Lean and Green Production Development
-Examples of Industrial Practices in China and Turkey

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Abstract

This master thesis project was initiated in connection to the research project “Green Production Systems”, which is being conducted at Mälardalen University with involvement of academics and Swedish automotive and manufacturing industries. This thesis is prepared in guidance of “Development of guidelines for environmental value improvement and cost decrease” work package and the work package associated “Lean and Green Production Systems” master thesis proposal (see Appendix I). The aim of the thesis is to provide the work package with an international aspect under the given master thesis proposal scoping. The main objective of this thesis has been to contribute to a further understanding of how approaches to lean and green can be used to develop competitive production systems. A theoretical frame of reference has been presented in order to provide the research with a theoretical foundation. Further, empirical studies of four companies from China and Turkey have been carried out to investigate how companies perceive and work with their production systems in terms of applications of lean and green approaches. The empirical studies also aimed at identifying good examples of current practices that the companies achieved within the area.

Keywords: Lean Production/Manufacturing, Green Production/Manufacturing, Lean and Green Production/Manufacturing, Clean Production/Manufacturing
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1. Introduction

1.1 Background

Today, environmental obligations of companies from various fields are increasing rapidly. Industries such as automotive and manufacturing industries deal with a lot of environmental regulations. It can be observed that automotive customers prefer to buy green (environmental friendly) products that consume alternative energy sources. Many companies thus try to supply their products locally in order to decrease transportation cost and CO2 consumption. Some automotive companies such as Toyota define their new production philosophies as a combination of lean and green approach in order to cope with market and society’s heavy environmental requirements. Lean production is a toolbox that aims to eliminating wastes in the production process through continuous improvement [1]. Green Manufacturing, on the other hand, is commonly defined as “elimination of environmental waste and reduction of energy consumption by re-defining existing production process or system” [16]. Even though green production is rapidly becoming an essential part to automotive and manufacturing industry, issues related with environment are usually dealt by environmental experts and are not included in many companies’ lean production philosophies and daily activities. Based on this it can be suggested that lean philosophies in companies should be better implemented with continuous environmental improvement approach in order to satisfy heavy environmental requirements of market and society and provide a competitive advantage. In this thesis, the combination of lean production and green manufacturing is referred to as “Lean and Green Production” and is regarded as an important development area towards future competitive production systems. To increase the knowledge around lean and green production, a comparative study of current practice in companies from different countries would be beneficial. Based on current state in industry regarding lean and green production, existing practices could be analyzed and good examples of current practices among the studied companies could be identified.

1.2 Aim of Project

The main aim of the project is: to compare the similarities and differences of the approaches to lean and green production development practices of some automotive companies in China and Turkey in order to identify good examples of current practices. The specific aims of the project are:

> To identify implication, application, views and priorities of lean, green, and “lean and green” (lean and green relation proving efforts) production development practices of automotive industry companies from different countries and provide
a comparison between applications.

- To observe similarities and differences between lean, green, and “lean and green” approaches of companies from different countries.

- To identify good examples of current practices. This will enable the companies, universities or other interested targets to observe lean, green and clean applications of different companies from different countries and good examples of current practices.

1.3 Research questions

Based on the background of this thesis as well as the specified aims of the project, the following research questions were formulated:

**RQ1 (Lean Production):** How has the lean philosophy been integrated, appreciated, and applied in the production system of the studied automotive companies?

a) The implication of lean philosophy

b) The application of lean practice

c) The views and priorities regarding lean practice

**RQ2 (Green Production):** How has the green (environmental perspective) been integrated, appreciated, and applied in the production system of the studied automotive companies?

a) The implication of green philosophy

b) The application of green practice

c) The views and priorities regarding green practice

**RQ3 (“Lean and Green” Production):** How has the lean and green been integrated or related (“lean and green” production), collectively appreciated and applied in the production system of the studied automotive companies?

a) The implication of “lean and green” philosophy
b) The application of “lean and green” practice

c) The views and priorities regarding “lean and green” practice

**RQ4 (Lean, Green, and “Lean and Green” Production):** What are the good examples of current practices that the companies have achieved within the area – successful approaches that have been performed at the plants?

**1.4 Expected outcomes**

Based on the background and aim of the project, the expected outcomes from this thesis are:

- To raise awareness on coordinating and integrating lean and green production.
- To identify opportunities for coordinating and integrating lean and green production implementation in order to develop future competitive production systems.

**1.5 Delimitations**

**Target Location:** The project will involve international companies from two different countries in order to do the comparison of approaches to lean and green in industry, China and Turkey are selected as target countries. The motivation behind choosing China and Turkey is that the master students who work on the project have Chinese and Turkish nationality and it will provide them with advantages when surveys are conducted in these countries because their native languages are Chinese and Turkish; China is an important country where lean practices are applied; Turkey is an important car manufacturer where investment in automotive industry is very high due to its advantages of geographical location and low labor cost.

**Target companies:** The chosen companies have similar business characteristics-range and scale of production in order to make them comparable. All sorts of manufacturing industry could be involved in such issues, but our study will focus on manufacturing automotive industry.

**Target contact person:** In this project, the target contact person refers to the persons in the companies that the researchers contacted. The target contact person will be e.g. engineers from a production department since our project is mostly related to production practice.
2. Methodology

This chapter aims to illustrate how the study has been conducted. The thesis is based upon a literature study as well as interviews of four automotive companies in China and Turkey.

2.1 Literature Study

The authors decided to study current examples of lean and green production development based on literature and industrial practices. The literature search was conducted to give support to the research. The literature sources that were used included: University Database, Internet Source and Text Books. The aims of literature studying are as follow:

1. To narrow down the research scope. The authors reviewed related research and studies in order to check what have been done in the related field as well as how they have done the studies. The related research and study were mainly acquired from the University Database such as Emerald, Science Direct and Diva, as well as the Internet Source like Google and EPA database. The key words that the authors used to search the articles were: lean, green, lean production, green production, green manufacturing, sustainable production, clean production, lean and green, lean and clean. After searching, 107 articles were found that were relevant.

2. To acquire the in-depth knowledge about the approach to lean and green, the books and EPA database were used as major sources of knowledge. The text books and EPA database were also applied to come up with a theoretical framework. 13 books were found that were useful.

3. To get an understanding of the methodology on how to conduct a thesis, for instance, how to evaluate the quality of the thesis.

4. To learn writing skills of a scientific paper by reviewing other thesis reports.

The literature study did identify theories that were used to create and support survey questions, as well as later analyze the results.

The theoretical framework has been grouped in three main subjects in regards to main
research content, that is, Lean Production (RQ1), Green Production (RQ2), and “Lean and Green” Production (RQ3). Lean Production and Green Production theoretical frameworks basically contains: definitions, principles, types of wastes, and tools and methods. “Lean and Green” Production subject contains a theoretical framework of how lean and green can be related or integrated in production systems. “Lean and Green” Production theoretical framework includes: relating lean and green via associating lean and green wastes (Waste Perspective); lean and energy use relation; lean and chemical waste relation; and finally, lean tools and their implications to environmental performance.

2.2 Choices of Data Collection

In this thesis, the researchers have collected data in terms of primary data. In order to collect the primary data, interview is used as the mainly research instrument. So it means that a qualitative method will be applied to the collection of the primary data.

Interview is the most common used method in qualitative research. Alan Bryman mentioned many types of interview such as standardized interview, open interview, semi structur ed interview and so on [54]. But most common types of interview are structured, semi-structured and unstructured.

In this thesis, the researchers used semi-structured interview. Bryman defined that “Semi-structured interview is a term that covers a wide range of instances. It typically refers to a context in which the interview the researchers have a series of questions that are in the general form of an interview schedule but is able to vary the sequence of questions. The questions are frequently somewhat more general in their frame of reference from that typically found in a structured interview schedule. Also, the interviewers usually have some latitude to ask further questions in response to what are seen as significant replies”. [54]

Different from a structured interview, a semi-structured interview is more flexible as it allows new questions to be brought up during an interview, which means interview schedule does not have to be followed. In a semi-structured interview researcher always has a framework or a list, such framework always called interview guide. In a semi-structured interview both researchers and respondents have much freer to design or answer researchers the questions by their own way. Even, sometimes there is a possibility to come up with new questions, which are not in the interview-guide when
they need to explain the question more deeply. The guiding questions of this thesis can be found in Appendix II.

According to Bryman (2001) researchers need also use an understandable language that is suitable for all interview persons [54]. In this thesis, the researchers are from the two countries, China and Turkey. Chinese and Turkish are their mother langue respectively, so Chinese and Turkish are the interview languages in this thesis.

2.3 Company Studies: Delimitation and Selection

Four companies were chosen to conduct the survey. The reasons to choose those companies were (1.) They are automobile companies or supplier of automobile companies, which are targeted in the research, and (2.) the researchers have a contact with them, therefore the researchers will have more time to focus on the literature study and other part of the research instead of spending time looking for companies. The information of the companies is as follow:

✧ KARSAN

KARSAN has been active in the Turkish automotive industry for exactly 45 years, manufacturing a wide range of 6 different brands of vehicles, including its own brand—from light commercial vehicles to busses, from light to heavy-duty trucks-at its two factories in Bursa” [46]. Karsan product brand range includes Karsan and BredaMenarinibus as passenger transport vehicles; Hyundai Truck as cargo transport vehicles; and Renault Truck as heavy trucks, Peugeot and Citroen as light commercial vehicles. Furthermore, “Karsan also provides marketing, sales and after-sales services for Karsan J Series minibuses, Hyundai HD Series trucks, and BredaMenarinibus busses” [47]. “Manufacturing about 26 thousand vehicles in 2010, Karsan achieved an approximate turnover of 600 million TL in 2010. The Company, standing as Turkey’s 7th in manufacturing and 6th in exports, intends to have a voice in the 75 billion-dollar export target set for the Turkish Automotive Industry in the year 2023, the centennial of the establishment of the Turkish Republic [48].

✧ TOFAS

Tofas engages in manufacturing, exporting, and selling passenger cars and light commercial vehicles under licenses from Fiat Auto S.p.A. in Turkey and internationally. It also produces mini cargo vehicles and various automotive parts
used in its automobiles. The company was founded in 1968 and is headquartered in Istanbul Turkey [49]. Tofas is one of Fiat Auto's 3 strategic international production centers. Tofas manufactures passenger cars for international export by virtue of its compact sedan models, the Fiat Linea, Doblo, and Fiorino. These vehicles are manufactured under the Fiat brand by the Minicargo plant in Bursa [50]. “Tofas achieved great success by increasing its sales at the rate of 38.8% in the total domestic market with an increase of 12.8% market share in 2009, and recaptured the leadership of the passenger car and light commercial vehicle market with a share of 15.3% after eight years. It closed in 2009 as the leader of the light commercial vehicles market with a share of 29.5%, the highest rate ever” [51].

✧ **DONGFENG**

As a limited liability company held by Dongfeng Motor Group Co., Ltd. and Liuzhou Industrial Shareholding Co., Ltd., Dongfeng Liuzhou Motor Co., Ltd. is China’s first-grade big enterprise, ISO9001 quality system attestation enterprise and 3C attestation enterprise [52]. With more than 3000 employees, total assets value of 2.38 billion yuan and land area of 878,000 m2, it has formed an annual production capacity of 60,000 commercial vehicles and 50,000 passenger vehicles, and has four major brands, i.e. “Dongfeng Chenglong”, “Dongfeng Balong”, “Dongfeng Longka”, and “Dongfeng Fengxing” [52].

✧ **JINXIANG**

Jinxiang Badge factory was founded in 1983. They have become the first on the list of large producing enterprises in badge industry in China. They are specialized in producing badges and accessories of motor or car. To follow up the demand of markets, the factory has been devoted a lot of time and efforts on improving its management, technique, quality, CI, and production process [53].

The information of the interviewees and the date of the interviews are shown as follow:

- **KARSAN**
  - Gokhan Celikliay (Lean Production Manager)
  - Cigdem Senturk (Environmental Engineer)
2.4 Validity and Reliability

In this research, the results are based on qualitative data. The two most commonly used terms when judging the quality of research are validity and reliability.
2.4.1 VALIDITY

Validity refers to the extent to which researchers are able to use their method to study what they had sought to study rather than studying something else [55]. Validity can be divided in two types: internal and external [54]. Internal validity refers to whether the conducted studies really indicate causal relationships in the cases where they exist [54]. Eternal validity is associated with the width of the results and whether it is probable that the results can be applied in other situations or at other occurrences than the ones actually studied [54].

2.4.2 RELIABILITY

Reliability is related with the reproducibility of the research and the extent to which two or more researchers studying the same phenomenon with similar purposes could reach approximately the same results [55]. It is more relying on the researchers’ own interpretations. Careful attention to how data and information is gathered, analyzed and interpreted can strengthen the reliability aspect [54].
3. THEORETICAL FRAMEWORK

The theoretical framework has been divided into three main subjects in regards to main research content, that is, Lean Production (RQ1), Green Production (RQ2), and “Lean and Green” Production (RQ3). Lean Production and Green Production theoretical frameworks basically contains: definitions, principles, types of wastes, tools and methods. “Lean and Green” Production subject contains a theoretical framework of how lean and green can be related or integrated in production systems: relating lean and green via associating lean and green wastes (Waste Perspective); lean and energy use relation; lean and chemical waste relation; and finally, lean tools and their implications to environmental performance.

3.1 Lean Production

3.1.1 DEFINITION OF LEAN PRODUCTION

Lean production is a toolbox that aims to eliminating wastes in the production process through continuous improvement [1]. Lean production also denotes creating the same outputs as created by mass production with less – time, space, human effort, machinery, and materials – while contributing increased varieties for the end customer [9].

The core goals of the implementation of lean production for a company are to improve profit by reducing cost, increasing output and shortening lead times (lead time is the period between a customer’s order and delivery of the final product) through eliminating wastes, as well as to provide the highest quality. The elimination of waste enables an increase in productivity and quality associated with reduction in cost and delivery time to the customer. Pascal (2002) also adds safety, environment, and moral to the core goals based on the expectations of customers [1]. It can be summarized as PQCDSM which means Productivity, quality, cost, delivery time, safety and environment, and morale.

More specific goals are described as the following:

● Defects and wastage – to eliminate defects and unnecessary physical wastage, which includes excess use of raw material inputs, preventable defects, costs associated with reprocessing defective items, and unnecessary product
characteristics which are not required by customers [2]. This, in turn, means converting all raw materials into end products as well as avoiding scrap and rework.

- **Inventory** – to minimize inventory levels at all steps in the production process, particularly WIP. Keep constant flow to the customer and to not have idle material. Lower inventories also mean lower researchers working capital requirements [2].

- **Overproduction**: Produce the exact quantity that customers need, and when they need it.

- **Time** – to eliminating lead time and production cycle times by reducing waiting times between processing stages, as well as process preparation times and changeover times.

- **Labor productivity** – to improve labor productivity by getting rid of unnecessary movement of workers, reducing the idle time of workers, and avoiding doing unneeded tasks.

- **Simplicity** - try to solve problems the uncomplicated way rather than the complex way. Complex solutions tend to produce more waste and are harder for people to manage.

- **Flexibility** – to be able to produce a more flexible range of product with minimum changeover costs and changeover time.

- **Energy** – to utilize equipment and people in the most productive ways. Avoid unproductive operations and excess power utilization.

- **Utilization of equipment** – to use equipment more efficiently by eliminating the six big losses like machine downtime. Six big losses refers to equipment breakdowns, changeover and adjustment delays, idling and minor stoppages, reduced speed losses, process defects, and reduced yield [3].

- **Space** – to reorganize equipment, people, and workstations to get a better space arrangement.

- **Transportation** – to reduce transportation of materials and information that does not add value to the product.
Unnecessary Motion – to avoid excessive bending or stretching and frequently lost items.

Most benefits of lean production can lead to lower unit production costs and increase productivity. For example, higher effectiveness of equipment utilization can help lower depreciation costs per unit produced.

3.1.2 PRINCIPLES OF LEAN PRODUCTION

The five principles are the fundament of lean production. Principles can be summarized as the following [9]:

1. Specify value from the point of view of the customer. It is critical to know what customers want to buy and who customers are at the starting point. Customers buy results but not products [9]. For example, they want to buy fresh food but not a refrigerator. This means the purpose they buy the refrigerator is to keep the food fresh, but not the refrigerator itself, since it doesn’t make sense if the refrigerator does not have the function which meets customers’ requirement. Meanwhile, it is important to know who the customers are. They can be external customers: final customers, the next company along the chain, or the customer’s customer. They can also be internal customers who are from next process.

2. Identify the value stream. It is significant to understand the sequence of processes all the way from raw material to final customer, or from product concept to market launch. As discussed in the first principle, from the customer’s perspective, value is equivalent to anything that the customer is willing to pay for in a product or service. Thereby the viewpoint of object (or product or customer) is the focal point but not the process. The tool, VSM-value stream mapping, is developed for mapping both value-added work and non-value-added work in the process.

3. Flow. Make the value-creating steps occur in tight sequence so the product will flow smoothly toward the customer. One-piece flow is developed to make value flow.

4. Pull. As flow is introduced, value is pulled by customers from the next upstream activity.

5. Perfection. Perfection refers to perfect value. As value is specified, value streams are identified, wasted steps are removed, and flow and pull are introduced, begin
the process again and continue it until a state of perfection is reached in which perfect value is created with no waste.

3.1.3 LEAN ‘MUDA’ WASTES

Waste elimination is one of the most effective ways to increase the profitability of any business. Processes either add value or waste to the production of goods or service. The seven wastes originated in Japan, where waste is known as “muda.” "The seven wastes" is a tool to further categorize “muda”. It was originally developed by Toyota’s Chief Engineer Taiichi Ohno as the core of the Toyota Production System [9]. To eliminate waste, it is important to understand exactly what waste is and where it exists. While products significantly differ between factories, the typical wastes found in manufacturing environments are quite similar. There is a strategy or method to reduce or eliminate each waste, thereby improving overall performance and quality. The seven wastes consist of [9]:

**Overproduction**

Overproduction means making more products than necessary, including production of an item before it is actually needed. Overproduction is the root cause of other muda [1]. For example, workers are producing items that are unneeded, and then the unneeded finish goods must be transport to warehouse. Meanwhile overproduction leads to poor flow of materials and actually degrades quality and productivity. The Toyota Production System is also referred to as “Just in Time” (JIT) because every item is made just as it is needed. Overproduction manufacturing is referred to as “Just in Case.” This creates excessive lead times, results in high storage costs, and makes it difficult to detect defects. The simple solution to overproduction is turning off the tap; this requires a lot of courage because the problems that overproduction is hiding will be revealed.

**Waiting**

Waiting occurs when a worker has to wait for materials to be delivered, for a line stoppage to be cleared, or for a machine to process a part [1]. It also can occur when there is excessive work-in-process because of large batch production, equipment problems downstream, or defect requiring rework [1]. Whenever goods are not moving or being processed, the waste of waiting occurs. Much of a product’s lead time is tied up in waiting for the next operation; this is usually because material flow
is poor, production runs are too long, and distances between work centers are too great. Time lost in bottleneck process can never be recovered. Linking processes together is a useful solution to reduce waiting time.

**Transportation**

Transportation refers to the movement of parts and products throughout the facility by using a forklift, hand truck, pallet jack, or other transportation tools [4]. Transporting product between processes increases cost since it adds no value to the product. Transportation can be difficult to reduce due to the perceived costs of moving equipment and processes closer together. Furthermore, it is often hard to determine which processes should be next to each other. Mapping product flows can solve the problem and make this easier to visualize.

**Over-processing**

This means doing more than what the customer requires. This often occurs when there is a poor plant layout. For instance, preceding or subsequent operations are located far apart.

**Inventory**

Inventory is related to hold unneeded raw materials, parts, and work in process (WIP) [1]. It costs lot money to hold these. Excess inventory is likely to hide problems on the plant floor, which must be identified and resolved in order to improve operating performance. Excess inventory increases lead times, consumes productive floor space, delays the identification of problems, and inhibits communication. By achieving a seamless flow between work centers, many manufacturers have been able to improve customer service and cut inventories and their associated costs.

**Motion**

This waste has both a human and machine element. Wasted human motion is related to ergonomics and is seen in all instances of bending, stretching, walking, lifting, and reaching. Poor ergonomic design can affect productivity and quality negatively as well as health and safety issues, which in today’s litigious society are becoming more of a problem for organizations. It is essential to analyze excessive motion and redesign it for improvement with the involvement of plant personnel.
Defects

This waste refers to any quality deficiency that causes scrap, warranty claims, or rework because of mistakes made in the factory, which are a tremendous cost to organizations [4]. Associated costs include quarantining inventory, re-inspecting, rescheduling, and capacity loss. In many organizations the total cost of defects is often a significant percentage of total manufacturing cost. Through employee involvement and Continuous Process Improvement (CPI), there is a huge opportunity to reduce defects at many facilities.

3.1.4 THE HOUSE OF LEAN PRODUCTION

In this part, the house of lean production will be introduced, shown in Figure 1, around which the theoretical framework is organized. As illustrated in the figure, the foundation of the lean system is stability and standardization. The walls are just-in-time delivery of parts of products and Jidoka, or automaton with a human mind. The goal of the system is customer focus: to provide the highest quality, at the lowest cost, in the shortest lead time. The heart of the system is involvement: flexible motivated team members continually seeking a better way. Meanwhile, the figure depicts various lean activities which are interconnected [1]. Lean activities support stability. Machine stability requires 5S and TPM. Quality is strengthened with Jidoka. Just-in-time techniques attack parts shortage problems. 5S, TPM, and standardized work improve safety [5].
3.1.5 LEAN TOOLS, METHODS AND TECHNIQUES

The correct application of Lean tools and techniques will illustrate how to peel away layer after layer of waste. It’s like peeling an onion - you take away the biggest outer layers first but there's always more. Lean tools, methods and techniques will be presented as follow:

**5S**

5S can be defined as a system of workplace standardization and organizations, referring to sort, set in order, shine, standardize, and sustain [1]. The goal of 5S system is to build a work environment that is self-ordering, self-explaining, self-regulating and self-improving, to hold visual information [6]. The 5S system comprises a series of activities for eliminating wastes that contribute to errors, defects, and injuries in the workplace.

5S aims to create a working environment that is clean, well-organized and efficient
It is also used with the other lean tools by providing a rapid, visible achievement. For instance, 5S efforts can be used with Point of Use Storage [36]. 5S efforts almost always improve workplace safety, operator morale, quality, and throughput [5]. 5S will be described specifically as follow [5]:

Sort (Seiri) – to clean out the work area by relocating or discarding all unneeded items from the workplace and keeping the needed items in the work area

Set in Order (Selton) – to arrange needed items so they are easy to find, use and return, to streamline production and eliminate time searching for them.

Shine (Seiso) – to clean and care for equipment and areas, and inspect while doing so in the work area (preventative cleaning also applies).

Standardize (Seiketsu) – to make all work areas similar so procedures are obvious and instinctual, and defects stand out. This, in turn, means maintain the improvements through discipline and structure.

Sustain (Shitsuke) – to make “rules” natural and instinctual in order to continue to support 5S efforts through auditing, job descriptions that include maintenance of the system, management support and expectations, etc.

