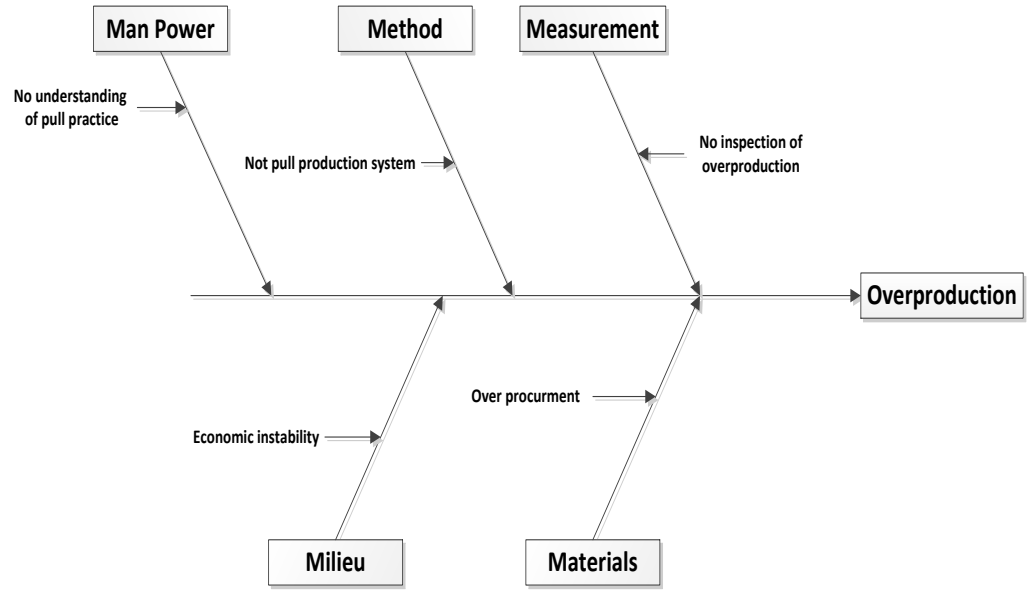

Figure 18 Cause and Effect Analysis for Overproduction

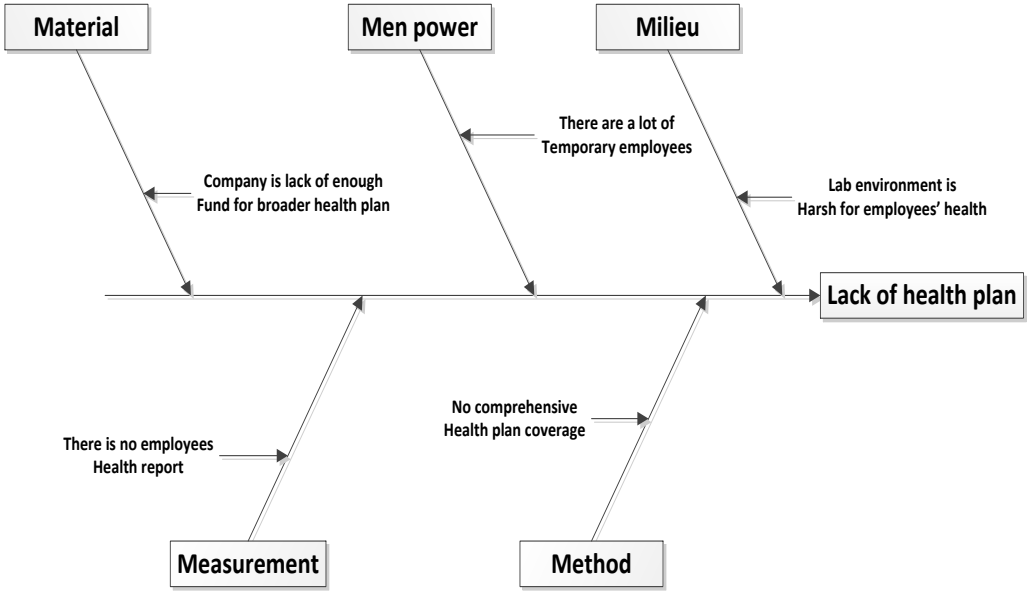

Figure 19 Cause and Effect Analysis for Lack of Health Plan

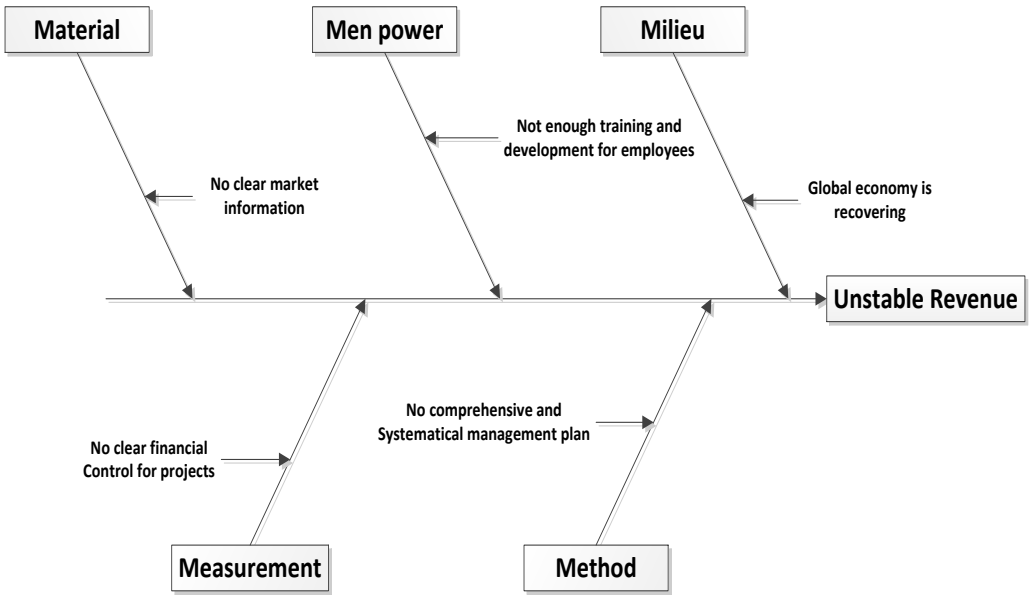

Figure 20 Cause and Effect Analysis for Unstable Revenue

From the Cause and Effect analysis process, it will help company to figure out the reasons behind of these problems. Based on different problems, different aspects of factors can be chosen instead of analyzing them all.

4.5 Sustainability Improvement

4.5.1 Kaizen EHS

