Green and Lean Production Visualization Tools;
A Case Study exploring EVSM

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ABSTRACT

There is a great need for an environmental, economic and social sustainable society, meeting the needs of the present without compromising the ability of future generations. Focusing on environmental sustainability, legislation and industrially accepted emission targets have emerged, on an overall level represented by e.g. the Kyoto protocol. Green as well as Lean production has thus become a more and more important topic in recent years. Based on the gigantic need for technologies and strategies that will reduce CO2 emissions globally, as well as customer demands for cost efficient and environmental friendly goods and processes, companies are starting to change their principles towards Green and Lean philosophies. In Green and/or Lean development, like other systematic approaches towards improved processes, there is a need for visualization tools to be used to analyze the supply chain and the manufacturing system. One possible visualization tool for this purpose is Environmental Value Stream Mapping, which has all the characteristics of its parent, VSM (Value Stream Mapping) and additional kaizen elements. In the EVSM, the environmental issues and the usage of material or energy have been added to the established VSM tool. However it has been almost four years since United States Environmental Protection Agency (USEPA) has introduced EVSM and there is no reliable evaluation how this tool really works and can be implemented. Therefore there is a need to evaluate and possibly improve this tool, based on practice and the applicability in industry. A case study has been performed testing the EVSM tool in industry and is presented in this paper. The aim of the case study is to analyze how the EVSM tool can be used as well as implementing suggested changes, summarized into, an Environmental Flow Process Chart. The EVSM tool seems suitable for showing the parts of the process in the supply chain which has more waste of energy or material. Still, it lacks information about where and how this waste are generated and which element of the process that is making the most waste, indicating a need for improvement

Keywords: EVSM, EFPC, Environmental production, Lean production
1. INTRODUCTION

1.1 BACKGROUND

It has been some years that Environmental Production has become the hot topic for nature supporter NGOs and governments. EU has signed protocols about environmental production and formulated goals for reducing the effects of production on the environment. (European Commission Environment 2011) But Sweden government has gone further and made a restricted proposal consists of sixteen objectives which should be achieved by 2020. (Miljomal.nu 2011)

Lean Production has common goals with environmental production in some parts, e.g. during improving manufacturing efficiency, energy and environmental benefits are often also attained. When using lean principles to achieve environmental production, it will bring us considerable cost benefits besides green production. (Florida 1996; King & Lenox 2001; Rothenberg et al. 2001)

The basic rule to solve a problem is first to define it and then to break it down into detailed components to accomplish the best possible improvement in it. FPC, Flow Process Chart, and VSM, Value Stream Mapping, are some methods in the field of production management which help developers to break down the process, identify problems, and analyze them. In Green and/or Lean development, similar to the other systematic approaches towards improved processes, visualization tools are needed to be used in order to analyze the supply chain and the manufacturing system. One possible visualization tool for this purpose is Environmental Value Stream Mapping, which has all the characteristics of its parent, VSM (Value Stream Mapping) and additional Kaizen elements. In the EVSM, the environmental issues and the usage of material or energy have been added to the established VSM tool. The aim of this paper is to describe and evaluate the EVSM tool. However it has been almost four years since United States Environmental Protection Agency (USEPA) has introduced EVSM but there is no reliable evaluation how this tool works and can be implemented.
Based on practice and the applicability in the industry, there is thus a need to evaluate and possibly improve this tool. Here we describe the EVSM and ENVSM briefly.

**Envsm** is the abbreviation form of Energy Value Stream Mapping, which is defined by EPA (USA Environmental Protection Agency) in their published handbook “The Lean and Energy Toolkit”. They describe ENVSM as a tool which has the information and data about energy usage of each process item as well as its regular lean data in the value stream mapping. Energy VSM contains the information of the process and the energy usage of each element of the process to the developer of the process at the same time in order to define the future state of the process. (EPA 2007a)

![FIGURE 1 ENVSM (EPA 2007A)](image-url)
**EVSM** is the abbreviation form of Environmental Value Stream Mapping (it should be not confused with Enterprise Value Stream Mapping), which is defined by EPA (USA Environmental Protection Agency) in their published handbook “The Lean and Environment Toolkit”. In EVSM the data for raw material or water usage will be added to the VSM and the opportunities of the environmental improvement will be signed. (EPA 2007b)

![Diagram of EVSM process](image)

**FIGURE 2 CURRENT STATE VALUE STREAM MAP WITH ENVIRONMENTAL DATA (EPA 2007B)**

This research can be used by the production managers and supply chain managers who can take advantage of it to make their own solution about a specific
firm or problem. It also can be useful for other researchers in this area to make further improvements in some lean tools which make them more “green”, or to analyze this problem from another point of views such as cost based approach.

1.2 PROBLEM STATEMENT

However it has been almost four years that United States Environmental Protection Agency (USEPA) has introduced EVSM and ENVSM but there is no reliable evaluation for them. There is not also any suggestion to change or improve, based on the practice or applicability of them, which has made them appear such a bury tools in this field.

Another problem is that however EVSM seems suitable for showing the cells or the part of the process which has more waste of energy or material, but it has lack of information about where and how this wastes are made and which element of the process makes the most waste, so it appears that the amount of information and details which are shown in EVSM are not enough to analyze the process and to find out the roots of the problems.

1.3 AIM OF THE RESEARCH

The objectives of this research are:

1. Well describe and evaluate the EVSM families and advantages and disadvantages of them and suggesting the possible changes and improvements to make it more useful.

2. Introducing possible tools which can have more details and analytical information for the expertise in order to have better vision of the process and the critical elements from environmental point of view.

1.4 RESEARCH DELIMITATION

This research focuses on the process mapping tools as a visualization method for analyzing and improving the current state of the process from lean and green point of view. The fundamental discussion about how lean and green can support
each other and the theories and practices which support the necessity of convenient mapping and visualization tool in order to analyze any process and have a clear picture to make the best improvements are out of the limitation of this research and is counted as an assumption which this research is based on. However they have been reviewed in the theoretical part of this research.

Environmental analysis of a process or green manufacturing has some different sections such as raw material, energy, water and hazardous material. But in this research our main focus is on Energy usage which we find it a more common problem for industries and government these days. Energy reduction is also closely related to improvement of production efficiency.

As EVSM is such a new topic and belongs much more to practical field than science and theory, there are limited numbers of scientific and reliable papers concerning this topic. So in the theory section of this research we have to use the information from some related organization.

The aim of the case study is to analyze the energy consumption of each machine, conveyer or other tools during the process. To gather this information we need to have the measurement tools such as energy meter or electricity meter beside each machine so we can measure the time of the process as well as the energy consumption for the activities by the machine. But in this firm these kinds of tools are not available so they don’t have any detailed information about the amount of energy each machine uses for each activity. There is not any information about the total amount of energy usage for each machine even for a month or any restricted period of time, they just know how much electricity they use in the whole plant which is not useful for our study. Due to this fact we use variable “E” and the name of the machine instead of the amount of energy which is used in each sequence of activities in the process.
2. RESEARCH METHODOLOGY

This research is the result of a thesis work about creating a new tool in order to visualizing the production process based on two points of view. First one is lean and second one is green. According to the nature of this research we can categorize it as a Parallel Action research. The research in this paper is based on a theoretical review as well as a case study with the goal to apply the EVSM tool in the real world. The goal is to see the implementation, the results and usability of the tool. (Coughlan & Coghlan 2002; Voss et al. 2002)

The knowledge which has generated in the theory part should be counted as a practical level in logistics and production field of engineering, because it is focused on managerial tools and the capability of them and difficulties which they can resolve, and it does not talk about any new phenomenon or concept in the philosophy of this field. (Arlbjørn & Halldorsson 2010)

Based on the aim of the research we choose the exploratory experiment case study method for our study. As Yin mentions in his book, this kind of research methodology is suitable for “testing the potential benefits of different kind of incentive” especially in case of first-time experimenting and highlighting the importance and differentiating of theories. (Yin 2009) The aim of the case study is to have practical example of implementing the new methods. Therefore improving the current state of the process is not the goal for this research and has not been studied seriously. However in the end of the case we deliver a couple of suggestions for the company.

We construct and design our case study based on the methods that are presented by; Yin (Yin 2009), Eisenhardt (Eisenhardt 1989) and Voss et al. (Voss et al. 2002). We review the available literature about the green and lean production system and visualization tools regarding to these two systems, we form two research questions; “How EVSM helps the development team to improve the current state of a process?” and “What is the improvement to this tool and how can it help?” then we choose a single case in a manufacturing company. We choose ABB Robotics to perform our case study there, and we select the washing station because it is the
combination of automated and manual process with a reasonable cycle time and sufficient work load. As a measurement method we choose “stop watch” method for work study and we gather the time data and the material flow and inventory information from the process. Afterward we start to analyze our pure data and prepare them to be able to use them as inputs in EVSM and EFPC. In the end we discuss the results of both tools and compare the outcomes and their specifications so that we answer our research questions.
3. THEORY

In the theory part we will go through the available literature about the lean and green and also about visualization tools and at the end we discuss about our improvements to these tools.