As illustrated in Figure 1 (the house of lean production), 5S is one of the most widely adopted tool from the lean toolbox. The primary objective of 5S is to create a clean, uncluttered and well organized environment. The specific benefits of application 5S are [56]:

- Reducing non-value adding activity
- Reducing mistakes from employees and suppliers
- Reducing time for employee orientation and training
- Reducing search time in navigating the facility and locating tools, parts and supplies
- Reducing parts stored in inventory, and associated inventory carrying costs
- Reducing unnecessary human motion and transportation of goods
- Improving floor space utilization
- Improving employee safety and morale
- Improving product quality
- Extending equipment life through more frequent cleaning and inspection
**Total Productive Maintenance (TPM)**

Total productive maintenance (TPM) refers to an integrated set of activities aimed at maximizing equipment effectiveness by involving everyone in all departments at all levels [1]. Operators take greater responsibility to take care of their machines. It is difficult to become truly lean without a solid TPM program. TPM program aims to achieve zero breakdowns and zero defects. It usually entails implementing the 5S system, measuring the six big losses, prioritizing problems, and applying problem solving [1]. The implementation of TPM can also help to maximize utilization of production assets and plant capacity. Here are some other benefits of implementing TPM [7]:

- Replace routine with development
- Increased commitment from all co-workers
- Continuous improvements
- Foreseeable operations
- Improved safety and environment

**The six big losses and OEE** is typical concept utilized in TPM. In TPM, all team members are involved to eliminate the six big losses that lower machine effectiveness [1]. The six big losses can be classified into three categories including availability, performance, and quality that are also the basis of OEE [3]. The six big losses can result from faulty equipment or operation as the following:

- **Availability**
  - Equipment breakdowns – unplanned stoppages that are requiring repair, usually greater than 10 minutes.
  - Changeover and adjustment delays occur when changing over between products.
- **Performance**
  - Idling and minor stoppages – stops that are less than 10 minutes, resulting from tip breakage, coolant top-up, jams, sward removal, and small adjustments [3].
  - Reduced speed losses – the actual machine running speed is less than the design speed resulting from flow restriction, program errors on a CNC machine, and worn tools, feeds or belts [3]
- **Quality**
  - Process defects – scrap, defects that need to be rework.
  - Reduce yield – losses resulting from machine start-up to stable production.
**OEE (overall equipment effectiveness)** is one of the key measures used in TPM. It shows the disturbances that reduce the productivity of the equipment as well as how effective the equipment is used by measuring loss factors. The formula for OEE is:

\[
OEE = \text{Availability} \times \text{Performance} \times \text{Quality}
\]

**TPM structure**

In this part, it illustrates how to implement TPM according to the TPM structure (See figure 2).

It is a good beginning to implement TPM according to the TPM structure that leads to “zero breakdowns” and “zero defects”. As showed in the figure, an implementation plan of TPM includes 13 steps that can be divided into two parts - preparation and implementation. They are:

**Preparation:**

- **Step 1**: management’s decision. It is critical to create an environment to support the introduction of TPM since skepticism and resistance will ruin the initiatives without the support of management.

- **Step 2**: education – to train everyone in the organization about TPM activities, benefits and the importance of contribution from everyone.

- **Step 3**: Organization and pilot – to create a group, consisting of members from all
levels, to support TPM activities.

- Step 4: Policy and goals – to establish basic TPM policies and quantifiable goals. In this step, it entails analyze the current state and set goals that are SMART: Specific, Measureable, Attainable, Realistic and Time-based.

- Step 5: Develop a master plan. This plan is to classify necessary resources and training schedule, equipment restoration and improvements, maintenance management systems and new technologies.

Kick-off – starting to implementation at this stage. Implementation:

- Step 6: Continuous improvements – to improve the effectiveness of each piece of equipment.
- Step 7: Autonomous maintenance – to develop an autonomous maintenance program for operators. This program teaches operators systematically to take care of the equipment with which they work. Operators’ routine cleaning and inspection help stabilize conditions and halts accelerated deterioration. The seven-step ladder is usually applied to implement autonomous maintenance [7]. This is illustrated in the following figure:

![The Seven-Step Ladder](image)

- Step 8: Planned maintenance – to create a schedule for preventive maintenance on each piece of equipment.
- Step 9: Education and training – to improve operators’ operation and maintenance skills.
- Step 10: Early equipment management. Apply preventive maintenance principles during the design process of equipment [15].
- Step 11: Quality maintenance.
- Step 12: Effective administration
- Step 13: Safety, hygiene and environment.

**Standardized work and standardization**
Productivity Press defined (2002) standard work as an agreed-upon set of work procedures that effectively combines people, materials, and machines to maintain quality, efficiency, safety, and predictability in terms of cycle time, work in process, sequence, time, layout, and the inventory needed to conduct the activity [8]. Standardized work is the basis for continuous improvement and Quality [5]. It also helps maximize performance and minimize waste.

Toyota President Cho (2004) describes that standardized work comprises three elements – takt time (time required to complete one job at the pace of customer demand), the sequence of doing things or sequence of processes, and how much inventory or stock on hand the individual worker needs to have in order to accomplish that standardized work [5]. The standardized work is set based upon these three elements, takt time, sequence, and standardized stock on hand [1].

**Benefits of Standardized work**
Standardized work can help company gain benefits by [8]:
- Reducing variability, waste, and costs.
- Improving quality and shortening lead times
- Leading the way to ISO certification (e.g., ISO9001)

Standardized work can assist operators by making it [8]:
- Easier for them to learn new operations.
- Easier for them to shift to different operations within a cell or to shift to operations in other cells, lines, or work area
- Easier for them to identify problems and contribute improvement ideas.

Standardized work also provides great benefits like [1]:
- Process stability
- Clear stop and start points for each process. This makes it easier for organizations to see the production condition.
- Organizational learning. Standardized work preserves know-how and expertise. An organization won’t lose his or her experience if a veteran employee leaves.
- Audit and problem solving. Standardized work makes checkpoints and vital process steps easier to track. Standardized work also allows organizations to assess their current condition and identify problems.
- Kaizen. Standardized provide a baseline for future improvement.

**How to implement standardization**

According to Productivity Press (2002), the implementation of standardization can be conducted as follows [8]:

1. Procedures explained by veteran workers – people
2. Standards manuals to clarify work sequences – methods
3. Standards for jigs, tools, and alarm devices – measurement
4. Building standards into equipment – production equipment, computer, etc.
5. Standardization of objects – materials
6. Improvement of management methods – information

There are three charts, which are considered as tools for analyzing and defining a process and for identifying improvement points, used to define standardized work [1]:

- Production capacity chart
- Standardized work combination table
- Standardized work analysis chart

**Value Stream Mapping**

Value Stream Mapping is a typical lean tool employed in lean manufacturing to illustrate the flow of material and information, as a product or service makes its way through the value stream [57]. The goal of VSM is to reduce or eliminate non-value added work, thereby to achieve lean manufacturing goals [57].

Womack & Jones (1996) visualized the value stream as this: raw materials along with knowledge and information enter the system upstream (the suppliers); and, products or services of value flow out from the system downstream (the customers) [9].

The value stream map, developed at Toyota, is a tool that:

- Allows you to diagram your current value stream;
- Identifies the bottlenecks that prevent you from making what your customers want, when they want it;
- Develops a vision of what your future lean system should look like.
Benefits of the Value Stream Mapping

Value stream mapping displays linked chains of processes and where value and non-value adding activities occur that will yield a baseline of information to envision future lean value streams. Underlying VSM is a philosophy of how to approach improvement. The philosophy is that it is necessary to straighten out the overall flow of the value stream before deep-diving into fixing individual processes. This, in turn, is to support the flow. VSM also gives a “common language” and understanding so that everyone has the same vision [10].

The steps of VSM are as follow [7]:

1. Identify product to analyze
2. Put together a team to perform the analysis
3. Go to the workshop and study
4. Overall process map of material flow when walking by. Start at the customer
5. Collect data
6. Identify information flow
7. Enter times and analyze
8. Draw future process

After the able 8 steps, start to map value stream step-by-step. The final look of VSM shows following:

![Value Stream Mapping Diagram]

FIGURE 4 VALUE STREAM MAPPING [7].
Kanban
Kanban is a visual tool used to achieve JIT production [1]. Kanban is considered to be “self-evident signals” that indicates what to produce or withdraw and when. It may also contain related information such as the supplier of the part or product, the customer, where to store it, how to transport it (i.e., the size of the container and the method of conveyance). It maintains an orderly and efficient flow of materials throughout the entire manufacturing process. Kanban is usually a printed card while sometimes it is an electronic message on a computer screen. There are two kinds of kanban [1]:

- Production kanban, which specifies the kind and quantity of product that the upstream process (supplier) must produce.
- Withdraw kanban, which specifies the kind and quantity of product that the downstream process (customer) may withdraw.

Kaizen Events
Kaizen is also named as Continuous Improvement. It refers to the philosophy of making frequent, on-going changes to production processes, the cumulative results of which lead to high levels of quality and efficiency, decreasing variation, decreasing costs, and improving the effectiveness of an organization [58]. A commitment to cultural change is required, which enhances workers to constantly make positive changes [58]. Kaizen can be used to fix specific problems, work flow issues, or a particular aspect of a business [58].

The steps for conducting a Kaizen event are [58]:

- Prepare and train the team
- Analyze present methods
- Brainstorm, test, and evaluate ideas
- Implement and evaluate improvements
- Results and follow-up

Cellular Manufacturing
Cellular manufacturing is one of the main tools of lean manufacturing that helps companies build a variety of products for their customers with as little waste as possible [11]. In cellular manufacturing, equipment and workstations are arranged in a
sequence that supports a smooth flow of materials and components through the process, with minimal transport or delay [11]. For example, if the process for a particular product requires cutting, followed by drilling and finishing, the cell would include the equipment for performing those steps, arranged in that order [11]. CM also required operators who are qualified and trained to work at the cell.

**Benefits of CM**

The advantages of cellular manufacturing can help to achieve two important goals of lean manufacturing by arranging people and equipment into cells – one-piece flow and high-variety production [11].

Firstly, the application of one-piece flow concept at a pace determined by the customer’s need, which refers to move each product through the process one unit at a time without sudden interruption, is one of the advantages of CM (See figure). Specific analytical techniques for assessing current operations and designing a new cell-based manufacturing layout, which will reduce cycle times and changeover times, are included in one-piece flow method [11].

![FIGURE 5 LOADING A MACHINE WITH ONE PIECE OF WIP [11]](image)

Another advantage of CM is to achieve high-variety production as well as to extend the product mix. Cellular manufacturing groups similar products into families that can then be processed on the same equipment in the same sequence, so that CM is able to offer the flexibilities to meet various requirements from customers when customers
demand a high variety of product as well as faster delivery rates (See Figure 6). In the other hand, it can also shorten changeover time by shorten lot-size. From this perspective, small, flexible and right-sized machines, which fit well in the cell, are much more preferable than large, high volume production machines.

![Figure 6: High-Variety Production](image)

Autonomation (Jidoka) is applied in CM to improve equipment to stop and signal when a cycle is completed or when problems occur [11].

Some other benefits include:

- Reduction of cycle time as well as lead time
- Decrease inventories (especially WIP)
- Reduce utilization of available space
- Reduce transport and material handling
- Enhance teamwork and communication
- Improve flexibility and visibility
- Improve quality by identifying causes of defects and machine problems easily
- Increase utilization of equipment

**How to implement Cellular Manufacturing**

EPA introduced the following steps and methods applied to implement the conversion to cellular manufacturing [12]:

Step 1: Learning the current situation, which refers to assessing the current work area condition (e.g., product type/quantity analysis, process route analysis, and value stream mapping or process mapping), is the first step in converting a work area into a manufacturing cell. It often starts with product and process data. For example, PQ (product type/quantity) analysis is employed to evaluate the current product mix. Process route analyses and VSM are applied to document the layout and flow of the current processes.

Assessing time elements is another important activity at this stage. This includes cycle
time for each operation, lead time needed to transport WIP between operations, takt time, or the number of units each operation in given time. Organizations illustrate time elements on worksheets that graphically show the relationship between manual work time, machine work time, and operator movement time for each step in an operation. These worksheets offer a baseline for measuring performance under a cellular flow.

Step 2: Converting to a process-based Layout. In this step, by rearranging the process elements, the production area is converted to a cellular layout so that processing steps of different types are conducted immediately adjacent to each other. Organizations usually place equipment in U or C shape in order to minimize the operator’s movement.

In this step, the following three tools are usually applied to assist effective cellular layout design and production:

- **Setup Reduction.** Single Minute Exchange of Die (S.M.E.D.), is the Lean tool used to create very fast changeovers and setups that greatly reduce machine downtime and increase throughput. The goal is to reduce machine changeover times from hours to less than ten minutes. While that may sound too good to be true, it happens time and time again. S.M.E.D. is a powerful tool for reducing downtime due to setups and changeovers. Results are almost always outstanding and inspiring. SMED supports an organization to promptly convert a machine or process to produce a different product type.

- **Automation.** Cellular Manufacturing uses automated machines that are able to stop, start, load, and unload automatically as well as detect the production of defective part, stop themselves, and signal for help. This can free operators for other value-added work.

- **Right-sized equipment.** It is considered to be small and flexible since it is often moveable and easily to be reconfigured into a different cellular layout in a different location.

Step 3: Continuously improving the process. This step aims to improve production time, quality, and costs by using continuous improvement tools (e.g., Kaizen, TPM, and Six Sigma) that can decrease equipment related losses such as downtime, speed reduction, and defects.

**One-Piece Flow**

One-piece flow describes the sequence of product or of transactional activities (e.g.,
insurance claims) through a process one unit at a time [11]. In contrast, batch processing creates a large number of products or works on a large number of transactions at one time – sending them together as a group through each operational step [11].

One-piece-flow focuses on the product or on the transactional process, rather than on the waiting, transporting, and storage of them [11]. One-piece flow methods require short changeover times and are conducive to a pull system [11].

One-piece flow can help eliminate all wastes. The benefits to conduct one-piece flow are concluded as follow [11]:

- Builds in quality
- Creates real flexibility
- Creates higher productivity
- Frees up floor space
- Improves safety
- Improves moral
- Reduces cost of inventory
- Reduces customer order to shipment times
- Reduces work in process
- Early detection of defects
- Increases flexibility for customer product/transactional demands
- Reduces operating costs through exposure/elimination of non-value-added waste

**Changeover Reduction**

One of Lean’s major objectives is reduction of lead time. To achieve this, the size of batches often needs reduction, which, in turn, creates a focus on reducing changeover times – i.e., the time from the last piece of one batch to the first piece of the next batch. Changeover time can have several components; e.g., internal, when a machine is stopped, and external, which involves preparation [42]. Other types of changeovers are manufacturing line changeover, maintenance operations, vehicle/aircraft loading/unloading, and office operations [42].

The methods to reduce changeover time [59]:

- Identify the set-up.
- Listing every step.
• Measure the time required for every step. Use a video camera to record the procedure
• Distinguish internal and external steps (internal = while the machine is stopped)
• Plot the current set-up time graph
• Convert as many internal steps to external steps as possible
• Reduce the time for internal steps
• Reduce the time for external steps
• Plot the improved set-up time graph
• Define the ideal set-up
• Plot the ideal graph and strive towards it
• Practice and improve

Andon
Andon is a tool of visual management, originating from the Japanese word “Lamp” [3]. Lights places on machines or on production lines to indicate operation status that are normal operations, changeover or planned maintenance, or abnormal, machine down [3]. Andon is an electronic device at many manufacturing facilities (i.e., audio and/or color-code visual display) [3]. For example, it can be used for calling an attention of and signaling operator to replenish certain materials.

Heijunka
Heijunka refers to production leveling. It is a traditional Lean scheduling methodology for environments that contain a repetitive mix of products or a family of products [5]. Heijunka is a kanban card post-box system that is usually at the pacemaker process [3]. A Heijunka box provides process level scheduling/pacing, schedule visibility, and early problem highlighting [3].

Pull systems and Heijunka work well hand-in-hand. However, system improvement may be needed for success, e.g., through quick change over. When the visual system indicates a problem, prompt identification and correction are absolutely essential.

Poka-Yoke (Mistake-proofing)
Poka-yoke is a Japanese word. It means inadvertent error prevention [1]. Poka-yoke is a device that works with Jidoka. Poka-yoke is used to detect errors that might lead to defects, and provides quick feedback so that countermeasures can be taken. Poka-yoke either shut down equipment or provide a warning when an error has been detected [1]. For example, an operator who creates customized assemblies from small bins in front of him: One approach would be to give the operator a list of parts to
assemble by taking them as needed from the bin [59]. This approach can lead to assembly errors since he or she might forget to include one of the parts or add parts that are not specified. A poka-yoke solution might be to install lights on all bins. When the operator is to create a new assembly, the bins that contain the specified parts for the assembly will be illuminated. The operator then systematically removes one part from each bin and places it in front of him. He does this until one part has been removed from each bin and he knows the assembly is complete when no parts remain in front.

Poka-yoke offers solutions to organizations that experience frequent discrepancies in the packaging of their products – e.g., someone forgot to include instructions or forgot to include amounting screw [59]. Poka-yoke ideas or devices can be more effective than simple demands on workers to “be more careful.” Improvement focus should always be given to what can be done to error-proof a process more than on inspecting the quality of the finished product [59].

**Point-of-Use Storage (POUS)**

Point of use storage refers to storing of materials in a given work area where used – such as in or near a manufacturing cell [13]. POUS is the storage of small amount of inventory in right-sized containers at the point in a manufacturing process where the materials are used [14]. It works best when suppliers can deliver frequent, on time, small shipments. POUS is widely used to get smaller parts and smaller volumes of chemicals and materials to the point of use. The benefits of POUS system are [14]:

- To simplify physical inventory tracking, storage, and handling.
- To reduce the time and walking distance
- To reduce overall material handling and support costs at a facility.
- To reduce material usage and wastes

**Right-sized Containers**

Right-sized container is the key to enable Lean Material Flow and affects the entire value stream. It ensures proper workstation design and layouts which optimizes value added labor, freight and protects product [14]. According to EPA, right-sized containers are typically associated with “unit of use ordering”, which involves purchasing items in quantities and packaging that makes it easy to use them in a manufacturing cell or lean workspace [14]. The benefits of using right-sized container are [14]:
- To limit the amount of item that may expire or become unusable due to contamination or spoilage.
- To reduce packaging waste as it is usually reusable.

**Six Sigma**

Six Sigma can be observed in lean tool context since EPA (2007) points out that many companies have added six sigma methods to the continuous improvement toolbox, and developed an improvement approach often named as Lean Six Sigma [12]. Six Sigma comprises a set of statistical methods for systemically analyzing processes to reduce process variation. According to EPA (2007), it also can be applied to assist and guide organizational continual improvement activities [12].

The objectives of Six Sigma are to reduce variation and to shift distribution inside customer requirements [3]. Six Sigma can add a powerful dimension in traditional lean area, especially for more complex issues. Six Sigma also focuses on eliminating defects through fundamental process knowledge. DMAIC, that is statistical process control, is an important part of six sigma methodology. It refers to Define, Measure, Analyze, Improve, and Control.

**Visual Controls**

Visual control refers to the design of just-in-time information of all types to ensure fast and proper execution of operations and processes [5]. Visual control methods aim to increase the efficiency and effectiveness of a process by making the steps in that process more visible. The concept of visual controls is a major part of a lean production system as it focuses on waste reduction.

### 3.2 Green Production

#### 3.2.1 DEFINITION OF GREEN MANUFACTURING

Green Manufacturing commonly defined as “elimination of waste by re-defining existing production process or system” [16]. The Center for Green Manufacturing at Alabama University defines green manufacturing in a detailed level as: “To prevent pollution and save energy through the discovery and development of new knowledge that reduces and/or eliminates the use or generation of hazardous substances in the design, manufacture, and application of chemical products or processes” [31].

Balan (2008) states that all problems solving approaches and innovative techniques
towards effective environmental solutions that result in cost savings from reduced work handling, effluent control, and process automation or other environmental and operational benefits can be named as applications of green manufacturing [16].

It can also be stated that green manufacturing concept does not only address the social and environmental impact of pollution-centric process but also process redundancy, ergonomics and cost implications due to inefficient methods of producing goods [16]. And according to Balan (2008), faster and cheaper are no longer the only two success measures of manufacturing a product or evaluating an existing process line but also other success factors such as materials used in manufacturing, generation of waste, effluents and their treatment method, life of the product and finally, treatment of the product after its useful life are important elements that added by green manufacturing approach as success factors [16].

Pal (2002) describes the issues that green manufacturing is mostly addressing in process level, and accordingly the objectives of green manufacturing can be stated as the following [32]:

- Provide a cleaner source of energy through new technology or approaches.
- Decrease energy consumption in processes by implementing new technology or approaches.
- Convert pollutants and wastes into byproducts and promote their use and recycling along with that of the product in order to reclaim the energy expended in the process and conserve resources.
- Maximize yield and minimize waste effluents via process improvements, such as by tailoring feedstock selection, selecting proper fuel mix, automation, and establishing control strategies via sensors with real-time feedback loops that control process parameters.

### 3.2.2 GREEN (ENVIRONMENTAL) WASTES DEFINITION

Environmental (Green) waste can be defined as an unnecessary use of resources or a substance released to the air, water, or land that could harm human health or the environment. When organizations use resources to provide products or services to their customers, and/or disposal or usage of products are made by customers, it leads to creation of environmental wastes [41].

According to EPA (U.S. Environmental Protection Agency), environment wastes do not
add value to customer and they represent costs to environment and society in general. And production flow, time, quality and especially cost values of an organization can directly be affected by environmental wastes. Furthermore, the costs associated with pollution and wasted energy, water, and raw materials can be substantial in many cases. It can also be stated that environmental waste can often be observed as an indication of inefficient production, and they create opportunities cost and time savings [35].

Environmental wastes can be found in almost any process and states that processes requiring environmental permits such as painting, metal finishing, and hazardous waste management processes, which are often a good place to identify for environmental wastes [35]. Additionally, the chemicals and hazardous materials that are used in production processes often creates dangers to labors’ health and safety together with resulting in waste which demands costly support activities [35].

Environmental wastes typically include [35]:

- Energy, water, or raw materials consumed in excess of what is needed to meet customer needs.
- Pollutants and material wastes released into the environment, such as air emissions, wastewater discharges, hazardous wastes, and solid wastes (trash or discarded scrap).
- Hazardous substances that adversely affect human health or the environment during their use in production or their presence in products.

Additionally, typical environmental impacts occur in the following processes in a facility [41]:

- Metal Fabrication (Milling, Welding, Stamping, and Machining)
- Parts Washing
- Surface Cleaning
- Plastic Forming (Extrusion and Molding)
- Metal Finishing
- Surface Coating
- Chemical Formulation
- Hazardous Materials Handling
- Waste Management
- Wastewater Treatment +
3.2.3 KEY ELEMENTS OF GREEN MANUFACTURING

**Principles of Green Engineering**
U.S. Environmental Protection Agency defines Green Engineering as “the design, commercialization and use of processes and products that are feasible and economical” while minimizing [33]:

- Generation of pollution at the source
- Risk to human health and the environment

According to Anastas & Zimmerman (2003), the progress of modern day technology leads to the new designs of sustainable waste treatment processes. The Principles of Green Engineering will help coordinate the development of green designing process that is sophisticatedly combine from the small decompose process of molecules, materials, product to the overall complex systems [17].

The Green Engineering Principles can be stated as not just simple rules; instead they are more like a set of methods that can be considerably adopted to succeed in the implementation of sustainable design process. It is important to optimize the whole line of unsustainable production process that is currently on progress due to the problem that it has caused to the logistics, economic and institutional system. Though, it still can be a limited measure, just in short hand. To change the old process into the new green one, reconstructing the whole logistics system is required. And to the most strengthen effect; it is suggested that green engineering principles should be implemented from the root to the top level of the whole process [17]. The principles can be stated as the following [17]:

**Be as inherently nonhazardous as possible**
Mostly, it is not an economical and environmentally sustainable approach to minimize negative effects of inherently hazardous substance. Limiting effects of inherently hazardous substances can only be accomplished through significant amount of capital, material, energy resources and time. Therefore, in order to decrease capital, time, energy and material consumed, organizations should have inherently nonhazardous material and energy inputs and outputs as possible. Inherently hazardous material and energy usage can lead to:

- Removal of the hazardous inputs with purification and cleanup steps.
- Constant monitoring and containment of hazards which may also require eventual removal to a permanent storage and disposal facility. The process requires strict safety precautions.
- Resource expenditure for monitoring and control (recycle or reuse) throughout the hazard’s lifetime when hazards are not removed but instead incorporated into the final product. Maintaining hazards in a closed-loop cycle can naturally increase risk of hazardous material releases through accidents, spills, and leaks.

Prevent waste rather than treat or clean up later

Waste generation and handling consumes money, time and effort where hazardous waste creates the need for additional investments for monitoring and control. Although, it may seem obvious that generation of waste should be prevented and avoided whenever possible, organizations may fail to design their process for preventing waste generation. It can be exemplified by the design fossil fuel based energy generation systems, which inherently produce waste at each life cycle stage. Fossil Fuel based energy mostly produces waste during use but waste is also generated during mining and processing. As a result, greenhouse gases and particulate matter released by burning fossil fuels contributes to global climate change and its subsequent impacts. Therefore, other energy generation systems that are designed to prevent the production of waste should be considered to minimize waste associated with treating and cleaning up efforts.