First step to tackle sustainability issues is to build EHS System. During this phase, companies are meant to draft EHS policies based on its current situation and implement them continuously.

The first step is to set targets and constrains which will lead to the generation of proper EHS policies (Figure 21).

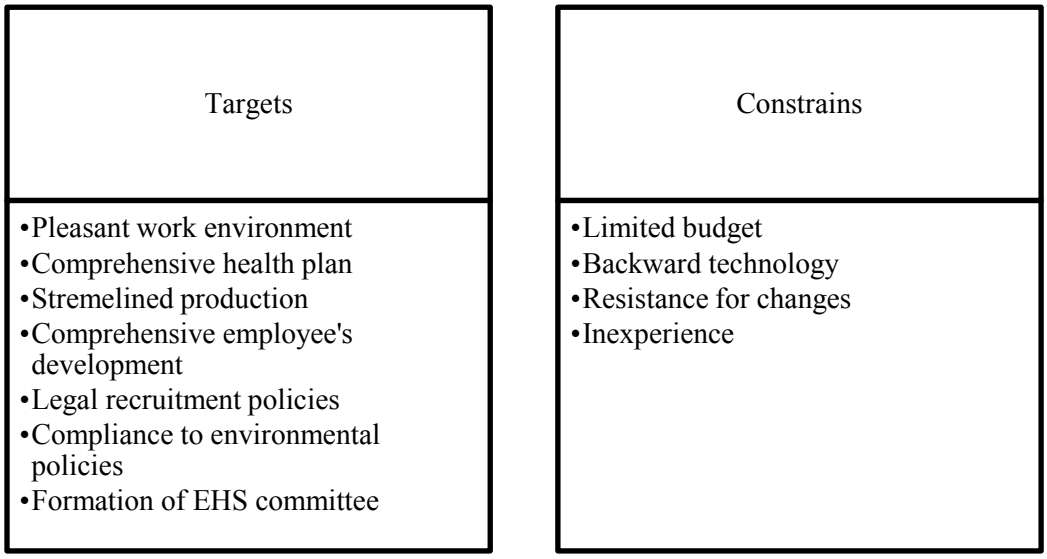

Figure 21 EHS Plan

In this case, employers are more interested in creating pleasant work environment, supplying comprehensive health plan and streamlined production, etc. On the other hand, there is limited budget due to economy status. Besides, there might be resistance from unionized employees who already get used to current operations