3.1 BACKGROUND THEORY

In the background theory we review the existing literature in both system; lean and green. And also visualization tools such as VSM, EVSM and FPC. Visualization tools are fundamental elements in improving any system. In order to evaluate such tools, the nature of the system should be clear.

3.1.1 LEAN

The history of lean began in early 1950s in Japanese’s car maker factory, Toyota. By that time Toyota has passed so many changes and difficulties. Toyota had started its journey as a textile manufacturing then they shifted to be a car manufacturing by the name of “Toyota Motor Company” in 1937 and during the war by the force of the military government they changed their direction from car manufacturing to truck vehicle provider. Just after the war, they needed to go back to their primary product and made themselves competitive in the car market. The problems that they faced were:

- Domestic market was little in number and wide in variety of need.
- Workforce’s demand has been changed and the work law and work union has restricted the power of the employers.
- Weak economy situation of Japan after the World War didn’t let the companies to import the western technology to Japan.
- They couldn’t compete with huge companies such as Ford in foreign market.

So they soon found out that with the current methods they cannot compete and have any share in international market. Taiichi Ohno, production manager of Toyota,
understood this situation and found new methods which later became the fundamental of lean production. (Womack et al. 1990)

One of the concepts that Ohno was going to change was the press machine or in general machining. In mass production system, the system that their competitors was working with, different parts was produced in huge numbers and so many machines were producing different parts for month and stock the parts in inventory and then they changed the setup of the machines to produce the other part because changing dies or other setups was so time consuming and needed experts. Ohno improved the process of changing the dies and reduced the setup up time for machines and used regular operator to make the production line more flexible and made it possible to produce different parts with the same machine and the same day. By this improvement he reduced the number of machines needed for the production line, reduced the inventory and the cost of inventory and transportation and also improved the quality of the production line during the production process. On the other hand it reduced the rework as the defected part would be indentified immediately and the failure reason would be repaired before making another defected batch. (Womack et al. 1990) Liker in his book describes this achievement as “when you make lead times short and focus on keeping production lines flexible, you actually get higher quality, better customer responsiveness, better productivity, and better utilization of equipment and space.” (Liker 2007)

By studying mass production Ohno realized that there are so many wastes in material, effort and time in the production system which enforced extra cost to the company and also its customers. To reduce these wastes, Ohno formed teams with team leaders instead of the simple assembly workers under supervision of a foreman. These teams were responsible for the jobs in the process, cleaning the work place, doing small repair and solving the quality issues. Ohno believed in finding the roots of any defected part immediately before the next defected part get to produce. As a consequence everyone in the production line could stop the whole line to identify the roots of the mistaken part and whole team would come together to solve the problem and rerun the line. In this fashion after a while there was no defected car at the end of the assembly line and by improving the teams, number of stops in the line also reduced almost to zero. (Womack et al. 1990)
According to Liker in his book, The Toyota Way, Ohno knew that Toyota did not have as much capital as Ford did and the technology and the machining facilities of Toyota were so tiny. Therefore it was not feasible for Toyota to have the same system as Ford had and could not make a huge number of works in process inventory and have mass production. Hence he tried to use the idea of Frederick Taylor, as also Ford has tried to use it, but in another way. Taylor’s idea was to have a continues flow in order to have high productivity, Ford used this idea to make a system in which all of the machines and workers be busy all the time to make parts to store them or push them to next station, but Ohno had his approach to that phenomena and designed the one-piece flow which was flexible flow to the customer change and demand and at the same time it was efficient and productive according to the orders.(Liker 2007)

In lean everything will focus on customer (internal or external) point of view. In each process there is a question: “What does the customer want from this process?” By answering this question we can divide the activities in the process into two types: value added and non-value added activates. Any non-value added activity will produce waste of material or at least waste of time and money in customer perspective. Toyota has categorized these wastes in eight categories:

- **Over production**: producing items where there is no order for them.
- **Waiting**: operators time waiting for a reason than lack of order.
- **Transportation**: any transportation is a waste however sometimes it is necessary.
- **Over processing**: having extra step in the process or rework or producing defected items.
- **Inventory**
- **Unnecessary movement**
- **Defects**
- **Unused employee creativity**.

Ohno believed that the most important waste is over production; hence it can produce other waste by itself. By having over production, an inventory of works in process is unavoidable and thus continues flow and perhaps quality in process will be affected.(Liker 2007)
Womack and Jones at 1996 in their book, Lean Thinking, give us a whole picture of lean system based on their study of Toyota and other Japanese company and also comparing them with the American lean manufacturers. They describe the whole system on the five basic principles:

- **Specifying the value**
- **Identifying the value stream**
- **Flow**
- **Pull system**
- **Perfection**

In the system, the "Value" is defined by the customer. It is the customer who specifies the value of a product. By this background anything (activities, movement, service or process) which is not involved in making this value, is a waste in the system. Value stream is the chain of steps in the system which prepares the final product to the customer. By mapping this chain of steps or processes we can easily identify the steps which are adding value to the product and the ones that are not adding value to the product. The next step is to ease the flow of material and information in the value stream by reducing the non value added steps of the process. In the pull system (in order to reduce the inventory between steps) each step will proceed and operate a new part only if the next step needs a part. Perfection in this system means that we produce based on the customer order (eliminating the overproduction, one of the eight wastes) and at the exact time that the customer needs it (Just in Time) and in the least waste process. (Womack et al. 1996)

Bergmiller and McCright has drawn a lean System Model based on the Womack theory about lean and other best practices and prizes such as Shingo prize for improving the manufacturing processes. Their coherent model is shown in the figure below. (Bergmiller & McCright 2009b)
One of the key steps in lean system is providing a good map and understanding over the value stream in order to be able to find and reduce the wasted steps and ease the flow in the value stream. One of the tools which has been used widely is value stream mapping.

### 3.1.2 Value Stream Mapping

Toyota has identified three kinds of flow in a company; Material flow, Information flow and people and process flow. Value Stream Mapping, VSM, is a tool that can cover two of these flows; material flow and information flow. (Khaswala & Irani 2001; Rother & Shook 2003)

Value Stream Mapping, as it is known today, is the adaptive form of “Material and Information Flow Mapping” which is a visualization tool in Toyota motor company. They use the tool to describe the current and ideal (future) state of a plant or process in order to develop or establish the Lean System. (Rother & Shook 2003; Manos 2006)

“A value stream is defined as all the value-added and non-value-added actions required to bring a specific product, service, or combination of products and services, to a customer, including those in the overall supply chain as well as those in internal
operations.” (McDonald et al. 2002) Value Stream Mapping is a visualizing tool which gives a preview to the whole process from raw material and suppliers to the end customer on the flow of material and information. This method can show the unconnected line in the entire enterprise. The aim of the technique is to eliminate the waste from all over the process and to identify the value added and non value added activities in the enterprise. (McDonald et al. 2002; Rother & Shook 2003; Abdulmalek & Rajgopal 2007; Manos 2006)

From scope or range of process point of view Manos has defined three levels in VSM:

- **Facility level:** It covers the processes from “door to door” which means the process from just one line, one facility or just one department.
- **Process Level:** It covers the processes from “interdepartmental” point of view in which the processes in a department and in between them are going to be considered.
- **Extended Level:** It covers the processes in multiple plants and it also considers different customer and suppliers in the map.