Minimize energy consumption and material usage in separation and purification

Large amount of time and resources are used in the particle separation processes. Moreover, in some cases, dangerous toxics are released to the environment from these processes. To cope with associated toxic related environmental impacts, easy to separate products and effective green recycling processes are suggested as key solutions. First, the designers can start from developing the product designs; all products particles should be identified and developed according to the green plan. Then, relevant to the design, waste management strategies should be coherently designed so that the most convenient product separation and recycling method can be issued. Effective green recycling processes come in various ways. It can start from avoid using all permanent- effected fasteners in production processes that can later on lead to the unable-to-recycle waste. Also, some chemical solutions and are another way to be used to reduce some mass of the waste amount and reduce the waste eliminating time.
Design to maximize mass, energy, space and time efficiency
A Good production system requires a brilliant management of time, space, energy and materials. This management should maximize efficiency of the production strategy that will reduce the unnecessary waste of time, material and storage space. Also, on the operating level, a scrutinized monitoring session is recommended, for the better optimizing plan will be issued and applied.

Same amount of supply to the demand
It is better to produce supplies exactly the same amount to the consumer demand in the first hand. This will help reduce the over production and will lead to the successful shrink of time and resources amount. In other words, this system is called “just-in-time” which is famous in the green manufacturing.

View complexity as an investment when making design choices on recycle, reuse, or beneficial disposition
Even though the good renewal processes are formed, still recycling processes can be problematic or not effective. And this problem is caused by waste management complexity. The complexity can be ranged variously from the initial materials that are used in producing to the consumers’ behaviors. Microchip is a good example of the waste management complexity in the material level. It is a small device that cannot be recycling; still people need to use it, and so the mountain of microchip disposal is left as a consequence. Also, the life cycle of the green, brown paper bags is a good example of waste management complexity that is concerned with user’s behaviors. Though considered as environmental friendly, the so-called bags demand a lot of time and energy in recycling process. Although they can be easily decomposed, still, when it comes to the mass production, the amount of waste is considering a big problem.

Design for durability rather than immortality
Durability is always associated with what people call good quality. However, when concerning with the green production process, durability of the products and the behind materials should be considering as long lasting, according to the accurate life cycle, not extravagantly last extremely long. The reason behind this conclusion is because the end wastes of the products or materials that last too long will cause huge waste treatment problems such as indestructible solid waste disposal and bioaccumulations. The proper long lasting products, moreover, are suggested to have an effective repair and maintenance solution in order to maintain a healthy life cycle that reduce the chance of extra maintenance that cost excess wastes and time later on.
Design for necessary capacity, minimize excess

Production process design can be overdone or excessively invested. First, the right idea in designing should be developed. If the idea is too extreme or unrealistic then the design is tend to become a trouble later. The drinking water system is a good example of an excessive design. The purifying process starts with dissolving chlorine to the raw water and then processed to other processes. However, there is a redundancy in purifying in each and every process, therefore, at the end process, the water is extremely clean. It may sound good that the water is extremely clean but instead, the cleanliness level is long passed the optimal point, and then the process is excessively using time and resource. To solve this problem, the control system is implemented in the purifying line, and the proper amount chlorine level is detected. The excess procedure and cleaning resources is cut off as a result.

Minimize diversity in multicomponent products

To analyze the design process from the molecular scale is essential, for the recycling process will be easier and less consuming, especially, great amount of time and resources. It is suggested that to have a single component recycling session is better than various wasteful recycling systems, which demand more amount of time, space and resources.

Car industry can be viewed as a good example. To manufacture cars, different materials are required. Polymer is a major substance that is used in car manufacturing, and it can be developed in a green way to serve the production process. Polymer can be specifically ordered; color and shape of the polymer pieces can be identified and produced in the first place. As a result, the polymer board painting and cutting processes are cut out. The manufacturers can save a lot of amount of time and resources by these processes.

Integration and interconnectivity with available energy and material flows

Reserving the outline of existing production operation is recommended when redesigning. It is easier to use the same locality, material flows and production facilities. According to the new design, in order to adopt the existing systems and materials, they should be identified and considered carefully. A lot of time and resources are saved as the reward of this scrutinized action because the issue of re-ordering materials is avoided. To the great extent, this principle also includes the reuse of the existing energy flow, which is called regenerate systems such as hybrid and cogeneration energy systems. The general idea for this principle is that a supposed waste of energy is collected and delivered back to energize systems. For
hybrid cars, the heat from break system is collected and supplied back to the motor; also the similar action is used in the cogeneration energy system.

**Design for commercial “afterlife”**
Technological trashes are disposed according to the customer’s satisfaction, which mostly depends on the current trend not the life cycle or major failures of the products. Electronic goods such as mobile phones, computers, digital cameras, televisions and etc. are fine examples of such trashes. Separating reusable part of materials from the non-expired wasted is a solution for this dynamic disposing fashion. The particles of the thrown away products are chosen back to reproduce in the new product bodies, the same way as the organ transplantation surgeries. To include the product’s afterlife plan in the designing stage is recommended also. Convenient separating products, which are easy to decompose and recompose, that are suit with the recycling and manufacturing processes should be developed. In doing this, the excessive amount of time and resources are diminishing as a result.

**Use renewable rather than depleting**
Instead of reducing Waste after productions, renewable resources should be promoted as a better alternative. Production processes are going to be sustainable or not depend on material and energy resources management. The common example of renewable resource is biological material such as feedstock and water. But also, the reusable waste from the non-biological material is counted such as the recycle bio based plastic. However, people need to keep in mind that there will always be environmental consequences after any type of production, so more attempt to create thorough sustainable recycling processes and systems is needed to solve this problem.

**EcoAudit**
An EcoAudit can be defined as systematic assessment of organizations’ operations. In a detailed level it can be explained as an integrated resource use analysis that identifies opportunities to reduce environmental impact, increase performance and save money [17].

According to Friend (2009), EcoAudit contains a wide range resource use examinations considering “climate control”, “lighting”, “motors and appliances”, “load management” and “Water” in facilities and equipment usage area. Most importantly, additional examinations of resource usage can be listed as “equipment use”, “waste and recycling” and “materials” when processes are taken into consideration. Friend (2009) claims equipment usage has to be operated correctly, and
an organization’s purchases define its wastes and he emphasizes the importance of Environmental Preferable Purchasing together with controlling of waste and recycling activities in an organization. And these essential process elements can be handled and greened by EcoAudit systematic assessments [17].

**Carbon Footprinting**
Carbon footprinting can be named as a strong tool that can give a starting point to organizations when greenhouse gases in manufacturing processes, the amount of fossil fuels used in facilities, energy-efficiency and carbon emission usage in transportation issues are being handled. “A carbon footprint is the measure of greenhouse gases (GHGs) produced by a given activity, product, business, or supply chain, expressed in tons of carbon dioxide equivalents (the standard unit for describing carbon dioxide emissions)”. The impact that businesses, products, people, and events have on climate change can be measured by carbon footprints. Identifying and knowing your carbon footprint leads to [17]:

- Identification and prioritization of efficiency improvements regarding carbon usage
- Evaluation of GHG reduction scenarios and strategies
- Availability of organization’s carbon position
- Developing strategies for green process design, environmental impact management and having better carbon footprint position through reduction.

Reduction of carbon emissions strategically can provide easy implementation of changes and increase the likelihood of changes to work. And reducing carbon emissions profitably can help organizations’ bottom line, in current and future states. Strategic and profitable handling of carbon emission is vital for organizations since “governments are now developing carbon markets, carbon taxes, and other economic incentives for businesses to reduce their emissions”. Additionally, shipping and transportation operations are going to have added costs if they are not managed effectively [17].

**Cleaner Production and Eco-Efficiency**
The World Business Council for Sustainable Development (WBCSD) and the United Nations Environment Program (UNEP) has developed Cleaner Production and Eco-Efficiency concepts aiming toward the common goal of sustainable development [19].
WBCSD defines Cleaner Production concept as “the continuous application of an integrated preventative environmental strategy applied to processes, products, and services to increase eco-efficiency and reduce risks for humans and the environment”. Its application areas include [20]:

- **Production processes**: reduction of the quantity and toxicity of all emissions and wastes, elimination of toxic raw materials and conservation of raw materials and energy.
- **Products**: From raw material extraction and its disposal, reduction of negative effects of a product during its life cycle.
- **Services**: Integration of environmental concerns into designing and delivering services.

Previous applications of Cleaner Production in the production processes shows that many improvements can be made at no or very little cost. Additionally, Cleaner Production requires adaptation of responsible environment managements and usage of supporting technology alternatives together with constant attitude change towards a more environmental aware approach. Therefore, when all the elements of Cleaner Production are taken into consideration, it can be stated that Cleaner Production can be an effective way to manufacture products, operate process and provide services. Furthermore, according to WBCSD and UNEP, the liabilities associated with adverse environmental and health effects, and the cost of wastes and emissions can be reduced and new markets can be created with Cleaner Production [19].

According to WBCSD Eco-Efficiency can be defined as being “reached by the delivery of competitively priced goods and services that satisfy human needs and bring quality of life, while progressively reducing ecological impacts and resource intensity throughout the life cycle, to a level at least in line with the earth’s estimated carrying capacity”. Related success factors for Eco-Efficiency can be listed as following [20]:

- Reduction of the material intensity of goods and services
- Reduction of energy intensity of goods and services
- Reduction of toxic dispersion
- Improved material recyclability
- Maximization of sustainable use of renewable resources
- Growth of the service intensity of goods and services
- Greater material durability
WBCSD and UNEP state that Eco-Efficiency is a key driver for organizations since it creates an understanding of producing better goods and services while using fewer resources and generating less impact, and Eco-Efficiency improves both their bottom line and environmental performance [19].

**Life Cycle Assessment (LCA)**

Life cycle assessment (LCA) concept considers the entire life cycle of a product and is defined as a “cradle-to-grave” approach for assessing industrial systems. “Cradle-to-grave” begins with the gathering of raw materials from the earth to create the product and ends at the point when all materials are returned to the earth. LCA is a tool that evaluates all stages of the product life cycle interdependently, meaning that one operation leads to the next. LCA provides the estimation of cumulative environmental impacts from all stages of the product life cycle, frequently including impacts such as raw material extraction, material transportation, ultimate product disposal, etc., which are not considered in more traditional analyses. For products and processes, LCA delivers a broad view of environmental aspects and a more precise visualization of the true environmental trade-offs in product and process selection [23].

The major activities that take place during the product's life-span from its manufacture, use, and maintenance, to its final disposal, including the raw material acquisition to manufacture the product, can be associated with the term “life cycle” [23]. The possible life cycle stages that can be considered in an LCA and the usual inputs and outputs measured can be illustrated as following (Figure 7):
In a detailed level, the environmental aspects and potential impacts related with a product, process or service can be assessed by LCA technique by applying following elements [23]:

- Accumulation of an inventory of relevant material and energy inputs and environmental releases
- Evaluation of the possible environmental impacts associated with identified inputs and releases
- Interpretation of the results that can guide decision-makers to make a more knowledgeable decision

According to EPA and Scientific Applications International Corporation (SAIC), the LCA process includes four components with a systematic and phased approach. These four components (systematic phases) can be named as goal definition and scoping, inventory analysis, impact assessment, and interpretation. These phases can be described and illustrated (Figure 8) as the following [23]:

- Goal Definition and Scoping: Definition and description of the product, process or activity. Establishing the context of the assessment, and identification of the boundaries and environmental effects that are going to be reviewed.
- Inventory Analysis: Identification and quantification of energy, water and material usage and environmental releases such as air emissions, solid water disposal, and waste water discharges.
- Impact Assessment: Assessment of the potential human and ecological effects of the elements listed in the inventory analysis.
- Interpretation: Evaluation of the obtained results of inventory analysis and impact assessment phases in order to reduce impact of products, processes or services.

LCA can be stated as a unique tool since it includes all processes and environmental releases starting from the extraction of raw materials and the energy usage to create the product through the use and final disposition of the product. When evaluating alternatives to reduce the environmental impact, LCA becomes an essential tool that helps decision-makers to compare all major impacts caused by products, processes, or services [23].

It can be stated that products and processes that create less impact to the environment
can be selected by decision-makers by the help of information provided in an LCA. This information can also be used with other factors such as cost and performance data to make a decision on selecting the environmental preferable, cost efficient product or process. Additionally, according to SAIC, the data obtained from life cycle Assessments provides the identification of “the transfer of environmental impacts from one media to another (e.g., eliminating air emissions by creating a wastewater effluent instead) and/or from one life cycle stage to another (e.g., from use and reuse of the product to the raw material acquisition phase)”. I can be stated that without performing an LCA, the described transfer might not be recognized and included in related product selection analysis [23].

Furthermore, EPA and SAIC list the benefits that organizations can obtain by performing an LCA as the following [23]:

- A systematic evaluation of the environmental consequences associated with a given product
- Analysis of the environmental trade-offs associated with one or more specific products/processes to help gain stakeholder (state, community, etc.) acceptance for a planned action.
- Quantification of environmental releases to air, water, and land in relation to each life cycle stage and/or major contributing process.
- Assistance in identifying significant shifts in environmental impacts between life cycle stages and environmental media.
- Assessment of the human and ecological effects of material consumption and environmental releases to the local community, region, and world.
- Comparison of the health and ecological impacts between two or more rival products/processes or identification of the impacts of a specific product or process.
- Identification of impacts to one or more specific environmental areas of concern.

**Design for the Environment (DfE)**

Design for the Environment can defined as an approach that organizations use to make environmental impact decisions along with traditional business considerations of cost and performance [22]. Design for Environment (DfE) has developed by Environmental Protection Agency (EPA) as a voluntary partnership program that aims to work directly with organizations to adapt environmental considerations in their business decisions [21]. It can be observed that “Design for” the environment
qualities or traits are increasingly involved in manufacturers’ product and process developments [22].

DfE program support organizations to design or redesign products, processes and management systems in order make them cleaner, more cost-effective and safer for workers, public and environment. While working with industries and organizations, DfE program aims to compare the human health and environmental risks, performance, and costs associated with existing and alternative technologies or processes. DfE solutions may involve redesign of manufacturing and service-sector processes, formulations and management practices [21].

Environmental Protection Agency defines the elements of Design for the Environment program to achieve a successful green business design as following [21]:

- Evaluation of the human health and environmental impacts of its processes and products.
- Identification of what information is needed to make human health and environmental decisions.
- Conducting an assessment of alternatives.
- Considering cross-media impacts and the benefits of substituting chemicals.
- Reduction of the use and release of toxic chemicals through the innovation of cleaner technologies that use safer chemicals.
- Implementation of pollution prevention, energy efficiency, and other resource conservation measures.
- Making products that can be reused, refurbished, remanufactured, or recycled.
- Monitoring the environmental impacts and costs associated with each product or process.
- Recognizing that although change can be rapid, in many cases a cycle of evaluation and continuous improvement is needed.

According to EPA, by taking listed activities into consideration, the general benefits of applying DfE program can stated as: cost savings, reduced business and environmental risks, and expanded business and market opportunities [21].

**Environmental Failure Mode and Effect Analysis (E-FMEA)**

Environmental Failure Mode and Effects Analysis (E-FMEA) can be described as a new Design for Environment (DfE) methodology that developed to be used in the product design process and was initiated by the Swedish consulting agency HRM/Ritline. It is can be named as a modification of “Failure Mode and Effect
Analysis” (FMEA) quality assurance tool. It can be stated that while traditional FMEA emphasizes potential failure risks, the E-FMEA-method environmental aspects at normal operations [26].

The aim of the E-FMEA method can be defined as identifying and evaluating potential impacts in all lifecycle phases of the examined product with a methodical approach. The aim is also to make the identification and evaluation actions in early phases of design process to have corrective and preventative actions to minimize the environmental impacts [26].

It can be stated that the definition and aim of E-FMEA can be regarded as similar to Life Cycle Assessment (LCA). According to Lindahl, there are two aspects that differs E-FMEA from a conventional LCA. Firstly, E-FMEA does not go into details, and secondly, by using the environmental requirements put on the product, it only focuses on the most significant environmental aspects as a basis for analysis [26].

Some examples of inputs needed to establish an E-FMEA can be illustrated by Figure 9. The inputs of E-FMEA are sorted into correct lifecycle phase of the product, reformed and analyzed in the E-FMEA. The outputs may contain a variety of different actions and E-FMEA can result in redesign and changes of material actions, the lower textboxes in the Figure 9 illustrates the action alternatives that associated with the input based E-FMEA results [26]:

![Figure 9: The overall input needed and the output in terms of recommended actions as a result of the E-FMEA](image-url)
The E-FMEA case studies performed by Lindahl indicates that the E-FMEA-method does not require high amount of environmental quantified data and its observed working procedure makes the E-FMEA-method is efficient and useful in the early phases of the design process. Furthermore, using E-FMEA in the early design phases leads to efficient environmental improvements when finding out where in the product’s lifecycle the major environmental impacts occurs. Efficient environmental improvements can be achieved since it is still easy to change, such as materials, at the early stage that E-FMEA applied [26].

According to Lindahl, the E-FMEA results can be used to support further detailed LCA in the design process. Instead of focusing the whole product’s lifecycle, organizations can focus on lifecycle phases pointed out by the E-FMEA results as most environmentally harmful [26]. Therefore, it can be stated that the information obtained from E-FMEA enlightens the most environmentally harmful product lifecycle phases and it leads to an earlier recognition of major environmental impacts that organizations can reduce and gain associated benefits.

**Environmental Management System (EMS)**

An Environmental Management System (EMS) can be basically defined as a systematic approach to ensure well management of environmental activities in any organization. The more specific definition of EMS is stated by International Organization of Standardization (ISO) as “that part of the overall management system which includes organizational structure, planning activities, responsibilities, practices, procedures, processes and resources for developing, implementing, achieving, reviewing and maintaining the environmental policy” [27].

EPA states that improving efficiency and reducing environmental risks throughout their environmental processes have enabled many organizations to have economical improvements. An EMS helps organizations to identify environmental issues which lead to economical improvements when handled, proactively and comply with regulations. Organizations can use process mapping to identify environmental impacts that occur during operations; cost accounting tools can be used to monitor cost associated environmental management; and to identify alternatives and solutions for environmental management decision-making tools can be used as a part of EMS [28].

Characteristics of a Basic EMS can be described as the following [28]:

The EMS is focused on and driven by environmental impacts of an organization. It
handles a core set of planning activities in order to provide:

- Identification of operations and process that impact the environment
- Evaluation of impacts that are significant
- Objectives and targets to reduce significant impacts
- Identification and implementation of activities to achieve identified targets

Integration of environmental management and business function is promoted by the EMS by integrating environmental management with other operations and overall management practices. Examples can include:

- Top management defined environmental policies
- The effect of operating conditions and controls on targeted environmental impact consideration
- Periodic management review of environmental performance and other results

Continual improvement is provided by the EMS through the following:

- EMS procedures to monitor compliance and correct or eliminate problems
- Monitoring and evaluation of activities related to targeted impacts
- Identification of needed improvements and periodic assess progress evaluation
- Specific authorities, timelines and designated responsibilities for executing the environmental performance and associated cost improvement plan

Moreover, Hillary (2004) states that there are two formal, mainly used EMSs in the industry that can be named as EMAS (The Eco-Management and Audit Scheme) and the International Environmental Management System standard ISO 14001 seek to provide all businesses with the means to develop systematic approaches to improve environmental performance [29].

According to U.S. Department of Energy and U.S. Environmental Protection Agency (EPA), an EMS can enable organizations to make a predictable structure for assessing, managing and continuous improvement of the efficiency and effectiveness of their environmental activities. Instead of a crises management, an EMS approach forms a periodic review of environmental activities with an emphasis on continuous improvement. Furthermore, an organization can focus on management implementation and take a more inclusive and proactive view of environmental protection by the systematic nature of the EMS. More inclusive and proactive environmental protection and management implementation focus will lead to an
improvement of environmental performance which enables organization to have improved relations with regulators, stakeholders and the public [27].

Additionally, throughout a facility’s waste management process, combining pollution prevention efforts with an EMS can provide organizations to guarantee that pollution prevention considerations are identified and considered. A well-designed EMS can enhance savings, as well as remove environmental management costs from overhead through integration and improved efficiency [27].

Potential benefits of implementing an EMS can be summarized as the following [30]:

- Improved environmental performance
- Reduced risk of noncompliance with environmental laws and regulations
- Reduced operating costs
- Bolstered corporate image
- Improved internal communications
- Enhanced environmental decision making
- Reduced constraints on process improvement activities
- Identification and elimination of hidden environmental wastes and costs

**Environmental Impact Analysis (EIA)**

“Environmental Impact Analysis (EIA) Global Guidelines Project” was initiated by International Association of Impact Assessment (IAIA) in order to satisfy the need for principles of, and guidance on, impact assessment in response to increasing interest in international standards. The principles of EIA Best Practice are defined in order to provide guidance in applying EIA processes. It aims to “promote the effective practice of environmental impact assessment consistent with the institutional and process arrangements that are in fore in different countries” [25].

Definition of Environmental Impact Analysis (EIA) can be given as “The process of identifying, predicting, evaluating and mitigating the biophysical, social, and other relevant effects of development proposals prior to major decisions being taken and commitments made” [25].

According to IAIA, benefits of applying EIA Best Practice can be obtained through achieving objectives of Environmental Impact Assessment. Its benefits can include optimized productivity and capacity of natural systems and ecological processes, minimization of the adverse significant biophysical, social and other relevant effects of environmental impacts together with promotion and selection of sustainable
development projects that uses optimized resources and environmental management opportunities. International Association of Impact Assessment (IAIA) defines the objectives of EIA as the following [25]:

- Ensuring that environmental considerations are explicitly addressed and incorporated into the development decision making process.
- Anticipating and avoiding, minimizing or offsetting the adverse significant biophysical, social and other relevant effects of development proposals.
- Protecting the productivity and capacity of natural systems and the ecological processes which maintain their functions.
- Promoting development that is sustainable and optimizes resource use and management opportunities.

**ISO 14000 Standards**

According to International Organization of Standardization, organizations are becoming increasingly aware of the need for environmental management, socially responsible behavior, and sustainable growth and development. And proactive management of environmental issues is being directly related to enterprise risk management, corporate governance, and sound operational and financial practices and performance. Therefore, International Standards (ISO 14000 series, International Organization of Standards for environmental management) are becoming more and more essential to organizations to achieve common and comparable environmental management practices to support the sustainability of their organizations, products and services [24].

Origins of ISO 14000 was established by ISO technical committee ISO/TC 207. Environmental management, which is responsible for developing and maintaining ISO 14000 family of standards. As a result of ISO/TC 207 studies, the ISO 14000 family of standards for environmental management was released in order to assist organization sustainable development implementation actions as a practical toolbox. ISO defines the scope of ISO/TC 207’s, which addresses several areas of work as following [24]:

- Environmental management systems
- Environmental auditing and related environmental investigations
- Environmental performance evaluation
- Environmental labeling
- Life cycle assessment
- Environmental communication
- Environmental aspects of product design and development
- Environmental aspects in product standards
- Terms and definitions
- Greenhouse gas management and related activities
- Measuring the carbon footprint of products.

International Organization of Standards (ISO) published various standards that form ISO 14000 Series. Information regarding the scope and aim of the published standards of ISO 14000 family can be stated as the following [24]:

ISO 14001: Can be named as the world’s most recognized framework for environmental management systems (EMS). Its aim is to help organizations to manage better the environmental impact of their activities and to exhibit comprehensive environmental management.

ISO 14004: Complements ISO 14001 by proving additional guidance and useful explanations.

ISO 14020: Addresses a range of different approaches to environmental labels and declarations, including eco-labeling, self-declared environmental claims, and quantified environmental information about products and services.

ISO 14031: Helps organizations to evaluate their environmental performance by delivering guidance on how to do performance evaluations.

ISO 14040: Provides guidelines on principles and conduct of Life Cycle Assessment (LCA) studies.

ISO 14063: Provides guidelines and examples on environmental communication which helps companies to make the important link to external stakeholders.

