USING A VALUE STREAM MAP TO ASSESS ENVIRONMENTAL IMPACTS

A Thesis by

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B. E., Anna University, 2005

Submitted to the Department of Industrial Engineering
and the faculty of the Graduate School of
Wichita State University
in partial fulfillment of
the requirements for the degree of
Master of Science

December 2009
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DEDICATION

To my family & friends
ACKNOWLEDGEMENTS

First and foremost I offer my sincere gratitude to my thesis advisor Dr. Whitman, who has supported me throughout my thesis with his patience and knowledge, whilst allowing me the room to work in my own way. I attribute the level of my Masters degree to his encouragement and effort and without him this thesis, too, would not have been completed or written. It is an honor for me to thank my thesis committee members, Dr. Twomey and Dr. Asmatulu for their help during my thesis. It is a pleasure to thank Dr. Overcash, Harikumar Rajendran, Samantha Corcoran, Siddhartan Ramamoorthy, Devi Kalla, and Prashanth Lodhia who made this thesis possible by providing their valuable suggestions. I owe my deepest gratitude to Ramprasaad Venkataraju, Arun Prakash Thiruvengadam and other members of enterprise engineering group for helping me in various stages of my research. Finally, I thank my parents and friends for their support in making this research a success.
ABSTRACT

In today's competitive world, companies focus on eliminating wastes to increase their profit, growth and ensure customer satisfaction. Among the known wastes, environmental wastes are typically the least considered. Organizations must comply with federal rules and regulations towards environmental friendly manufacturing. Lean Manufacturing provides opportunities for improving the environmental performance along a production line.

This thesis discusses previous work performed in analyzing environmental impacts and wastes. Based on this previous work, a method is developed to assess and document the impact of environmental factors in a production line using a value stream map. This new approach to calculate the environmental factors of a manufacturing/assembly line and to incorporate the environmental factors in a value stream map is explained in detail with case studies. The result of the case studies as tested in a production line is discussed and concludes with significant opportunities for improvement if implemented in a large scale.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td></td>
</tr>
<tr>
<td>1.1</td>
<td></td>
</tr>
<tr>
<td>1.2</td>
<td></td>
</tr>
<tr>
<td>1.3</td>
<td></td>
</tr>
<tr>
<td>1.4</td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td></td>
</tr>
</tbody>
</table>

## 1. INTRODUCTION

1.1 Thesis objective

1.2 SWOT analysis

1.2.1 Strengths

1.2.2 Weakness

1.2.3 Threats

1.2.4 Opportunities

1.3 Thesis road map

1.3.1 Initial condition

1.3.2 Desired condition

1.3.3 Obstacles

1.3.4 Strategy

1.3.5 Objectives

1.4 Chapter summary

## 2. LITERATURE REVIEW

2.1 Lean Manufacturing

2.1.1 Value stream mapping

2.1.2 Need for value stream mapping in an industry

2.2 Environmental impacts

2.2.1 Need for assessing environmental impacts

2.2.2 Need for Integration of lean and environment

2.3 Environmental assessment methods

2.3.1 Green Productivity Index (GPI)

2.3.2 Air Pollution Index (API)

2.3.3 Estimation of carbon di-oxide (CO₂)

2.3.3.1 CO₂ emissions from fossil fuel combustion

2.3.3.2 CO₂ emissions from the cement manufacturing process

2.3.4 Ozone depletion index
### TABLE OF CONTENTS (continued)

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.3.5</td>
<td>Global warming index</td>
</tr>
<tr>
<td>2.3.6</td>
<td>Incorporating environmental index as waste into VSM</td>
</tr>
<tr>
<td>2.4</td>
<td>Environmental strategies towards sustainability</td>
</tr>
<tr>
<td>2.4.1</td>
<td>Passive, lobbying- based environmental strategy</td>
</tr>
<tr>
<td>2.4.2</td>
<td>Re-active environmental strategy</td>
</tr>
<tr>
<td>2.4.3</td>
<td>Anticipatory environmental strategies</td>
</tr>
<tr>
<td>2.4.4</td>
<td>Innovation based green strategies</td>
</tr>
<tr>
<td>2.4.5</td>
<td>Pollution prevention</td>
</tr>
<tr>
<td>2.4.6</td>
<td>Product stewardship</td>
</tr>
<tr>
<td>2.4.7</td>
<td>Clean technology</td>
</tr>
<tr>
<td>2.5</td>
<td>ISO 14001 Environmental management system</td>
</tr>
<tr>
<td>2.6</td>
<td>Environmental measures for organizations</td>
</tr>
<tr>
<td>2.7</td>
<td>Chapter summary</td>
</tr>
<tr>
<td>3.1</td>
<td>Lean manufacturing</td>
</tr>
<tr>
<td>3.1.1</td>
<td>Value stream mapping</td>
</tr>
<tr>
<td>3.1.2</td>
<td>Need for value stream mapping in an industry</td>
</tr>
<tr>
<td>3.2</td>
<td>Environmental impacts</td>
</tr>
<tr>
<td>3.2.1</td>
<td>Need for assessing environmental impacts</td>
</tr>
<tr>
<td>3.2.2</td>
<td>Need for Integration of lean and environment</td>
</tr>
<tr>
<td>3.3</td>
<td>Method</td>
</tr>
<tr>
<td>3.3.1</td>
<td>Hierarchy of environmental factors</td>
</tr>
<tr>
<td>3.3.2</td>
<td>Environmental VSM</td>
</tr>
<tr>
<td>3.4</td>
<td>Case study scenario</td>
</tr>
<tr>
<td>3.5</td>
<td>Case study 1: Class project case study</td>
</tr>
<tr>
<td>3.5.1</td>
<td>Measure of the environmental factors</td>
</tr>
<tr>
<td>3.5.1.1</td>
<td>Energy use</td>
</tr>
<tr>
<td>3.5.1.2</td>
<td>Workspace use</td>
</tr>
<tr>
<td>3.5.1.3</td>
<td>Materials use</td>
</tr>
</tbody>
</table>
TABLE OF CONTENTS (continued)

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.5.2 Incorporating environmental values in a VSM</td>
<td>40</td>
</tr>
<tr>
<td>3.6 Case study 2: Sheet metal shop in company X</td>
<td>44</td>
</tr>
<tr>
<td>3.6.1 Router</td>
<td>44</td>
</tr>
<tr>
<td>3.6.1.1 Energy used calculations</td>
<td>44</td>
</tr>
<tr>
<td>3.6.1.2 Workspace used</td>
<td>45</td>
</tr>
<tr>
<td>3.6.1.3 Materials used calculations</td>
<td>45</td>
</tr>
<tr>
<td>3.6.2 Debur</td>
<td>46</td>
</tr>
<tr>
<td>3.6.2.1 Workspace used</td>
<td>46</td>
</tr>
<tr>
<td>3.6.3 Inspection</td>
<td>46</td>
</tr>
<tr>
<td>3.6.3.1 Workspace used</td>
<td>46</td>
</tr>
<tr>
<td>3.6.4 Incorporation of environmental factors in a VSM</td>
<td>46</td>
</tr>
<tr>
<td>3.7 Case study 3: Clip manufacturing in company Y</td>
<td>47</td>
</tr>
<tr>
<td>3.7.1 Router</td>
<td>48</td>
</tr>
<tr>
<td>3.7.1.1 Energy used calculations</td>
<td>48</td>
</tr>
<tr>
<td>3.7.1.2 Workspace used</td>
<td>48</td>
</tr>
<tr>
<td>3.7.1.3 Materials used calculations</td>
<td>49</td>
</tr>
<tr>
<td>3.7.2 Punch</td>
<td>49</td>
</tr>
<tr>
<td>3.7.2.1 Energy used calculations</td>
<td>50</td>
</tr>
<tr>
<td>3.7.2.2 Workspace used</td>
<td>50</td>
</tr>
<tr>
<td>3.7.2.3 Materials used calculations</td>
<td>50</td>
</tr>
<tr>
<td>3.7.3 Debur</td>
<td>51</td>
</tr>
<tr>
<td>3.7.3.1 Workspace used</td>
<td>51</td>
</tr>
<tr>
<td>3.7.4 Press</td>
<td>52</td>
</tr>
<tr>
<td>3.7.4.1 Energy used calculations</td>
<td>52</td>
</tr>
<tr>
<td>3.7.4.2 Workspace used</td>
<td>52</td>
</tr>
<tr>
<td>3.7.5 Incorporation of environmental factors in a VSM</td>
<td>52</td>
</tr>
<tr>
<td>3.8 Summary</td>
<td>54</td>
</tr>
<tr>
<td>4. RECOMMENDATIONS AND FUTURE STATE VSM</td>
<td>55</td>
</tr>
<tr>
<td>4.1 Case study 1: Class project case study</td>
<td>55</td>
</tr>
</tbody>
</table>
TABLE OF CONTENTS (continued)

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.1.1</td>
<td>Energy use (set up reduction) .................................................................</td>
</tr>
<tr>
<td>4.1.2</td>
<td>Material use (Reduction of scrap and rework) ........................................</td>
</tr>
<tr>
<td>4.2</td>
<td>Case study 2: Sheet metal shop in company X ...........................................</td>
</tr>
<tr>
<td>4.2.1</td>
<td>Energy use (set up reduction) .................................................................</td>
</tr>
<tr>
<td>4.2.2</td>
<td>Material use (Aluminum sheet size reduction) ...........................................</td>
</tr>
<tr>
<td>4.3</td>
<td>Case study 3: Clip manufacturing in company Y .......................................</td>
</tr>
<tr>
<td>4.3.1</td>
<td>Energy use (set up reduction) .................................................................</td>
</tr>
<tr>
<td></td>
<td>4.3.1.1 Router ..............................................................................................</td>
</tr>
<tr>
<td></td>
<td>4.3.1.2 Punch ...............................................................................................</td>
</tr>
<tr>
<td></td>
<td>4.3.1.3 Brake press .....................................................................................</td>
</tr>
<tr>
<td>4.3.2</td>
<td>Material use (Reduction of unused material) ............................................</td>
</tr>
<tr>
<td></td>
<td>4.3.2.1 Router ..............................................................................................</td>
</tr>
<tr>
<td></td>
<td>4.3.2.2 Punch ...............................................................................................</td>
</tr>
<tr>
<td>4.4</td>
<td>Summary .........................................................................................................</td>
</tr>
</tbody>
</table>