practices. It is crucial to control these risks and changes during the implementation. At the same time, the organization needs to form an EHS committee which consists of employees from Engineering, Procurement, Planning, Configuration Management, Finance, Marketing, Customer Support, Manufacturing and Human Resources. Employees from different functions will generate ideas that can supplement and enrich the specific actions.

After understanding the targets and constrains, EHS committee should draft detailed policies regarding how to tackle these targets in a precise way (Figure 22).

Figure 22 EHS Implementation Procedures

At EHS Implementation phase (Figure 20), EHS committee will draft the policies based on the targets and constrains. It will be preliminary policies before tabling to the public. Due to the limitations of EHS committee members' experience and specific knowledge in different functions, there will be a few consultation sessions for unionized workers, office workers and managers exclusively. EHS

committee will absorb opinions gathered from these consultation sessions to improve the drafted policies. After the consultation, EHS committee will publish the official policies to public both internally and externally to help prompt company's image. It is very crucial to host training sessions for unionized workers, office workers and managers to understand the meaning of these policies and the actions needed to perform these policies. Following the detailed and systematical training from EHS committee, the company will start to make changes to current actions based on EHS policies.

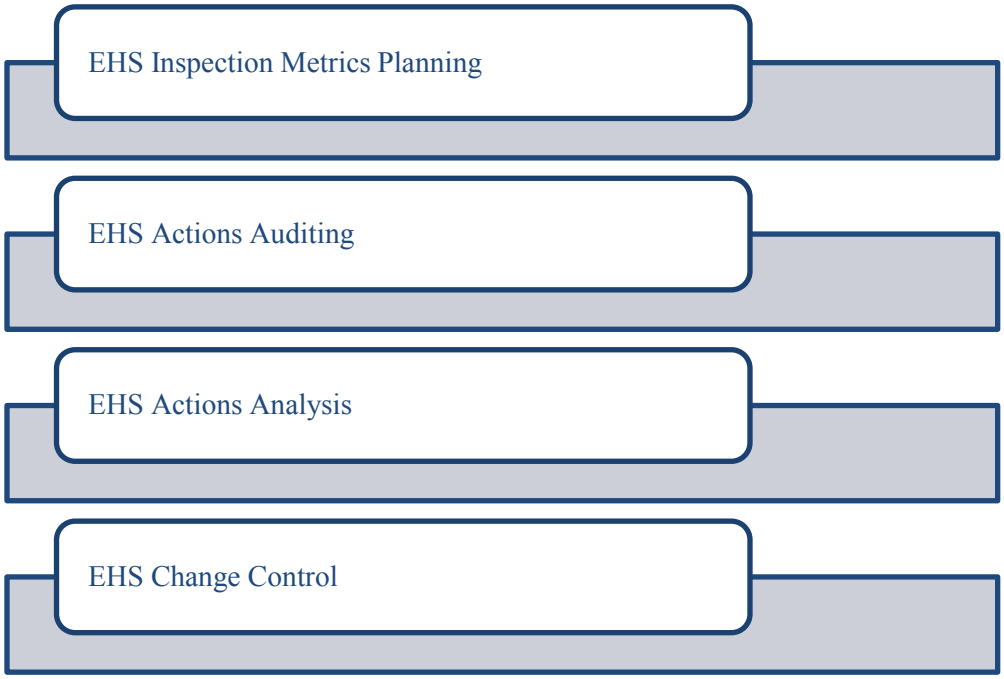

Figure 23 EHS Inspection

During EHS Inspection phase (Figure 23), there needs EHS Inspection Metrics that can highlight the important actions and/or results based on the EHS policies. The inspection will be done by internal auditors and external auditors separately to assure neutrality. There will be detailed analysis based on departments and specific policies after the inspection. Another crucial action at this stage is to have

EHS Change control specialist. When EHS policies have been implemented, there will be resistance, unwillingness and confusion from employees and managers. There must be some specialist who will be as facilitator to help these employees to understand the importance and benefits of EHS policies. Also the specialist will give concrete advices to each individual or department with regard of the right direction and resources to implement EHS policies. There will be no end for this consultation due to the continuous improvement, meaning there will be always new policies or changes based on the implementation results and new technologies and regulations, etc.