Manos recommended starting from Facility level of mapping in all cases to keep the balance in optimizing different processes. (Manos 2006)

The common items that are used in all level of value stream mapping can be seen in the figure below. Manos as a guideline, suggested different areas in the map:

- “The upper right corner for customer information.
- The upper left corner for supplier information.
- The top half of the paper for information flow.
- The bottom half for material (or product) flow.
- The gutters on top and bottom to calculate value added and nonvalue added time.” (Manos 2006)
To apply the Value Stream Mapping in an enterprise Rother and Shook described five steps that a team should take to achieve an acceptable improvement in the process, these phases has summarized by Lasa, Laburu and Vila as below:

- “Selection of a product family.
- Current state mapping.
- Future state mapping.
- Defining a working plan.
- Achieving the working plan.”\(^{(\text{Lasa et al. 2008; Rother & Shook 2003})}\)

By the same approach Manos defined four phases which are almost the same as the first four phases of Rother approach. He instead, in the fourth phase suggests to “draw a plan to arrive at the future state”. Manos defined the process (product) family as: “A process family, also known as a product family, is a group of products or services that go through the same or similar processing steps.” (Manos 2006)
There are some guidelines in order to develop the future state of the Value Stream Mapping status based on lean principle. Their focus is on improving the value added steps in the processes and eliminating non-value added steps (waste).(Rother & Shook 2003; Lasa et al. 2008; Khaswala & Irani 2001)

These guidelines are:

- “The production rate must be imposed by the product demand. Takt time is the concept that reflects such a rate.
- Establishment of continuous flow where possible (unique product transfer batches).
- Employment of pull systems between different work centres when continuous flow is not possible.
- Only one process, called the pacemaker process, should command the production of the different parts. This process will set the pace for the entire value stream. Downstream this point the items would flow in a First In First Out (FIFO) sequence; upstream, the production will be triggered by pull signals.
- Pacemaker process scheduling will deal with the maximization of production levelling on mix and volume.
- Improvement of the overall process efficiency. Projects such as work methods and cycle time improvements, changeover time reductions and maintenance management could be launched by the VSM team.”(Lasa et al. 2008)

Manos looks at Value Stream Mapping as a Kaizen event and he suggests forming a group or cross functional team from different departments and also customers and suppliers to perform a reliable analyze. He suggests seven to ten people to perform a three days event.(Manos 2006)

In short we can say; Value Stream Mapping is a time base tool which is used for monitoring the process in a lean production system or supply chain. “Pictorial representations of VSM are easy ways to learn a language that anyone in your organization can understand—a key element when communicating with process maps.”(Manos 2006) VSM has the capacity of viewing single process line without any sub process line and the sequence of the map is based on time, so it is kind of
difficult to show the parallel processes or elements in a process as they have different duration or different changeover and inventory time. On the other hand VSM gives useful information from managerial point of view to see a process as a whole plant, but in operational point of view VSM has not the capacity of showing the work elements of each station or the jobs in each process block or station, so it is not useful for the operation developer to have a good picture of the jobs in order to improve or diagnose them. Another weakness in common VSM is the absentness of the transportation item with the full info in the process line, not just between the firms or departments, which may not be necessary during the process analysis when developers are working on Value added time and non Value added time, but it is one of the items which is mostly used when the subject of the development is improving the operation and designing the layout. It seems that VSM is a good tool for giving us a whole picture of the process and more applicable in logistics studies such as developing the whole flow in the line or making decision about the batch sizes and inventory level, but it becomes too general when the objective of the study is about operational development.

So at the end we can list the advantages and disadvantages of VSM as follow:

**3.1.2.1 Advantages:**

Khaswala and Irani have come up with some advantages of VSM in their research:

- “Relates the manufacturing process to supply chains, distribution channels and information flows.
- Integrates material and information flows.
- Links Production Control and Scheduling (PCS) functions such as Production Planning and Demand Forecasting to Production Scheduling and Shopfloor Control using operating parameters for the manufacturing system ex. takt time which determines the production rate at which each processing stage in the manufacturing system should operate.
- Helps to unify several IE techniques for material flow analysis, such as Production Flow Analysis (PFA), Business Process Reengineering (BPR), and
Process Analysis and Improvement (PA&I) that, to date, have been taught and implemented in isolation.

- Provides important descriptive information for the Operation and Storage icons that, to date, has not been captured in standard Flow Process Charts used by IE’s.
- Forms the basis for implementation of Lean Manufacturing by designing the production system based on the complete dock-to-dock flow time for a product family.
- Provides a company with a “blueprint” for strategic planning to deploy the principles of Lean Thinking for their transformation into a Lean Enterprise.” (Khaswala & Irani 2001)

From our point of view it has some additional advantages:

- Visualizing the waiting time between each jobs.
- Showing the waste of time for each single product.
- Give a whole picture of the process in one map.
- Screening the value added and non value added jobs and time.

3.1.2.2 Disadvantages:

- “Fails to map multiple products that do not have identical material flow maps.
- Fails to relate Transportation and Queuing delays, and changes in transfer batch sizes due to poor plant layout and/or material handling, to operating parameters (ex. machine cycle times) and measures of performance (ex. takt time) of the manufacturing system.
- Lacks any worthwhile economic measure for “value” (ex. profit, throughput, operating costs, and inventory expenses) that makes it similar to the Flow Process Charting technique used by IE’s.
- Lacks the spatial structure of the facility layout, and how that impacts inter-operation material handling delays, the sequence in which batches enter the queue formed at each processing step in a stream, container sizes, trip frequencies between operations, etc.
• Tends to bias a factory designer to consider only continuous flow, assembly line layouts, kanban-based Pull scheduling, etc. that are suitable mainly for high volume and low variety (HVLV) manufacturing systems.

• Fails to consider the allocations and utilization of an important resource – factory floor space – for WIP storage, production support, material handling aisles, etc.

• Fails to show the impact on WIP, order throughput and operating expenses of in-efficient material flows in the facility ex. backtracking, criss-cross flows, non-sequential flows, large inter-operation travel distances, etc.

• Fails to handle complex product BOM’s, branched and multi-level Operation Process Charts and Flow Diagrams that result in complex value streams.

• Fails to factor queuing delays, sequencing rules for multiple orders, capacity constraints, etc. in any map.

• Lacks the capability, due to the manual mapping method, for rapid development and evaluation of multiple “what if” analyses required to prioritize different alternatives for improving a Current State Map when time and/or budget constraints exist.”(Khaswala & Irani 2001)

From our point of view it has one additional disadvantage:

• There is no information on the map about the actions and motions in each job or station.

3.1.3 ENVIRONMENTAL (GREEN) PRODUCTION

In the recent decades as a consequence of fast growth in the population, industrialization, usage of fossil fuel, growth in the economy and need of accelerated production, mankind has started a massive use of natural resources to meet its demand in a way that in some area it has passed the limitation of sustained trend of resources. On the other hand such a massive consumption has ended up in polluting the environment by the waste of its product and production. Thus there has been such pressure on the companies to minimize their emission and pollution of their activities from their supply chain to their product.(Hart 1995; Corbett & Klassen 2006)
Hart has introduced three strategies from the natural resource perspective to the firms (Hart 1995):

<table>
<thead>
<tr>
<th>Strategic Capability</th>
<th>Environmental Driving Force</th>
<th>Key Resource</th>
<th>Competitive Advantage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pollution Prevention</td>
<td>Minimize emissions, effluents, &amp; waste</td>
<td>Continuous improvement</td>
<td>Lower costs</td>
</tr>
<tr>
<td>Product Stewardship</td>
<td>Minimize life-cycle cost of products</td>
<td>Stakeholder integration</td>
<td>Preempt competitors</td>
</tr>
<tr>
<td>Sustainable Development</td>
<td>Minimize environmental burden of firm growth and development</td>
<td>Shared vision</td>
<td>Future position</td>
</tr>
</tbody>
</table>

FIGURE 5(HART 1995)

Pollution prevention argues about changing the focus of the firm from investing in the “end of pipe” strategies (trying to recycling the waste or putting filters for the air pollution) to the more continues development methods.(Rooney 1993; Florida 1996) Product stewardship is a strategy that aims to combine the customer needs with environmental issues in the design phase of the product life cycle. In sustainable development strategy, the aim is to bring the environmental perspective to the long term plan and strategy in the companies. Making the shared vision for the top managers of the companies about the environmental issues not only in the developed countries but also in the developing countries (where the 90% of the raw material for the developed countries are coming from) is the main line of this strategy (Hart 1995)

Companies and also environmental organizations have shown more interest in Preventive Actions comparing to end-of-the-pipe strategies. Florida has concluded from a survey that companies have three main elements in their pollution preventive strategies:

- Utilize source reduction
- Recycling
- Production process improvements

Companies who involved in the survey mentioned that: “The implementation of new technologies in the form of production process improvements is a central factor
in the development of joint improvements in environmental and manufacturing methods.” (Florida 1996)

Wide usage of quality management systems is irrefragable. TQM and ISO standards are the example of these families. Based on the brilliant philosophy of these methods, in the field of environmental management, there exist TQEM and ISO 14000 families. Florida defines TQEM as:

“Total quality environmental management (TQEM) extends the principles of quality management to include manufacturing practices and processes that affect environmental quality.”(Florida 1996)

The first stage in environmental production system (like other management systems) is top management engagement. An Environmental Management System (EMS) is a good frame work for the whole organization which should be established from the top level management. “The EMS defines the corporate environmental policies and procedures that assure good environmental performance” (Bergmiller 2006) however EMS, itself does not reduce the environmental impact of the production but it makes the whole system proper for being more resource saver and makes the suitable environment for performing the practical solutions for being green. One of the well known standards for EMS is ISO 14001 which is widely used in the industries and also service companies nowadays. Three disciplines which are helping reduce the resource and energy usage in a manufacturing process are (Bergmiller 2006):

1. **Design for Environment**: it has an engineering perspective in to a production process and the scope is the whole life cycle. “The premise of Design for the Environment is to design a product with minimum impact on the environment. It is during the design phase that almost all potential environmental effects of the product are determined.”(Bergmiller 2006)

2. **Total Cost Accounting**.