5. CONCLUSION AND FUTURE WORK ................................................................. | 64 |

5.1 Summary ..................................................................................................... | 64 |
5.2 Achievements .............................................................................................. | 65 |
5.3 Future work ................................................................................................ | 65 |

REFERENCES ....................................................................................................... | 67 |
# LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table 2. 1: Environmental impacts of the lean wastes (EPA, 2006)</td>
<td>10</td>
</tr>
<tr>
<td>Table 2. 2: Air pollution rating scale (Basu et al., 2008)</td>
<td>15</td>
</tr>
<tr>
<td>Table 2. 3: Environmental measures (EPA, 2006)</td>
<td>22</td>
</tr>
<tr>
<td>Table 2. 4: Summary of the literature review</td>
<td>25</td>
</tr>
<tr>
<td>Table 3. 1: Difference between environmental VSM's</td>
<td>31</td>
</tr>
<tr>
<td>Table 3. 2: Amount of CO\textsubscript{2} emitted from Energy</td>
<td>37</td>
</tr>
<tr>
<td>Table 3. 3: Workspace data</td>
<td>39</td>
</tr>
<tr>
<td>Table 3. 4: Materials data</td>
<td>40</td>
</tr>
<tr>
<td>Table 3. 5: Amount of CO\textsubscript{2} emitted from the environmental factors</td>
<td>41</td>
</tr>
<tr>
<td>Table 4. 1: Amount of CO\textsubscript{2} emitted from energy data</td>
<td>55</td>
</tr>
<tr>
<td>Table 4. 2: Amount of CO\textsubscript{2} emitted from materials data</td>
<td>56</td>
</tr>
</tbody>
</table>
## LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure 1.1</td>
<td>SWOT analysis for assessing environmental impacts using VSM</td>
<td>2</td>
</tr>
<tr>
<td>Figure 1.2</td>
<td>Thesis road map</td>
<td>4</td>
</tr>
<tr>
<td>Figure 2.1</td>
<td>GPI development</td>
<td>13</td>
</tr>
<tr>
<td>Figure 3.1</td>
<td>Hierarchy of environmental factors</td>
<td>30</td>
</tr>
<tr>
<td>Figure 3.2</td>
<td>Current state VSM of the class project</td>
<td>34</td>
</tr>
<tr>
<td>Figure 3.3</td>
<td>Load controls portable power cell (<a href="http://www.loadcontrols.com">www.loadcontrols.com</a>)</td>
<td>36</td>
</tr>
<tr>
<td>Figure 3.4</td>
<td>Sample workspace data in a VSM</td>
<td>38</td>
</tr>
<tr>
<td>Figure 3.5</td>
<td>Sample CO$_2$ value in a VSM</td>
<td>41</td>
</tr>
<tr>
<td>Figure 3.6</td>
<td>A sample of the environmental factors in a VSM</td>
<td>42</td>
</tr>
<tr>
<td>Figure 3.7</td>
<td>Environmental VSM of the class project</td>
<td>43</td>
</tr>
<tr>
<td>Figure 3.8</td>
<td>Sheet metal shop current state environmental VSM</td>
<td>47</td>
</tr>
<tr>
<td>Figure 3.9</td>
<td>Clip manufacturing current state environmental VSM</td>
<td>53</td>
</tr>
<tr>
<td>Figure 4.1</td>
<td>Class project future state VSM</td>
<td>57</td>
</tr>
<tr>
<td>Figure 4.2</td>
<td>Sheet metal shop future state VSM</td>
<td>59</td>
</tr>
<tr>
<td>Figure 4.3</td>
<td>Clip manufacturing future state VSM</td>
<td>62</td>
</tr>
</tbody>
</table>
CHAPTER 1
INTRODUCTION

Lean production is a philosophy with a set of principles and practices that assists in the determination and elimination of waste in various processes. The quality of the product is improved by reduction of waste, time, cost and resources. Lean production also assists in the determination and reduction of non-value-added activities at various stages such as design and production (APICS Dictionary, 12th Edition).

Lean is a Toyota production system concept which integrates different tools for eliminating waste and increasing productivity. “Lean manufacturing uses tools such as kaizen, one-piece flow, cellular manufacturing, synchronous manufacturing, inventory management, poka-yoke, standardized work, workplace organization and scrap reduction to reduce manufacturing waste” (Pavnaskar et al., 2002).

According to Jones and Womack (2000) a value stream map (VSM) is “the simple process directly observing the flows of information and materials as they now occur summarizing them visually and then envisioning a future state with much better performance.”

A VSM gives a pictorial representation of the information flow such as cycle time, inventory, resources, and takt time. There are two stages in a VSM: current state and future state. The current state VSM depicts the information flow of the processes from which the potential improvements can be identified. The future state VSM depicts how the processes should include improvements (Seth & Gupta, 2005).

1.1 Thesis objective

Lean principles are mainly used for increasing the productivity, reducing the lead time,
and eliminating waste. Environmental impacts can also be assessed by using lean principles. The objective of the thesis is to assess the environmental impacts using a VSM.

1.2 SWOT analysis

Strengths, weaknesses, opportunities and threats for assessing the environmental factors using a VSM are addressed in this section as shown in figure 1.1.

- **Strengths**
  - Identifies and assesses the environmental effects
  - Identifies areas of improvement (Seth & Gupta, 2005)
  - Improves the health and safety of the workplace (EPA, 2006)

- **Opportunities**
  - Improves profit and performance
  - Integrates with the business strategy (Pun & Hui, 1999)

- **Threats**
  - Support from top management (Pun & Hui, 1999)

- **Weaknesses**
  - Assessment of environmental factors has no standard approaches (Lawrence et al., 2002)
  - Impacts are different for different processes (EPA, 2006)

**Figure 1.1: SWOT analysis for assessing environmental impacts using VSM**

1.2.1 Strengths

A VSM can be used to identify and assess the environmental impacts of a manufacturing process. The VSM helps to set the priorities and a target for minimizing environmental impacts (EPA, 2006). During lean activities and events the areas of improvement in a production line can be clearly identified. The assessment of environmental impacts in a VSM provides many opportunities to address the company’s regulatory compliance issues by which the health and safety of the workplace is improved.
1.2.2 Weakness

Many processes have different kinds of environmental impact. The impacts have to be determined by using different approaches for different processes. In a painting process, chemicals and hazardous wastes have to be addressed while in other processes water usage may have to be addressed (EPA, 2006).

1.2.3 Threats

Top management hesitates to consider these environmental impacts using lean techniques because of the complexity and technicality of the issues. The conflicts between employees and management, lack of technical knowledge, economic, social and political impacts also act as a barrier for management to take necessary steps against these environmental impacts (Pun & Hui, 1999).

1.2.4 Opportunities

The assessment of environmental impacts can be included with the business strategy because customers prefer products from those who provide environmentally friendly goods. By reducing environmental impacts a company can provide quality products and also increase productivity (Pun & Hui, 1999).

1.3 Thesis road map

In this section the thesis road map is explained. The thesis road map shown in figure 1.2 consists of the initial condition (where the environmental factors are not considered), the desired goal, obstacles, objectives and strategy.

1.3.1 Initial condition

Organizations typically neglect environmental impacts. Therefore, environmental impacts
are not considered as a factor in a VSM.

### 1.3.2 Desired condition

The goal of this thesis is to develop a method for assessing environmental impacts using a VSM. The environmental impact is entered as a factor like cycle time, change over time etc. in a VSM. The environmental factor provides an idea of the amount of impact the process causes to the environment. The environmental factor can be used as a basis for continuous improvement.

![Thesis Road Map](image)

**Figure 1.2: Thesis road map**

### 1.3.3 Obstacles

The obstacles that could be faced while trying to achieve the goal are listed below:
- **Lack of knowledge**

Most employees and management do not understand the importance of the environmental impacts. Management hesitates to assess the environmental impacts because of the complexity and lack of technical knowledge and experience (Sarkis et al., 2006).

- **Inability to determine the correct environmental factors**

Different processes may have different environmental impacts and a single process may also have many impacts. Therefore it is difficult to determine the correct environmental factors based on severity or occurrence.

- **No standard techniques**

Standard techniques are not available as different techniques are used to analyze the environmental impacts for different processes (EPA, 2006).

### 1.3.4 Strategy

The proposed strategy is to develop a method for assessing and documenting environmental factors using a VSM. This strategy will help to identify the areas where the environmental impact is high.

### 1.3.5 Objectives

The desired condition could be achieved by following the objectives that are listed below:

- **Develop a hierarchy for the environmental factors of the manufacturing system**

A hierarchy is developed for the environmental factors which show the relationship between the various factors. A hierarchy is developed for environmental impacts caused
by manufacturing sectors.

- **Develop a measure for the environmental factors**

  For assessing the environmental impacts, a measure was determined for including the environmental impacts in the VSM. A particular method was developed for measuring the environmental impact.

- **Develop a method for incorporating values in the VSM**

  Once the measure is identified, the value has to be included in the VSM like that of cycle time, change over time etc. A unique method was identified for including the value in the VSM.