ISO 14064 parts 1, 2 and 3: Provides a set of clear and verifiable requirements to support organizations and proponents of Greenhouse gas (GHG) emission reduction projects with international GHG accounting and verification standards.

ISO Guide 64: Provides guidance in stating environmental aspects in products standards. Primarily, it targets standard developers but also useful for designers and manufacturers.
ISO 14065: Provides additional information to ISO 14064 by establishing requirements to accredit or recognize organizational bodies that undertake GHG validation or verification by using ISO 14064 or similar standards.

ISO 19011: The auditing standard ISO 19011 is a useful tool for assessing whether an Environmental Management System (EMS) is properly implemented or maintained. It provides guidance on principles of auditing, managing audit programs, the conduction of audits and on the competence of auditors.

It can be stated that ISO 14000 standards plays a crucial role in assisting organizations to cope today’s environmental needs, International Organizations of Standards (ISO) has also been working on several standards to address future priorities of environmental management. These standards will provide the following to organizations [9]:

ISO 14005: Guidelines for the phased implementation of an EMS in small and medium-sized enterprises which also will include the use of environmental performance evaluation.

ISO 14006: Guidelines for eco-design. Eco-design can be associated with design related green engineering principles [2].

ISO 14033: Guidelines and examples for compiling and communicating quantitative environmental information.


ISO 14051: Guidelines for general principles and framework of material flow cost accounting (MFCA). MFCA can be described as “a management tool to promote effective resource utilization, mainly in manufacturing and distribution processes, in order to reduce the relative consumption of resources and material costs”. MFCA measures the flow and stock of materials and energy within an organization by taking physical unit such as weight, capacity and volume into account. And it evaluates the flow and stock of materials and energy within organization by using manufacturing costs. It can be stated that MFCA is one of the major tools of environmental management accounting (EMA) and it focuses on internal material and energy uses within an organization.
ISO 14066: Competency requirements for GHG gas validation and verifiers.

ISO 14067: Mainly, on carbon footprint of products. The standard will provide Requirements for the quantification and communication of greenhouse gases (GHGs) associated with products.

ISO 14069: Guidance to calculate the carbon footprint of products, services and supply chain of organizations.

Furthermore, International Organization of Standards (ISO) states that listed ISO 14000 standards can be used independently from each other in order to achieve environmental goals, although the ISO 14000 standards are designed to be mutually supportive. ISO 14000 family of standards delivers management tools for organizations to assess their environmental performance and manage their environmental aspects. International Organization of Standards (ISO) claims collective usage of these management tools can create significant tangible economic benefits in addition to distinct environmental ones. These benefits can be stated as the following [24]:

- Reduced raw material/resource use
- Reduced energy consumption
- Improved process efficiency
- Reduced waste generation and disposal costs
- Utilization of recoverable resources.

3.3 “Lean and Green Production”

3.3.1 WASTE PERSPECTIVE

According to EPA, lean manufacturing significantly improves the environmental performance of organizations through its methodical focus on the elimination of non-value-added activities. Reduction of defects, waiting, overproduction, movement, inventory, complexity and unused creativity (common types of manufacturing wastes) leads to a set of environmental benefits, including less energy usage; generation of solid and hazardous waste reduction; an lower researchers emissions of hazardous air pollutants [34].

Lean’s inherent waste elimination focus enables it to naturally reduce some of the
Environmental impacts that can occur in organizations’ operations. As a result, a significant amount of environmental benefits arise since the manufacturing wastes that are aimed to be limited by Lean are directly associated with environmental impacts [30].

EPA also states that substantial environmental gains can be obtained by lean initiatives where it enables organizations to continually reduce the materials, energy, water, space, and equipment needed per unit of production while improving resource productivity and production efficiency [34].

Environmental impacts of an organization’s operations can be decreased through lean implementation by reduction of manufacturing wastes (defects, waiting, overproduction, movement, inventory, complexity and unused creativity). An example can be reduction of defects. The defective products and their related environmental impacts associated with materials and processing used can be limited by defect elimination. Meanwhile, the waste and emissions produced from reworking and disposing of the defective products is reduced also. Likewise, the facility space requirements, together with water, energy, and material use associated with heating, cooling, lighting, and maintain the facility can be reduced when associated inventory levels are reduced. The following Table 1 illustrates environmental impacts associated with seven types of common manufacturing wastes that lean aims to eliminate [34]:

<table>
<thead>
<tr>
<th>Waste Type</th>
<th>Environmental Impacts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Defects</td>
<td>• Raw materials consumed in making defective products</td>
</tr>
<tr>
<td></td>
<td>• Defective components require recycling or disposal</td>
</tr>
<tr>
<td></td>
<td>• More space required for rework and repair, increasing energy use for heating, cooling, and lighting</td>
</tr>
<tr>
<td>Waiting</td>
<td>• Potential material spoilage or component damage causing waste</td>
</tr>
<tr>
<td></td>
<td>• Wasted energy from heating, cooling, and lighting during production downtime</td>
</tr>
<tr>
<td>Overproduction</td>
<td>• More raw materials consumed in making the unneeded products</td>
</tr>
<tr>
<td></td>
<td>• Extra products may spoil or become obsolete requiring disposal</td>
</tr>
<tr>
<td>Movement</td>
<td>• More energy use for transport</td>
</tr>
<tr>
<td></td>
<td>• Emissions from transport</td>
</tr>
<tr>
<td></td>
<td>• More space required for work-in-process (WIP) movement, increasing lighting, heating, and cooling demand and energy</td>
</tr>
</tbody>
</table>
consumption
- More packaging required to protect components during movement

| Inventory               | More packaging to store WIP  
|                        | Waste from deterioration or damage to stored WIP  
|                        | More materials needed to replace damaged WIP  
|                        | More energy used to heat, cool, and light inventory space  

| Complexity             | More parts and raw materials consumed per unit of production  
|                        | Unnecessary processing increases waste, energy use, and emissions  

| Unused creativity       | Fewer researchers suggestions of pollution prevention and waste minimization opportunities  

TABLE 1 ENVIRONMENTAL IMPACT OF LEAN WASTES [34]

3.3.2 LEAN AND ENERGY USE RELATION

Organizations can reduce the energy needed to power equipment, lightning, heating, and cooling by eliminating lean manufacturing wastes, such as transportation and unnecessary processing. It can also be stated that Energy is an essential and often costly input to most production processes and value streams. EPA states that by focusing on unnecessary energy use as a lean “deadly waste” and establishing waste reduction efforts, organizations can significantly reduce costs and enhance competitiveness, at the same time achieve environmental goals. The reasons for integrating Lean and energy use efforts can be explained as the following [37]:

- **Cost Savings:** Reducing energy costs has a significant impact on business performance, though costs may be hidden in overhead or facility accounts.
- **Climate Change and Environmental Risk:** Proactively addressing the environmental and climate impacts of energy use is increasingly important to industry and society. Failure to do so is a potential business risk.
- **Competitive Advantage:** Lowering recurring operating costs, improving staff morale, and responding to customer expectations for environmental performance and energy efficiency increases your competitive advantage.

Additionally, according to EPA benefits of coordinating Lean and Energy Management can be stated as the following [37]:

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55
- Reduction of operating and maintenance costs
- Reduction of vulnerability to energy and fuel price increases
- Meeting customer expectations
- Enhancing productivity
- Improving safety
- Improving employee morale and commitment
- Improving environmental quality
- Reducing greenhouse gas emissions
- Remaining below air permitting emission thresholds
- Increasing overall profit

Moreover, getting senior managers' attention to focus on energy use can be problematic in many organizations. EPA states that energy efficiency efforts often have difficulty to gain organizational attention and energy use is often regarded as a necessary support cost of doing business compared to other core operational needs. However, energy reduction efforts can be connected to processes improvement efforts that are viewed by senior management as being vital to organization’s success by connecting energy management activities to Lean activities. Accordingly, energy efficiency efforts become a part of Lean activities while providing substantial benefits to the organization [37].

Organizations may have observed or can observe energy use reductions from implementing Lean since EPA claims energy use is related to, or embedded in the lean wastes. Following table 2 lists wastes targeted by Lean methods and their associated energy use implications [37]:

<table>
<thead>
<tr>
<th>Waste Type</th>
<th>Energy Use</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Overproduction</strong></td>
<td>- More energy consumed in operating equipment to make unnecessary products</td>
</tr>
<tr>
<td><strong>Inventory</strong></td>
<td>- More energy used to heat, cool, and light inventory storage and warehousing space</td>
</tr>
</tbody>
</table>
| **Transportation and Motion** | - More energy used for transport  
- More space required for work in process (WIP) movement, increasing lighting, heating, and cooling demand and energy consumption |
| **Defects**                 | - Energy consumed in making defective products  
- More space required for rework and repair, increasing energy use |
for heating, cooling, and lighting

| Over processing | • More energy consumed in operating equipment related to unnecessary processing  
|                 | • Use of right-sized equipment often results in significant reductions in energy use per unit of production |

| Waiting         | • Wasted energy from heating, cooling, and lighting during production downtime |

**TABLE 2 LEAN WASTES AND ENERGY USE IMPLICATIONS [37]**

It can be stated that Lean methods and events can be used to understand how energy is used in facilities and identify opportunities to reduce energy use and costs. In the stated context, the lean and energy use identification relation can be established by Value Stream Mapping, Lean Six Sigma and Kaizen Events.

EPA claims that while handling a value stream mapping event, energy use of processes can be observed together with lean metrics such as cycle time, changeover time, and up time to obtain “current state” of the value stream. When lean and energy use data are both available in value streams it enables organizations to prioritize improvement ideas for the “future state” of the value stream and it will lead to an holistic thinking if Lean to maximize operational gains and energy savings. Furthermore, combining lean and energy use efforts will enable to incorporate energy use data directly into current and future value stream maps. Adding average energy use or energy intensify of each process to the process data in value stream maps together with regular collected lean metrics will make it easier to identify key energy saving opportunities which lead to improvement opportunities. Following Figure 10 exemplifies a process data box with energy use data in a value stream map:

![Milling](image)

**FIGURE 10 EXAMPLE PROCESS DATA BOX WITH ENERGY USE DATA**

Moreover, when a significant amount of process-level data and energy use are observed in a process, Lean Six Sigma analytical tools can be beneficial for
identifying energy waste since EPA claims that isolation of root causes of energy use fluctuations and identification of factors that result in energy waste can be handled by lean six sigma statistical analysis and process control methods [37].

Organizations can obtain further analysis and elimination of wasteful energy use through Kaizen Events after identifying the production processes that consume large amounts of energy. Kaizen events identify and implement process changes to reduce wastes such as defects, inventory and idle time with a cross-functional team of employees. According to EPA, kaizen events create possibilities to consider ways to eliminate energy waste, and asking energy related key questions during kaizen events and having an energy focus help ensure that energy reduction opportunities identified as a part of Lean implementation [37]. Table 3 exemplifies key energy use question can be asked during kaizen events [37]:

<table>
<thead>
<tr>
<th>Energy Use</th>
<th>Key Questions</th>
</tr>
</thead>
</table>
| Motors and Machines | • Are machines left running when not in operation? If so, why?  
                      • Are energy efficient motors, pumps, and equipment used?  
                      • Are motors, pumps, and equipment sized according to their loads?  
                      Do motor systems use variable speed drive controls? |
| Compressed Air     | • If compressed air is used, do you notice any leaks in the compressed air system?  
                      • Do compressed air systems use the minimum pressure needed to operate equipment? |
| Process Heating    | • Are oven and process heating temperatures maintained at higher levels than necessary? |

**TABLE 3 KEY KAIZEN EVENT ENERGY USE QUESTIONS WITH POSSIBLE PRODUCTION PROCESS ELEMENTS THAT LEAD ENERGY USAGE [37]**

Some of the lean tools and strategies that focus on process-level opportunities can be used to reduce energy use in addition to the lean tools that can provide identification of energy usage. In the stated context, lean and energy use reduction relation can be established by Total Productive Maintenance (TPM), Right-sized Equipment, Standardized Work, Visual Controls and Poka-Yoke (Mistake-proofing).

Firstly, it can be stated that increased equipment operating efficiency reduces energy waste and optimal tuning of machines to achieve desired work leads energy inputs to be the most efficient. Accordingly, efficient energy inputs together with reduced costs,
increased productivity, and fewer defects can be obtained by TPM’s emphasis on equipment efficiency [37]. The six main big loses that TPM focuses on to increase equipment efficiency can be stated as the following [37]:

- Breakdowns
- Setup and adjustment loss
- Idling and minor stoppages
- Reduced speed
- Defects and rework
- Start and yield loss

EPA claims that limiting the stated six big loses with TPM approach, organizations can reduce manufacturing defects and make significant energy use and cost savings [37]. Additionally, TPM autonomous maintenance and its activities such as daily inspections, lubrication, parts replacement, simple repairs, abnormality detection, and precision checks enable to integrate process-level energy reduction activities into ongoing equipment maintenance. Accordingly, EPA states that TPM effectiveness and energy use reduction can be directly increased by integrating energy reduction “best practices” and ongoing autonomous maintenance together [37]. Following Table 4 provides an example set of energy reduction activities based on “best practices” compiled by the U.S. DOE’s Energy Efficiency and Renewable Energy Department [38]:

<table>
<thead>
<tr>
<th>Target</th>
<th>Energy Reduction Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Combustion Systems</strong></td>
<td>• Operate furnaces and boilers at or close to design capacity</td>
</tr>
<tr>
<td></td>
<td>• Reduce excess air used for combustion</td>
</tr>
<tr>
<td></td>
<td>• Clean heat transfer surfaces</td>
</tr>
<tr>
<td></td>
<td>• Reduce radiation losses from openings</td>
</tr>
<tr>
<td></td>
<td>• Use proper furnace or boiler insulation to reduce wall heat losses</td>
</tr>
<tr>
<td></td>
<td>• Adequately insulate air or water-cooled surfaces exposed to the furnace environment and steam lines leaving the boiler</td>
</tr>
<tr>
<td></td>
<td>• Install air preheat or other heat recovery equipment</td>
</tr>
<tr>
<td><strong>Steam Generation Systems</strong></td>
<td>• Improve water treatment to minimize boiler blow down</td>
</tr>
<tr>
<td></td>
<td>• Repair steam leaks</td>
</tr>
<tr>
<td></td>
<td>• Minimize vented steam</td>
</tr>
<tr>
<td></td>
<td>• Implement effective steam trap maintenance program</td>
</tr>
<tr>
<td><strong>Process Heating Systems</strong></td>
<td>• Minimize air leakage into the furnace by sealing openings</td>
</tr>
<tr>
<td></td>
<td>• Maintain proper, slightly positive furnace pressure</td>
</tr>
</tbody>
</table>
Reduction of or eliminate material handling fixtures
Modify the furnace system or use a separate heating system to recover furnace exhaust gas heat
Recover part of the furnace exhaust heat for use in lower-temperature processes

Secondly, replacing over-sized equipment with right-sized equipment enables facilities to have energy use reductions. As it is stated in lean and chemicals relation, conventional manufacturing equipment is usually formed to handle the maximum anticipated demand, and oversized [36]. And right-sized equipment is often much more energy efficient than conventional, over-sized equipment since right-sized equipment is geared toward a specific end use and production capacity. Over-sized equipment often works significantly below capacity and substantially reduces energy efficiency per unit of production [37].

Thirdly, energy efficiency efforts can be encouraged by the usage Standardized Work, Visual Controls and Poka-Yoke (Mistake-Proofing) lean methods in organizations. It can be stated that Standardized work is used in order to establish the best and most reliable way of performing an operation and its aim can be stated as maximizing performance while minimizing waste in operations. Standardized work is used to sustain previous lean improvements and creates base for future improvement such as kaizen events [8]. Accordingly, EPA claims that facilities can maximize their energy gains by connecting energy reduction “best practices” [38] into standardized work [37]. Example uses of incorporating energy use with standardized work can be listed as the following [37]:

- Building energy reduction best practices into training materials, in-house regulations, and standard work for equipment operation and maintenance
- Including energy reduction tips in weekly team meetings and monthly facility newsletters
- Adding energy reduction best practices into “shine” checklists used when implementing 5S (or 5S+Safety)

Poka-Yoke which also known as Mistake-Proofing refers to technology and procedure designed to limit defects and equipment malfunctioning during manufacturing processes. And operational errors can be smoothly identified and prevented, and equipment use can be standardized by poka-yoke [1]. Accordingly, EPA states that
Poka-Yoke can be used to automatically power researchers down energy-consuming equipment use. Additionally, poka-yoke provides a simple, low cost approach to power researchers down equipment which is not in use by its related technology and procedures approaches. In relation to stated context, using poka-yoke enables organizations’ facilities to have less waste energy, time, and resources together with preventing rework [37].

Moreover, according to EPA, Lean Visual Control efforts enables also provide a standardization of energy and equipment usage and can provide energy reduction benefits when incorporated with energy reduction efforts. One good example can be provided as installing a sign over on/off switches or power outlets to remind operators to turn off or unplug equipment that is not in use [37].

3.3.3 LEAN AND CHEMICAL WASTE RELATION

Chemical waste as a subset of environmental waste refers to any unnecessary or excess use of a chemical, or a chemical substance that could harm human health or the environment when released to the air, water, or land. And many chemical wastes can be classified as hazardous, which can be regarded as the most dangerous to human health and the environment [36].

EPA states that elimination manufacturing by using lean methods enables unnecessary chemical use and chemical management improvements where businesses can reduce costs and risks, while meeting customer needs better. When a chemical waste improvement approach takes place in an organization, EPA claims Value Stream Mapping (VSM) and Kaizen Events can be critical tools for identifying chemical and hazardous wastes and implementing process improvements to eliminate chemical and hazardous wastes [36].

Value Stream Mapping can be a strong tool to observe chemical wastes that occur in processes and how chemicals effects time, quality, and cost values with some minor additions. According to EPA, there are two strategies to integrate chemicals into value stream mapping method [36]:

- Adding chemical metrics to value stream maps
- Examining key environmental inputs and outputs in value stream maps

Adding chemical waste information to value stream map together with original lean
metrics used enables to have a complete picture of the wastes in the value stream and the possible improvement opportunities. Therefore, the development of a future value stream map and an implementation plan to achieve the future state of value stream map can be informed by chemical waste data. Figure 11 exemplifies a current state of a value stream map with chemical metrics added into processes boxes [36].

Secondly, according to EPA, planning for and conducting kaizen events on environmentally sensitive processes can be pointed as one of the most important ways to reduce chemical wastes and avoid regulatory issues. Chemical waste containing processes that kaizen events can be conducted on named and exemplified as the following [36]:

- Bonding and sealing
- Chemical and hazardous materials management
- Chemical manufacturing
- Cleaning and surface preparation
- Metal fabrication and machining
- Metal finishing and plating
- Painting and coating
- Waste management
• Welding

Using Five Whys and Value Stream Mapping lean events during application of kaizen events as a sub event on environmental sensitive processes can be named as essential. Value stream can be used to identify processes that generate significant amount of hazardous waste and cross-functional team of employees in a kaizen event can be used to identify and implement process changes to limit hazardous wastes. Five Whys approach is a useful strategy to identify root causes of wastes and it makes the waste identification easier to handle. Solutions to eliminate wastes that save time, cut costs, and improve the quality of processes can often be provided by Five Whys. The following usage example shows how the five whys method can identify causes of chemical wastes [36]:

• Why is the solvent a waste? Because the solvent is contaminated with oil.
• Why is it contaminated with oil? Because the solvent was used to clean oil off the parts.
• Why are the parts oily? Because the manufacturer puts a coating of oil on them before shipping them to this facility.
• Why does the manufacturer put a coating on them? To prevent the parts from corroding after manufacture.
• Why is this type of corrosion protection absolutely necessary? We don’t know any other ways to protect the parts from corrosion. Let’s form a team to identify and test some alternatives.

Moreover, classic lean manufacturing approaches aims to convert batch-and-queue production with large materials inventories to optimal-sized manufacturing cells with one-piece flow and just-in-time delivery. EPA claims the conversion enables major improvement opportunities for chemical use and management. Accordingly, lean strategies: Cellular Manufacturing and Right-sized Equipment, Just-in-Time (JIT) Delivery, Right-sized Containers, and Point-of-Use Storage (POUS) can be used to dramatically reduce chemical use and waste [36].

The amount of chemicals used in a production process can be significantly reduced by Cellular Manufacturing and Right-sized Equipment lean strategies. Firstly, through the production process, cellular manufacturing related one-piece flow of products minimizes overproduction and enables labors to detect defects rapidly, and limits the amount of chemical use needed to meet customer needs. Secondly, EPA claims right-sized equipment only requires a part of the chemical inputs required in
conventional equipment and it leads to a decreased usage of chemicals since conventional manufacturing equipment is usually formed to handle the maximum anticipated demand, and oversized. Accordingly, oversized equipment can cause an organization to use significantly more chemicals than needed to establish the product [36].

Just-in-time (JIT) delivery can be observed as an inventory strategy implementation to limit in-process inventory and its carrying costs by enabling material deliveries to better fit with process consumption. Therefore, when JIT is applied to chemical management it will generally mean and result to fewer chemicals stored on-site and it will lead chemical suppliers to deliver chemicals more frequently in smaller batches. It can be stated that JIT creates possibilities to reduce chemical risks and wastes. The volume of chemicals that are mandatory to store on-site can be significantly reduced by small chemical inventories that enabled with JIT application and it leads to the following advantages [36]:

- Lower likelihood of a large chemical spill or accident
- Reduced need to purchase and maintain chemical storage tanks
- Reduced space needed for storing chemical inventories
- Reduced need for chemical spill prevention equipment and measures
- Elimination of certain regulatory, permitting, and reporting requirements, including the need to develop and implement Risk Management Plans

An essential Lean chemical use strategy can be named as Right-Sized Containers. Right-sized containers can be associated with “unit of use ordering”, which refers to chemical use as purchasing of chemicals in quantities and packing that provides easy usage chemicals in a manufacturing cell or Lean workspace [36]. According to EPA, the amount of a chemical that may expire or become unusable due to contamination or spoilage, and the need for transferring materials from larger containers into smaller ones can be limited by right-sized equipment, which is often reusable. As a result, the potential for chemical spills in facilities are being reduced [36].

Point-of-Use Storage (POUS) offers an approach that refers to the storage of small amounts of inventory in right-sized containers at the point in a manufacturing process in or near a manufacturing cell. Therefore, chemicals and materials needed for processes can be obtained by the workers with a significant reduction of time and walking distance necessities. Additionally, EPA states that material handling and support cost at a facility can be substantially reduced by POUS systems, and POUS
usage enhances chemical use and waste reduction efforts by support JIT delivery strategies [36].

Furthermore, management of chemicals and hazardous wastes in workspaces can be improved by lean tools: Visual Controls, Standardized Work, 5S, and Total Productive Maintenance (TPM) together with benefits that tools are proving such as decreasing costs and improving safety.

Visual controls can enable organizations to manage chemical related tasks efficiently. EPA claims that visual controls can be used in order to make sure workers are aware of chemical hazards and are prepared to execute necessary action to handle and manage chemicals appropriately [36]. Combining point-of-use storage efforts with visual controls can particularly useful for chemical management; Figure 12 can be observed in order to visualize the efforts [36]. Additionally, locations of storing, using and transporting chemicals can be clearly marked with lines on the floor and signs and placards on walls or hanging from the ceiling to make sure chemicals and hazardous waste management and storage information is available to workers at all times [36]. Moreover, information regarding level of chemical remains in a container or how much chemical to put into equipment or a tank can be managed by visual controls to assist worker in minor tasks. Usage of transparent containers enables to observe the amount of chemicals that remain easily, and visual chemical level markings on containers, tanks or tubs help workers in adding the right amount of chemicals to a process step or piece of equipment [36].

FIGURE 12 POINT-OF-USE STORAGE WITH VISUAL CONTROLLING EFFORTS [36]

Associating Standardized work with chemical use include all actions necessary to appropriately manage, use, and dispose of chemicals in a manufacturing cell or a Lean workspace. According to researches handled by EPA, chemical management procedures rarely become a part of routine work practice, if they are not associated
with standardized work efforts [36]. Therefore, chemical activities that happen on
workspaces should be referenced as a standard work and made available in the work
area for easy reference.