3. **Industrial Ecology**
Later on Bergmiller and McCright in 2009 by studying other best tested Green System models draw their own aggregative Advance Green System model. Their model is shown in the figure below. (Bergmiller & McCright 2009b)

![FIGURE 6 ADVANCE GREEN SYSTEM (BERGMILLER & MCCRIGHT 2009)](image)

### 3.1.4 LEAN GREEN PRODUCTION

It has been thought that industrial performance (cost efficiency) is in a “trade-off” relation with environmental performance. The only motive or actual pressure for the companies to take action in environmental performance improvement is the regulations and policies. The results of these regulations are the end-of-the-pipe methods to reduce the environmental emission and wastes. (Florida 1996)

There are some empirical and theoretical researches and scholars that have argued to neither sacrificing environmental performances nor cost performances for the other one. In other words they tried to proceed some innovative methods in production and operation management to reduce the environmental emission and cost of the process at the same time. (Rothenberg et al. 2001; King & Lenox 2001; Helper et al. 2002; Florida 1996; Miller et al. 2010; Mollenkopf et al. 2010)

Florida in his survey research concludes that companies prefer “source reduction, recycling and production process improvement” over the end of the pipe
treatment. In overall of his study he provided a conclusion that: “firms and plants that are R&D-intensive and manufacturing innovators possess the capacity to both improve productivity and reduce environmental costs and risks.” (Florida 1996)

In the line with Florida, Helper et al. support this idea and make it clearer by studying some examples of empirical practices and quoted that: “firms were simultaneously able to reduce pollution and increase efficiency by adopting innovations in manufacturing practice (lean manufacturing) and in environmental management (pollution prevention).” (Helper et al. 2002) the issues that are involved in success of lean system in the pollution prevention management are:

- Reducing set-up times
- Less inventories
- Root cause of defects and therefore less scrap

“In sum, these efforts are directed toward preventing the generation of waste in the first place, in ways that actually reduce production cost” (Helper et al. 2002)

The essence of lean production system, the most famous innovative production system, is “to produce more with less”. (Found 2009) This phrase suggests that lean firms use less non renewable resources in the position of raw material and also are more energy saving in their process. “This concept can be extended to determine whether Lean thinking can be applied to producing less pollution and emissions and whether Lean manufacturers are therefore more eco-friendly than traditional manufacturers.” (Found 2009) King and Lenox propose in their study that “lean production is complementary to environmental performance”. They believed that adopting the lean production system will reduce the overall cost of pollution prevention by decreasing the source wasting in the firms. Consequently they assert that “lean is green”. (King & Lenox 2001)

Based on some case studies and by the lean experts and environmental experts team, Sawhney et al. has drawn a table in which the main lean principle has shown and the impact of each on different aspects of environment has been shown. To come to a conclusion the joint team of environmental and lean experts, have performed case studies and the lean experts has explained the lean principle which has an impact on the case and then environmental experts has described the
environmental impact scenarios for each principle. The result is shown below. (Sawhney et al. 2007)
<table>
<thead>
<tr>
<th>Lean manufacturing principles</th>
<th>Employee’s</th>
<th>LCA</th>
<th>Solid waste</th>
<th>Toxic chemical</th>
<th>Water pollution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cellular manufacturing</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>NI</td>
</tr>
<tr>
<td>Employee’s involvement and empowerment</td>
<td>P/N</td>
<td>P/N</td>
<td>P/N</td>
<td>P/N</td>
<td>P/N</td>
</tr>
<tr>
<td>Mistake proofing</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>NI</td>
</tr>
<tr>
<td>Product mix/variability</td>
<td>P/N</td>
<td>NI</td>
<td>N</td>
<td>NI</td>
<td>P</td>
</tr>
<tr>
<td>Pull systems</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
</tr>
<tr>
<td>Quick changeover</td>
<td>NI</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>NI</td>
</tr>
<tr>
<td>Small lot production</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>NI</td>
<td>P/N</td>
</tr>
<tr>
<td>Supplier development</td>
<td>P/N</td>
<td>P/N</td>
<td>P/N</td>
<td>P/N</td>
<td>P/N</td>
</tr>
<tr>
<td>Total productive maintenance</td>
<td>P</td>
<td>P/N</td>
<td>P</td>
<td>P</td>
<td>P/N</td>
</tr>
</tbody>
</table>

Note: P = Positive impact which corresponds to A and B in Figure 3; N = Negative impact which corresponds to D and E in Figure 3; NI = No impact which corresponds to C in Figure 3; P/N = Positive or negative impact which corresponds to A, B, D or E in Figure 3.
From a systematic point of view to the green lean production, and based on the management system models that we have seen before in this research, now we can think of a cumulative management system model for green lean system. According to the best practices and comparing the two models of management systems for environmental management system and lean management system, and similarities between their business results and waste reduction techniques Bergmiller et. al. has suggested a comprehensive “Lean and Green System Model”. The figure below is his model which is so similar to its parents; lean model and green model.(Bergmiller & McCright 2009b)

Overall looking to the literature and researches beside the best practices in green lean, we can conclude that there exist strong similarities between lean system and green system and in fact they seem to go a parallel path through the manufacturing system. (Bergmiller & McCright 2009b) these two systems mainly act complimentary to each other. Some aspects of lean like; inventory minimization, work system and human resource practices can end up with the environmental resource inventory reduction, environmental improvement due to the personnel continues improvement and can make the whole organization and people more amendable for the further environmental training.(Rothenberg et al. 2001) A statistical survey shows that “plants with Lean systems yield higher Green Results”.

---

**FIGURE 8 COMPREHENSIVE LEAN AND GREEN SYSTEMS MODEL (BERGMILLER & MCCRIGHT 2009)**
It seems that having lean system will act as catalyst to implement environmental best practices. (Bergmiller & McCright 2009a)

However lean and green seem so complimentary to each other but sometimes some conflict may occur. For instance the quality technology which might be used in lean system may not satisfy properly the environmental expectation. (Rothenberg et al. 2001) Or some other aspects such as JIT and one piece flow, while they can reduce the in-process inventory, they may cause over transportation, more packaging and handling which are not so convenient from environmental point of view. (Mollenkopf et al. 2010)

It appears that lean and green combined system is not initatively considered as win-win situation for plants however these firms can use innovative technology or solution to overcome these conflicts like using reasonable batch size or reusable packages.(Mollenkopf et al. 2010; Rothenberg et al. 2001)

3.1.5 Environmental/Energy Value Stream Mapping

Resources (material and energy) are limited for every firm, and beside that the growing price of resources has become one of the problems for the companies which force them to be more conservative in their resource consumption. Researches and experiences show that however there is high level of inefficient resource consumption in the factories but they have difficulties to improve them as they suffer from lack of proper measurement tool. Schmidt et al. describe the problem in this way: “If potentials for saving energy and materials are to be identified in manufacturing enterprises, both the quantity and the value framework of material movements in the company must be recorded.” (Schmidt et al. 2007)

3.1.5.1 Energy Value Stream Mapping

EPA in “lean-energy-toolkit” suggested a VSM event in which the VSM team measures and adds the data from the energy usage of each process at the same time that they are collecting the data from the current state of the process such as; cycle time, change over time and up time. The aim of this process is to have both data from the value added action and process beside the energy usage or waste in a same picture to give this opportunity to the analyzer team to improve the future state
of the process in a way that has better and more efficiency in both ways; lean principle and energy saving. (EPA 2007a)

Another suggestion by this handbook is to add the energy usage data directly to the each process data boxes in the Value Stream Mapping. In this method VSM team can add the average energy usage for each process and each cycle time in the process boxes. (EPA 2007a)

In figure 9 the last line of the data in the box is concerning about the average energy usage which is one kilo watt-hour per pound of output.