- **Test the method on two real world cases**

  This method was tested in two different real world cases. The data in a manufacturing line was collected and the environmental impacts are included in the value stream map.

1.4  **Chapter summary**

The chapter focused on the current situation where environmental impacts are not assessed using a VSM, the obstacles that might prevent from achieving the desired goal, the strategy and the objectives that will be used to achieve the desired goal. Strengths, weakness, opportunities and threats for assessing environmental factors using a VSM are also discussed.
CHAPTER 2

LITERATURE REVIEW

In this chapter the literature is reviewed concerning lean manufacturing, environmental performance and the need for assessing environmental impacts. This chapter also reviews the importance of a VSM in an organization, integration of lean and the environment, environmental management systems and the basic measures to be identified for environmental performance. Then, it describes the different environmental strategies followed by companies.

2.1 Lean Manufacturing

Lean manufacturing is known as the Toyota Production System and is followed by many companies across the world because of increasing competition, operating cost and operational problems. Lean production is practiced to eliminate waste, inconsistency and reduce the work load (Wu, 2003).

The main objective of lean production is to reduce lead time, cycle time and resources and to improve the quality and productivity. Top management hesitates to implement changes because of the belief that productivity will decrease during the implementation stages. Continuous improvement is an important feature in lean production for products and processes which requires the support of employees and management (Sanchez & Perez, 2001).

According to Hines and Rich (1997) “there are seven types of wastes in lean production and they are (a) over production (b) waiting (c) transport (d) inappropriate processing (e) unnecessary inventory (f) unnecessary motion (g) defects.”

According to Womack and Jones (1996) the five main principles of lean production are defining value, identify the value stream, work flow, pull the work and pursue to perfection. The
lean principles can be applied at three stages namely demand, flow and leveling. A VSM is used in lean production for depicting the flow and information (Tapping et al., 2002).

2.1.1 Value stream mapping

According to Womack and Jones (1996), a VSM is “the simple process of directly observing the flows of information and materials as they now occur, summarizing them visually and then envisioning a future state with much better performance.” A VSM gives a pictorial representation of the activities, cycle time, lead time, information flow and material flow. A VSM gives an idea of the process wastes when the above mentioned factors are mapped. The lead time, cycle time and resources can be reduced by eliminating waste (Tapping et al., 2002).

VSM is a lean production tool which was developed to focus on disconnected flow lines and improving it. The initial step for creating a VSM is preparing the current state map for the production line with the data collected from the shop floor. The shop floor has to be observed a few times to get all the required data. The immediate step is to analyze the VSM and identify the areas of improvement. The final step is preparing the future state map with the improvement ideas along the value stream (Braglia et al., 2006).

There are three types of operations in a manufacturing environment which can be categorized into (a) Non-value adding: the unnecessary actions like waiting time, buffer inventory, unnecessary movements that must be completely eliminated, (b) necessary but non-value adding: the actions like picking up parts from distant areas, movement of materials which are necessary for the production activity but non-value adding operations, (c) value adding: the production of finished goods from the available raw materials is known as value added operations (Hines & Rich, 1997).
The main disadvantages of the VSM are (a) the accuracy level is limited as the implementation of ideas at the shop floor is difficult, (b) difficulty in preparing the VSM for complex production lines with the standard approach (Braglia et al., 2006).

2.1.2 Need for value stream mapping in an industry

A VSM emphasizes the requirement for redesigning the production line. It visualizes the whole production line and also identifies waste in the value stream. This tool mainly improves the material and information flow of a production line. The VSM forms a base for implementing the lean techniques and the concepts across the organization. A VSM integrates lean concepts and techniques and also provides a general language about the production processes. A VSM is a qualitative tool which shows the relationship between information flow and material flow (Rother & Shook, 1999).

2.2 Environmental impacts

According to the EPA (2006) “Environmental waste is an unnecessary or excess use of resources or a substance released to the air, water, or land that could harm human health or the environment.” Environmental factors which affect the quality, time and cost does not add any value to the customer. The major impacts are contamination of soil and water, air and noise pollution.

2.2.1 Need for assessing environmental impacts

Assessment of environmental impacts helps in identifying and evaluating the relevant effects of the social and the environment. Environmental wastes increase the costs of business because of disposal costs, waste of raw materials, and pollution control. Customers tend to buy products from those companies who produce products with less environmental impacts as they
do not want to give up on the product quality, cost, and time. The environmental impact assessment provides a cleaner and safer environmental workplace for employees and the environmental and operational performance can be improved along the production line. The environmental impacts of the lean wastes are shown in table 2.1(taken from EPA, 2006).

**Table 2.1: Environmental impacts of the lean wastes (EPA, 2006)**

<table>
<thead>
<tr>
<th>Waste Type</th>
<th>Environmental Impacts</th>
</tr>
</thead>
</table>
| Overproduction         | • More raw materials and energy consumed in making the unnecessary products  
                         • Extra products may spoil or become obsolete requiring disposal  
                         • Extra hazardous materials used result in extra emissions, waste disposal, worker exposure, etc  |
| Inventory              | • More packaging to store work-in-process (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  |
| Transportation and Motion | • More energy use for transport  
                                • Emissions from transport  
                                • More space required for WIP movement, increasing lighting, heating, and cooling demand and energy consumption  
                                • More packaging required to protect components during movement  
                                • Damage and spills during transport  |
| Defects                | • Raw materials and energy consumed in making defective products  
                         • Defective components require recycling or disposal  
                         • More space required for rework and repair, increasing energy use for heating, cooling, and lighting |
Over processing
• More parts and raw materials consumed per unit of production
• Unnecessary processing increases wastes, energy use, and emissions

Waiting
• Potential material spoilage or component damage causing waste
• Wasted energy from heating, cooling, and lighting during production downtime

Nowadays, environmental impacts are also linked with the economy of an organization. Management is under pressure to improve the profit of the organization by increasing productivity and reducing environmental impacts. Companies view environmental protection as an obstacle in achieving profit, so they are motivated to improve environmental performance of their facility. The growth of a company will be based on integration of environmental performance with business strategy (Gandhi et al., 2006).

2.2.2 Need for Integration of lean and environment

Integration of lean and the environment provides certain techniques and strategies for improving lean results and enhancing the environmental performance. Lean along with the environment helps to reduce costs and lead times, improves process flow and environmental quality. Lean and the environment help in eliminating environmental hazards, and providing a safer environment for the employees. The productivity can be increased by improving the quality, time and cost and by eliminating environmental hazards. Lean events and activities helps in identifying the environmental benefits and eliminating potential risks (EPA, 2006).

Value stream mapping can be used to visualize the environmental wastes along the production line. A VSM acts as a critical tool in identifying opportunities during the analysis stage for improving the environmental performance. A VSM helps in identifying environmental waste such as energy use, raw materials, solid wastes, air emissions, pollutants, and hazardous...
wastes (EPA, 2006).

2.3 Environmental assessment methods

In recent days many organizations are trying to achieve ISO 14001 certification by following various techniques. The organizations measure environmental performance using different techniques as there is no standard techniques available for measuring the environmental performance. Qualitative audit and quantitative mass balance are the two major techniques used in determining the environmental impacts (Lawrence et al., 2002).

2.3.1 Green Productivity Index (GPI) (Gandhi et al., 2006)

The main purpose of this method is to develop an indicators framework integrating environmental performance and productivity. Pollution intensive companies can use GPI as a basis for reducing pollution and improving environmental performance. Environmental indicators and economic indicators of the organization should be linked together when their performance is measured.

GPI is a quantitative mass balance approach used in determining the environmental performance. GPI can be used to measure the direct environmental impacts and the indirect environmental impacts cannot be measured. GPI forms a basis for continuous improvement and sustainability through productivity and environmental protection. GPI integrates both economical and environmental indicators. Many value drivers like production cost, selling price, solid wastes, gaseous wastes and water usage are combined to provide a single measure indicating the performance of an organization. The GPI development method is shown in figure 2.1.
Figure 2.1: GPI development (Gandhi et al., 2006)

GPI = Economic Indicator/Environmental Impact (EI)

Economic Indicator = Selling Price (SP)/Production Cost (PC)

\[ \text{GPI} = \frac{\text{SP}}{\text{PC}}/\text{EI} \]

\[ \text{EI} = w_s \text{SWG} + w_g \text{GWG} + w_w \text{WC} \]

\[ = 0.17\text{SWG} + 0.5\text{GWG} + 0.33\text{WC} \]

Where:

SWG - solid waste generation,

GWG - gaseous waste generation,

WC - water consumption,

w_s, w_g, w_w are corresponding weights of solid, gas and water respectively.

The corresponding weights are the values obtained from environmental sustainability index.

The green productivity indexing method acts a powerful tool for measuring the company’s performance which can be used as a basis for improving the environmental and
2.3.2 Air Pollution Index (API) (Basu et al., 2008)

In this method, the quality of the air has been quantified by the combination of environmental impact assessments and geographical information systems. The air pollution due to transportation in a highway is analyzed using API.

Integration of geographical information system and API helps in stressing the importance of environmental impacts due to pollution. The environmental stability can be maintained after assessing the environmental impacts. The quality of the air can be evaluated based on the API technique.

\[ I = \frac{\sum_{i=1}^{n} A_i}{n} ; i = 1,2,3...n \]

Where \( A_i = (C_i \times S_i) \times 100 \)

- \( C_i \) - concentration of \( i^{th} \) pollutant.
- \( S_i \) - air quality standard for \( i^{th} \) pollutant.
- \( i \) - air pollution index.
- \( n \) - number of pollutants selected.

The quality of the air is judged based on the rating scale shown in table 2.3 from the obtained index value.
The API approach helps in identifying air pollution due to transportation. The API is used to indicate an overall entity value for the pollution instead of individual pollutants. The combination of environmental impact assessment and geographical information system assessment was used to determine the quality of air.