5S aims to provide and sustain a clean, orderly, and safe environment and its aim can
be directly related to chemical management since usage of chemicals demand for safe,
clean and orderly environment because many chemical are classified as hazardous,
dangerous for human health and the environment. Therefore, each pillar of 5S with an
additional safety pillar the 6thS can be associated with chemical management as the
following [36], and Figure 13 exemplifies connecting 5S and chemical management
efforts [36]:

- Safety (Respect workplace and employee): Create a safe place to work that is
  free of chemical hazards.
- Sort (Get rid of it): Separate out and eliminate chemicals that are not needed in
  the work area.
- Set in order (Organize): Organize the chemicals that remain in the work area.
- Shine (Clean and solve): Clean and inspect areas where chemicals are stored,
  used, and disposed.
- Standardize (Make consistent): Standardize cleaning, inspection, and safety
  practices related to chemical management activities and locations.
- Sustain (Keep it up): Make sure that chemical management procedures
  become part of standard work, that problems are quickly addressed, and that
  systems are routinely assessed for improvement opportunities.

FIGURE 13 POINT-OF-USE STORAGE WITH 5S EFFORTS [36]

TPM can be stated as relevant to chemical management and waste elimination since
TPM aims to maintain equipment and machines in a way that creates possibility to
labors to identify and fix problems that may result in chemical leaks or spills in a
quick fashion. Additionally, amount of chemicals, such as lubricants or solvents,
necessary to operate and equipment can also be reduced by effective routine maintenance as a part of TPM approach [36].

Lean Tools and Implications for Environmental Performance and Benefits

In addition to the stated lean tools/methods relationship in chemicals and energy use sections, lean tools can also have further implications to environmental waste in general. EPA’s lean tools based researches conducted in organizations from various industries has provided an extensive knowledge regarding 5S, TPM, Cellular Manufacturing, JIT/Kanban, Kaizen Events, Six Sigma and their implications for environmental performance and benefits in waste reduction sense. Following Table 5 lists and summarizes lean tools and their implications for environmental performance and benefits from a broad environmental waste aspect including implications for chemicals and energy use:

<table>
<thead>
<tr>
<th>Lean Tools</th>
<th>Implications for Environmental Performance and Benefits</th>
</tr>
</thead>
</table>
| **5S [40]** | • Energy needs can be decreased under the Shine pillar when equipment is painted light colors and surroundings are cleaned.  
• Enables workers to be aware of spills or leaks promptly in such workplace so that it makes less waste generation from spills and clean-up.  
• Clearly-marked and obstacle-free thoroughfares can reduce potential for accidents of spills and associated hazardous waste generation (e.g., spilled material, absorbent pads and clean up materials).  
• Cleaning regularly, in case cuttings, shavings, dirt, and other substances are accumulated as well as contaminate production processes which can result in defects, can reduce energy and resources needs and avoid waste.  
• Organizing and disposing of unused equipment and supplies, which can reduce floor space needed for operations, is benefit for environment because it can save heat and light.  
• EPA has proved that organizing equipment, parts, and materials and making them easy find can reduce unneeded consumption because workers prefer to finish one batch of materials or chemicals before opening or ordering more when things are in good order. It can also lead to less fewer materials expiring and needing disposal.  
• 5S visual cues (e.g., signs, placards, scoreboards, laminated |
<table>
<thead>
<tr>
<th><strong>procedures in workstations) can improve employee environmental management as well as increasing their awareness of waste handling and management procedures, workplace hazards and emergency response procedures.</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TPM [41]</strong></td>
</tr>
</tbody>
</table>
| • Appropriate equipment and systems maintenance makes fewer defects from a process. Defects reduction can conversely help eliminate waste from processes in three fundamental ways:  
  o Fewer defects make fewer products scrapped.  
  o Less number of product scrapped means fewer energy and resource waster generation.  
  o Fewer defects decrease the amount of energy, raw material, and wastes that are used or generated to fix defective products that can be reworked.  
• TPM can prolong using-life of equipment. Hence, pressure is released for purchasing and/or making replacement equipment. In the other hand, it can also reduce the environmental impacts caused in processes to produce new equipment.  
• A TPM program may also decrease the solid and hazardous wastes (e.g., contaminated rags and adsorbent pads) associated with the number and severity of spills and leaks, upset conditions. |
| **Cellular Manufacturing [42]** |
| • Cellular production can eliminate overproduction. Overproduction can increases the number of products that must be scrapped or discarded as waste, the amount of raw materials used in production, and the amount of energy, emissions, and wastes (solid and hazardous) that are generated by the processing of the unneeded output.  
• Cellular manufacturing can help avoid waste by reducing defects from processing and product changeovers. Because operators can easily identify defects when products or parts move through a cell piece by piece. Fewer defects also means fewer environmental impacts since it can decrease the number of products that must be scrapped, eliminate the raw materials, energy, and resulting waste associated with the scrap, and also reduce the amount of energy, raw material, and wastes that are used or generated to fix defective products that can be re-worked.  
• As a part of cellular manufacturing, right-sized equipment can help to use less material and energy than conventional, large-scale equipment. Because equipment is sized to work best for the specific product mix.  
• Less floor space is required for Cellular production layouts as |
| **JIT/Kanban** [43] | • Overproduction can be eliminated by the tool of JIT/Kanban. As stated in the part of Cellular manufacturing implications, overproduction impacts the environment in three key ways. Hence, JIT/Kanban can also reduce waste and the use of energy and raw materials by elimination overproduction.  
• JIT/Kanban systems can be applied to reduce inventory both in-process and post-process, which can help to avoid potential wastes caused by product handling. |
| **Kaizen Events** [44] | • The core of Kaizen is to eliminate waste from a targeted process. The typical outcomes of Kaizen culture and process have many similarities to those required by environmental management systems (EMS), ISO 14001, and pollution prevention programs. Kaizen involves all workers who may play a critical part in a certain process as well as encourages them to take part in waste reduction activities. Suggestions or opinions on process improving and waste reduction are usually from employees who work in a particular process. |
| **Six Sigma** [45] | • Six Sigma can reduce defects by removing variation from production processes. This, in turn, can help to remove waste from processes in three key ways:  
  o Decrease the number of products that must be scrapped;  
  o Reduce the raw materials, energy and resulting waste resulting from the scrap;  
  o Decrease the amount of energy, raw material, and wastes caused by fixing defective products that need to be re-worked.  
• Six Sigma tool can free workers to focus more on improving conditions that can cause accidents, spills, and equipment malfunctions. This can also help to achieve reduction of solid and hazardous wastes (e.g., contaminated rags and adsorbent pads) associated with spills, leaks, and their clean-up. |
Six sigma can extend product lifetime by increasing durability and reliability of product, in the other words, it can reduce the frequency to replace products, as well as decrease the environmental impacts resulting from meeting customer needs.

TABLE 5 LEAN TOOLS AND THEIR ASSOCIATED ENVIRONMENTAL PERFORMANCE AND BENEFIT IMPLICATIONS

4. RESULTS

Primary data obtained from the interviews handled in Karsan, Tofas (Turkey); Dongfeng Nissan and Jinxiang Badge (China) automotive industry companies are presented as the results of the thesis project. The results have been grouped in three main subjects in regards to main research content as the theoretical framework. Firstly, implication, application, and views and priorities of Lean Production (RQ1) in the companies are presented; accordingly, implication, applications, and views and priorities of Green Production (RQ2) and “Lean and Green” Production (RQ3) is going to be presented as subjects of the results.

4.1 COMPANY 1 - KARSAN

Integration of lean into production system

Karsan has had the experience of implementing lean into production system since the beginning of the year 2000. Different units in production department spend different times for lean practice and improvements. The time spent for lean practice and improvements highly varies depending on production unit’s functionally such as paint, assembly, and logistics. Karsan does not consider the hours and labor amount spend for lean improvements as a performance indicator to measure the success of improvements. Currently 30% of production department employees are actively involved in kaizen events (lean improvement activities).

There are kaizen teams in the production department. And they are responsible for organizing lean improvement studies. There are three types of kaizen teams and events in the production department. First type can be named as Before-After Kaizen which is handled by a small group of people in order to solve basic level problems which are only handled by blue collar labors or team leaders. Second type of kaizen events deal with higher level of difficulty problems with a broad cross-functional employee attendance (Production, Quality, Logistics, and Maintenance Departments) and with applying kaizen cycles (Plan, Do, Check, and Act). This type of kaizen events typically last between 8 to 12 weeks in the organization. The third type of
kaizen event that has been handling in the production department mainly does not contain any physical material involvement but deals with information based processes improvements.

**Appreciation of lean in production department**

One of the main expectations of Karsan is to integrate lean practice into blue collar level as much as possible as part of employee involvement aspect in lean philosophy; the aim is to have blue collar workers to identify problems and handle lean improvements possibilities and practices continuously without white collar involvement or supervision. Mainly, kaizen events form majority of lean practice in the production department and kaizen events: their context, associated employee involvements, lean improvements are appreciated with the attendance of blue and white collar workers, and management in weekly scheduled kaizen meetings.

The implication of lean to Karsan can be described in two main points: Continuous Flow and Problem Solving. It also includes creating an employee culture that can solve the problems which can occur during creating a continuous flow in the system. In order to provide continuous flow: JIT, Quality, and Standardization can be named as necessary elements to achieve for Karsan, where in problem solving: Kaizen, and Respecting Employees (Employee Empowerment and Active Involvement in Kaizen events) can be stated as an implication of lean for Karsan and as necessary elements to achieve problem solving. There is a direct relationship between continuous flow and problem solving since continuous flow cannot be provided without achieving problem solving.

Karsan has defined its production system based on lean philosophy. Karsan adapts lean thinking, strategies and methods by not directly implementing them but by internalizing them in order to blend with company culture. Therefore, it can be stated that there is a specific lean way of producing goods as the Karsan Way in the organization but it is not established as defined standards, and as a Karsan Production System. The Karsan Way can be stated as similarity and parallelism in different departments and sections of the company in employee behaviors, lean practices, internalization and level of complexity of problem solving approaches, quality practices, and management and employee relationships.

**None-value added work elimination**

Generally, none-value added works (Defects, Inventory, Overproduction, Waiting, Transportation and Motion, Over-processing) are handled by Kaizen Events, targeting waste, unnecessary transportation and motion, and inventory in production line.
Defect reduction is provided by Built-in Quality (Jikotei Kanketsu), which means minimizing defects and achieving quality in first time production for a product. Andon is used in raw material feeding of production process in the company but not effectively integrated in Karsan’s all over production mentality. Kaizen Events and Heijunka (Production Leveling) are used together to target overproduction in the system. JIT (Just-In-Time) and Kanban are integrated into the system and used to provide continuous production flow, and target and support continuous elimination of all lean wastes.

A significantly dominant lean waste cannot be named in Karsan, since every type of lean wastes is constantly occurring and constantly targeted by lean methods and tools, and elimination of one lean waste usually lead to elimination of another in the production system with no dominant occurrence.

**Cost and Productivity, Quality and Safety Improvements, and Continuous Improvement Culture**

When lean wastes are eliminated by Kaizen Events, production department obtains extra capacity to allocate different systems and new project and accordingly significant cost reduction is obtained. Additionally, when Built-in Quality is increased, rework and defective part and tool cost are reduced. Quality and Workforce improvements can be stated as two significant areas of cost and productivity improvements.

Quality is achieved through Build-in Quality and Kaizen Events. There are no significant lean tools or methods exist in production department regarding safety. But Safety issues usually are identified, presented and solved by Blue Collar Lean Team Leaders together with Kaizen Events.

Continuous improvements can be stated as a Kaizen Culture. Every Friday, organization has regular Kaizen Meetings where continuous improvements activities are acknowledged and rewarded.

**Lean Tools and Methods**

All the principles, tools, strategies are being put in to practice with a direct relation to employee capability to handle the changes because Karsan wants to handle lean improvements in blue collar level as much as possible.

**VSM:** Value Stream Mapping is generally used for a process to be mapped from beginning to the end, observing and solving associated problems in the process. It is usually handled by production engineers and blue collar Lean Group Leaders. Several
rework, waiting and transportation wastes identified and eliminated by using value stream mapping technique. Solutions to waste elimination is usually expected to be identified and solved by blue collar production floor workers since a production engineer cannot have a detailed information as a blue collar worker about a process. According Karsan, VSM is an important tool to have a holistic understanding of a process that contains several production sections and group of production personnel. 3 VSM Projects have handled so far in the production department and other than eliminating wastes it also helped production personnel to have a general understanding of production system since supply and lead time information is taken into consideration in Value Stream Mapping. The focus in VSM Projects can be named as Improving Product Flow, New Product Implementation, and Spare Parts. Results of stated Value Stream Mapping Projects can be described as reduction of processing times, decrease in waiting, reduction of quality related issues, and improved communication within the production sections.

Kaizen: Spaghetti Diagrams, Fishbone Diagrams, 5 why tools are being used as a part of Kaizen Events. Kaizen culture contains involvement of Kaizen team members, team leaders and group Leaders. Team Leader is a blue collar worker who is responsible for a specific production area, personnel and process.

One-piece-flow and Continuous Flow: One-piece-flow is used as a natural result of producing automotive products. Every vehicle enters production line one by one and processed through the line.

5S: 5S is generally is being used for reduction and standardization of searching, moving, and space related lean wastes on production line. Karsan does not have an approach to label production sections or elements to provide a standardize use.

Built-in Quality: In Karsan, the aim is to produce right in the first time. Therefore, increasing competence of operators, creating an environment that enables easy identification of problems, preventing defective material to process to the next station, and increasing solution creation pace can be named as essential for Karsan to achieve the stated quality aim. Karsan has obtained drastic improvements in quality with an increase in competence, awareness, and problem solving abilities of employee regarding quality.

JIT/Kanban: Kanban is used as continuously integrating parts in to one-piece-flow production line. In Karsan, Kanban is fully integrated to production system. It acts a communication system between parts and production line. If Kanban were not used, the system would not have a continuous flow and have several stoppages, and parts
would be located next to the production line which would cause several critical wastes in the system.

**Pull System:** Pull System is established and supported by Kanban and one-piece flow. It cannot be named as a pure pull system and Karsan tries to act as efficient as possible based on short and long term demand forecasts. And pure pull system will be hard to achieve since the business is usually produces vehicles for both internal and external market.

**Visual Control:** Visual Controls are being used in some stages of production. There is no holistic approach to integrate visual controls in to the production department or search for necessity to integrate. Visual Controls are being integrated when necessity is stated by line level worker and approved by lean management.

**Production leveling:** Production Leveling is used to balance the current workforce with production requirements.

**Poka-Yoke:** It contains mistake-proofing systems usually enables to provide built-in quality and targets unnecessary motion in Karsan. Poka-Yoke System constantly being created as a part of Built-in Quality in order to prevent same mistake to happen again.

**Andon:** Andon is being used only for raw material feeding process to production line. There is no holistic approach to investigate the necessity of use within production department.

**Successful Projects**

120 Before/After Kaizen presentation have handled since Lean was being put into practice. 30 Kaizen Cycle Presentation have occurred. Their focus can be named as Quality, 7 Lean wastes, Ergonomics, and Safety. The two dominant focus of Kaizen Projects in Karsan is increasing available operator time, quality, and increasing available space. Increasing available operator time can be associated with elimination of unnecessary motion and transportation, loading, defects, and rework. And it creates possibility for Karsan to use the available workforce in different areas in production.

Three main subjects of handled lean improvement projects can be stated as Kaizen, Built-in Quality, and Line Management which contains training and improving lean competency and Leadership of blue collar Lean Team and Group Leaders.

As a result of Lean Projects, defect per vehicle measures decreased and built-in quality measures increased significantly in Karsan. Employee lean competency
significantly increased and self-sustainability goal of a blue collar worker regarding waste identification and lean improvements without white collar supervision is achieved.

**Views and Priorities of Lean**

The most observed non-value added works (lean wastes) that lean approach addressing at in Karsan production department can be stated as: Quality and Defect Problems, Transportation, Unnecessary Motion.

The lean tools and methods that can be stated as the most effective in providing cost/productivity improvements are: Kaizen, Built-in Quality, VSM (Value Stream Mapping).

**Integration of green into production system**

Karsan is using ISO 14001 Environmental Management System. Karsan have been integrating environmental considerations (green) into production system since 2004 (Nearly more than 7 years). Karsan production department spend 9 hours in a week for environmental considerations integration and environmental performance improvements, and 3% of production department personnel are responsible for green aspect integration and performance improvements.

There is only one team regarding integration of environmental considerations and into the production system and environmental performance improvements. The team members are from production and production supporting departments.

**Appreciation of green in production department**

Green manufacturing concept is appreciated in the production system as to comply with all environmental laws and regulations for protect environment and ensure the continually, improve environmental performance.

Karsan aims to implement and improve a proactive environmental management system in product, in production process and service activities in the perspective of sustainable development principle.

Karsan has defined its production system based on green philosophy. Green production philosophy includes: defining all kind of waste disposal operations as a loss of resource and develops methods to prevent pollution at source; accepting compliance to all legal and other requirements they subscribe is the fundamental of its processes; aiming to minimize natural resource consumptions, energy losses and wastes by means of applying continual improvement tools and training The
employees and contractors; and producing vehicles that have less environmental impact and having more recycled materials.

**Strategies to Cope with Environmental Regulations and Safety Issues, and Cost and Productivity, Environmental Performance and Environmental Impact Elimination Improvements**

The production department cope with the environmental regulations and safety issues in accordance with the requirements of applied ISO 14001 standards (Karsan Environmental Management System) and ISO 18001 standards (Karsan Health and Safety Standards).

Karsan is constantly implementing and improving a proactive environmental management system in product, in production process and service activities in the perspective of sustainable development. The aim of green production in Karsan is to minimize natural resource consumptions, energy losses and wastes by means of applying continual improvement tools and training the employees and contractors. And to produce vehicles having less environmental impacts and having more recycled materials. Karsan defines all kind of waste disposal operations as a loss of resource and develops methods to prevent pollution at source.

**Green Tools and Methods**

**ISO 14001 (Environmental Management System):** is being used to reduce all hazardous and non-hazardous wastes. Guiding principles of ISO 14001 established standards used in design, use of processes and products to provide cost/productivity improvements and better environmental performance. Overall environmental management in order to provide identification and continuous improvement of environmental impacts with constant monitoring of environment associated processes is also provided by ISO 14001. ISO 14001 is also being used in production department as a published standard to manage environmental impacts, evaluate environmental performance, and provide appropriate usage and implementation of green manufacturing tools and methods into production processes.

**EcoAudits:** Karsan is handling periodical ecoaudits to assess equipment use, waste and recycling, and material usage processes. The objective is to produce vehicles having less environmental impacts and having more recycled materials by handling ecoaudits in production department.

**Carbon Footprinting:** Emission permission laws and regulations are being used in order to reduce Carbon usage and Green House Gases production in production department. There are no additional efforts within the production department to
improve Carbon usage and Green House Gases production more than the limits stated by emission permission laws and regulations.

**Life Cycle Assessment (LCA), and Environmental Failure Mode and Effect Analysis (E-FMEA):** are being used in Karsan to identify and evaluate potential environmental impacts that can occur life-cycle phases of a product to have corrective and preventative actions to minimize the environmental impact.

**Design for the Environment (DfE):** Karsan is applying DfE to design or redesign products, processes and management systems in order make them cleaner, more cost-effective and safer for workers.

**The Eco-Management and Audit Scheme (EMAS), Cleaner Production and Eco-Efficiency:** are being used to provide identification and continuous improvement of environmental impacts with constant monitoring of environment associated processes.

**Environmental Impact Analysis (EIA):** There are guidelines used within production department for assessing environmental impacts of new development proposals prior to execution of proposals.

**Successful Projects**

Mainly, includes reducing the amount of hazardous wastes by using methods such as; separating hazardous wastes correctly and eliminating them in appropriate manners. Karsan has reduced the cost of eliminating hazardous wastes as a result.

**Views and Priorities of Green**

Mainly, production department has a major green improvement focus on waste water treatment of the production plant, and total waste management (waste oils, waste solids, waste chemicals, and waste cleaning materials).

The environmental waste types that the production department mostly focuses to eliminate are: Paint sludge, waste water treatment sludge, waste oils and waste chemicals.

Green strategies, tools or methods that can be named as significantly effective in cost/productivity improvements and environmental impact reduction are: Environmental Impact Analysis, Auditing the Production Areas, Environmental Action Plan Forms.

“Lean and Green” refers to relating and integrating lean and green production
Integration of lean and green in production system

Efforts to integrate lean and green practices are associated with environmental focused Kaizen Events (kaizen events that provides green waste reduction results) in Karsan. The production department has been conducting environmental focused Kaizen Events for a year, since 2010. 3 Kaizen Events with an environmental focus has conducted in production department so far and approximately 40 employees involved out of 1000 production employees. Kaizen teams are formed to conduct environmental focused kaizen events. The main objectives of kaizen teams formed are reduction of waste water, chemical and energy usage.

Appreciation of “lean and green” in production department

Karsan has not defined its production system based on a “lean and green” philosophy. There is no direct appreciation of integration of lean and green concepts in the production department. Therefore, production development operations has never been tried to analyze from a lean and green connection or relationship aspect.

Efforts to Associate Lean and Green Philosophies, and Lean Wastes with Environmental Wastes

There are no direct efforts to associate lean and green philosophies since integration of lean and green concepts (“lean and green production”) currently is not analyzed or appreciated in the company. Consequently, there are no efforts to associate lean “muda” wastes and environmental wastes in the production department.

“Lean and Green” Tools and Methods

Kaizen Events: Energy use and waste water generation is targeted and reduced by Kaizen events.

Just-in-Time (JIT): Is being used to reduce chemical and hazardous waste containment in production department.

Point-of-use Storages (POUS): Chemical and hazardous waste containment is being limited by the usage of POUS.

Successful Projects

The successful projects with lean and green relation focus (kaizen events with environmental focus) can be presented as the below:
Energy reduction Kaizen Projects is being conducted in the company, a Kaizen Team was formed in Karsan regarding Natural Gas, Air, and Electricity Usage. The team contains Blue Collar Lean Group Leaders and Maintenance Team Leaders. Kaizen Team has identified Energy usage related problems and wastes, and provided solution proposals. Currently, Energy usage related kaizen projects are still progressing and deliver short term results.

Waste water reduction kaizen events Karsan also conducted in production department. An important result can be named as reduction of waste water amount in paint shop. 1.9 tons of waste water creation was reduced to 1.5 tons, which enabled approximately 300 to 400 liters of water reduction per vehicle produced. Optimal time of vehicle wash was achieved and new environmental friendly washing technologies started to being used and the new technology enables cost reduction both in long and short term. Associated energy and chemical reduction due to vehicle wash waste water reduction noted as additional environmental gains of conducted kaizen event.

JIT and POUS (Point of usage Storage) Lean mentalities are collectively used in order to reduce chemical and hazardous material containment in the product department. Chemical and hazardous material point of use storages are being filled by a third-party company with JIT supply mentality (storage levels are continuously being measured) and production department only stores the amount that they will use in a short period of time. The approach is directly leading reduced amount hazardous and chemical materials and associated risks, environmental management costs, and inventory level together with improved safety. Additionally, POUS drastically reduces unnecessary labor motions since the storages are located next to the processes that they are being used.

**Views and Priorities of “Lean and Green”**

The type of environmental wastes that can be stated as the most targeted by lean environmental waste reduction efforts are: Energy use and waste water generation.

The lean strategies, tool or methods that can be named as significantly effective in environmental impact reduction are: Kaizen Events, JIT, POUS (Point-of-Use Storages).

**4.2 COMPANY 2 - TOFAS**

**Integration of lean into production system**

Tofas has been using lean practice related tools and methods since early 1980s by initiating TPM (Total Productive Maintenance), and Rapid and Before-After Kaizen
Events. An overall, disciplined, and systematic usage of Lean has being practiced since 2007 as World Class Manufacturing System as being a part of Fiat and Chrysler Group.

The production department handles lean improvements on the established lean production system during all available production hours since all blue collar production personnel is assigned to a specific production section and a lean team. Blue collar production personnel are responsible for identifying and handling lean improvement opportunities during their available production hours together with maintaining daily production operations. Blue collar worker hierarchy and production team grouping is directly handled as a result of lean production mentality (World Class Manufacturing) in Tofas.