EPA introduces another view of ENVSM in their “The Lean and Chemicals Toolkit” publication. In this view energy usage line is just beside the time line of the VSM in which the amount of energy usage in process and energy waste in process and out of the process is shown. (EPA 2011)
3.1.5.2 Environmental Value Stream Mapping

Technically EVSM has the same structure as ENVSM in form and appearance. EPA suggests that the VSM team in cooperation with EHS experts should try to collect the data of the process, beside one or two environmental issues such as hazardous material, raw material or water in a same VSM which would be called EVSM. (EPA 2007b)
FIGURE 11: VALUE STREAM MAP WITH EHS ICONS AND A MATERIALS LINE (EPA 2007B)

Annual Production Plan

Production Control

Market Forecast

Customer A

Customer B

Supplier 1

Supplier 2

EHS

EHS

EHS

Milling

2 people

C/T = 2 min
C/O = 2 hr
Uptime = 74%

Welding

2 people

C/T = 4 min
C/O = 3 hr
Uptime = 67%

Painting

3 people

C/T = 7 min
C/O = 4 hr
Uptime = 48%

Assembly & Inspection

3 people

C/T = 2 min
C/O = 30 min
Uptime = 93%

2x Week

5 days

10 days

15 days

8 days

<90 lbs

<25 lbs

80 lbs

15 lbs

5 lbs

2 min

4 min

7 min

2 min


Lead Time = 68 days
Value Added Time = 15 min

Total Materials Used < 150 lbs
Materials Needed = 110 lbs
In this EVSM the top line of the material line is the amount of the material which has gone to the process and the bottom line is amount of material which has used during process and is value added from the customer point of view. So the difference between the bottom line and top line is the waste of the material in the process.

### 3.1.5.2.1 Advantages

Additional to the advantages which has mentioned about VS, EVSM has more advantages such as:

- It shows the Energy/Material waste in the process.
- Comparing the future state and current state gives a good understanding of how lean improvement has influenced the energy/material efficiency.
- It would highlight the stations which need environmental analyses.

### 3.1.5.2.2 Disadvantages

Beside the energy which is used in the process for the value added component of the process such as drilling, welding, screwing and etc, the other energy consumption component in a firm or factories are the transportation, movement of material and inventory. Inventory in the process can consume energy for heating or cooling and etc. and transportation between stations with lift truck or crane is such big energy consumption in factories. By this point of view EVSM has the weakness or disadvantages as below:

- The energy usage for transportation between the stations is not visible.
- The energy for inventory between processes is not visible.
- The roots of wasted energy in the processes are not visible.
- Non value added energy in each process is a secondary information.

### 3.1.6 Process Flow Chart

In 1947, American Society of Mechanical Engineering (ASME) provided a visualization tool based on Gilberth publication on 1921 “Process Chart- First step in finding the one best way” which consisted of set of the symbols which could cover all kind of work independent of the nature of the process with the meanest confusion. This tool is famous by the name of “Operation and Flow Process Chart” which is
usually a long line of symbols that are showing the flow of the items in any process. “This was (and still is) a simple and effective way to track the flow of one item, a person, or a piece of material through a work process.” (Graham 2004)

The five symbols in Flow Process Chart during the time have some changes but the main symbols which have been used since the beginning, are the same in all versions:

⊙

**Operation (Doing work):** “An operation occurs when an object is arranged or prepared for another step, assembled or disassembled or intentionally changed.” (Graham 2004)

“In practice, the operation symbol is filled in when representing a physical change to an object. This way, the value-added steps stand out.” (Graham 2004)

↔

**Transportation (Moving work):** “A transportation occurs when an object is moved from one work area to another.” (Graham 2004)

□

**Inspection (Checking work):** “An inspection occurs when an object is verified for quality or quantity in any of its characteristics.” (Graham 2004)

▼

**Storage/Delay (Nothing happening):** “A storage occurs when an object is kept and protected against unauthorized removal.” (Graham 2004)

 ■

**Delay:** “A delay occurs when an object waits for the next planned action. (A “D” symbol is sometimes used to distinguish a delay from storage.)” (Graham 2004)
3.2 DISCUSSION ON THEORY

3.2.1 ENVSMEVSM

The improvement suggested for EVSM/ENVSM is about how to demonstrate the value added and non value added energy or other resources in each block in the bottom line for energy or resources. The current state for demonstrating is showing the total energy/resource on the upper line before the block, at the place we show the waiting time or lead time in VSM, and used energy/resource in the station on the lower line under the block. In this method, we need some calculation in order to achieve the non value added energy/resource which has been wasted during the process. And also the energy/resources which have been wasted during the inventories or transportations between stations are missed.

We suggest changes in the method in a way that the value added energy/resource can be shown on the lower line, non value added can be shown under the lower line and the energy/resource used during the inventory and transportation between the stations can be shown on the upper line between the blocks. Therefore the schematic view of the block and lines would be like:
In this figure, “E0” is the energy/resource used in the transportation or inventory, E1 is the value added energy/resource in the process and E2 is non value added energy/resource used in the process.

### 3.2.2 ENFPC/EFPC

FPC has operational point of view in the process mapping comparing to the VSM, therefore using FPC in the energy/material analysis gives us more detailed and operational information about the process and should give this opportunity to the developer team to have a better understanding of the process in order to make improvements in both efficiency of energy/material and time consumption. So by trying to add energy/material information to the regular FPC we introduce ENFPC/EFPC in both versions; diagram and table.
Since there is a clear difference between transportation/move, operation, inspection, inventory and delays in the FPC even in jobs, determining any action that is even value added or non value added is easy in this kind of mapping, so it would be easy as well to determine the energy/material used in that action if they are value added or not.

The design of the EFPC/ENFPC diagram would be the same as FPC diagram just by adding the energy/material data next to the time, beside the symbols. In the EFPC/ENFPC table, we can have an extra column for energy/material and a column for value added or non value added determination. So each action which is not value added in the process would have non value added energy/material used as well. By this definition schematic diagram and table for EFPC/ENFPC would be as below:

![EFPC Diagram]

FIGURE 13 ENFPC DIAGRAM
<table>
<thead>
<tr>
<th>ID</th>
<th>Activity</th>
<th>Symbol</th>
<th>Time (in second)</th>
<th>Operator</th>
<th>VA/NVA/NVABN</th>
<th>Energy</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Inspection</td>
<td>□</td>
<td>sec</td>
<td>1</td>
<td>NVA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Operation</td>
<td>□</td>
<td>sec</td>
<td>2</td>
<td>VA</td>
<td>E</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>transportation/move</td>
<td>□</td>
<td>sec</td>
<td>1</td>
<td>NVABN</td>
<td>E</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Delay</td>
<td>□</td>
<td>sec</td>
<td>-</td>
<td>NVA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>transportation/move</td>
<td>□</td>
<td>sec</td>
<td>1</td>
<td>NVABN</td>
<td>E</td>
<td></td>
</tr>
</tbody>
</table>
4. CASE STUDY

In order to have an example of the new method, EFPC, and find the strength and weakness of it, we take a case study in ABB Robotics plant in Västerås.

4.1 COMPANY INTRODUCTION

“ABB is a leading supplier of industrial robots, modular manufacturing systems and service. A strong solutions focus helps manufacturers improve productivity, product quality and worker safety. ABB has installed more than 175,000 robots worldwide.” (ABB 2011b)

4.1.1 ABB ROBOTIC PLANT

The information in this part, about plant, production system components and the process has been provided by Sofia Zackrisson one of the production managers in ABB Robotic Department.

In this plant all the process for assembling and producing different kind of robots which are produced by ABB will take place. Main deviations of the factory in this plant are:

- Assembling small robots
- Assembling large robots
- Painting
- Testing

Different stations and process line are separated in the plant by the storage places for inventory in process. The storage places are two to three times higher than the stations heights in most cases. Floating inventory system is used in this plant and for this purpose they use optimization software which controls and manages the place for each part of inventory in process and assigns a place to it, according to availability and minimization of transportation based on the distance between current and future process stations. Transportation in factory is mostly by lift trucks and they are equipped with computer systems which are connected to the
inventory system to give and take the storage place information for each material and goods. The lift trucks’ source is a battery which is rechargeable.

There is a general lighting system in the plant which gives a smooth and equal light and visibility to the whole plant either storage places or working stations. In this system the florescent lamps are placed in the ceiling and because of the height of the ceiling the light in the stations are smooth and in most cases enough. In some special station which the process is more accurate or the light is not sufficient, extra local lighting is used.

A central heating system is used to make the proper temperature for the whole plant. In this case, since the working stations are among the inventory places, the heating system should make the average temperature stable even for the inventory places and also unused spaces like the upper space of the stations which is almost four times higher than the stations height.

This plant has the certification for ISO 9000 and ISO 14000 so they have the system to separate the wastes and recycle the wasting water.

4.1.2 Energy Efficiency

“Energy efficiency has become critically important to companies, governments and consumers due to soaring energy prices, rising demand in power-hungry developing nations, and concern about the effect of man-made emissions on climate change.

It’s one of ABB’s key areas of focus – in its own manufacturing processes and the products provided to customers. The company also promotes energy efficiency as a member of international organizations committed to fostering economic growth while limiting emissions of greenhouse gases.