2.3.3 Estimation of carbon di-oxide (CO$_2$) (Das & Kandpal, 1997)

This method is developed to determine the CO$_2$ emissions in a cement manufacturing industry. CO$_2$ is a green house gas which is formed due to combustion of fossil fuels is a major contributor to global warming. An analysis is made in a cement manufacturing plant for determining CO$_2$ emission. CO$_2$ is also produced due to the kind of chemical reaction in a cement manufacturing plant.

2.3.3.1 CO$_2$ emissions from fossil fuel combustion

Coal and petroleum are the major fuels used in manufacturing cement. The empirical formula for determining the carbon content when coal is used as a fuel which is directly related to the heating value of coal is:

\[ C = [0.0248\text{GCV}+0.017] \]

Where GCV – gross calorific value in joules.
2.3.3.2 **CO$_2$ emissions from the cement manufacturing process**

In the cement manufacturing process, CO$_2$ is emitted from lime which is directly proportional to each other. When the limestone is heated to a particular temperature CO$_2$ is emitted which is known as calcination.

\[
\text{CaCO}_3 + \text{Heat} \rightarrow \text{CaO} + \text{CO}_2
\]

The emission factor of CO$_2$ is calculated using the following expression.

\[
\text{EF}_{\text{cement}} = 0.785 \text{ (fraction of CaO in cement).}
\]

The above discussed methods can be used to determine CO$_2$ emissions in a cement industry. This method can also be used to determine the best quality cement based on CO$_2$ emissions.

2.3.4 **Ozone depletion index (Bare et al., 2003)**

This method discusses the potential contribution of a chemical towards ozone depletion. Formation of holes in the ozone layer due to ozone depleting substances is known as ozone depletion.

Ozone depleting substances like emissions of chlorofluorocarbons, hydro fluorocarbons, halons and other substances affect the ozone layer forming ozone holes and lower levels of ozone. The ultraviolet rays reach the earth due to lower levels of ozone and ozone holes affecting human, plant and marine life. The major effects of ultraviolet rays due to ozone depletion are skin cancer, cataracts, crop damage, material damage, and other plant effects. The ozone depletion potential (ODP) is based on the degradation caused to the ozone layer, chemical reactivity or lifetime of the chemicals used.
Ozone Depletion Index = \sum e_i \times ODP_i

Where \( e_i \) is the emission (in kilograms) of substance \( i \).

\( ODP_i \) is the ozone depletion potential of substance \( i \).

The above discussed model can be used to find the potential contribution of a chemical leading to the depletion of ozone layer.

2.3.5 Global warming index (Bare et al., 2003)

This method discusses the potential contribution of a substance towards global warming. Formation of holes in the ozone layer due to ozone depleting substances is known as ozone depletion. The earth remains warm due to the green house gases like water vapor, carbon dioxide, methane, chlorofluorocarbons, and hydro fluorocarbons which hold the sun rays otherwise it escapes through the atmosphere. The concentrations of green house gases are increasing as the emission rate is higher than the absorption rate which will result in extreme weather conditions.

The method to determine the global warming index of any substance is:

\[
\text{Global Warming Index} = \sum e_i \times GWP_i
\]

Where \( e_i \) is the emission (in kilograms) of substance \( i \)

\( GWP_i \) is the global warming potential of substance \( i \).

The above discussed model can be used to determine the potential contribution of a substance towards global warming.

2.3.6 Incorporating environmental index as waste into VSM (Patil, 2005)
This method discusses identifying waste in a value stream and incorporating the waste as a value in a VSM.

A study was done on chemicals used for manufacturing processes in an automobile industry. The chemicals used were rated on a scale of 1 to 10 based on the hazardousness using software SimaPro for life cycle assessment. The environmental index for each process along the manufacturing line is determined using the formula:

\[ EI = \sum W*R \]

Where,

- \( EI \) – Environmental index,
- \( W \) - Relative weight of the chemical,
- \( R \) - Hazardousness rating of the chemical,

The above discussed method is used to determine the waste for each process and the value is added as a waste in the VSM.

2.4 Environmental strategies towards sustainability

According to Azzone et al., (1996), companies need to improve their environmental performance to compete in the fast developing market. Environmental strategies are the set of norms and values which should be implemented along with the corporate culture for environmental change. Resources like organization, human resources, facilities and equipment, and relationship networks determine the effectiveness of an organization towards environmental change. The different types of strategies that an organization can use are described in the following sections.
2.4.1 Passive, lobbying-based environmental strategy

Management with a compliance based strategic attitude follows this strategy in order to survive the market with the competitors and because of pressure from public for cleaner production. Companies try to follow the rules and regulations formed by the government for green manufacturing to meet customer expectations. Even though a company has only limited infrastructural resources they try to improve their environmental performance and reduce costs to compensate for the money they spent for introducing new technologies.

2.4.2 Re-active environmental strategy

Management with a compliance based attitude follows this strategy as they react to market demand for producing environmental friendly products. Companies think there is a tradeoff between environmental management systems and profit. Empirical studies state that companies which possess less environmental risk, fewer resources and less financial availability tend to adopt this strategy.

2.4.3 Anticipatory environmental strategies

Management with an anticipatory strategic attitude tends to improve technologies predicting the future requirements of their customers and environmental policies to gain a competitive advantage. Companies should make sure that the forecasted environmental changes bring value by utilizing the available resources. Since there is a risk involved in an anticipatory environmental strategy, many companies opt for lobbying environmental strategy.

2.4.4 Innovation based green strategies

Management introduces such strategies to sustain their competitive advantage over a long term. This strategy focuses on the product and process innovations to improve the environmental
performance of an organization also considering future requirements. Employees should be briefed about the importance of environmental benign manufacturing (EBM) and EBM should be included in the company’s objective.

According to Hart (1996), many years ago, a few environmentalists calculated the environmental burden as a measure to find environmental impact.

\[ EB = P \times A \times T \]

Where, EB - environmental burden

P - Population

A - Affluence (consumption)

T - Technology

According to Hart (1996), the feasible way to reduce environmental burden is by changing technology which will help in achieving sustainability. Companies try to achieve sustainability using three stages in environmental strategies.

2.4.5 Pollution prevention

Companies should focus on preventing pollution rather than controlling it. Pollution prevention aims in reducing waste using lean techniques. Pollution prevention helps in decreasing the product costs and risks.

2.4.6 Product stewardship

Product stewardship aims to minimize the environmental impacts and pollution. Design for the environment is a tool which should be used by companies at the design stage so that
recycling and re-using is made easier. A complete assessment of inputs and outputs, and a cradle
to grave analysis is done during the design phase.

2.4.7 **Clean technology**

To achieve sustainability, companies should think of upgrading their manufacturing
technology as earlier technologies may not be sustainable. Environmental performance will be
improved with clean technology whereas the performance is limited with the existing one.

The above mentioned strategies and stages in strategies can be used to improve
environmental performance of an organization and achieve sustainability.

2.5 **ISO 14001 Environmental management system (ISO 14001, 2004)**

The environmental management system (EMS) ISO 14001 is developed for maintaining a
standard approach in the environmental policies and regulations. EMS can collaborate with
other management systems for improving the profit and environmental performance of the
organization. Each organization has to develop an environmental policy, targets and objectives
within the limits of EMS. The environmental performance of the manufacturing, processing and
servicing organizations are assessed with ISO 14001 standards. EMS mainly concentrates on
certain issues like sustainable development, life cycle analysis, and minimization of
environmental impacts, pollution, and waste. ISO 14001 was developed from the quality based
ISO 9000 management series which stresses the importance of plan-do-check-act, continuous
improvement and organizational development. For maintaining ISO standards, an organization
has to implement and maintain the objectives and targets for continuous improvement and
enhancing the environmental performance.

2.6 **Environmental measures for organizations**
Environmental measures mentioned in table 2.2 helps the organization to document cost benefits, environmental benefits, prevention of pollution and quantity of the resources reduced. The basic measures mentioned in table 2.2 are obtained from the EPA and green supplier network. Many organizations use this table as a reference and report their environmental performance measures to environmental reporting systems (taken from EPA, 2006).

### Table 2.3: Environmental measures (EPA, 2006)

<table>
<thead>
<tr>
<th>Category</th>
<th>Definition</th>
<th>Metric</th>
<th>Unit of measure</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Input Measures</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy Use</td>
<td>Any source providing usable power or consuming electricity Transportation and non-transportation sources</td>
<td>Energy Used</td>
<td>Specific to energy source such as BTUs or kilowatt sources hours, % reduction, energy use/ unit of product</td>
</tr>
<tr>
<td>Land Use</td>
<td>Land covered by buildings, parking lots, and other impervious surfaces Land/habitat conservation</td>
<td>Land Converted, Land Restored or Protected, Area of Impervious Surfaces</td>
<td>Square feet, acres.</td>
</tr>
<tr>
<td>Materials use</td>
<td>Materials used (total or specific), ex. packaging materials Proportion of input materials that were recycled or recovered (vs. virgin materials)</td>
<td>Materials Used, Percent Utilization of materials Post-consumer Recycled Content</td>
<td>Tons/year, pounds/ unit of product, % materials utilization</td>
</tr>
<tr>
<td>Water Use</td>
<td>Incoming raw water, from outside sources, e.g., from municipal Water supply or wells, for operations, facility use, and grounds maintenance.</td>
<td>Volume of Water Used, P2 to reduce Priority Chemicals/ Quality Standards/ Pretreat Standards</td>
<td>Gallons/year % reduction, % recycled Pounds Priority Chemicals/ year, % reduced, % recycled</td>
</tr>
</tbody>
</table>

**Non-Product Output Measures**
<table>
<thead>
<tr>
<th>Table 2.3 (cont.)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Air emissions</strong></td>
</tr>
<tr>
<td><strong>Water Pollution</strong></td>
</tr>
<tr>
<td><strong>Solid Waste</strong></td>
</tr>
</tbody>
</table>

**Downstream/Product Measures**

| **Product Impacts** | Expected lifetime energy and water use Wastes (to air, water, & land) from product use and disposal or recovery | Energy—BTU, kWh, mWh Water use gallons Wastes pounds, tons |

**Other Measures**

| **Money Saved** | Money saved in the reduction of materials or other changes in processes | Dollars saved |
| **Qualitative Measures** | Other environmental improvements that cannot be directly or accurately quantified. For example: implementing an EMS | Dollars saved |

Savings and environmental benefits from leaning out of permits/ Design for Environment/ Clean Production/ EMS implementation/ Extended Product Responsibility
2.7 Chapter summary

This chapter discussed the importance of lean manufacturing, need for a VSM and need for assessing environmental impacts for an organization. The benefits of integrating lean manufacturing and the environmental impacts were also discussed. The different types of environmental impacts of the lean wastes also suggest the importance of integrating lean and environment.