Every Production Employee is an integral part of the Lean production system. Therefore, it can be stated as 100% of the production department has constant involvement with Lean Production System in Tofas. Constant involvement includes continuous lean improvements, obtaining blue collar workers opinions about their production section, and kaizen events which require constant involvement of every production employee. Additionally, 3 white collar engineers are spending 100% of their working hours just for Lean production management and improvements.

White collar workers (Lean Production Engineers) are not an integral part of lean production teams and have no direct involvement in lean operations handled by blue collar production workers. The lean teams are managed by blue collar Lean Leaders. Responsibility of white collar engineers can be described as providing support to lean leaders. Every Lean Leader has their only sectional areas in the production department and responsible for 10 to 16 production personnel. There are 30 production stations in Tofas, and 30 production stations are divided into responsibility of 5 Lean Teams. The lean wastes are constantly tracked by the responsible by the lean team assigned to a production station.

**Appreciation of lean in production department**

Tofas acknowledges the importance of blue collar involvement in lean practice. A successful lean practice can be handled by having capable, leadership driven, self-sustainable blue collar production workers that can continuously identify lean improvement opportunities and propose improvement methods through kaizen events. Tofas has only 3 white collar lean production personnel (lean production engineers), and the company believes that success of lean practice will be defined by capability of lean blue collar workers and not by the involvement and capability of white collar workers who cannot have the same level of detailed focus and knowledge on
production processes as blue collar production workers.

Cost deployment can be described as the core of lean philosophy in Tofas which can be explained as identifying the lean waste reduction opportunity that can lead to the most cost reduction in the production department. Therefore, lean improvement possibility is being prioritized in Tofas according to their possible cost (the current amount of associated losses in the system) reduction magnitude and total available resources to carry out lean improvements.

Tofas has defined its production system based on lean philosophy. Tofas production system is formed and systematical defined as WCM System (World Class Manufacturing System: Lean production system used by Fiat production plants).

**None-value added work elimination**

In the production department, material classification is used to categorize material inventory used in assembly. Categorization enables production line level workers to handle assembly in a shorter period of time. As a result waiting, labor motion is directly being reduced due to more visible and standardized use of material inventory.

Kaizen events in the production department can be named as main identifier and improver of lean wastes (non-value added works). Established poka-yokes through kaizen events enables standardized and improved handling of waiting, transportation and motion, and over-processing.

**Cost and Productivity, Quality and Safety Improvements, and Continuous Improvement Culture**

Tofas is using Hours per Vehicle Measure in order to measure productivity. Hours per vehicle can be defined as the labor and machining hours spend on a vehicle from the beginning of the production line to the end. And this measure is constantly being improved by lean production improvements and cost (production loss) reduction.

Rework can be defined as one of the most essential losses of the production system. And rework loss is continuously being targeted by built-in quality mentality and quality gates. Quality gates include one specialist who is performing dynamic and static quality checklists. Dynamic checklists are updated by using daily human errors. Static checklists mainly include chronic defects that can lead high amount of time and cost to eliminate the defect and they are valid for 3 months, and performed daily.

There is no direct lean mentality or approach to deal with safety issues in production environment in Tofas. As a part of 5S related production environment cleaning approaches, safety issues are considerably being reduced in the production department.
Additionally, a blue collar worker becomes a safety captain for a day to report safety issues observed in his/her assigned production section.

JIT and Kanban are being used to reduce the time to produce a car in the production line and as a result it has a direct impact on reduction of the lead time to customer.

Continuous improvement culture in Tofas can be directly associated with Kaizen Events. Kaizen events require 100% involvement of the production department. Additionally, Tofas set targets for lean improvement suggestions for a production line employee in a year. Currently, Tofas receives 32 lean improvement suggestions per production line employee in a year.

**Lean Tools and Methods**

**VSM:** Value Stream Mapping in Tofas is handled mainly by blue collar workers with the support of lean white collar engineers in the production department. It is essential to let blue collar lean team leaders and workers to handle Value Stream Mapping activities since it is highly unlikely for a lean engineer to know the problems in the production line as a blue collar line worker. Value Stream Maps are handled in production department if a capacity change occurs in a process and the current value stream maps are being revised monthly. When VSM is applied for a process or a group of processes for the first time, it approximately takes 5 hours to complete and 45 minutes to update the existing VSM later.

**One-Piece-Flow/JIT:** One-Piece Flow and JIT lean tools are generally used to eliminate Mura waste (unevenness in production), to standardize the work processes and supply the production processes with the right part, at the right time and in the right amount in Tofas.

**5S:** Is only used for sort, strengthen and shine elements of 5S. Therefore, there is no full usage of 5S tool approach to sustain and standardize the workplace in Tofas production system. However, Tofas using World Class Manufacturing production mentality (such as Standardized Work in Toyota Production System) handle sustain and standardize gaps that production department is not covering through a similar approach to 5S. 5S approaches are continuous being handled on a daily basis in Tofas production department. The area that 5S tool is being significant used and resulted with an important lean waste elimination to department can be pointed as physical waste elimination which results in space availability, external cleaning cost reduction, and cost reduction of cleaning vehicles and their negative effects to environment and workers.

**TPM:** Contains Autonomous Maintenance and Preventative Maintenance activities in
the production department. It is essential in Tofas production department to limit potential maintenance needs through autonomous maintenance. Therefore, the main objective in Tofas’ TPM can be stated as to achieve a high level of autonomous maintenance in order to limit necessary preventative maintenance. Limiting preventative maintenance with successful autonomous maintenance enables Tofas to reduce the comparably high cost of preventative maintenance since it is handled by maintenance specialists who are significantly more costly compare to a blue collar production worker who handles the autonomous maintenance.

**Standardized Work:** is achieved by providing standardized work manuals that labors are obligated to work according to in a work space to achieve standard time in a process. Additional efforts can be named as defining and standardization of a labor’s workspace to enable worker to only work in a defined work space which is optimized for standardization.

**Visual Controls:** Visual controls in Tofas are used based on Visual Factory Concept in the company which includes mistake proofing and standardization of operations with Visual Management. Visual Controls are not being added to processes as a part of Kaizen practices in general but as result of general quality improvement and standardization practices. Therefore, they only occur when an opportunity arise to improve quality or standardization through visual controls.

**Built-in Quality:** Built-in Quality studies are triggered directly when a defect occurs and with routine established quality control matrixes (checks). In order to produce eliminate rework and produce right in the first time, preventative measures are being put into the quality control practice for an identified defect or a identified fail quality control matrixes. Chronic problems that have observed for more than 3 years are handled by Quantum Projects. Quantum Projects refers to intense level quality projects that involve production managers and production directors in addition to production engineers and line level workers.

**Heijunka (Leveled Production):** Is being used in some specific sections of the company such as in vehicle passenger door production process in order to balance and optimize the utilization of the labors in a day.

**Kanban:** Is used to support One-piece-flow/Just-in-time to provide efficiency in internal material handling to support production processes to reduce waiting, transportation and motion, and inventory lean waste parameters.

**Poka-Yoke:** Poka-Yoke (Mistake Proofing) is used in production department in order to not to observe a proven process mistake again. Poka-Yoke approaches aim a full
limitation of an observed process mistake therefore, and identified mistake will not
occur again even with a significantly lower rate. Poka-Yoke is mainly being used
within the Kaizen Events, kaizen improvement events can be stated as the direct
trigger of Poka-Yoke improvements. Since Poka-Yoke approach limits the occurrence
of a mistake to zero, it is considered as one of the most significant lean tools by the
production department. Therefore, a database has created in order to the track all the
poka-yoke improvements within Fiat Corporation to apply the poka-yoke
improvements in other fiat plants that suffer similar process mistakes. It can also be
stated as significantly important to identify the relative processes that an established
poka-yoke mistake proofing can be applied within the production department.

**Kaizen Events:** Kaizen Events are classified depending on the level (complexity of
proving a solution) of the problem observed in the production department. Depending
on the level of the problem, methodology of the kaizen event applied varies.
“Standard and Rapid Kaizen Event” types with low level of complexity are generally
applied by blue collar workers without white collar worker involvement in kaizen
event handling process. The Target for number events for Standard Kaizen Events is
defined as 15 Standard Kaizen per Lean Team per year. “Advance Kaizen event” type
with high level of complexity is handled by white collar workers (lean production
engineers) by using an advance kaizen methodology. The Target for number events
for Advance Kaizen Events is 3 per year, given that an advance kaizen takes 6 months
to complete. Associated tools that are being used within Kaizen Event Handling can
be named as Fish-Bone Diagrams, 5 Whys, and Process Point Analysis which enable
Tofas to lead the kaizen events in an external facility by tracking all the process data
starting from the point that the facility connects with the production department in
Tofas. A database is formed by Tofas in order to store lean production wastes and
improvement opportunities, which is a source to trigger kaizen events in the
production department, other than the ones that have higher priority for initiation.

**Cost Deployment:** Every lean improvement possibility is prioritized based on their
possible cost (the current amount of associated losses in the system) reduction
magnitude and total available resources to carry out lean improvements.

**Successful Projects**

Can be exemplified with kaizen events handled towards limiting unnecessary motion,
Tofas has got several patent for unique poka-yoke approaches that being also put into
practice in other Fiat production plants. Results can be explained as making the labor
idle for operation as highest level as possible by limiting rework with electronic and
mechanic poka-yokes, and proving cost efficient and smart solutions to limit labor
motion and waiting.

Another successful approach in Tofas can be stated as examining competitor vehicle models. Competitor vehicles are being disassembled and later reassembled in order to identify possible lean improvement possibilities that can be integrated to Tofas production system. Value Stream Mapping is handled on the competitor vehicle and associated assembly times and costs are measured in order make a comparison with a competitor vehicle and detailed analysis are handled on the sub assembly that gives better timing and cost value compare to Fiat vehicles. Impact of this competitor vehicle analysis on lean improvement possibility creation in Tofas production system can be named as significant.

**Views and Priorities of Lean**

The most observed non-value added works (lean wastes) that lean approach addressing at in Karsan production department can be stated as: *Unnecessary labor motions and waiting, transportation, rework, and inventory.*

The lean tools and methods that can be stated as the most effective in providing cost/productivity improvements are: *Kaizen Events, Poka-Yoke, and Value Stream Mapping.*

**Integration of green into production system**

Tofas has been integrating environmental considerations into the production system since 1997, started with efforts to obtain ISO 14001 Environmental Management Certificate.

Every sub section (such as such as Assembly, Paint, Body) of production department has an assigned Environmental Management Employee that guides and audits the sub section in environmental issues. It can be stated that total number of direct green production employees has a direct relation with number of sub sections in Tofas production department. Currently total number of employees that are directly responsible for Green production management can be stated as 18 white collar workers and 100% of their working time is allocated to environmental management activities. Every environmental management employee is responsible for providing green improvements in his/her assigned production department sub section. There is no blue collar worker who is directly responsible for sustainment of green in the company but their continuous involvement are required if they are associated with an environmental auditing or improvement activity. Green production management teams are generally formed according to two main subjects under Green field:
Environment and Energy.

**Appreciation of green in production department**

Green philosophy of Tofas regarding production development operations can be described as: Environmental waste prevention, limitation and control; integration with legal requirements; and continuous environmental improvement.

Integrating the environmental perspective to the production system successfully also creates possibility to be selected as the Fiat plant that will produce the new vehicle models.

**Strategies to Cope with Environmental Regulations and Safety Issues, and Cost and Productivity, Environmental Performance and Environmental Impact Elimination Improvements**

Environmental regulations are continuously being track by company and being integrated. It can be stated that company directly obeys the local environmental regulations but also currently environmental performance of the company is quite close to match European Union Environmental Regulations.

Tofas production department works with environmental performance improvements and environmental impact elimination by using continuous improvement tools and adopting proven best practices. Fiat’s portal for best practices is a significant resource to improve green performance, by adopting best practices that are being used in other Fiat facilities. Additionally, Environmental performance and impact elimination measures are significantly increased by WCM mentality’s Green pillar. Tofas production system acknowledges green waste as a lean waste and limits it by using WCM lean tools and methods. Another green production tool can be stated as “EMAT” (Tofas Production System Environmental Auditing Tool) in Tofas production system, which is a part of WCM and it overlooks all the processes in the production system and analyzes them from environmental performance and impact perspective. “EMAT” directly gives inputs to provide increase in environmental performance and impact elimination.

Cost and productivity mainly increased by handling energy usage improvement practices on production processes. Additionally, standardizing energy, chemical waste, and waste water usage in processes that show variability in usage is also an important way reduce the cost in production system. Kaizen Practices with environmental focus: Before-After, Standard, Rapid, and Major Kaizen Events can be stated as essential tools. Natural Gas, Electrical Energy, Pressured Air, and Dangerous Waste reduction approaches, Recycling and Reuse of waste material can be named as additional efforts.
to improve cost and productivity measures.

**Green Tools and Methods**

**ISO 14001 (Environmental Management System):** The core of environmental management in Tofas is ISO 14001 (The International Environmental Management System Standard). ISO 14001 is used to provide overall environmental management of production system and used to provide identification and continuous improvement of environmental impacts with constant monitoring of environment associated processes.

**Environmental Process Auditing (EcoAudits):** Productions processes are continuously being audited by green production (environmental management department) employees, and green wastes are being identified and corrective actions are being taken. It is called in Tofas production system as Environmental Process Auditing. And at least 10 green issues are expected to be identified in a year for each sub section of the production department, which makes a least 180 green wastes identification in a year. Environmental Auditing is established in production department as a natural result of obtaining ISO certificates and sustaining them. Environmental auditing over production processes is handled once a year together with ISO certificate provider firm’s once a year auditing.

**Carbon Footprinting:** Tofas recently received an ISO certification in regards to Carbon usage and Green House Gases which is a first in all Fiat production plants. Therefore, there are approaches in production department regarding measuring and limiting Carbon usage and Green House Gases in production processes. Carbon usages and greenhouse gas productions that do not meet ISO Certification criteria or regulations after audits are targeted to be limited within 3 months in the production department. Kaizen events and usage of best practices can be stated as important approaches for limitation and achieving the required level.

**Environmental Impact Analysis (EIA):** There are approaches specifically used for assessing environmental impacts of new development proposals prior to execution of proposals in Tofas. Whenever Fiat has a new product (vehicle) release, its environmental impact on the production system is analyzed in a detailed level. And the production system is adjusted according to limit environmental impacts before starting to produce the new product.

**ISO14000 Series:** Can be named as guiding green principles used in the design, use of processes and products to provide cost/productivity improvements and better environmental performance.
Successful Projects

Environmental waste classification project enabled production department to group and approach (assess and improve) more efficiently to an environmental waste. Classification of environmental wastes includes: hazardous wastes, emissions, waste water, chemical material, and energy management.

Another project that has been taken into practice is using Fiat’s Best Practices. Fiat’s company portal is being used to observe best practices within Fiat production plants and integrate the ones which are required and applicable for environmental impact reduction and performance improvements.

Additionally, green (environmental friendly) purchasing and logistics activities development projects were taken into practice and selection of ISO 14000 certified suppliers are prioritized. And currently, Tofas is initiating a project to reduce the amount of materials that leads to environmental impacts on a vehicle.

Views and Priorities of Green

The environmental waste types that the production department mostly focuses to eliminate are: Hazardous wastes, chemical wastes, energy usage, waste water and emissions.

Green strategies, tools or methods that can be named as significantly effective in cost/productivity improvements and environmental impact reduction are: Environmental Auditing, ISO 14001 (Environmental Management System), and Environmental Kaizen Events (Kaizen Events with Environmental Waste Reduction Focus).

“Lean and Green” refers to relating and integrating lean and green production concepts.

Integration of lean and green in production system

Tofas has been integrating lean and green philosophies in production system since 2006, by the implementation of WCM (World Class Manufacturing) Lean Production System. WCM contains a green pillar (environmental waste focus) and acknowledges and defines environmental waste as a lean production waste. Therefore, observed green wastes over the production system as part of environmental process auditing are systematically targeted and eliminated or limited by WCM lean production tools and methods.
Appreciation of “lean and green” in production department

Tofas production system is based on WCM (World Class Manufacturing) System. One of the lean wastes that defined by WCM System is called the Green Pillar (Green Waste related activates), and refers to environmental impacts and environmental performance improvement opportunities over production system. Therefore, environmental management within the production department has a direct connection with lean production via approaches over the Green Pillar and company’s green philosophy is integrated directly into the production system.

Efforts to Associate Lean and Green Philosophies, and Lean Wastes with Environmental Wastes

There are no efforts to associate a defined lean waste (such as Defects, Inventory, Overproduction, Waiting, Transportation and Motion, Over-processing) with an environmental waste but environmental wastes as a whole integrated in to Tofas lean production system (WCM) as an additional lean waste under Green Pillar (Green waste).

Other than the stated lean waste and environmental waste relating approaches above, there are no direct efforts to associate lean and green philosophies.

“Lean and Green” Tools and Methods

Kaizen Events: Energy use, waste water generation, carbon usage and greenhouse gases are targeted and reduced by kaizen events. Kaizen events also have been used to handle environmental waste collection and transportation optimization in the production department.

Poka-Yoke: Is being used to create mistake-proofing approaches to eliminate environmental wastes and assure a poka-yoke applied environmental waste is not occurring in the observed production process.

5S: 5S is being used to create a location plan for each hazardous waste, waste water generation source, and chemical in production department. 5S enables production department to have an overall mapping of all the hazardous and chemical wastes, and waste water generation sources in production department.

Cost Deployment: Every environmental waste reduction possibility is being collectively analyzed in the production department before taking any eliminating or limiting action. Environmental wastes are being prioritized based on their cost deployment factor. Cost deployment factor of an environmental waste is formulated by its legal requirements, frequency of occurrence, probability of occurrence, and
intensity of occurrence over production system. Cost deployment methodology is being used in production department to prioritize lean improvement opportunities and the same mentality is adapted to assess and prioritize green production wastes and improvements.

**Successful Projects**

The successful projects with lean and green relation focus (kaizen events with environmental focus) can be presented as the below:

Tofas has achieved 5% energy reduction via energy reduction focused kaizen events within the production department. Energy reduction kaizen events have had the focus on processes that contains air usage, heating, refinement, and pumping. Kaizen events have been handling with involvement of environmental management employees and blue collar lean production workers from lean teams.

Currently, an ongoing waste water generation reduction kaizen event is being handled in the production department. The kaizen event aims to reduce the waste water generation in the production department by 10%.

Another project was initiated to form a database in to order to store all poka-yokes (mistake proofing) approaches that deal with environmental improvements within the production department. It can be stated that Tofas has integrated lean poka-yoke methodology to environmental performance improvements. When environmental wastes are identified, Tofas seeks for the opportunity to eliminate reoccurrence of environmental wastes via creating mistake-proofing approaches. All the identified environmental poka-yokes are being stored in order to integrate an identified poka-yoke to different processes with production department when a similar poka-yoke implementation opportunity is observed. Additionally, the database is also accessible to other Fiat production plants to observe and use environmental poka-yoke approaches within Tofas production department as a best practice.

**Views and Priorities of “Lean and Green”**

The types of environmental wastes that can be stated as the most targeted by lean environmental waste reduction efforts are: **Energy use and waste water generation**.

The lean strategies, tool or methods that can be named as significantly effective in environmental impact reduction are: **Kaizen Events, Poka-Yoke, and Cost Deployment**.
4.3 COMPANY 3 - DONGFENG

Integration of lean into production system

DONGFENG has integrated lean into production system. They have been working with lean philosophy since 2003 when Dongfeng started a joint venture with Nissan. DONGFENG implements Nissan production way – QCD production management way. QCD refers to quality, cost, and delivery time. Nissan production way has two principles which are named two ‘never ending’, that is, never ending synchronization (Douki) their manufacturing with the customers, and never ending quests to identify problems and put in place solutions. They focus on reducing lead time and delivering products to customers at right time.

Totally the production department spends 30 minutes to 60 minutes on lean improvements every week. But it depends on the specific situation. The duration sometimes can be longer, while sometimes can be shorter. As they calculated, in the past few years, around 85% of the employees have participated all kinds of kaizen events that are covering proposing improvement suggestions or ideas, QCD (Quality, Cost, and Delivery) kaizen events, and NHC activities. There are some teams formed in order to provide lean implementation and /or production development in the production department. They have QC (Quality control circle) kaizen team and QCD (quality, cost, and delivery) kaizen strategy and promotion department. QC team concerns improvement of product. QCD team focuses on kaizen of production process. Quality, Cost, and Delivery (QCD) Kaizen approach in Dongfeng evaluates the investment cost of a lean improvement opportunity and associated cost reduction after the improvement to prioritize improvement opportunities.

Appreciation of lean in production department

The implication of lean philosophy regarding production development operations to DONGFENG is to integrate Kaizen culture into production development. Their production system is defined based on principles of lean production. It is quality-driven and waste free. The goal is to reduce cost, enhance quality, and increase productivity.

None-value added work elimination

In DONGFENG, elimination of none-value added works (defects, inventory, overproduction, waiting, transportation, motion, and over-processing) is mainly handled by Kaizen Event. They use VSM to identify none-value added work, use just in time manufacturing to enable the production of product only when it is ordered,
and use Kanban to enable pull of production through the process. None-value added work can be reduced by using these tools.

**Cost and Productivity, Quality and Safety Improvements, and Continuous Improvement Culture**

The basic idea of cost is to produce with the least resources. Cost and productivity improvement are done by lean tools associated with elimination of wastes.

The basic idea of quality is to achieve full digital quality assurance, that is, to make 100% assurance of the quality that customers need. DONGFENG introduces ISO9001 quality management system. They expect to continuously improve quality management system under the supervision, audit, and review of the third party. Meanwhile, DONGFENG utilizes Kaizen to improve Quality through standard work, visual management, proactive management, and 5why.

Safety is handled by Kaizen through KYT and 5S. KYT (kiken (hazard), Yochi (prediction), and training) refers to training for hazard prediction. KYT aims to detect and to take preventive measures against potential errors or hazards utilizing the Kiken Yochi Training Sheets, which depict the work place situation with potential accidents and danger. This training is to develop the workers’ attention to maintain safe working conditions so as to prevent such circumstances. The method of KYT includes predicting Hazards, preventative measures, and confirming safety objectives.

DONGFENG apply PDCA cycle on Kaizen. Meanwhile they implement QCD (quality, cost, and delivery) evaluation system and QCD kaizen regular meeting.

**Lean Tools and Methods**

DONGFENG seeks to produce the highest quality vehicles in the most efficient way possible. They deploy all the principles, tools, strategies of Nissan production way (see figure 14) that includes Genba Kanri, SQC (statistic quality control), TPM, JIT, TQM, and Douki-seisan. The foundation of NPW is Genba-kanri which is shop floor management. The ultimate goal is to achieve ideal situation of production - Douki-seisan – a build-to-order system schedule which means synchronized production, through SQC (statistic quality control), TPM (total productive maintenance), and JIT (Just In Time). Dongsheng Nissan is committed to a culture of continuous improvement, called Kaizen, and is guided by a Total Quality Management system, in order to ensure making progress towards Douki Seisan. Besides, some other basic lean tools are adopted in the production system of DONGFENG, such as 5S, standardized work, Heijunka (production balancing), visual controls, one piece flow, 5 Why, Poka-yoke (mistake-proofing), and andon. IT
The application of Nissan production way in DONGFENG

Douki Seisan & JIT: Douki Seisan is a Japanese term meaning synchronized production. That is an ideal situation of production where the whole manufacturing process receives order information at the same time, allowing them to schedule and build to order. This requires a consistent flow of products without any disruption to the production sequence.

Just-in-time is an approach that enables specific product be delivered just-in-time to meet the demand for them. For instance, sub-assemblies move into the final assembly plant just as final assemblers are ready to work on them, components arrive just in time to be installed, and so on. In DONGFENG, every vehicle is monitored automatically throughout each stage of production.