How do we define energy efficiency? For ABB it means cutting energy use without reducing the output of energy-consuming plants and equipment. It means promoting behavior, working methods and manufacturing techniques which are less energy-intensive.
Energy efficiency is embedded in the products, systems and services that ABB provides throughout the supply chain, from the extraction of energy to its use by consumers. Life Cycle Assessment studies of installations using ABB products show their main environmental benefit consists in reducing customers’ energy use.” (ABB 2011a)

“ABB’s own activities are not energy-intensive, with annual greenhouse gas emissions from its operations totaling approximately 1.5 million tons. Nevertheless, the company is in the midst of a two-year program to cut energy use by 2.5 percent per employee per year.

Simple measures can have a large impact. In Sweden, 140 energy saving projects have been identified in technical and behavioral categories. With more than one-third of these projects now completed, energy savings equal to 4,150 tons of C02 emissions annually have been generated, reducing annual energy costs for ABB in Sweden by USD 0.8 million.

ABB in China launched a campaign in 2009 that has yielded hundreds of practical suggestions from employees on ways to save energy and costs in ABB's operations, from reducing the number of overhead lights to turning off air conditioning half an hour before the work day ends.

The savings are measured and monitored by ABB's global network of some 400 employees responsible for sustainability issues.” (ABB 2011a)

**4.2 STUDIED PROCESS DESCRIPTION**

The operation which has been chosen for the study is “Washing Process”. Washing process is a pre operation for both Small Robots and Large Robots assembly. In this process all the metallic material and components for the robots such as gear, shafts, body and covers which are provided by the suppliers and have been stored in outdoor inventory or have moved inside the plant and have been stored in the float inventory system before get to the assembly line, should be washed and dried.
In the first step the items are brought to the station by lift truck and in the palettes and packages from the inventory. Then operators open the pallets and unpack the items. In the next step they move the items from the pallets to the washing boards on the working table by crane. There are four washing board available but just three of them will be used because they want to save one of them for emergency loading from other stations. When the board is loaded operator push the washing button next to the board and this board gets in to the queue for the washing machine. On its turn washing board pulls back by a magnet to an automatic conveyer which takes the board to the washing machine. The items are washed by 60 degree hot water. When the washing process in the washing machine finishes the conveyer brings back the board and takes the next board to the washing machine. When the board has been back to the work table, two operators start to dry the items on the board by using the pressed air blow. After drying the items operator takes the items back to the pallets by help of crane. Then the lift truck gets pallets to the inventory.

There are some notes about the process:

- The tools on the crane should be changed for different kind of items.
- There are 2 washing machines but only one of them is used.
- Both washing machines are using the hot water from the same tank which has the capacity for both and is keeping warm the water on 60 degree.

4.2.1 Work Flow Diagram

At this point we use work flow diagram to have a brief picture of whole process in washing station.
FIGURE 14 WORK FLOW

1. Start
2. Unpack and unload the pallets
3. Move to the washing board
4. Washing
5. Drying
6. Load to the pallets
7. End
### 4.2.2 TIME TABLE

The time measurement for the five process items is shown in the table below:

<table>
<thead>
<tr>
<th>ID</th>
<th>Tasks</th>
<th>TIME</th>
<th></th>
<th></th>
<th>Average, sec</th>
<th>Max, sec</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Unpack and unload the pallets</td>
<td></td>
<td>1.5 5 6 2 3.5</td>
<td></td>
<td>220</td>
<td>360</td>
</tr>
<tr>
<td>2</td>
<td>Move to the washing machine</td>
<td></td>
<td>2</td>
<td></td>
<td>120</td>
<td>120</td>
</tr>
<tr>
<td>3</td>
<td>washing</td>
<td>15.5</td>
<td></td>
<td></td>
<td>930</td>
<td>930</td>
</tr>
<tr>
<td>4</td>
<td>drying</td>
<td>2 2.5 2.5 2.33 1.8 2</td>
<td>131.3 150 170 170 4 170 4</td>
<td>170 170 170 170 170 170 170 170 170 170 170 170 170 170 170 170</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Load to the pallets</td>
<td>2 3 3.5 2 2.5 4</td>
<td></td>
<td></td>
<td>170 170 170 170 170 170 170 170 170 170 170 170 170 170 170 170</td>
<td></td>
</tr>
</tbody>
</table>

Time table with the operation information would be as below:

<table>
<thead>
<tr>
<th>ID</th>
<th>Average, sec</th>
<th>Max, sec</th>
<th>operated by</th>
<th>number of operator</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>220</td>
<td>360</td>
<td>man</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>120</td>
<td>120</td>
<td>machine</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>930</td>
<td>930</td>
<td>machine</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>131.3</td>
<td>150</td>
<td>man</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>170</td>
<td>240</td>
<td>man</td>
<td>1</td>
</tr>
</tbody>
</table>

In this process job number 2 and 3 are automated and do not need any operator. So these two jobs together are the bottleneck for this process by total time of 1050 seconds. In the table below we see the time for the bottleneck comparing with the other jobs and maximum time for the jobs:

<table>
<thead>
<tr>
<th>ID</th>
<th>Average T*person</th>
<th>Max T*person</th>
</tr>
</thead>
<tbody>
<tr>
<td>bottleneck/automated</td>
<td>1050</td>
<td>1050</td>
</tr>
<tr>
<td>other jobs</td>
<td>652.6</td>
<td>900</td>
</tr>
</tbody>
</table>
In this table the time for the other jobs has multiplied to the number of operators in order to have the total work unit (man second) to be able to compare the jobs in the process. It seems that the time for the bottleneck is longer than the cumulative time for all other process items or jobs when they are using just one operator. Primary conclusion for this time table is the cycle time which is 1050 seconds.

For the efficiency analysis in this station we assumed that the number of operator in this station is one (however it was 3 operators working in that station). Because of the sequence of the jobs, which has been told before, the process could not have the parallel jobs, and adding more operators doesn’t help to reduce the cycle time which is due to the automated operation. And also we assumed that the process works with one of the washing machines and three of the working plates. So the efficiency table would be:

<table>
<thead>
<tr>
<th>machine</th>
<th>working time</th>
<th>cycle time</th>
<th>efficiency percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>operator</td>
<td>652.6</td>
<td>1050</td>
<td>%62</td>
</tr>
</tbody>
</table>

4.2.3 Value Stream Mapping

As we already mentioned, this process is the first step or operation for the large or small robots assembling lines. So from VSM point of view, whole this process would be one operation block in robot assembling VSM in which the materials reach this block from inventory after a period of time (which we are not aware of it), and after this process they go to the inventory for another period of time (which we are not aware of it as well), and then they go to the first station of the assembling line.

In this block the value added time are the time for the washing process and for drying process and three other jobs are non value added which we can count them as Change Over Time for this block. The number of operator is one and the available time is eight hours per day. The cycle time for this block according to the time table is 1050 seconds. Schematic VSM for this process would be:
FIGURE 15 VSM
4.2.4 Flow Process Chart (FPC)

From our value stream mapping, we know; the cycle time, value added time and non value added time for our process. But in order to make improvements for the station and the sequence of jobs or changing or eliminating jobs which are not value added to our product, we need more accurate and detailed information or tools. One of the useful tools in the process and work study, which gives detailed information about the activities in a process, is FPC. The FPC for our current process according to our process description is:
Transporting from inventory to the station by lift truck

Waiting to unpacking

Unpacking and moving to the board by crane

Waiting for the turn to move to the washing machine

Moving to the washing machine automatically

Automatically washing

Moving to the work place automatically

Drying by air presser

Moving to the pallets by crane

Waiting for transportation to the inventory

Transport to the inventory by lift truck

Time: NA

Time: 220 sec

Time: 120 sec

Time: 810 sec

Time: 120 sec

Time: 131 sec

Time: 170 sec

FIGURE 16 FPC
In the chart above (figure 16) we have all the elements of the job and we can see which activities will take apart in order to finish the process of washing and drying. By this tool we can freely study the reason of the non value added time in our VSM and can come up with the solutions for them. In this chart all the delays and transportations are not Value Added to our process however some of them are necessary for our process, and we cannot eliminate them from our process.