The literature review was helpful in identifying different methods used in identifying different types of environmental impacts. Environmental strategies which help the organization to improve their environmental performance and to achieve sustainability were also discussed. A brief description about the ISO 14001 environmental management system was described in this chapter. The basic measures for finding environmental performance of an organization are also discussed.

Most methods for assessing environmental impacts discussed in this chapter are not suitable for employees of a company to implement. The concept of assessing environmental impacts using a VSM seems to be vital for an organization towards green manufacturing. The basic environmental measures obtained from EPA will be used for studying environmental impacts in this thesis. The method for assessing the environmental impacts using a VSM will be discussed in chapter 3.

The literature is best explained in table 2.5. Table 2.5 explains the concepts that are obtained from this chapter. This section also explains why the concepts that are used for environmental assessment is not applicable for this thesis.
Table 2. 4: Summary of the literature review

<table>
<thead>
<tr>
<th>Topics</th>
<th>Abstract(A) or specific(S)</th>
<th>Quantifiable 1- No 2- Partially 3- Yes</th>
<th>Applicable 1- No 2-Partially 3- Yes</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green productivity index</td>
<td>A</td>
<td>3</td>
<td>3</td>
<td>The concept of determining environmental impacts along the production line will be used in this thesis</td>
</tr>
<tr>
<td>Air pollution index</td>
<td>S</td>
<td>2</td>
<td>1</td>
<td>This method is not applied as pollution is not considered for this thesis</td>
</tr>
<tr>
<td>Estimation of CO₂ emissions</td>
<td>S</td>
<td>1</td>
<td>3</td>
<td>The concept of determining the amount of CO₂ that could be emitted along the production line will be used in this thesis.</td>
</tr>
<tr>
<td>Ozone depletion index</td>
<td>S</td>
<td>1</td>
<td>1</td>
<td>This method is not applied as it does not fit in the system boundary</td>
</tr>
<tr>
<td>Global warming index</td>
<td>S</td>
<td>1</td>
<td>1</td>
<td>This method is not applied it does not fit in the system boundary</td>
</tr>
<tr>
<td>Incorporating environmental index as a waste in VSM</td>
<td>A</td>
<td>3</td>
<td>3</td>
<td>The concept of using a VSM to assess environmental factors is obtained from this topic</td>
</tr>
<tr>
<td>Environmental strategies</td>
<td>A</td>
<td>3</td>
<td>1</td>
<td>It is not applicable for this thesis as it does not fit in the system boundary. But it has to be followed by a company for measuring environmental performance</td>
</tr>
<tr>
<td>Environmental stages</td>
<td>A</td>
<td>3</td>
<td>1</td>
<td>It is not applicable for this thesis as it does not fit in the system boundary. But a company has to implement the changes in different stage for improving environmental performance</td>
</tr>
</tbody>
</table>
Lean principles are mainly used for increasing productivity, reducing lead time, and eliminating waste. Environmental impacts can also be assessed by using lean principles. The objective of this paper is to assess and document the environmental impacts as a component in a VSM.

3.1 Lean manufacturing

Lean is a Toyota Production System concept which integrates different tools for eliminating waste and increasing productivity. According to Hines and Rich (1997), “there are seven types of wastes in lean production and they are (a) over production (b) waiting (c) transport (d) inappropriate processing (e) unnecessary inventory (f) unnecessary motion and (g) defects.”

The five main principles of lean production are define the value, identify the value stream, work flow, pull the work and pursue to perfection (Womack and Jones, 1996). The lean principles can be applied at three stages namely demand, flow and leveling. A VSM is used in lean production for depicting the flow and information (Tapping et al., 2002).

3.1.1 Value stream mapping

According to Womack and Jones (1996), a VSM is “the simple process of directly observing the flows of information and materials as they now occur, summarizing them visually and then envisioning a future state with much better performance.” A VSM gives a pictorial representation of the activities, cycle time, lead time, information flow and material flow. The lead time, cycle time and resources can be reduced by eliminating waste (Tapping et al., 2002).
A VSM is a lean production tool which was developed to focus on disconnected flow lines for improvement. The initial step for creating a VSM is preparing the current state map for the production line with the data collected from the shop floor. The immediate step is to analyze the VSM and identify the areas of improvement. The final step is preparing the future state map with the improvement ideas along the value stream (Braglia et al., 2006).

3.1.2 Need for value stream mapping in an industry

A VSM emphasizes the requirement for redesigning the production line. It visualizes the whole production line and also identifies waste in the value stream. The VSM forms a base for implementing lean techniques and concepts across the organization. A VSM is a qualitative tool which shows the relationship between information flow and material flow (Rother & Shook, 1999).

3.2 Environmental impacts

According to the EPA (2006) “Environmental waste is an unnecessary or excess use of resources or a substance released to the air, water, or land that could harm human health or the environment.” Environmental factors which affect the quality, time and cost do not add any value to the customer.

3.2.1 Need for assessing environmental impacts

The assessment of environmental impacts helps in identifying and evaluating the relevant effects of the environment. Environmental wastes increase the costs of business because of disposal costs, waste of raw materials, and pollution control. Customers tend to buy products from those companies who produce products with less environmental impacts. The environmental impact assessment provides a cleaner and safer environmental workplace for
employees.

Nowadays, environmental impacts are also linked with the economy of an organization. Management is under pressure to improve the profit of the organization by increasing productivity and reducing environmental impacts. The growth of a company will be based on integration of environmental performance with business strategy (Gandhi et al., 2006).

3.2.2 Need for Integration of lean and environment

Integration of lean and the environment provides certain techniques and strategies for improving lean results and enhancing the environmental performance. Lean along with the environment helps to reduce costs and lead times, improves process flow and environmental quality. Integration of lean and the environment helps in eliminating environmental hazards, and providing a safer environment for the employees. Lean events and activities helps in identifying the environmental benefits and eliminating potential risks (EPA, 2006).

Value stream mapping can be used to visualize the environmental wastes along the production line. A VSM acts as a critical tool in identifying opportunities during the analysis stage for improving the environmental performance. A VSM can help in identifying environmental waste such as energy use, raw materials, solid wastes, air emissions, pollutants, and hazardous wastes (EPA, 2006).

3.3 Method

This section begins with a description of the hierarchy of environmental factors derived from the EPA. The factors that are considered for measuring environmental impacts are also explained in this section. Then, the method for calculating the environmental factors is explained in detail with a class project in section 3.5. Incorporation of the environmental factors in a VSM
is also explained in detail.

3.3.1 Hierarchy of environmental factors

The hierarchy of environmental factors for a manufacturing system shown in figure 3.1 was developed based on a list obtained from the EPA (2006). These environmental factors help in documenting cost benefits, resource quantities and environmental improvement opportunities which forms the basis for improving the environmental performance of an organization. The environmental measures are divided into (a) input measures (b) non product measures (c) downstream / product measures and (d) other measures. Among these four measures from the hierarchy, only input measures are considered for the case studies. From the input measures only energy use, workspace use, and material use are considered for incorporation of environmental factors in a VSM. Energy use is the power consumed for a machine/transportation purpose. Workspace use is the area used for any activity required for a particular process in a production/assembly line. Materials used for each activity are also determined as an environmental measure for incorporating in a VSM.
Figure 3.1: Hierarchy of environmental factors

3.3.2 Environmental VSM (EPA, 2006)

The different ways followed by EPA for addressing environmental values in a VSM are:

- **EHS icon in a VSM**

  These icons are used to indicate the processes which can be a hazard to workers, or have opportunities for reducing the environmental impacts.

- **Environmental data in a VSM**

  A key environmental performance metric, hazardous material wasted for each process is calculated and added to the process box as additional information to the existing ones like cycle time, change over time.

- **Comparison of materials needed with usage data**
A materials line is added to the VSM similar to the existing time line. Weight of the material used by the process and that is ended up in the finished product is shown. Similarly this method is extended to other resources like water, energy, trash, and wastes.

The difference between the environmental VSM’s created in this thesis and EPA (2006) is shown in table 1.

**Table 3.1. Difference between environmental VSM's**

<table>
<thead>
<tr>
<th></th>
<th>Environmental VSM in this thesis</th>
<th>Environmental VSM in EPA (2006)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EHS icon</td>
<td>Not used</td>
<td>Used to indicate processes that require attention</td>
</tr>
<tr>
<td>Environmental metrics</td>
<td>Energy and materials used are combined together in terms of amount of carbon dioxide emitted for each process. Workspace used is also shown in the VSM</td>
<td>Any one environmental metric is measured and added as it is in the VSM</td>
</tr>
<tr>
<td>Materials needed versus used</td>
<td>Not used</td>
<td>Used to show the difference between the materials required and used</td>
</tr>
</tbody>
</table>

According to EPA (2006) approach, any one environmental metric is measured and shown in the VSM. The particular metric used will not be the major environmental impact contributor for all cases as different processes have different types of impacts. Materials needed versus material used method gives an idea of minimizing the materials used for each processes. Both the method does not show the amount of reduction in environmental impacts for the improvements made.