Hence, DONGFENG integrated JIT philosophy and Douki Seisan philosophy into the production line. As shown in the figure 15, DONGFENG build a mixed-model production line, very frequent in JIT and Douki Seisan, so that it is able to handle several variants of one or more products.
TQM refers to total quality management. It is an ongoing process. In DONGFENG, every employee is involved to look for ways of to improve quality of products, people and work. This Kaizen culture, in turn, makes every employee feel their contributions are valued and helps them to develop their capabilities.

**Kaizen:** Kaizen activities and a ‘kaizen culture’ have had a significant part to play in the way DONGFENG conducts their business. And Kaizen is an essential element of GENBA KANRI (shop floor management). DONGFENG applies Kaizen in improving productivity, products, service quality, cost reductions, safety, production process and working environment. They continuously seek improvements in all actions. They think that no improvement is too small. In DONGFENG, Kaizen process is based on the never-ending ‘PDCA’ cycle. Fishbone Diagrams and 5why tools are used as analysis tools of Kaizen Events.

In DONGFENG, Kaizen is undertaken in three main ways in the shop floor – QC (quality control circle) team, QCD (quality, cost, delivery) team, and individual Kaizen.

- Typically, improvements are initiated by teams that QC (quality control circle) kaizen team and QCD (quality, cost, delivery) kaizen team. Group of employees meet together regularly and share ideas of improvements for particular issues.

- Individual Kaizen – improvement suggestions coming from individuals not from a grouped team and actually making the improvement that may be applied to any aspect of works. Every employee in DONGFENG is responsible for contributing their efforts on continuous improvement.

5S: is applied in the production site of DONGFENG to enhance the company image, assure quality, increase efficiency, promote standardization, support TPM, and
improve the safety of production site. Evaluation of 5S work is handled regularly, which enhances involvement of employees.

**Kanban:** In the workshop of DONGFENG, Kanban is used as a visual tool to education and announce achievement of improvements.

Kanban for Education

DONGFENG built a training area in every workshop where workers obtain knowledge of basic skills, standard operation, quality assurance, 5S, and Kaizen including ergonomics, KYT (Kiken-hazard, yochi-prediction, Training), seven wastes. The leader of the production unit is responsible for tutoring the other workers.  (See figure16)

![Figure 16: Kanban Training Area, DONGFENG](image1)

**Visual kanban:** is used to announce the current state and achievement of several aspects of improvements including Policy management, safety, quality, cost/delivery, Moral, Kaizen, and team information. (See figure 17)

![Figure 17: Visual Kanban, DONGFENG](image2)

**Successful Projects**

In recent years, they obtained 17587 successful kaizen projects per year, covering all
kinds of kaizen events. The production department mainly concerns QCD (quality, cost, delivery) kaizen. The achievements of QCD kaizen are reflected in KPI (Key performance indicator), for example, quality evaluation indicator, after sale service compensation indicator, and cost indicator. All those indicators have reached annual objectives. They successfully manage the situation that prices of raw materials are increasing by implementing QCD (quality, cost, and delivery) KAIZEN. They reached 10% reduction rate of manufacturing cost, which was 5% more than the original objective that they expected, which means they succeeded in offsetting increase of variable cost caused by increase of raw material.

**Views and Priorities of Lean**

Defects are the most targeted lean waste.

The top three effective lean tools and methods in providing cost/productivity improvements are: **Kaizen, JIT, 5S.**

**Integration of green into production system**

DONGFENG is ISO 14001 accredited. They have integrated environmental considerations (green) into production system since 2003. DONGFENG production department spend 5 hours in a week for environmental considerations integration and environmental performance improvements, and 2% of production department personnel are responsible for green aspect integration and performance improvements.

Environmental, Health, and Safety (EHS) Manager is responsible for integration of environmental considerations and into the production system and environmental performance improvements.

**Appreciation of green in production department**

Green and Green manufacturing concept are appreciated in the production system in accordance with all environmental laws and regulations for pollution prevention, accidents prevention, and continuously improving environmental performance.

The implication of implementing green philosophy is to integrate 3R –Reduce, Reuse, and Recycle into production development.

DONGFENG has defined its production system based on green philosophy. DONGFENG green production system is designed based on clean production, cyclic economy. It aims to achieve improvements of overall environmental performance, in accordance with environmental regulations. They minimize natural resource consumptions, energy losses and wastes by using continual improvement tools and
In order to cope with the environmental regulations and safety issues, the production department established a system through integration of the two standards that ISO 14001:2004 standards and OHS 18001:2001 standards.

Environmental performance improvement and environmental impact elimination are handled by continuous improvement through constantly strengthen the environment management system and occupational health and safety management system. The production department obtains cost/productivity improvements by eliminating environmental waste.

**Strategies to Cope with Environmental Regulations and Safety Issues, and Cost and Productivity, Environmental Performance and Environmental Impact Elimination Improvements**

ISO 14001 (Environmental Management System): is guiding principles used in design, use of processes and products to provide cost/productivity improvements and better environmental performance.

EcoAudits: Ecoaudits is used to assess equipment use, waste and recycling, and material usage processes.

Carbon Footprinting: Carbon Footprinting is the approaches specifically used to improve Carbon usage and Green House Gases production.

Life Cycle Assessment (LCA), and Environmental Failure Mode and Effect Analysis (E-FMEA): are applied to identify and evaluate potential environmental impacts that can occur life-cycle phases of a product to have corrective and preventative actions to minimize the environmental impact.

Design for the Environment (DfE): is used to design or redesign products, processes and management systems in order make them cleaner, more cost-effective and safer for workers.

The Eco-Management and Audit Scheme (EMAS), Cleaner Production and Eco-Efficiency: are adopted to provide identification and continuous improvement of environmental impacts with constant monitoring of environment associated processes.

Environmental Impact Analysis (EIA): are the guidelines used within production department for assessing environmental impacts of new development proposals prior
Successful Projects

The success projects conducted in DONGFENG are mainly focus on reduction of CO2 emission, resource utilization, and reduction of pollutant emissions by implementing green improvements. The achievements are: 95% of the utilization of resources, 100% utilization of water (zero waste water emission), 95% utilization of solid waste, and the attainment discharge of various pollutant.

Views and Priorities of Green

The environmental waste types that the production department mostly focuses to eliminate are: waste water, solid wastes, and waste gases.

Green strategies, tools or methods that can be named as significantly effective in cost/productivity improvements and environmental impact reduction are: Carbon footprint printing, Life-cycle assessment, Design for the environment.

Integration of lean and green in production system

The production department has efforts integrate lean and green philosophies in production system in DONGFENG. They have been working on integration of lean and green philosophies since 2006. Nissan production way is implemented to optimize the production system as well as reducing CO2 emission. Around 0.5% of employees are working with lean and green integration in the production department. There is a Kaizen team formed to integrate lean and green efforts and provide cost/productivity and environmental performance improvements in the DONGFENG. The team members are including production engineers from production department; industrial engineers form central department, and EHS (environment, health, and safety) manager. Industrial engineer is the main person in charge of integration work. Manufacturing engineer and EHS manager assist Industrial engineer with associated work. The main objectives of the Kaizen team are promoting cleaning production by applying approaches to lean and green.

Appreciation of “lean and green” in production department

DONGFENG utilizes Lean and EMS for waste elimination and cost reduction. They have continuous improvement that focus on both lean and EMS. Lean implementation activities enhance EMS outcomes in a way. And EMS can add value to lean by clearing environmental blind spots.
Efforts to Associate Lean and Green Philosophies, and Lean Wastes with Environmental Wastes

DONGFENG is making efforts to redefine the concept of lean waste associated with green wastes based on lean and green philosophy. The goal is to produce only what the customer wants.

“Lean and Green” Tools and Methods

Kaizen Events: Energy use and waste water generation is targeted by Kaizen events.

5S: is used to segregate recyclable materials and hazardous wastes from other wastes and to improve waste management and recycling practices.

Standard Work: is used to illustrate EHS (environmental, health, safety) procedures.

Just-in-Time (JIT): Is being used to reduce chemical and hazardous waste containment in production department.

Andon: is used to draw attention when environmental problems occur.

Successful Projects

Environmental focused Kaizen Events are including utilization of resources, waste water utilization of water (zero waste water emission), utilization of solid waste, and the attainment discharge of various pollutants. DONGFENG has obtained 95% of the utilization of resources, 100% utilization of water (zero waste water emission), 95% utilization of solid waste, and the attainment discharge of various pollutants so far.

Views and Priorities of “Lean and Green”

The types of environmental wastes that can be stated as the most targeted by lean environmental waste reduction efforts are: Energy use.

The lean strategies, tool or methods that can be named as significantly effective in environmental impact reduction are: Kaizen Events, JIT, 5S.

4.4 COMPANY 4 - JINXIANG BADGE

Integration of lean into production system

Jinxiang Badge has been working with lean philosophy since 2006. They did not have chance to implement lean because of a lack of awareness of lean system until the customers required the certification of ISO 9001 quality management system. They acquired knowledge of lean guided by the certification system, and started to
integrated lean philosophy into their production system.

Every production unit which is divided by production process has a routine meeting every morning before production. It usually takes 5 minutes to 10 minutes. The leader of its production unit holds the meeting. All the workers from the production unit are required to attend the meeting. The contents of the meeting are: 1. 5S work, 2. Techniques and quality, 3. Safety, 4. Summarize yesterday’s work and arrange today’s tasks, 5. Equipment maintenance. Perform required equipment maintenance and record in logbook in order to ensure workshop equipment in a good working state. 6. Summarize wastes of material, energy, water and electricity. 7. Carry out the instruction and tasks arranged by higher organization. 8. Solve promptly problems reflected by the employees and collect new improving suggestions from employees. 9. Labor disciplines.

Jinxiang Badge has a weekly routine meeting in Monday. It takes 30 minutes to 60 minutes depending on the specific situation. The staffs required to attend are general manager, managers from each department, and directors of each workshop. The contents of the meeting are: to summarize the work occurred a week earlier, to collect improvement suggestions, to resolve problems generated within the production process, to confirm achievements, and to arrange new production tasks.

Jinxiang Badge encourages every employee to participate the continuous improvement activity by rewarding them with bonuses. Production Director and Administration Director take responsible for the works associated with lean implementation or improvement. Production Director is responsible for: 1. learning and reporting the situation of production including problems occur during the production process and improving suggestions from the employees, 2. Implementing lean through training employees, 3.taking care of improvements project. Administration Director is responsible for: 1. reporting production performance and requirements of improvement to the top management; 2. Assist the production director to implement lean improvement. There is no special team formed to provide lean improvements other than the two persons.

Appreciation of lean in production department

The implication of lean philosophy is having continuous Kaizen culture permeate the whole organization. Every employee enjoys contributing their effort on the improvement of production process, through providing suggestions for reducing all sorts of wastes they observed. Meanwhile, the working area is improved by 5S.

Jinxiang Badge has defined its production system based on lean philosophy. The
production system is aimed to achieve better quality, less wastes, faster delivery time, environmental friendly, better safety through continuous Kaizen. They have made lots of efforts on above aspects and they are still working on it. It is hard to survive in the increasingly competitive market, if they do not build lean concepts into the production system essentially.

**None-value added work elimination**

Jinxiang Badge handles elimination of none-value added work generally by Kaizen events.

**Cost and Productivity, Quality and Safety Improvements, and Continuous Improvement Culture**

**Cost and productivity improvement:** In Jinxiang Badge, cost and productivity improvements rely on innovation and improvement - innovation of production process, innovation and improvement of equipment, and continuously improvement.

**Quality:** Jinxiang Badge strictly comply with ISO 9001:2000 quality management systems. They adopt 5 Whys for quality problem analysis. They obtained the concept of 5 Why from their customer, HONDA. Basically, the quality related problems targeted by 5 Why analyses are categorized in 5 main root causes in Jinxiang Badge: People, Machine, Law, Material, and Other aspects. Standardized work is also used to assure quality.

**Safety:** Jinxiang Badge acquired Occupational Health and Safety Management System Certification (B/T28000-2001). Safety work is handled according to the certification. 5S, standardized work, and TPM are applied on safety management. Every employee is involved in the safety Kaizen activities.

**Continuous improvement:** In Jinxiang Badge, continuous improvement is undertaken in two ways in the production site – small kaizen and big kaizen. Small kaizen is handled in each workshop. They have routine Kaizen meeting every day that focus on 5S and elimination of wastes occurs in the working place. And every worker is involved. Big Kaizen is handled by both production engineers and production unit leaders. They have routine meeting every week that focus on solving problem that occurs in the production process. Production director and Administration Director are mainly responsible for the Kaizen events.

**Lean Tools and Methods**

**Process Mapping:** Jinxiang Badge uses Process Mapping as a technique for streamlining work. It is handled by the production engineer. The process map visually
depicts the sequence of events to build a product. It includes additional information such as cycle time, inventory, and equipment information. They use this technique to analyze and identify non-value added work.

**One-Piece-Flow/JIT:** One-Piece Flow and JIT lean tools are generally used to provide the production processes with the right part, at the right time and in the right amount in Jinxiang Badge.

**Kaizen:** Jinxiang Badge applies continuous improvement in quality, technology, processes, company culture, productivity, production design and safety. 5why is used with Kaizen. In Jinxiang Badge, continuous improvement is undertaken in two ways in the production site – small kaizen and big kaizen. Small kaizen is handled in each workshop, while Big Kaizen is handled by both production engineers and production unit leaders.

**Five-Why:** Jinxiang Badge applies this tool to solve problems. They consider it is a very useful and effective tool as it really drives employees involved using their brains and challenging the ‘status quo’. By repeating why five times, the root of the problem and its solution becomes clear.

**5S:** Basically, 5S is used for improving the working area and warehouse (Figure 18) in Jinxiang Badge. 5S work is done every day in every workshop. Every employee is involved in the 5S improvement. Production leader of each production unit reports the evaluation results of 5S work in the routine meeting every morning.

**TPM:** In Jinxiang Badge, TPM is applied to reduce defects, breakdown and accidents in the production site as well as prolong equipment service life. Preventive maintenance is the typical type of maintenance in Jinxiang Badge. This maintenance is conducted both daily and monthly. Daily maintenance, including cleaning, inspection, oiling and re-tightening, is handled by the workers daily. Monthly maintenance, equipment inspection or diagnosis, is handled by the technician from the
equipment factory.

**Heijunka (Production Leveling):** It is used to improve the production flow, which is handled by the Production Scheduling Engineer.

**Successful Projects**

Jinxiang Badge has done 17 projects since 2006, which focus on optimizing production process, improving quality, eliminating waste, reducing lead time, ergonomics, and safety, and productivity.

**New Plant Layout:** In order to upgrade the production system from traditional production system to lean production system, they built a new plant. The new plant layout including warehouse to streamline production flow is designed based on Lean principles and Processing Mapping. The shape looks concentric circle. The warehouse is located in the center of circle. The production workshops are located in the circle outside one by one based on production process. The warehouse is used for stocking raw materials and parts. Through this plant layout improvement, lean implement or improvement is able to carry out. In the meantime, wastes are greatly reduced. The waste of transportation is obviously reduced.

![FIGURE 19 NEW PLANT LAYOUT OF JINGXIANG BADGE.](image)

**Views and Priorities of Lean**

The most targeted lean waste is: **Defects.**

The top three effective lean tools and methods in providing cost/productivity improvements are: **Kaizen, TPM, 5S.**

**Integration of green into production system**

Jinxiang Badge is using ISO 14001:2004 Environmental Management System. Jinxiang Badge has been integrating environmental considerations (green) into
production system since 2005. Jinxiang Badge production department spend 6 hours in a week for environmental considerations integration and environmental performance improvements, and 1.5% of production department personnel are responsible for green aspect integration and performance improvements.

There is only one team regarding integration of environmental considerations and into the production system and environmental performance improvements. The team members are from Production departments and Administration departments. The responsibilities of the team are: 1. To implement and maintain ISO14001:2004 Environmental Management System, 2. To present the achievement of environment and improvement demand to the top management, 3. To collect occupational health and safety information from employees, 4. Handle environmental improvement.

**Appreciation of green in production department**

Green and Green manufacturing concept are appreciated in the production system in accordance with all environmental laws and regulations for protecting the environment and ensuring the continually, improve environmental performance.

The implication of implementing green philosophy is to integrate sustainable development concept into production development.

Jinxiang Badge has defined its production system based on green philosophy. It is named as green production. It aims to achieve improvements of overall environmental performance, in accordance with environmental regulations. They minimize natural resource consumptions, energy losses and wastes by using continual improvement tools and training their employees.

**Strategies to Cope with Environmental Regulations and Safety issues, and Cost and Productivity, Environmental Performance and Environmental Impact Elimination Improvements**

In order to cope with the environmental regulations and safety issues, the production department established a system through integration of the two standards that ISO 14001:2004 standards and OHS 18001:2001 standards.

Environmental performance improvement and environmental impact elimination are handled by continuous improvement through constantly strengthen the environment management system and occupational health and safety management system. The production department obtains cost/productivity improvements by eliminating environmental waste. Process Mapping is used to identify wastes.
Green Tools and Methods

ISO 14001 (Environmental Management System): is guiding principles used in design, use of processes and products to provide cost/productivity improvements and better environmental performance.

EcoAudits: Ecoaudits is used to assess equipment use, waste and recycling, and material usage processes.

Carbon Footprinting: Carbon Footprinting is the approaches specifically used to improve Carbon usage and Green House Gases production.

Life Cycle Assessment (LCA), and Environmental Failure Mode and Effect Analysis (E-FMEA): are applied to identify and evaluate potential environmental impacts that can occur life-cycle phases of a product to have corrective and preventative actions to minimize the environmental impact.

Design for the Environment (DfE): is used to design or redesign products, processes and management systems in order make them cleaner, more cost-effective and safer for workers.

The Eco-Management and Audit Scheme (EMAS), Cleaner Production and Eco-Efficiency: are adopted to provide identification and continuous improvement of environmental impacts with constant monitoring of environment associated processes.

Environmental Impact Analysis (EIA): are the guidelines used within production department for assessing environmental impacts of new development proposals prior to execution of proposals.

Successful Projects

The success projects conducted in Jinxiang Badge are mainly focus on elimination of hazardous wastes by separating hazardous wastes correctly and eliminating them in appropriate manners, wastewater treatment by PLC controlled process, and waste gas treatment. As a result, environmental, occupational health and safety performance has been greatly improved. The attainment rate of discharge of ‘three waste’ reached 87%. The incidence rate of occupational diseases decreased to 2.3%. The rate of energy consumption decreased 0.5% annually.

Views and Priorities of Green

The environmental waste types that the production department mostly focuses to eliminate are: waste water, waste chemicals, and waste gas.
Green strategies, tools or methods that can be named as significantly effective in cost/productivity improvements and environmental impact reduction are: DFE, Environmental Impact Analysis, and POUS with 5S efforts.

“Our Lean and Green” refers to relating and integrating lean and green concepts.

Integration of lean and green in production system

The company has effort to integrate lean and green practices in production system. But the production department has been working on integration of lean and green philosophies since 2009. No employees from the production department are working with lean and green integration and associated cost/productivity and environmental performance improvements. There is no team formed to conduct lean and green wastes focus Kaizen event.

Appreciation of “lean and green” in production department

Jinxiang Badge has not defined its production system based on a “lean and green” philosophy. There is no appreciation of integration of lean and green concepts in the production department.

Efforts to Associate Lean and Green Philosophies, and Lean Wastes with Environmental Wastes

Production development uses process mapping tool to analyze both lean and green wastes from a lean and green connection.

“Lean and Green” Tools and Methods

5S: is used to segregate recyclable materials and hazardous wastes from other wastes and to improve waste management and recycling practices. In a meantime, 5S work concerns energy conservation. Employees are required to turn off the power researchers when they finish using the machine.

Standard Work: is used to illustrate EHS (environmental, health, safety) procedures.

Process Mapping: is used to analyze green wastes generated in the production process.

Point-of-Use Storage (POUS) with 5S: is used for chemicals and hazards management. (See Figure 20)
Successful Projects

Environment focused Kaizen Events conducted mainly focus on energy reduction, waste water reduction, chemical and hazardous material minimization.

Views and Priorities of “Lean and Green”

The most targeted environmental waste by lean environmental waste reduction efforts is: Energy use.

The lean strategies, tool or methods that can be named as significantly effective in environmental impact reduction are: 5S and Process mapping
5. Discussions

This chapter analyzes and discusses the results obtained from interviews associated with the theories acquired from literature studying. The aim is to answer the research questions posed in Section 1.3. Therefore, in responding to the four research questions, the discussions of the results are described respectively as follow:

**RQ1 (Lean Production): How has the lean philosophy been integrated, appreciated, and applied in the production system of automotive industry companies?**

a) The implication of lean philosophy

All the companies interviewed have been practicing lean for the last 4-21 years. Currently, the production system is defined based on lean philosophy in every interviewed company. Lean improvements are mainly handled by Kaizen Events. Hence, Kaizen events are the part of each and every organization (interviewed companies in China and Turkey). They are used to form and group production teams and to manage lean improvement activities. Every lean tool can be used with Kaizen to improve different problems. The results of cost and productivity improvements that every organization achieved indicate that Kaizen is a solid systematic tool for an improvement project. Kaizen events aim to involve every production employee to lean improvements in addition to their daily production operations, and directly provide the continuous improvement culture in the interviewed companies.

Moreover, Tofas has put more emphasis on blue collar capability and involvement in lean production compare to other companies that are interviewed. In Tofas, all the production personnel have been group into lean production teams (other than kaizen team organization, which is a common aspect in each interviewed company) with an assigned lean team leader. Lean team leaders are responsible for managing lean improvements in their teams and white collar lean production engineers only provide supervision for lean teams and not have a direct involvement in lean improvement activities since white collar workers cannot have the same level of detailed focus and knowledge on production process as blue collar production workers according to Tofas’ lean production appreciation.

In Tofas, a lean improvement cost deployment strategy is being used to identify the lean waste reduction opportunity that can lead to the most cost reduction in the production department. Therefore, lean improvement possibility is being prioritized in
Tofas according to their possible cost (the current amount of associated losses in the system) reduction magnitude and total available resources to carry out lean improvements. Similarly, QCD (Quality, Cost, and Delivery) Kaizen approach in Dongfeng evaluates the investment cost of a lean improvement opportunity and associated cost reduction after the improvement to prioritize improvement opportunities.

b) The application of lean practice

Generally, non-value added works (defects, inventory, overproduction, waiting, transportation and motion, over processing) are identified by Value Stream Mapping (VSM) or similar approaches (Process Mapping, Jinxiang Badge) in production departments of the interviewed companies.

Built-in Quality (Jikotei Kanketsu) and Kaizen Events are used as tool to approach quality related lean production wastes (defects and rework) in Tofas and Karsan (Turkey), whereas Jinxiang Badge and Dongfeng (China) uses ISO9001 management system, 5Why approach and Kaizen Events to deal with quality related lean wastes.

Tofas, Jinxiang Badge and Dongfeng deal safety related issues with application of 5S in the workspaces. Kaizen events can be a common tool in all the interviewed companies to approach safety issues within the production department. Additionally, Dongfeng uses KYT (Hazard Prediction Training) to detect and take preventative measures against potential errors and hazards that can lead to safety issues in the production environment.

Continuous flow within the production systems of the interviewed companies are provided by JIT (Just-in-time), Kanban and One-piece flow lean approaches. All the interviewed companies (Turkey and China) adopted and integrated the stated continuous flow providing approaches into their production systems.

Standardized work has been achieved through 5S or similar workspace standardization operations in all the interviewed companies. And Poka-Yoke (mistake proofing) standardizing approaches are appreciated as essential part of lean improvement practices by Tofas and Karsan (Turkey). Total Productive Maintenance (TPM) is being used in all interviewed companies except Karsan to limit potential maintenance needs and to reduce high cost of maintenance in long term.
c) The views and priorities regarding lean practice

In the interviewed companies from Turkey and China, the most observed non-value added work that lean approach addressing at in the companies is identified as Defects. The lean tool/method that can be stated as the most effective in providing cost/productivity improvements is identified as Kaizen Events.

A combined list of prioritized lean wastes (non-value added works) and lean tools/methods in the interviewed companies can be presented as the below:

- **Non-value added works:** Defects and Rework, Transportation, Unnecessary Motion, Waiting, and Inventory.

- **Lean tools/methods:** Kaizen Events, Poka-Yoke, Value Stream Mapping, JIT (Just-in Time), 5S, and TPM (Total Productive Maintenance).