Another view of the FPC is the one in a table in which we can have some extra information for our activities which can help us to have a better view and analysis of our process. We can see the same process in the FPC table in Table six:

<table>
<thead>
<tr>
<th>ID</th>
<th>Activity</th>
<th>Symbol</th>
<th>Time (in second)</th>
<th>Operator</th>
<th>VA/NVA/NVABN</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Transporting from inventory to the station by lift truck</td>
<td>NA</td>
<td>1</td>
<td>NVABN</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Waiting to unpacking</td>
<td></td>
<td>-</td>
<td>NVA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Unpacking and moving to the board by crane</td>
<td>220</td>
<td>1</td>
<td>NVABN</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Waiting for the turn to move to the washing machine</td>
<td></td>
<td>-</td>
<td>NVA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Moving to the washing machine automatically</td>
<td>120</td>
<td>Auto</td>
<td>NVABN</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Automatically washing</td>
<td>810</td>
<td>Auto</td>
<td>VA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Moving to the work place automatically</td>
<td>120</td>
<td>Auto</td>
<td>NVABN</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Drying by air presser</td>
<td>131</td>
<td>2</td>
<td>VA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Moving to the pallets by crane</td>
<td>170</td>
<td>1</td>
<td>NVABN</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Waiting for transportation to the inventory</td>
<td></td>
<td>-</td>
<td>NVA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Transport to the inventory by lift truck</td>
<td>NA</td>
<td>1</td>
<td>NVABN</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
In this view (table view) beside the elements such as; job description, symbols and time, we have the number of operators, type of activity from Lean point of view and notes. In Type of activity we can divide jobs as Value Added (VA), Non Value Added (NVA) and Non Value Added but Necessary (NVABN). And the column, Note, is for the note from the experts and improvement team members during the improving project. Improvement process usually will lead to eliminate the NVA items and reduce the NVABN items by using lean theory and tools.

4.3 ENERGY ANALYSIS

In this chapter we will discuss about the process from energy usage perspective. We will start with the process description from energy point of view then ENVSM and EFPC at the end.

But before process description we will talk about the limitation and situation of the plant as energy analysis point of view. The aim of our study is to analyse the energy consumption of each machine, conveyer or any other tools during the running of the process. For gathering that kind of information we need to have the measurement tools like energy meter or electricity meter beside each machine so we can take the time of the process as well as the energy consumed by the machine for the activities. But in this firm this kind of tools was not available so they didn’t have any detailed information about the amount of energy each machine is using for each activity. There was not any information about the total amount of energy usage for each machine even for a month or any restricted period of time, they just know about how much electricity they have used in whole plant which was not useful for our study. Due to this fact we used variable “E” and the name of the machine instead of the amount of energy which is used in each sequence of activities in the process, for example “Ecr1” for Energy used in first transportation step by crane.

4.3.1 PROCESS DESCRIPTION BY ENERGY POINT OF VIEW

Pallets are brought to the station by lift truck. Items are taken from pallets to the board by the help of crane which used “Ecr1” kW energy. Board is taken to the washing machine with an automated conveyer by using “Econ1” kW energy. Items are washed by automated washing machine by using “Ewt” kW energy. Board is taken
back to the station by automated conveyer by using “E_{con2}” kW energy. Items are getting dried with pressed air by using “E_{air}” kW energy. Items are taken to the pallets by crane by using “E_{cr2}” kW energy. Pallets are taken to the inventory by lift truck.

In this description E_{cr1} and E_{cr2} are the energy used by crane; first from pallet to board and then from board to pallet. E_{con1} and E_{con2} are the energy used for the conveyer for taking boards to washing machine and taking them back. E_{air} is the energy used for making the pressed air and the flow to the station. E_{wt} is the total energy used in the washing machine which consists of the energy used for making hot water for both washing machines, that in this case just one of them is used but the tank will keep the hot water ready for both of them so the energy is used to keep hot water for double size of the amount which is going to be used, we will call this energy hot water energy and the variable would be “E_{hw}”, and the energy used in the washing machine to do the functions and wash the items, which we will call it in this study washing energy and will use “E_{w}” as its variable.

4.3.2 Energy Value Stream Mapping

According to the ENVSM introduction and description we tried to draw the energy value stream mapping for this process. The improvement we have made to the ENVSM is that we used the up line for visualizing the amount of energy which is used during the transportation or inventory and in the lower line we used two different numbers, one number shows the value added energy which would positioned on top of the lower line, and one number shows the non value added energy which has used during the process that would be positioned under the lower line.

By this improvement in the tool the ENVSM for the process is shown in the figure 17. In this figure E0 is the amount of energy which is used during transportation and inventory before washing process start, E1 is value added energy which is used in the process and E2 is non value added energy which is used in the process. This improvement obviously is applicable for other Environmental Value Stream Mapping tools like water or material.
FIGURE 17 IMPROVED ENVSM
This tool is helping us to see how much energy is wasted during our process comparing with the amount is value added for customer, but as well as the regular VSM we cannot find the root of wastes and improve the process just by having the ENVSM. So in the next step we draw the ENFPC which is more detailed about the activities in the process so we can find a better opportunity to analyze the wasteful jobs and make relevant improvements.

4.3.3 Energy Flow Process Chart (ENFPC)

In this chapter we will use our new tool for visualizing our process in a way that the exact jobs which made waste to our process from energy consumption point of view become clear.

In this flowchart we have the amount of energy used for each activity in the process and due to value added or non value added being of jobs, the energy which has used is also value added or non value added. The improvement can be made by changing the process activities in a way that they use less energy or if it was possible to remove those activities by using regular methods in lean system or changing the technology which is used in the process.

In next two figures we will see the ENFPC chart and then the relevant table to the chart.
<table>
<thead>
<tr>
<th>ID</th>
<th>Activity</th>
<th>Symbol</th>
<th>Time (in second)</th>
<th>Operator</th>
<th>VA/NVA/NVABN</th>
<th>Energy</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Transporting from inventory to the station by lift truck</td>
<td>NA</td>
<td>NA</td>
<td>1</td>
<td>NVABN</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Waiting to unpacking</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>NVA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Unpacking and moving to the board by crane</td>
<td>220</td>
<td>1</td>
<td>NVABN</td>
<td>Ecr1 kw</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Waiting for the turn to move to the washing machine</td>
<td>-</td>
<td>-</td>
<td>NVA</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Moving to the washing machine automatically</td>
<td>120</td>
<td>Auto</td>
<td>NVABN</td>
<td>Econ1 kw</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Automatically washing</td>
<td>810</td>
<td>Auto</td>
<td>VA</td>
<td>Ewt kw</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Moving to the work place automatically</td>
<td>120</td>
<td>Auto</td>
<td>NVABN</td>
<td>Econ2 kw</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Drying by air presser</td>
<td>131</td>
<td>2</td>
<td>VA</td>
<td>Eair kw</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Moving to the pallets by crane</td>
<td>170</td>
<td>1</td>
<td>NVABN</td>
<td>Ecr2 kw</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Waiting for transportation to the inventory</td>
<td>-</td>
<td>-</td>
<td>NVA</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Transport to the inventory by lift truck</td>
<td>NA</td>
<td>1</td>
<td>NVABN</td>
<td>NA</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Here we can see that the energy which has been used for transportations and movements in this process are red and count as wasted energy as their relevant activities have been wasted of time and man power and according to lean production principal we should eliminate or reduce the non value added activities, and here, energy.
This tool has the capability to be used in more purposes by just adding the relevant column for having those data next to the present one, like we could have the column for the number of items which proceed in each cycle time for each activity, or having the number of defected items in each activity in the process for quality purpose, or up time for each activity and OEE to the necessary activities.

According to our recent two visualization tools and lean philosophy we offer some improvements for the plant in order to reduce the operation time and energy consumption.

4.4 SUGGESTED IMPROVEMENT

The improvements for this case study are divided into two parts, first part is the general improvements about issues which seem not so proper according to lean production or energy efficiency, the second part is about specific process that we have studied and according to our data gathering and our tools results.

4.4.1 GENERAL IMPROVEMENT

The main general problem for this plant is due to large amount of inventory places which are situated through the working stations. Because of this lay out the lighting system and heating system are consuming more energy and therefore more cost than what is necessary. However this inventory system may have a good optimization system for reducing the lift trucks movement and there after reducing the distances for transportation in the firm but its side effect is making more energy consumption in the plant because of the light and heat and also lift truck traffics’ between the stations have risked the operators and human resources safety.

The improvement we suggest for this firm is to run a study project about the layout and analyzing the energy consumption of the heating and lighting and distances that lift trucks moves and the area each station would need. A value stream mapping event about the inventory in process for whole plant to find out the perfect amount of inventory needed for different lines seems reasonable. In the field of lay out study, what we can say now is that; the area above the working stations could be one third of the current situation and each line can be surrounded by three
dimensions with pre made walls and ceilings. This way the heating system should just warm up these area in which the operators are working and the lighting system can be separated from the inventory part so it would be more energy saving. The product in the inventory doesn’t need special temperature as they mostly are metallic goods, so they can be stored even outside of the plant in open inventory. About the work stations we can have separate line in separate premade room or salon or we can even have like villages in the plant such as assembly village or painting village, in which for example in assembly village we gather all the assembly work station and surround them in the pre made walls and roof and then next to it we could keep the inventory related to them outside of this village and have separate heating and lighting for inside and outside of the village to perform a better energy saving process.