In this thesis, three environmental metrics are shown in a VSM as an example. In practice, the actual metrics used will vary according to each specific situation. Energy use and
materials use, the major contributors of environmental impacts are measured and shown as a single value in terms of carbon dioxide emissions. This measure gives us an idea of how much carbon dioxide is released to the atmosphere. This method shows the amount of reduction in environmental impacts for the improvements made in the future state VSM.

3.4 Case study scenario

The objective of this section is to show the calculation and incorporation of the environmental factors in a VSM. The current state VSM for each case study is shown in this section. The VSM is used to document the environmental performance of an assembly/manufacturing line and also to show improvement opportunities across the line which in turn benefits the organization and society. This section also describes the calculation of the environmental factors like energy, work space, and material use for each case study. Finally, the incorporation of the environmental factors in the VSM is presented.

3.5 Case study 1: Class project case study

A class project is used as a scenario for explaining the method to determine environmental factors and incorporation of the same in the VSM. The activities and the processes in the project are considered for this case study.

The class project user’s manual (2002) is used for collecting the information for preparing the current state VSM. The project has a demand of five planes per week. The information flow and material flow from raw material acquisition to the delivery of airplanes are shown in the current state VSM in figure 3.2. There are fourteen workstations in this simulation project. The time taken and the resources utilized for each workstation are shown in the VSM. Many processes are performed parallel to each other. The timeline for each path are in the VSM.
The value added time for each process and non-value added time and inventory between each process are presented in different timelines. Raw materials for various processes are purchased from the supplier. The interiors to be assembled during the final assembly are either produced or purchased. The resources of buildup crew, wing crew and assembly crew are shared for certain processes. Applicable information like cycle time, changeover time, scrap/rework rate, rework time, inventory, resources and setup time are shown for each workstation in the VSM. Lead time is calculated and entered between workstations.
Figure 3.2: Current state VSM of the class project
3.5.1 Measure of the environmental factors

As discussed, the above input measures like energy use, workspace use and material use from the hierarchy shown in figure 3.1 are utilized for incorporating the environmental factors in a VSM. This section describes how input measures are measured for incorporating into a VSM.

3.5.1.1 Energy use

Energy use in manufacturing industries has a major impact on their business and environmental performance. According to the EPA (2007), industry and manufacturing sectors consume more energy than other sectors like transportation, commercial, and residential. Assessment of energy use in industry and manufacturing sectors can identify many opportunities to reduce environmental impacts.

Assessment of energy use with a VSM helps to identify areas of improvement for environmental performance, safety and productivity and decreasing operating costs of an organization. According to the EPA (2007), companies like the Eastman Kodak Company, General Electric and Lasco Bathware saved millions of dollars by energy use reduction. General Electric and Toyota Motor Manufacturing reduced greenhouse gas emissions by 250K metric tons and 30% respectively.

For measuring energy consumption a power measuring device and a data logger are used. According to Drake (2006), the power measuring device is connected to a machine’s power box in such a way that the power for the entire machine is drawn through this device. A power measuring device as shown in figure 3.3 is used to determine the power consumption of a machine for machining a part or a batch over a particular time in hours. From the obtained power consumption, energy used for machining a part at each workstation is calculated. Measuring
energy consumption for each process will identify where excess energy is utilized. Measured energy can be used as a basis for minimizing energy use and maximizing energy efficiency for reducing costs and improving environmental quality.

The energy measured as described above for each applicable process is in terms of kilowatt-hours. Then the amount of carbon dioxide emitted during the process is identified from the measured energy. Table 3.1 shows the assumed energy values for each process. As shown in table 3.1, the energy used for shear process is 20 kWh per part. According to the EPA (2008) the amount of CO$_2$ emitted for producing 1 kWh of energy by coal fired power generation is 1.894 lbs per kWh. So the total amount of CO$_2$ emitted in shear process is 53.03 lbs per part. The
amount of CO\(_2\) emitted for all the other processes is shown in table 3.1.

**Table 3. 2: Amount of CO\(_2\) emitted from Energy**

<table>
<thead>
<tr>
<th>S. No</th>
<th>Process</th>
<th>Energy used in kWh per part</th>
<th>Amount of CO(_2) emitted in lbs per part</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Shear</td>
<td>28</td>
<td>53.032</td>
</tr>
<tr>
<td>2</td>
<td>Bond</td>
<td>30</td>
<td>56.82</td>
</tr>
<tr>
<td>3</td>
<td>Rivet &quot;Auto&quot;</td>
<td>20</td>
<td>37.88</td>
</tr>
<tr>
<td>4</td>
<td>Rivet &quot;Manual&quot;</td>
<td>10</td>
<td>18.94</td>
</tr>
<tr>
<td>5</td>
<td>Build &quot;Tail&quot;</td>
<td>3</td>
<td>5.682</td>
</tr>
<tr>
<td>6</td>
<td>Build &quot;Fuselage 1&quot;</td>
<td>4</td>
<td>7.576</td>
</tr>
<tr>
<td>7</td>
<td>Build &quot;Fuselage 2&quot;</td>
<td>5</td>
<td>9.47</td>
</tr>
<tr>
<td>8</td>
<td>Build &quot;Wing&quot;</td>
<td>4</td>
<td>7.576</td>
</tr>
<tr>
<td>9</td>
<td>Complete &quot;Wing&quot;</td>
<td>7</td>
<td>13.258</td>
</tr>
<tr>
<td>10</td>
<td>Complete &quot;Fuselage&quot;</td>
<td>6</td>
<td>11.364</td>
</tr>
<tr>
<td>11</td>
<td>Assemble &quot;Primary&quot;</td>
<td>3</td>
<td>5.682</td>
</tr>
<tr>
<td>12</td>
<td>Assemble &quot;Final&quot;</td>
<td>2</td>
<td>3.788</td>
</tr>
<tr>
<td>13</td>
<td>Install &quot;Interiors&quot;</td>
<td>10</td>
<td>18.94</td>
</tr>
<tr>
<td>14</td>
<td>Complete &quot;Plane&quot;</td>
<td>3</td>
<td>5.682</td>
</tr>
</tbody>
</table>

Thus the amount of CO\(_2\) emitted for each process from the assumed energy values is identified.

**3.5.1.2 Workspace use**

Efficient use of the available space in a manufacturing plant plays an important role in improving productivity and environmental performance. Proper usage of the available space reduces operating cost, and material handling cost. Assessment of workspace use using a VSM gives an opportunity to improve space utilization and reduce energy use in those areas which indirectly reduces environmental impacts.

Workspace used for each process in a production line/assembly line is measured using a measuring tape or any other distance measuring device. The objective of measuring workspace
use for each station is to give an idea of how much workspace is wasted or not utilized properly. This includes workspace used for machining/assembly and for storage of raw materials, inventory, tools and other substances for a particular process.

The assumed workspace in terms of area (square feet) for each process is shown in a VSM as a separate component as shown in figure 3.4. The assumed workspace values are shown for each process in the VSM. The workspace used for inventory storage is shown below the inventory symbol in the VSM. Table 3.2 represents the assumed workspace for each process. The workspace used for a machine/assembly is known as a value added workspace. The workspace used for storage of raw materials, inventory, tools and other substances for a particular process is known as non-value added workspace.

From table 3.2 the workspace used for building the tail and fuselage are 2000 and 3200 square feet respectively. The workspace used for storing inventory for building fuselage is 900 square feet.

![Figure 3. 4: Sample workspace data in a VSM](image)

<table>
<thead>
<tr>
<th>Build “Tail”</th>
<th>Build “Fuselage”</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cycle time 22 hrs</td>
<td>Cycle time 16 hrs</td>
</tr>
<tr>
<td>Rework time 1 hr</td>
<td>Rework time 1 hr</td>
</tr>
<tr>
<td>Rework Rate = 25%</td>
<td></td>
</tr>
<tr>
<td>WS = 2000 sqft</td>
<td></td>
</tr>
</tbody>
</table>

| 21 - 0,18 |
| 23 - 0,9 |

| WS = 900 sqft |
| WS = 3200 sqft |

| Rework Rate = 10% |

Figure 3. 4: Sample workspace data in a VSM
### Table 3.3: Workspace data

<table>
<thead>
<tr>
<th>S.No</th>
<th>Process</th>
<th>Non-value added workspace in square feet</th>
<th>Value added workspace in square feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Shear</td>
<td>500</td>
<td>600</td>
</tr>
<tr>
<td>2</td>
<td>Bond</td>
<td>500</td>
<td>400</td>
</tr>
<tr>
<td>3</td>
<td>Rivet &quot;Auto&quot;</td>
<td>450</td>
<td>500</td>
</tr>
<tr>
<td>4</td>
<td>Rivet &quot;Manual&quot;</td>
<td>450</td>
<td>500</td>
</tr>
<tr>
<td>5</td>
<td>Build &quot;Tail&quot;</td>
<td>500</td>
<td>2000</td>
</tr>
<tr>
<td>6</td>
<td>Build &quot;Fuselage 1&quot;</td>
<td>900</td>
<td>3200</td>
</tr>
<tr>
<td>7</td>
<td>Build &quot;Fuselage 2&quot;</td>
<td>1000</td>
<td>3200</td>
</tr>
<tr>
<td>8</td>
<td>Build &quot;Wing&quot;</td>
<td>600</td>
<td>2500</td>
</tr>
<tr>
<td>9</td>
<td>Complete &quot;Wing&quot;</td>
<td>700</td>
<td>3200</td>
</tr>
<tr>
<td>10</td>
<td>Complete &quot;Fuselage&quot;</td>
<td>700</td>
<td>3200</td>
</tr>
<tr>
<td>11</td>
<td>Assemble &quot;Primary&quot;</td>
<td>850</td>
<td>3400</td>
</tr>
<tr>
<td>12</td>
<td>Assemble &quot;Final&quot;</td>
<td>1050</td>
<td>3400</td>
</tr>
<tr>
<td>13</td>
<td>Install &quot;Interiors&quot;</td>
<td>1000</td>
<td>3500</td>
</tr>
<tr>
<td>14</td>
<td>Complete &quot;Plane&quot;</td>
<td>2000</td>
<td>3800</td>
</tr>
</tbody>
</table>

#### 3.5.1.3 Materials use

Assessment of materials use with a VSM gives an idea of how much material is used for each process which can be used as a basis for minimizing usage of hazardous materials and cleaning solvents. Hazardous materials and cleaning solvents greatly affect the environment. Materials usage can also be minimized by comparing usage data with materials required data.