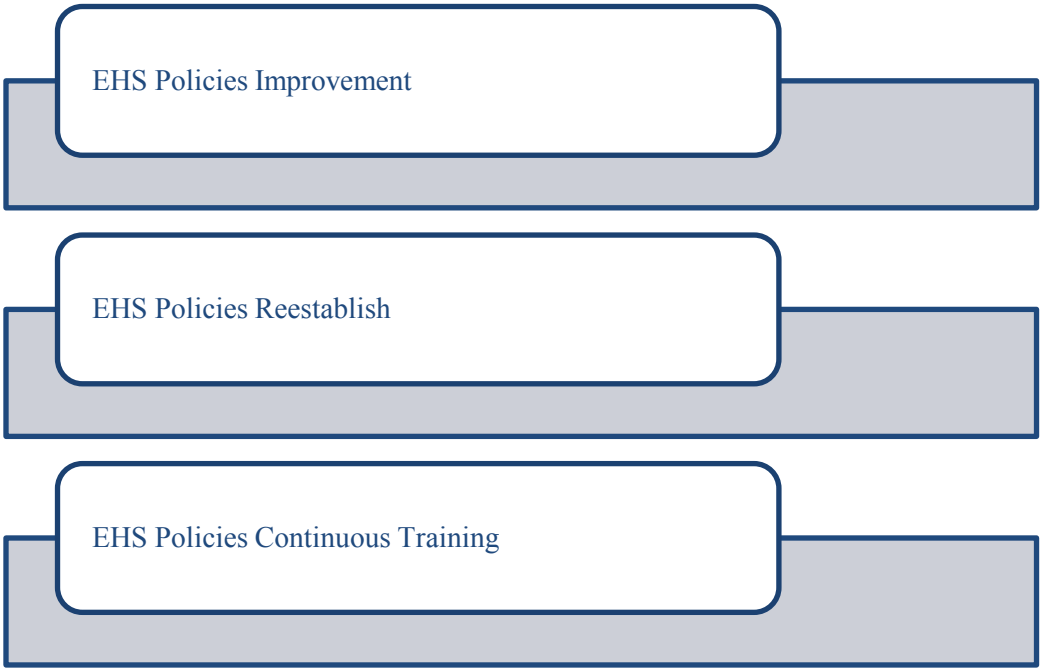

Figure 24 EHS Correction

After the inspection of the performance of EHS policies, there will be improvement based on the new regulations, new technologies and adaptation to current company situation shown in Figure 24. It will enhance the feasibility and compliance to company's situation. Following the changes, EHS committee will publish new version of EHS policies and make sure that there will be proper

training and enough time frame to adapt to new policies. The training will be on going with change control specialist as well to ensure the success of EHS policies.

4.5.2 Kaizen Lean

As similar with Kaizen EHS, there will be a continuous cycle for Lean policies implementation. Different from EHS policies making, Lean Principles can be made by production and industrial engineers who are specialists in improving work process. The Kaizen Lean Implementation procedures are shown in Figure 25.

Besides, there will be Lean Champion show cases from different departments. It gives employees encouragement and rewards to continuously contribute to best practices. Also different departments will have chance to learn from each other and break down the “Wall” (barriers between departments caused by inefficient communication).