4.4.2 STUDIED PROCESS IMPROVEMENT

Following wastes, according to our FPC chart and table comparing with lean principals which has mentioned in Toyota Way by Jeffry K.Liker, have been seen in the washing process:

1. **Overproduction:** the system for this process was almost push system; the finished item in this process was moved to the storage shelves instead of next operation station.

2. **Waiting:** as we saw in the time table the process time for the automation machine was 1050 and the total time for other jobs which has been done by operators was 652 it shows that in each cycle operator should wait 398 seconds for the next cycle.

3. **Unnecessary transport or conveyance:** according to our FPC the second moving of items from washing board to the pallets and then move them to the storage place is unnecessary if we had the one piece flow process the transportation between the storage place and the station was eliminated.

4. **Excess inventory:** as we have overproduction, we have excess inventory as well.
As energy efficiency point of view any energy which is used in a job or in a facility which has not any influence in adding any value to the product in customer point of view is wasting of energy. By this perspective activities and situation listed below are example of waste of energy in this process:

1. Energy which crane uses for moving the items from or to the pallets.
2. Energy conveyer uses for transporting the items to the washing machine.
3. The share of the energy used by the water warmer for the second washing machine which is not used in the process.

By looking to these problems and highlighted wastes, our suggested improvements are:

1. If we use plastic pallet in this station we can omit the job number nine “moving from board to the pallet”. So the process would be like: operator on pack the pallets and then move the items from wooden pallets to the plastic pallets on the washing board. Then the plastic pallet will get to the washing machine by automated conveyer and then they would return to the work station. Operator will dry them by pressed air flow and then lift truck will take the pallet from washing board directly to the store place.

Right now they cannot use the pallets inside the washing machine because they are wooden and will be damaged by water in 60 degree temperature but plastic pallets are stronger with water and also with temperature. Plastic pallets are also more environmental friendly as they have longer life cycle than wooden pallets. And when we use them in the first moving of the item from wooden pallets, we don’t need to move items back, this way we have reduced the operating time by 170 second and also reduced the energy usage by $E_{cr2}$.

Some other advantages of plastic pallets are; they last longer, weight less and don’t need paint or chemical treatment. As they can handle 100 trips they reduce the green house gas emission realized to the atmosphere. (Franco 2009)
Time table after the omitting the last transportation from the board to the pallets would be like:

<table>
<thead>
<tr>
<th></th>
<th>Average T*person</th>
<th>Max T*person</th>
</tr>
</thead>
<tbody>
<tr>
<td>bottleneck/automated</td>
<td>1050</td>
<td>1050</td>
</tr>
<tr>
<td>other jobs</td>
<td>482.6</td>
<td>660</td>
</tr>
</tbody>
</table>

As we can see here the total working time for the operators in each cycle is less than half of the cycle time or automated jobs. This gives the idea for the next improvement.

2. The main idea for this improvement is to use the whole capacity of this station. As we mentioned in the process description in the current status, just one of the washing machines and three of the working tables are in use, and this caused so much waiting time for operators, less productivity for station and waste of energy in the warming water tank for the washing machines.

Our suggested improvement is bringing the next washing machine in the process and by having two operator in the station in a way that each of them are responsible for two boards they can manage to operate both washing machine. We can make sure about satisfying the emergency load from the other lines, which is the reason to keep one board out of the process, because the total waiting time for each pallet that is arrived to the station would be maximum 1050 seconds which is reasonable even for emergency load.

We suggested two operators for this station. However if we just count on our average timing, one operator can handle all four boards and two washing machines because the operator cycle time is less than the automated cycle time, but because of the variation between the pallet and then the time for unpacking and moving them to the board, it is safer to have two operators to keep this process going and we should keep in mind that this station already has three operators and is working just by half capacity.
The result for this improvement would be; omitting the wasting energy in the energy variable for hot water energy “E_{hw}”, increasing the productivity of the station by two times, decreasing the waiting time for the operator and increasing the efficiency of the operators’ jobs in the process.

<table>
<thead>
<tr>
<th></th>
<th>working time</th>
<th>cycle time</th>
<th>efficiency percentage</th>
<th>efficiency 1st impr</th>
<th>efficiency 2nd impr</th>
</tr>
</thead>
<tbody>
<tr>
<td>machine</td>
<td>1050</td>
<td>1050</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>operator</td>
<td>652.6</td>
<td>1050</td>
<td>62</td>
<td>46</td>
<td>92</td>
</tr>
</tbody>
</table>

As energy efficiency point of view in the first improvement we omit the energy used for the crane to move the items from board to the pallets and in the second improvement we reduce the energy waste in the water warming for the washing machines.
5. Discussion and Conclusion

Green and Lean production has become a more and more important topic in recent years. In Green and/or Lean development, like other systematic approaches towards improved processes, there is a need for visualization tools to be used to analyze the supply chain and the manufacturing system. One possible visualization tool for this purpose is Environmental Value Stream Mapping. In the EVSM, the environmental issues and the usage of material or energy have been added to the established VSM tool. There is a need to evaluate and possibly improve this tool, based on practice and the applicability in industry. A case study has been performed testing the EVSM tool in industry and is presented in this paper. The aim of the case study was to analyze how the EVSM tool could be used as well as implementing suggested changes, summarized into, an Environmental Flow Process Chart.

In the case study both methods EVSM and EFPC have been used and the difference between their appearances and abilities of each have been tried to be shown. According to the aim of the study for each plant or process the first goal for an analyzer is to find the wasteful points and jobs in the process even from energy efficiency point of view or lean and time efficiency point of view. Here we will discuss about the relevant information from each tool that the analyzer can get in order to make the improvement to the process.

By studying the ENVSM for the process the information regarding to the sequence of the cells, the waiting time between each cell, the flow of the information between managerial department and suppliers, customers and cells, value added time and energy and non value added time and energy regarding to each cell are achievable. By using these data, analyzer can tell if any cell has a problem even as energy consumption (which means that cell is wasting large amount of energy) perspective or as wasting time in the cell or between each cell in the process, but the source of these wastes are invisible in this kind of chart. On the other hand at the VSM event or the process of drawing the VSM the information about the actions in the process have been observed and based on that information the VSM has been drawn but because of the absence of the proper tool that information have been missed in the report.
What we did in this case study was first using the EFPC. First in the cell we broke down the actions in the cell, well defined them and then drew the map of the process by using the FPC symbols then the time data for each job was registered and at the end the data regarding the energy consumption based on the observation and the information from the maintenance department was added to the EFPC. Based on the present EFPC we drew the EVSM and the calculation for the total value added and non value added time and energy has been done and added to the EVSM. However in this case because of the absence of the measuring tools for the energy consumption for each machine and component in the process and after asking from the maintenance personnel for providing any detailed information about the energy distribution in the plant we had to use variables instead of the measured number for the energy consumption but it is obvious that by using the measurement tools each variable can be replaced by relevant number in the chart.

So now we have two kinds of charts that each of them can show us the information for same process but in different details. We believe that the data in EVSM is useful to have an overall picture of the process and to make decision about the cells that would need more improvements and their influence to whole process but in order to make those improvements we need the information from EFPC to highlight the non value added actions in the cell and take the corrective actions due to them.

As an aggregate conclusion to this research now we suggest a procedure for mapping a process in which we start with breaking down the action of each cell in the process according to the five symbols of FPC and then gather the relevant data for each symbol even energy, time, job description, number of operators, etc. then drawing the EFPC and based on it drawing the EVSM for the whole process. These two tools beside each other are the good documentation for the process in which we have an over view of the process and detailed view of it can be useful for top managers and also production engineers.

By our perspective on this case study, developing or improving the current process is much easier, accurate and understandable by using these visualizing tools and according to the demand we could have detail or general report out of them in the projects.
6. **FURTHER STUDY**

1. In this research and for supporting the new tool one case study has been done and even the improvement suggested in this report has not been implemented. So the need of operated projects in this field is existed and an analysis for the share of the operational waste of energy in the total production cycle and supply chain is necessary. It should be studied that how much operational wastes have influence on the product life cycle comparing with the logistics problems and general energy consumption to make it clear for the companies to find their most wasteful activities in their whole process.

2. A statistical report is advisable. In which the opinion of the number of production managers beside environmental expertise should be gathered about the performance of this new method and if it has solved any problem from their processes or if they have some comment on it. Obviously it can be done if some projects have been run via this method.

3. Absence of measuring tools in the field of energy in companies will result the lack of information about the energy performance of the process and this way analyzing and improving the process is impossible as there is no problem acquire because the companies are blind in the energy efficiency status of their own. Therefore if the national target of environmental agency is to reduce the energy consumption of the firms there should be a plan for it and should motivate the companies to have a monitoring system for their energy usage in the production field. May be having an annual report of energy consumption, should be a must for companies.