Materials used in terms of pounds or tons per day or week are observed for each workstation. Materials like raw materials and scrap in a production line are considered for the purpose of incorporating the environmental factors in a VSM. Measurement of materials usage gives an idea of how much material is wasted for each and every process. Table 3.3 shows the weight of the material used for each process. The weight of the aluminum used in the shear process is 500 lbs. According to the ERAP (2007), the amount of CO$_2$ emitted for producing 1 lb of aluminum is 9.81 lbs of CO$_2$. The total amount of CO$_2$ emitted for producing 500 lbs of
aluminum is 4905 lbs. Similarly the total amount of CO\textsubscript{2} emitted for all the other processes are shown in table 3.3. The calculation for materials used is not done for engines, interiors, landing gear, avionics and windows as those parts are not made of aluminum.

**Table 3.4: Materials data**

<table>
<thead>
<tr>
<th>S.No</th>
<th>Process</th>
<th>Weight of the material used in lbs</th>
<th>Total amount of carbon dioxide emitted in lbs</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Shear</td>
<td>500</td>
<td>4,905</td>
</tr>
<tr>
<td>2</td>
<td>Bond</td>
<td>100</td>
<td>981</td>
</tr>
<tr>
<td>3</td>
<td>Rivet &quot;Auto&quot;</td>
<td>50</td>
<td>491</td>
</tr>
<tr>
<td>4</td>
<td>Rivet &quot;Manual&quot;</td>
<td>30</td>
<td>294</td>
</tr>
<tr>
<td>5</td>
<td>Build &quot;Tail&quot;</td>
<td>400</td>
<td>3,924</td>
</tr>
<tr>
<td>6</td>
<td>Build &quot;Fuselage 1&quot;</td>
<td>2000</td>
<td>19,620</td>
</tr>
<tr>
<td>7</td>
<td>Build &quot;Fuselage 2&quot;</td>
<td>1500</td>
<td>14,715</td>
</tr>
<tr>
<td>8</td>
<td>Build &quot;Wing&quot;</td>
<td>1000</td>
<td>9,810</td>
</tr>
<tr>
<td>9</td>
<td>Complete &quot;Wing&quot;</td>
<td>50</td>
<td>491</td>
</tr>
<tr>
<td>10</td>
<td>Complete &quot;Fuselage&quot;</td>
<td>100</td>
<td>N/A</td>
</tr>
<tr>
<td>11</td>
<td>Assemble &quot;Primary&quot;</td>
<td>6000</td>
<td>N/A</td>
</tr>
<tr>
<td>12</td>
<td>Assemble &quot;Final&quot;</td>
<td>500</td>
<td>N/A</td>
</tr>
<tr>
<td>13</td>
<td>Install &quot;Interiors&quot;</td>
<td>2500</td>
<td>N/A</td>
</tr>
<tr>
<td>14</td>
<td>Complete &quot;Plane&quot;</td>
<td>200</td>
<td>1,962</td>
</tr>
</tbody>
</table>

3.5.2 **Incorporating environmental values in a VSM**

In the previous section, the method for developing a measure for three environmental factors was discussed. In this section, incorporation of the environmental factors in a VSM is now discussed.

In figure 3.5, a sample VSM with the CO\textsubscript{2} value is shown which indicates the amount of CO\textsubscript{2} emitted for producing the energy used and the materials used in the shearing operation. Workspace utilization is added to the VSM as a separate component as shown in figure 3.4. Table 3.4 shows the amount of CO\textsubscript{2} emitted for each process.

From table 3.4 the total amount of CO\textsubscript{2} emitted for the shearing process = CO\textsubscript{2} emitted
(energy) + CO₂ emitted (materials) = 53 + 4905 = 4958 lbs

**Table 3.5: Amount of CO₂ emitted from the environmental factors**

<table>
<thead>
<tr>
<th>S.No</th>
<th>Process</th>
<th>CO₂ emitted for producing energy in lbs per part</th>
<th>carbon dioxide emitted for producing aluminum in lbs per part</th>
<th>Total carbon dioxide emitted in lbs per part</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Shear</td>
<td>53</td>
<td>4905</td>
<td>4958</td>
</tr>
<tr>
<td>2</td>
<td>Bond</td>
<td>57</td>
<td>981</td>
<td>1038</td>
</tr>
<tr>
<td>3</td>
<td>Rivet &quot;Auto&quot;</td>
<td>38</td>
<td>491</td>
<td>528</td>
</tr>
<tr>
<td>4</td>
<td>Rivet &quot;Manual&quot;</td>
<td>19</td>
<td>294</td>
<td>313</td>
</tr>
<tr>
<td>5</td>
<td>Build &quot;Tail&quot;</td>
<td>6</td>
<td>3924</td>
<td>3930</td>
</tr>
<tr>
<td>6</td>
<td>Build &quot;Fuselage 1&quot;</td>
<td>8</td>
<td>19620</td>
<td>19628</td>
</tr>
<tr>
<td>7</td>
<td>Build &quot;Fuselage 2&quot;</td>
<td>9</td>
<td>14715</td>
<td>14724</td>
</tr>
<tr>
<td>8</td>
<td>Build &quot;Wing&quot;</td>
<td>8</td>
<td>9810</td>
<td>9818</td>
</tr>
<tr>
<td>9</td>
<td>Complete &quot;Wing&quot;</td>
<td>13</td>
<td>491</td>
<td>504</td>
</tr>
<tr>
<td>10</td>
<td>Complete &quot;Fuselage&quot;</td>
<td>11</td>
<td>N/A</td>
<td>11</td>
</tr>
<tr>
<td>11</td>
<td>Assemble &quot;Primary&quot;</td>
<td>6</td>
<td>N/A</td>
<td>6</td>
</tr>
<tr>
<td>12</td>
<td>Assemble &quot;Final&quot;</td>
<td>4</td>
<td>N/A</td>
<td>4</td>
</tr>
<tr>
<td>13</td>
<td>Install &quot;Interiors&quot;</td>
<td>19</td>
<td>N/A</td>
<td>19</td>
</tr>
<tr>
<td>14</td>
<td>Complete &quot;Plane&quot;</td>
<td>6</td>
<td>1962</td>
<td>1968</td>
</tr>
</tbody>
</table>

The identified CO₂ value is incorporated in a VSM as shown in figure 3.5.

![Figure 3.5: Sample CO₂ value in a VSM](image)
A sample of the calculated environmental factors is incorporated in a VSM as shown in figure 3.6. The CO$_2$ content identified can be used as a basis for improving the environmental performance of the organization. Energy use and materials use data in the VSM can be used as a basis for minimizing the operation and inventory cost which in turn reduces the environmental impact. Then an environmental timeline is drawn in the VSM indicating the CO$_2$ emitted and the workspace used for each process as shown in the environmental VSM in figure 3.7.

Figure 3. 6: A sample of the environmental factors in a VSM
Figure 3.7: Environmental VSM of the class project
The section described the method for measuring and incorporating the environmental factors in a VSM. This method assisted in assessing and documenting the environmental factors using a VSM.

### 3.6 Case study 2: Sheet metal shop in company X

This company produces different types of business jets located in Wichita, Kansas. For this case study, the process involved in a sheet metal shop for machining a bracket is considered. This company gets aluminum sheets from its supplier with a lead time of fourteen days. The demand for this line is fifty five parts per day. The activities taking place in each process are explained below in detail. Three workstations are considered for this case study.

#### 3.6.1 Router

Aluminum sheets are machined using a router. The setup time for this process is six minutes which includes fixing an aluminum sheet on the bed and running the program on the monitor. As per the program, the tool is routed on the aluminum sheet according to dimensions of the part required. The cycle time for this process is three minutes. This machine is operated for three shifts per day. Total time available for this process is 1206 minutes.

#### 3.6.1.1 Energy used calculations

The data logger shown in figure 3.3 was fixed to the router machine as explained in section 3.5.1.1 to measure the energy consumption of the machine.

Energy consumed to machine 1 part (incl. setup) = 27.5 kWh

\[ \text{CO}_2 \text{ emitted for producing 1 kWh of energy} = 1.894 \text{ lbs/kWh} \text{ (EPA, 2008)} \]

Total amount of \text{CO}_2 emitted for producing 1 part = 1.894 * 27.5
Thus the amount of CO₂ emitted for router from the measured energy is identified.

3.6.1.2 Workspace used

The workspace used for storing the router machine is 551 square feet. The workspace used for storing raw materials, and other substances is 289 square feet.

3.6.1.3 Materials used calculations

An aluminum sheet with dimensions of 60”x18.5”x0.063” is purchased from the supplier. The weight of the aluminum sheet used is 7 lbs. A single part with the dimensions of 43”x17.5’ is obtained from the whole sheet. The weight of the used sheet is 4.78 lbs. So the weight of the unused sheet is 2.22 lbs.