*RQ2 (Green Production): How has the green (environmental perspective) been integrated, appreciated, and applied in the production system of automotive industry companies?*

a) The implication of green philosophy

The interviewed companies have been integrating environmental perspective into production system for the last of 2-14 years. Green manufacturing concept is appreciated by all companies in the production system as to comply with all environmental laws and regulations for protect environment and ensure the continually improve environmental performance and accordingly, the production systems has been defined based on green philosophy. ISO14001 (Environmental Management System) is used to collectively and continuously manage environmental improvements in every interviewed organization (Turkey and China). And all the interviewed companies have acquired ISO 14001 certification.

Karsan, Dongfeng and Jinxiang have only one team for coordinating environmental management and performance improvements, whereas, in Tofas environmental management and performance improvement are divided into two main teams and areas: Energy and Environment.
b) The application of green practice

Majority of the companies cope with the environmental regulations and safety issues by complying with the requirements of ISO 14001 Standards and OHS 18001 Standards. All the companies handle environmental performance improvement and environmental impact elimination by continuous improvement through constantly strengthens the environment management system and occupational health and safety management system.

Green tools and methods, such as EcoAudits, Carbon Footprinting, Life Cycle Assessment, E-FMEA, DfE, EMAS, and EIA, are widely applied to handle various environmental issues and safety issues occurring during the production processes, as well as to be used for cost/productivity improvements. For instance, EcoAudits can be used to assess equipment use, waste and recycling, and material usage processes. Carbon Footprinting can be used to improve Carbon usage and Greenhouse Gases production. LCA and E-FMEA can be applied to identify and evaluate potential environmental impacts.

c) The views and priorities regarding green practice

In the interview companies from Turkey and China, the environmental waste type that the production departments mostly focus to eliminate is identified as waste water generation. Green tool/method can be named as significantly effective in cost/productivity improvements and environmental impact reduction differs from company to company.

A combined list of prioritized green wastes (environmental wastes) and green (environmental performance improvement) tools/methods in the interviewed companies can be presented as the below:


RQ3 ("Lean and Green" Production): How has the lean and green been integrated or related ("lean and green" production), collectively appreciated and applied in the production system of automotive industry companies?

a) The implication of “lean and green” philosophy

All of the companies interviewed have been integrating lean and green philosophies in production system for the last 1-5 years. Two of the companies have defined their production system based on “lean and green” philosophy. Tofas implements WCM (World Class Manufacturing) lean production system which focuses on eliminating green waste related activities (green pillar) by using WCM lean production tools and methods. Dongfeng defines their production system as clean production that is based on “lean and green” philosophy. In Karsan and Dongfeng, there is a Kaizen team formed to conduct environmental focused improvements. It indicates that Kaizen is a tool that can link lean and green together.

b) The application of “lean and green” practice

Generally, there are no direct efforts to associate lean and green philosophies other than simply adding green wastes related activities to lean wastes. The results indicate that lean tools can be applied on improving green in the aim to enhance EMS. Processing Mapping (Jinxiang) and Kaizen Events (all companies) can be used to target green wastes. JIT, POUS and 5S can be used to reduce chemical and hazardous material containment in the production department. Poka-Yoke can be applied to create mistake-proofing approaches to eliminate environmental wastes. Cost Deployment

c) The views and priorities regarding “lean and green” practice

The type of environmental waste that can be stated as the most targeted by lean environmental waste reduction efforts is identified as Energy use. The lean tool/method that can be named as significantly effective in environmental impact reduction is identified as Kaizen Events.

A combined list of prioritized green wastes (environmental wastes) targeted by lean tools/methods (“lean and green” wastes) and lean tools/methods applied for environmental performance improvements (“lean and green” tools/methods) in the interviewed companies can be presented as the below:

“Lean and Green” tools/methods: Kaizen Events, JIT (Just-in-Time), POUS (Point-of-Use-Storages), Poka-Yoke and 5S.

RQ4 (Lean, Green, and “Lean and Green” Production): What are the good examples of current practices that the companies have achieved within the area – successful approaches that have been performed at the plants?

a) Lean

Karsan:

- Built-in-Quality, Line Management, and Kaizen are applied to increase employee lean competency and ability to identify waste and lean improvements without white collar supervision.

- 120 Before/After Kaizen presentation have handled since Lean was being put into practice. 30 Kaizen Cycle Presentation have occurred. Their focus can be named as Quality, 7 Lean wastes, Ergonomics, and Safety. The two dominant focus of Kaizen Projects in Karsan is increasing available operator time, quality, and increasing available space. Increasing available operator time can be associated with elimination of unnecessary motion and transportation, loading, defects, and rework. And it creates possibility for Karsan to use the available workforce in different areas in production.

- As a result of Lean Projects, defect per vehicle measures decreased and built-in quality measures increased significantly in Karsan. Employee lean competency significantly increased and self-sustainability goal of a blue collar worker regarding waste identification and lean improvements without white collar supervision is achieved.

Tofas:

- Tofas uses poka-yoke yoke database to store all poka yoke
improvements and shares it with all Fiat plants, which enables implementation and sharing of successful poka-yoke approaches within Fiat organization.

- Can be exemplified with kaizen events handled towards limiting unnecessary motion, Tofas has got several patent for unique poka-yoke approaches that being also put into practice in other Fiat production plants. Results can be explained as making the labor idle for operation as highest level as possible by limiting rework with electronic and mechanic poka-yokes, and proving cost efficient and smart solutions to limit labor motion and waiting.

- Another successful approach in Tofas can be stated as examining competitor vehicle models. Competitor vehicles are being disassembled and later reassembled in order to identify possible lean improvement possibilities that can be integrated to Tofas production system. Value Stream Mapping is handled on the competitor vehicle and associated assembly times and costs are measured in order make a comparison with a competitor vehicle and detailed analysis are handled on the sub assembly that gives better timing and cost value compare to Fiat vehicles. Impact of this competitor vehicle analysis on lean improvement possibility creation in Tofas production system can be named as significant.

- **Dongfeng:**

  - Nissan Production System is proved as a successful manufacturing methodology, developed by Nissan, which comprises philosophy, principles, strategies, standards, and tools or methods.

  - QCD (Quality, Cost, Delivery) Kaizen approach helped the company successfully achieved 10% reduction rate of manufacturing cost, which is 5% more than they expected, while offsetting the increasing variable cost caused by increasing raw material. It indicates that QCD Kaizen is a good tool for reducing manufacturing material.

  - KYT (Kiken (Hazard), Yochi (Prediction), Training) Kaizen which
refers to training for hazard prediction is used to improve Safety. The company utilizes this method to detect and take preventive measures against potential errors or hazards.

- Douki Seisan & JIT Mixed-Model Production Line is used to handle several variants of one or more products.

- **Jinxiang:**
  - Improvement of new layout plants suggests that a company who want to integrate lean, layout of plant could be a good starting point.
  - Process Mapping is used to analyze and identify non-value added work.
  - Five-Why is proved as a very useful and effective tool to find the root causes of problems.
  - 5S helps the company to improve the working area and warehouse.

b) **Green**

- **Karsan:**
  - Mainly, includes reducing the amount of hazardous wastes by using methods such as; separating hazardous wastes correctly and eliminating them in appropriate manners. Karsan has reduced the cost of eliminating hazardous wastes as a result.

- **Tofas:**
  - Environmental waste classification project enabled to group waste and thesis categorized approach enabled efficient assessment and improvement of wastes.
  - Another project that has been taken into practice is using Fiat’s Best Practices. Fiat’s company portal is being used to observe best practices within Fiat production plants and integrate the ones which are required and applicable for environmental impact reduction and
performance improvements.

- Additionally, green (environmental friendly) purchasing and logistics activities development projects were taken into practice and selection of ISO 14000 certified suppliers are prioritized. And currently, Tofas is initiating a project to reduce the amount of materials that leads to environmental impacts on a vehicle.

- **Dongfeng:**

  - Green tools that comprise Carbon Footprinting, Life Cycle Assessment (LCA), Design for the Environment (DfE), and Environmental Impact Analysis are used to increase resource utilization and reduce CO2 emission and pollutant emissions.

- **Jinxiang:**

  - Design for the Environment (DfE) is used to design or redesign products, processes and environment management systems.

**c) “Lean and Green”**

- **Karsan:**

  - Energy reduction Kaizen Projects is being conducted in the company, a Kaizen Team was formed in Karsan regarding Natural Gas, Air, and Electricity Usage. The team contains Blue Collar Lean Group Leaders and Maintenance Team Leaders. Kaizen Team has identified Energy usage related problems and wastes, and provided solution proposals. Currently, Energy usage related kaizen projects are still progressing and deliver short term results.

  - Waste water reduction kaizen events Karsan also conducted in production department. An important result can be named as reduction of waste water amount in paint shop. 1.9 tons of waste water creation was reduced to 1.5 tons, which enabled approximately 300 to 400 liters of water reduction per vehicle produced. Optimal time of vehicle wash was achieved and new environmental friendly
washing technologies started to being used and the new technology enables cost reduction both in long and short term. Associated energy and chemical reduction due to vehicle wash waste water reduction noted as additional environmental gains of conducted kaizen event.

- JIT and POUS (Point of usage Storage) Lean mentalities are collectively used in order to reduce chemical and hazardous material containment in the product department. Chemical and hazardous material point of use storages are being filled by a third-party company with JIT supply mentality (storage levels are continuously being measured) and production department only stores the amount that they will use in a short period of time. The approach is directly leading reduced amount hazardous and chemical materials and associated risks, environmental management costs, and inventory level together with improved safety. Additionally, POUS drastically reduces unnecessary labor motions since the storages are located next to the processes that they are being used.

➢ Tofas:

- The production department has integrated green waste as a lean waste into its production systems therefore it enables to approach green wastes with lean methodologies and tools.

- Tofas has achieved 5% energy reduction in the production department by the help of kaizen events with energy focus. Energy reduction kaizen events have had the focus on processes that contains air usage, heating, refinement, and pumping.

- Currently, an ongoing waste water generation reduction kaizen event is being handled in the production department. The kaizen event aims to reduce the waste water generation in the production department by 10%.

- Another project was initiated to form a database in to order to store all poka-yokes (mistake proofing) approaches that deal with environmental improvements within the production department. It can be stated that Tofas has integrated lean poka-yoke methodology
to environmental performance improvements. When environmental wastes are identified, Tofas seeks for the opportunity to eliminate reoccurrence of environmental wastes via creating mistake-proofing approaches. All the identified environmental poka-yokes are being stored in order to integrate an identified poka-yoke to different processes with production department when a similar poka-yoke implementation opportunity is observed. Additionally, the database is also accessible to other Fiat production plants to observe and use environmental poka-yoke approaches within Tofas production department as a best practice.

- **Dongfeng:**
  - Kaizen with a focus on environment is proved to be the most efficient way to improve environmental performance.

- **Jinxiang:**
  - Process Mapping is used to analyze green wastes and lean wastes generated during the production process.
  - Storage of chemicals and hazards are handled by POUS with 5S efforts. It improves environmental health and safety of workers, as well as enables the chemicals and hazards are easy to be found.
6. CONCLUSIONS & FUTURE STUDY

In this chapter, the outcomes of the research are discussed. Further, the chapter concludes with a discussion of possible future study.

6.1 CONCLUSIONS

The main objective of this thesis has been to contribute to a further understanding of how approaches to lean and green can be used to develop competitive production systems. A theoretical frame of reference has been presented in order to provide the research with a theoretical foundation. Further, empirical studies of four companies from China and Turkey have been carried out to investigate how companies perceive and work with their production systems in terms of applications of lean and green approaches. The empirical studies also aimed at identifying good examples of current practices that the companies achieved within the area.

From the literature studying, the three main subjects in regards to main research content were presented: Lean Production (RQ1), Green Production (RQ2), and “Lean and Green” Production (RQ3). Lean Production and Green Production theoretical frameworks basically contains: definitions, principles, types of wastes, and tools and methods. “Lean and Green” Production subject contains a theoretical framework of how lean and green can be related or integrated in production systems. “Lean and Green” Production theoretical framework includes: relating lean and green via associating lean and green wastes (Waste Perspective); lean and energy use relation; lean and chemical waste relation; and finally, lean tools and their implications to environmental performance.

A survey study was conducted with the aim of showing the current state of the approach to lean and green in the companies. The study presented the implication, application, and views and priorities of Lean Production (RQ1) in the companies; accordingly, implication, applications, and views and priorities of Green Production (RQ2) and “Lean and Green” Production (RQ3). As a result, good examples of current practices of each company have been identified.

The results from the thesis are the following:

• **Literature study** has been accomplished. It is presented in the theoretical framework part. Based on that, the guiding interview questions have been created. It also supports Discussions.

• **Interview** as a survey instrument has successfully delivered with a good result. The primary data obtained from interview is reported in Results part.

• **Discussions** of the results associated with theories have answered the research
questions. The picture of current state of the approach to lean and green in China and Turkey is clearly illustrated in the Discussions.

The specific results in the thesis are the following:

- Lean and green approaches of the automotive companies in China and Turkey have been identified and compared.
- Good examples of lean and green practices in the automotive companies in China and Turkey have been identified.

Based on the results of the thesis, the authors believes that the automobile companies should have more efforts to identify or find opportunities to enhance the environmental performance outcomes associated with the implementation of both lean and green (EMS). The recommendations for the efforts are:

- Production department and Environment department should work together to integrate lean and green into production system by having meetings or discussions regularly. They can share ideas with each other on how to improve production system and environmental issues. The aim is to raise awareness on coordinating lean and green initiatives as well as to identify opportunities for integrating lean and green implementation activities.

- If the ideas of lean and green integration are agreed as a potential improvement by both departments, the company should test them in reality. The aim is to identify best practice examples in order to develop a guide to lean and green integration.

### 6.2 FUTURE STUDY

Continued work with this thesis project could involve associating ongoing strategies, tools and methods with general lean, green and “lean and green” strategies, tools, and methods used in manufacturing organizations today. This continued study could further inspire and guide companies to make additional studies and investments regarding tools to use for additional cost/productivity improvements as well as environmental performance improvements. The project could also direct companies to make investment analysis regarding general strategies, tools and methods that they today are not using.
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8. APPENDICES

Appendix I Master Thesis Proposal

Karin Romvall
Green Production Systems
2010-4-17

Master Thesis Proposal

Lean and Green Production Systems

Green Production Systems
The vision of the Green Production Systems research project is to develop environmentally sustainable production systems to be a competitive mean to Swedish automotive and manufacturing industry. It requires the mindset and incentives of manufacturing industry to define and implement a ‘green’ strategy in integration with a lean philosophy. It also requires the development of knowledge as well as supporting tools to facilitate the needed visualization, control and management o environmental parameters within the production system.

Master Thesis on Lean and Green
This master thesis proposal is connected to work package 4 “Development of guidelines for environmental value improvement and cost decrease” of the Green Production Systems research project.

Even though the Swedish manufacturing and automotive industry is aware of the benefits of environmental activities within the production system, most of the work is managed by environmental experts and not integrated in day-to-day operations. In order to escape the complexity found in companies today and improve the situation, one suggestion is to integrate the green perspective with the lean philosophy and hence, create a culture of continuous environmental improvements. An interesting perspective to cover is how these issues are dealt with in different countries in order to make a comparison and try to identify best practices.

Objective
The objective is to compare the approach to lean and green in different countries. The following research questions are suggested:

RQ1: To what extent has the lean philosophy been implemented in manufacturing companies in the countries compared?

RQ2: To what extend has the environmental perspective been integrated in the production system of the manufacturing companies in the countries compared?

RQ3: How do lean and green relate when applied on the production system?
The goal is to present the current state of lean and green activities in different countries in order to identify best practices.

**Research methodology**
Literature review + interview/survey study comparing the Swedish manufacturing industry with the manufacturing industry in other countries on the topic of lean and green.

**Project start**
Immediately or according to agreement.

**Supervisor**
Karin Romvall and Mats Jackson
Appendix II Guiding Interview Questions

LEAN PRODUCTION (RQ1)

1. Has the production department integrated lean into production system?
   a) How long have the organization been implementing lean or working with lean philosophy?
   b) Have many hours does the production department spend in a week for lean implementation and/or improvements?
   c) How many percent of employees working with lean implementation and/or production development in the production department?
   d) Are there any teams formed in order to provide lean implementation and/or production development in the production department? And what are assigned responsibility of each team?

2. How is Lean concept appreciated (implication of lean) in the production department?
   a) How can company’s lean philosophy (implication of lean) regarding production development operations be described?
   b) Has company defined its production system based on lean philosophy? And How?

3. How does the production department works with elimination of non-value added work (Defects, Inventory, Overproduction, Waiting, Transportation and Motion, Over-processing, etc.)?

4. How does the production department work with reducing cost while improving productivity (cost/productivity improvements)?

5. How does the production department work with quality, safety and lead time improvements?

6. How does the production department work with continuous improvement?

7. What are the lean production principles, strategies, standards, tools or methods applied to handle following issues in production department? And how do they apply each tools or methods in production development (which lean “muda” wastes, non-value added activities they target at)?
   a) How do you work with these tools and methods in the production development?
   b) What is the implication of these tools and methods to your company?
   c) Who are involved in a company level? How many percent of people are involved in the company?
   d) How much time does production development spend on this approach per week or per month?
e) What are the typical projects in terms of this approaches look like that you have done? What the results have been achieved? And how?

f) Are there any tools or methods for identifying non-value-added work in the process? (VSM)

g) Are there any approaches for enabling the value-added flow fast and flexible? (one piece flow or continuous flow)

h) Are there any tools or methods that are used for stabilizing and standardizing production processes? (5S, TPM, standardized work, jidoka, heijunka, kanban)

i) Are there any tools or methods used in visual control systems? (5S, kanban)

j) Are there any approaches for organize the working area that to sustain and to standardize the works including sort, set in order, and shine? (5S)

k) Are there any approach for maintenance or improving equipment effectiveness associated with breakdowns, equipment setup and adjustment losses, idling and minor stoppages, reduced speed, defects and rework, spills and process upset conditions, and startup and yield losses? (TPM)

l) Are you working with Just-in-time? Are there any tools or methods applied on Just-in-time production which can produce products that customers want, when they want, in the quantities they want? (one piece flow, heijunka, takt time, pull system, kanban, 5S)

m) Are there any tools or methods for communication in the process? For example, how do you tell workers what and when to produce or to withdraw? (kanban)

n) Are there any approaches for balancing and leveling production volume and production time in order to keep rate of production constant irrespective of the fluctuation in demand? (Production leveling)

o) Are there any tools or methods for problem solving? For example, how do they identify errors or defects occur during the process? (JIDOKA>POKA-YOKE, andon, 5s, )

p) Are there any tools or methods used for enhancing employee involvement? (Kaizen, standardized work, 5s, tpm,)

8. How many successful lean (cost/productivity improvement, non-value added activity elimination or continuous improvement) projects were observed in process level? What are their focus and which results are obtained?

9. What are organizations views and priorities regarding lean practice?
   a) What are the most observed non-value added work (lean wastes) that lean approach addressing at (Name 3 at least)?
   b) What are the lean tools and methods that can be stated as the most effective in providing cost/productivity improvements (Name 3 at least)?
GREEN PRODUCTION (RQ2)

10. Has the production department integrated environmental perspective (green or green manufacturing concepts) into production system?
   a) How long have the organization been integrating environmental considerations (green) into production system other than necessary environmental regulations to be fulfilled?
   b) Have many hours does the production department spend in a week for environmental considerations integration and/or environmental performance improvements?
   c) How many percent of employees working with environmental considerations (green) integration and/or environmental performance improvements in the production department?
   d) Are there any teams formed in order to integrate environmental considerations to the production system and/or provide environmental performance improvements in the production department? And what are assigned responsibility of each team?

11. How are Green and Green Manufacturing (environmental perspective integration) concepts appreciated in the production department?
   a) How can company’s green philosophy (implication of green) regarding production development operations be described?
   b) Has company defined its production system based on green philosophy? And how?

12. How does the production department cope with environmental regulations and safety issues?

13. How does the production department works with environmental performance improvement and environmental impact elimination?

14. How does the production department obtain cost/productivity improvements by using green practice (environmental waste elimination)?

15. What are the green manufacturing principles, strategies, standards, tools or methods used in production department? And how are they used in production development (which environmental wastes they target at)?
   a) Are there any guiding green principles used in the design, use of processes and products to provide cost/productivity improvements and better environmental performance [Green Engineering Principles]?
   b) Are there any approaches specifically used to assess equipment use, waste and recycling, and material usage processes [EcoAudit]?
   c) Are there any approaches specifically used to improve Carbon usage and Green House Gases production [Carbon Footprinting]?
d) Are there any approaches to identify and evaluate potential environmental impacts that can occur life-cycle phases of a product to have corrective and preventative actions to minimize the environmental impact? [Life Cycle Assessment (LCA), Environmental Failure Mode and Effect Analysis (E-FMEA)]

e) Are there any approaches or strategies to design or redesign products, processes and management systems in order make them cleaner, more cost-effective and safer for workers, public and environment [Design for the Environment (DfE)]?

f) Are there any approaches or overall environmental management systems used to provide identification and continuous improvement of environmental impacts with constant monitoring of environment associated processes [EMAS (The Eco-Management and Audit Scheme), ISO 14001 (The International Environmental Management System Standard), Cleaner Production and Eco-Efficiency]?

g) Are there any guidelines or approaches specifically used for assessing environmental impacts of new development proposals prior to execution of proposals [Environmental Impact Analysis (EIA)]?

h) Are there any published standards used in production processes to manage environmental impacts, evaluate environmental performance, and provide appropriate usage and implementation of green manufacturing tools and methods [ISO 14000 Series]?

16. How many successful green practice (environmental waste elimination) projects were observed in process level? What are their focus and which results are obtained?

17. What are organizations views and priorities regarding green practice?
   a) What type of environmental wastes does the production department mostly focus to eliminate (Name 3 at least)?
   b) Which green strategies, tools or methods that can be named as significantly effective in cost/productivity improvements and environmental impact reduction (Name 3 at least)?

“LEAN AND GREEN” PRODUCTION (RQ3)

18. Does the production department have efforts integrate lean (cost/productivity improvement strategies) and green (environmental considerations) philosophies in production system?
   a) How long have the organization been working on integration of lean and green philosophies?
b) How many percent of employees working with lean and green integration and/or associated cost/productivity and environmental performance improvements in the production department?

c) Are there any teams formed in order to integrate lean and green efforts and provide cost/productivity and/or environmental performance improvements in the production department? And what are assigned responsibility of each team?

19. How is Lean and Green Relation (Clean) concept appreciated in the production department?
   a) How can company’s lean and green relation (Clean) philosophy regarding production development operations be described?
   b) Has company defined its production system based on Clean (lean and green relation) philosophy? And how?

20. What type of efforts does the production department have to associate lean and green philosophies?

21. Does the production department has efforts to associated lean “muda” wastes (non-value added activities) with environmental impacts?
   a) What are the implications to environmental impact reduction and environmental performance improvement when lean “muda” wastes eliminated?

22. What are the lean strategies, tools or methods used in production department to decrease environmental impact or improve environmental performance?
   a) What are their implications to environmental impact reduction or environmental performance improvement?

23. What type of lean efforts does the production department has to improve energy use?
   a) Are there any lean strategies, tools or methods used to identify energy use of production process?
   b) Are there any lean strategies, tools or methods used to improve energy use of production process?
   c) What type of environmental performance improvements were obtained so far? And how were they achieved?

24. What type of lean efforts does the production department has to improve chemical and hazardous waste?
   a) Are there any lean strategies, tools or methods used to identify chemical and hazardous waste of production process?
   b) Are there any lean strategies, tools or methods used to improve chemical and hazardous waste of production process?
   c) What type of environmental performance improvements were obtained so far? And how were they achieved?
25. How many successful projects with a lean and green relation focus were observed in process level? What are their context and which results are obtained?

26. What are organizations views and priorities regarding lean and green relation?
   a) What type of environmental waste can be stated as the most targeted by lean environmental waste reduction efforts (Name 3 at least)?
   b) Which lean strategies, tools or methods that can be named as significantly effective in environmental impact reduction (Name 3 at least)?