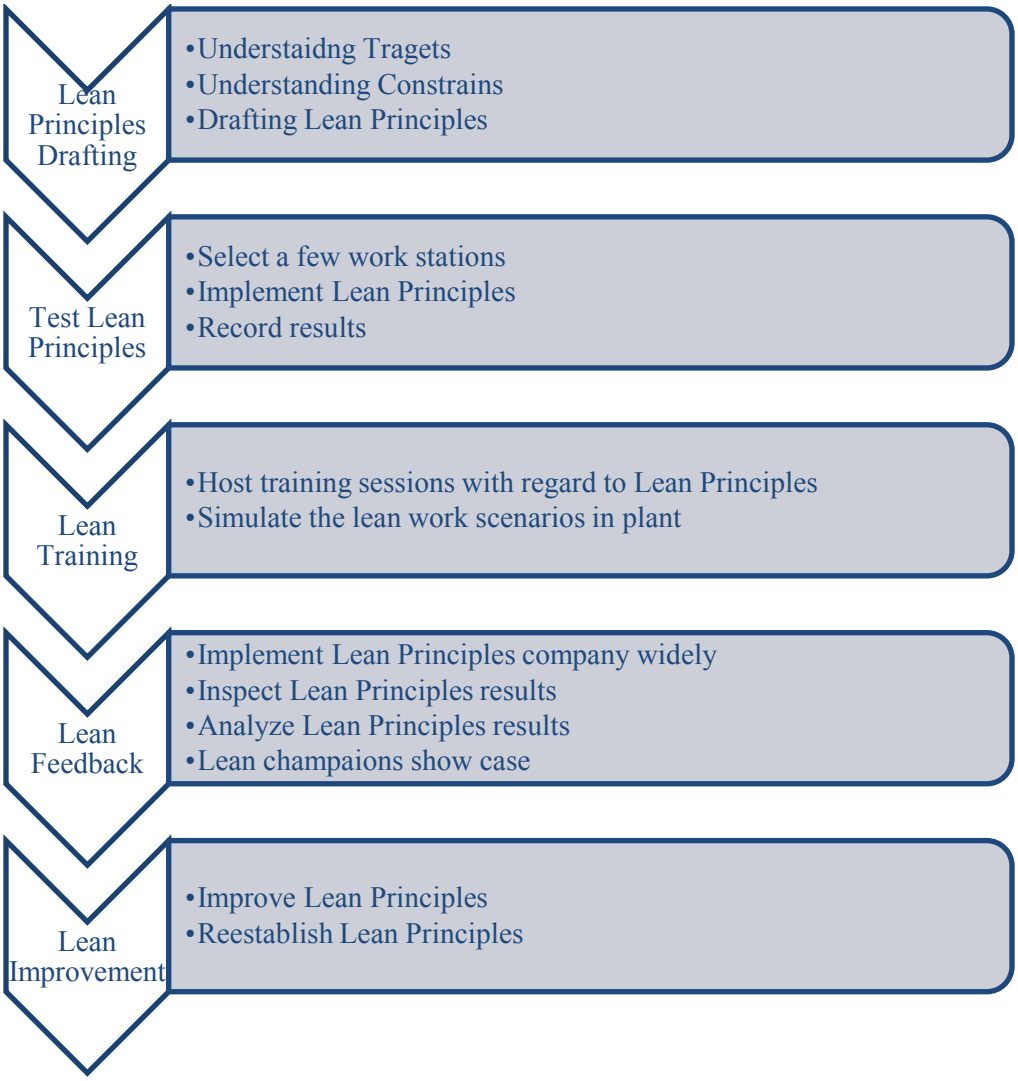

Figure 25 Kaizen Lean Implementation Steps

4.5.3 Achieving Leadership

In order to lead the market and occupy the market share as much as possible, sustainability should be elevated as a strategic level to expand its impact from suppliers to agents to compete as a whole supply chain.

It can be called as Pyramid Sustainability Leadership (Figure 26). The basic level is to implement sustainability to manufacturing environment, which is the current situation. The upper level is to expand the sustainability strategy to its suppliers and retailers. The final stage is to work towards sustainability as a competitive supply chain.

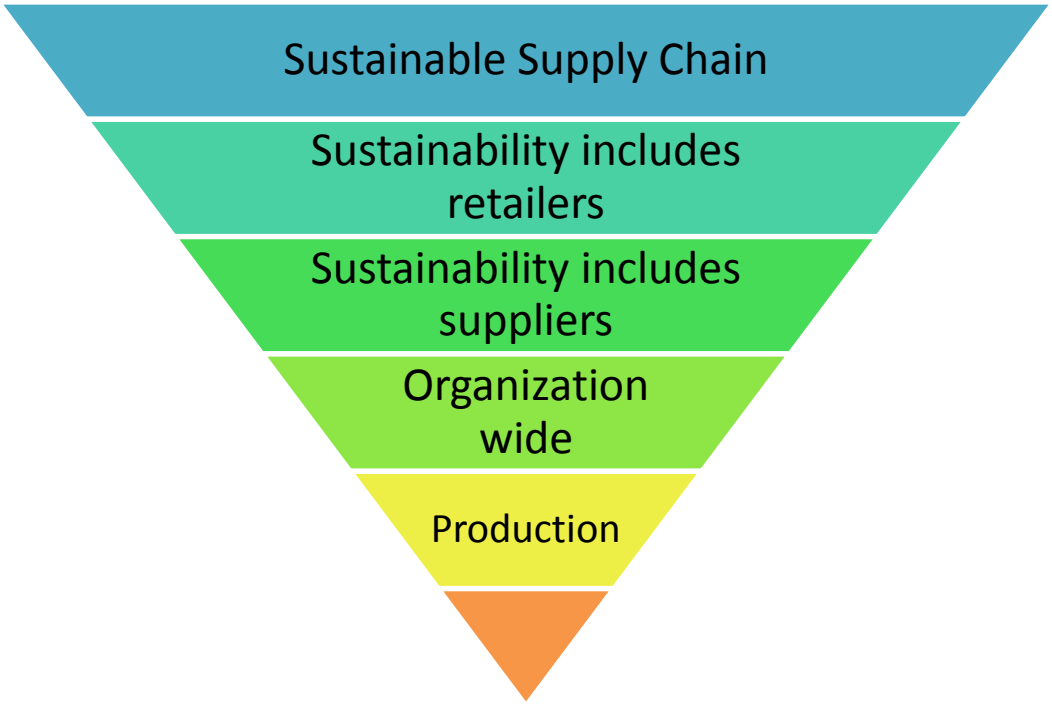

Figure 26 Pyramid Sustainability Leadership

In each level, the above mentioned actions can be implemented. Among all the actions, there will be collaboration and training stages which are very crucial to work together with all shareholders. Besides, the auditing and documenting procedures can help the core organization to monitor the performance of both

internal teams and also external teams, for example suppliers, retailers. By collaborating with all shareholders, all the companies along the supply chain can benefit with leading position.

Chapter 5 Conclusions and Future Works

5.1 Conclusions

Through SWOT analysis (Figure 27), the advantages and disadvantages of this thesis have been examined. This framwwork has evolved from Six Sigma and combined with all quality tools and concepts in order to improve sustainable performance. It has given weight to both quantitative and qualitative measurement to neutralize the bias.

Different from other framework, it showed progressive work from sustainable manufacturing to sustainable supply chain in order to achieve leadership in the market. It emphasizes continuous improvement and wide collaboration internally and externally.

As for weakness of this thesis, there is lack of complete validation of the whole process since the outcome for sustainability development is a long term process. Additionally, this thesis has included all manufacturing processes, such as producing, packaging, movement, etc. Every process has its unique characteristics, it is necessary to distinguish them based on the sustainability requirements for each sub process. Nevertheless, this thesis has put more efforts on social and environmental criteria, the economic factors are not considered thoroughly.

Talking about opportunities, there can be potential to categorize the measurement metrics. There are already a lot of publications and reports with regards to different types of sustainability measurement metrics. But there is no clear comparison of these metrics regarding its advantages, disadvantages and suitability for different industries.

While as for threats, the rapid change of global supply chain environment can impede the application of this method due to the complexity of global supply chain. What's more, the requirements for sustainability are changing as well,

which can bring more challenges for organizations who want to continuously improve its sustainability performance.

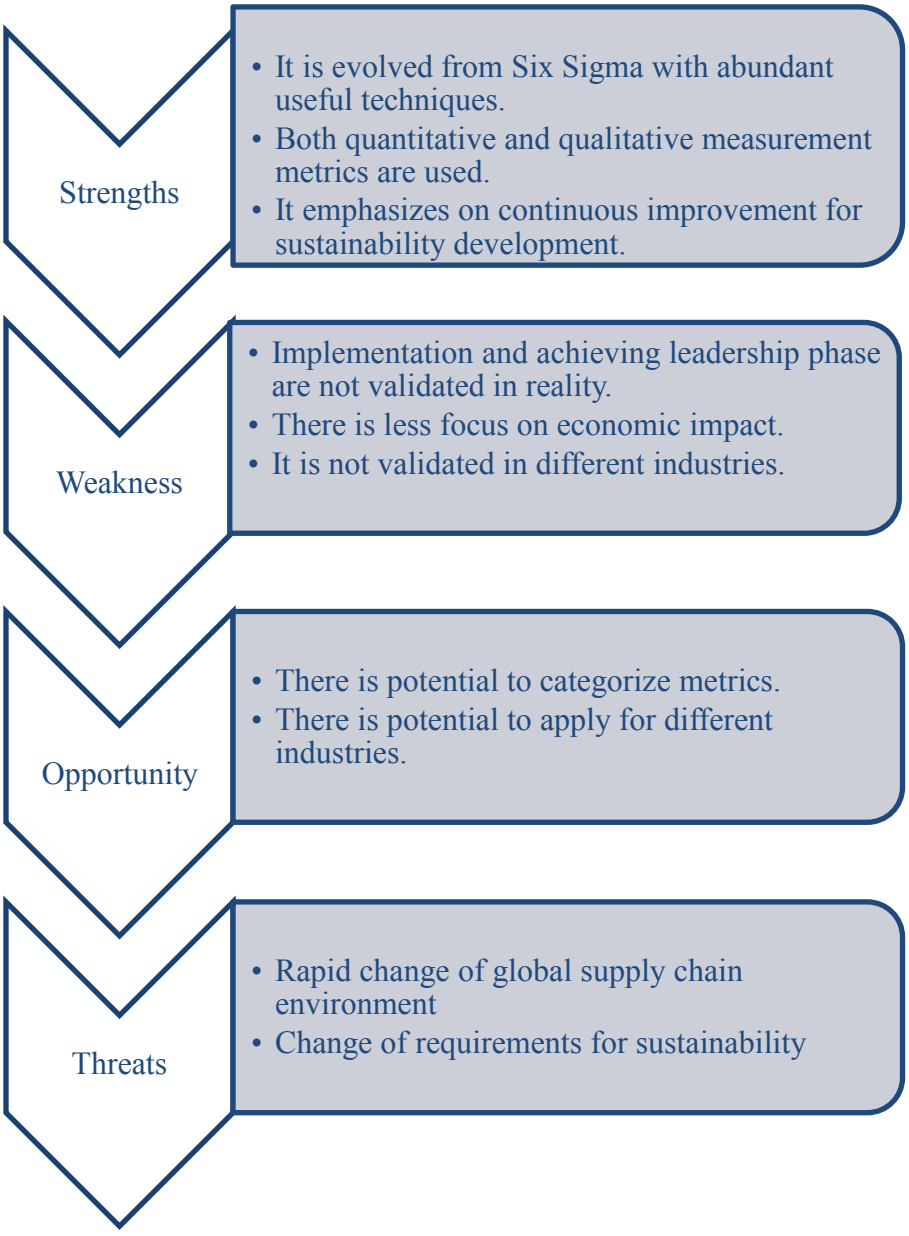

Figure 27 SWOT Analysis

5.2 Future work

1) Validation of whole process

As nature of sustainability, it takes long term to display the benefits and results of sustainable actions. It is not feasible to implement all the actions to the case study target and acquire all results to validate the framework. In the future, there should be more case studies to adjust the suitability of the framework.

2) Expansion to whole supply chain

Besides, this thesis has given more weight to sustainable manufacturing, while in order to be competitive in the market, there needs to be collaboration among all stakeholders along the supply chain. The sustainability research has to be expanded from manufacturing to all functions of supply chain and integrate them together.

3) Suitability to all industries

As a powerful framework for sustainable manufacturing, it is necessary to validate its suitability in different industries since different industries have specific characteristics. Under this situation, some tools and/or metrics should be adjusted accordingly.

4) Summary of measurement metrics

There are a lot of different metrics to measure sustainability performance from social, environmental and economic aspects. It is necessary to summarize these different metrics. It will help organizations to choose the most suitable one from all these metrics.

5) Investigation of gaps between different departments

As a strategy for an organization, sustainability cannot be achieved by one person, there needs close collaboration among different departments. The research of how to align the efforts among different departments seamlessly should be fully discussed in order to achieve leadership under supply chain environment.

6) Investigation of interactions of sustainability measurement metrics

Sustainability measurement metrics are both subjective and objective at the same time. In the future, there is need to research if there is any interaction between these metrics and how these interactions can be controlled when organizations measure the sustainability performance.

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