CO₂ emitted for producing 1 lb of aluminum (including all the processes)

\[\text{= 9.81 lbs of CO₂/lb of AL (ERAP, 2007)}\]

So the total amount of CO₂ emitted for producing 7 lbs of aluminum

\[\text{= 7* 9.81 = 68.67 lbs of CO₂/part}\]

Thus the amount of CO₂ emitted for the material used in router is identified.

So the amount of CO₂ emitted from the energy and materials used for this process is calculated as shown below

Total amount of CO₂ emitted from the energy and materials used for routing process

\[\text{= 52.09 + 68.67 = 120.76 lbs of CO₂/part}\]
3.6.2 Debur

The machined part from the router is sent to the debur workstation. The debur process is done using hand tools. The setup time for this process is nine minutes and the cycle time is 3.7 minutes. The debur process is also operated for three shifts per day. Total time available for this process is 1206 minutes. Scrap from this process is negligible. Since the scrap rate is negligible the materials used calculation is omitted. Energy used calculations cannot be carried out as hand tools are used for this process.

3.6.2.1 Workspace used

The value added workspace for this process is 127 square feet. The non-value added workspace is 77 square feet.

3.6.3 Inspection

Aluminum parts from the debur process are sent to inspection. The cycle time for inspecting the part is twenty minutes. The inspection process uses two shifts per day. Total time available for this process is 804 minutes. Since the company follows six sigma, the defect rate for this part is negligible. Since the defect rate is negligible, the materials used calculation is omitted. Energy used calculations cannot be carried out as machines are not used for this process.

3.6.3.1 Workspace used

The value added workspace for this process is 148 square feet. Non-value added workspace is 124 square feet.

3.6.4 Incorporation of environmental factors in a VSM

In this section the current state VSM with environmental factors is shown in figure 3.8.
The VSM shown above represents all the information discussed above. An environmental timeline in the VSM represents the environmental factors for each activity. This section described all the activities and environmental factors calculation. This completes the case study in a sheet metal shop.

3.7 Case study 3: Clip manufacturing in company Y

This company produces different types of business jets located in Wichita, Kansas. The processes involved in for manufacturing a clip are considered for this case study. The lead time for getting aluminum sheets from the supplier is assumed to be ten days. In this case study, two
types of clips are considered. The demand for each clip is twelve pieces per day. The activities
taking place in each process are explained below in detail. Four workstations are considered for
this case study. For this case study the defect rate is assumed to be zero.

3.7.1 Router

Aluminum sheets are machined using a router. The setup time for this process is ten
minutes which includes fixing aluminum sheet on the bed and running the program on the
monitor. As per the program, tool is routed on the aluminum sheet according to dimensions of
the part required. The cycle time for this process is 0.5 minutes. This machine is operated for one
shift per day. The total time available for this process is 450 minutes. For this case study the
defect rate is assumed to be zero.

3.7.1.1 Energy used calculations

A data logger was used to measure the energy consumption of the machine.

Energy consumed to machine 1 part (incl. setup) = 45.6 kWh

CO$_2$ emitted for producing 1 kWh of energy = 1.894 lbs/kWh (EPA, 2008)

Total amount of CO$_2$ emitted for producing 1 part = 1.894 * 45.6

= 86.36 lbs of CO$_2$/part

Thus the amount of CO$_2$ emitted for router from the energy is identified.

3.7.1.2 Workspace used

The workspace used for storing the router machine is 425 square feet. The workspace
used for storing raw materials, and other substances is 2376 square feet.
3.7.1.3 Materials used calculations

An aluminum sheet with dimensions of 40”x48”x0.063” is purchased from the supplier. The weight of the aluminum sheet used is 12.2 lbs. The dimension of one piece is 4”x1.25’. The weight of the part is 0.03 lbs. The total number of pieces machined from one sheet is assumed to be 270 pieces (70% usage) since the company does not have a count of the number of pieces.

So the weight of the used sheet = 8.1 lbs

Weight of the unused sheet = 12.2 – 8.1 = 4.1 lbs

Weight of the unused material per part = 4.1/270 = 0.015 lbs

Total weight per part in routing process = 0.03+0.015 = 0.045 lbs

CO₂ emitted for producing 1 lb of aluminum (including all the processes)

= 9.81lbs of CO₂ /lb of AL (ERAP, 2007)

So the total amount of CO₂ emitted for producing 0.045 lbs of aluminum

=0.045* 9.81 = 0.45 lbs of CO₂ /part

Total amount of CO₂ emitted from the energy and materials used for routing process

= 86.36 + 0.45 = 86.81 lbs of CO₂ /part

3.7.2 Punch

Aluminum sheets for manufacturing the second type of clip are machined using a punching machine. The setup time for this process is ten minutes which includes fixing aluminum sheet on the bed and running the program on the monitor. As per the program,
aluminum sheet is punched according to dimensions of the part required. The cycle time for this process is one minute. This machine is operated for one shift per day. The total time available for this process is 450 minutes.

3.7.2.1 Energy used calculations

A data logger was used to measure the energy consumption of the machine.

Energy consumed to machine 1 part (incl. setup) = 26.5 kWh

CO₂ emitted for producing 1 kWh of energy = 1.894 lbs/kWh (EPA, 2008)

Total amount of CO₂ emitted for producing 1 part = 1.894 * 26.5

= 50.19 lbs of CO₂/part

Thus the amount of CO₂ emitted from the measured energy is identified.

3.7.2.2 Workspace used

The workspace used for storing the punching machine is 1328 square feet. Workspace used for storing raw materials, and other substances is 2508 square feet.

3.7.2.3 Materials used calculations

An aluminum sheet with dimensions of 32”x48”x0.063” is purchased from a supplier. The weight of the aluminum sheet used is 9.77 lbs. The dimension of one piece is 5.75”x2.71”. The weight of the part is 0.1 lbs. The total number of pieces machined from one sheet is assumed to be sixty eight pieces (70% usage) since the company does not have a count of the number of pieces.

So the weight of the used sheet = 0.1*68 = 6.80 lbs
Weight of the unused sheet = 9.77 – 6.80 = 2.97 lbs

Weight of the unused material per part = 2.97/68 = 0.043 lbs

Total weight per part in routing process = 0.1+0.043 = 0.143 lbs

CO₂ emitted for producing 1 lb of aluminum (including all the processes)

\[ = 9.81 \text{ lbs of CO}_2/\text{lb of AL} \text{ (ERAP, 2007)} \]

So the total amount of CO₂ emitted for producing 0.13 lbs of aluminum

\[ = 0.143 \times 9.81 = 1.40 \text{ lbs of CO}_2/\text{part} \]

Thus the amount of CO₂ emitted for the material used is identified.

Total amount of CO₂ emitted from the energy and materials used for routing process

\[ = 50.19 + 1.40 = 51.59 \text{ lbs of CO}_2/\text{part} \]

3.7.3 Debur

A machined part from the router and the punch is sent to the debur workstation. The debur process is done using hand tools. The setup time for this process is five minutes and the cycle time is 2.4 minutes. The debur process is also operated for one shift per day. The total time available for this process is 450 minutes. The scrap from this process is negligible. Since the scrap rate is negligible, the materials used calculation is omitted. Energy used calculations cannot be carried out as hand tools are used for this process.

3.7.3.1 Workspace used

The value added workspace for this process is 127 square feet. The non-value added
workspace is 200 square feet.

3.7.4 Press

The parts after debur is sent to the press workstation. The setup time for this process is fifteen minutes and the cycle time for this process is 1.5 minutes. This machine is operated for one shift per day. The total time available for this process is 450 minutes. Since the defect rate is assumed to be zero, the materials used calculation is omitted.

3.7.4.1 Energy used calculations

A data logger was used to measure the energy consumption of the machine.

Energy consumed to machine 1 part (incl. setup) = 18.66 kWh

\[ \text{CO}_2 \text{ emitted for producing 1 kWh of energy} = 1.894 \text{ lbs/kWh (EPA, 2008)} \]

Total amount of \( \text{CO}_2 \) emitted for producing 1 part = \( 1.894 \times 18.66 \)

\[ = 35.34 \text{ lbs of } \text{CO}_2/\text{part} \]

Thus the amount of \( \text{CO}_2 \) emitted from the measured energy is identified.

3.7.4.2 Workspace used

Workspace used for storing the machine is 35 square feet. The workspace used for storing raw materials, and other substances is 288 square feet.

3.7.5 Incorporation of environmental factors in a VSM

In this section, the current state VSM with environmental factors is shown in figure 4.2. The VSM shown represents all the information previously discussed. An environmental timeline in the VSM represents the environmental factors for each activity. This section described all the
activities and environmental factors calculation. This completes the case study for clip manufacturing process in a sheet metal shop.

Figure 3.9: Clip manufacturing current state environmental VSM
3.8 Summary

The objective of this paper is to describe the method for measuring and incorporating the environmental factors in a VSM. This method assisted in assessing and documenting the environmental factors using a VSM. Initially, a hierarchy was developed for the environmental factors. Then, a method was developed for calculating the environmental factors from the hierarchy and incorporating the measured environmental factors in a VSM using a class project. Case studies performed at two different aircraft companies are also shown.
This chapter describes the recommendations for reducing CO\textsubscript{2} emissions for the energy used and materials used. Environmental factors calculations are done based on the recommendations and the values are incorporated in the future state VSM for the case studies explained in chapter 3.

4.1 Case study 1: Class project case study

The details of all the processes involved in this class project were explained in section 3.5. In this project, the setup time, scrap rate and rework rate can be reduced by 50%. The environmental factors were calculated based on these assumptions.

4.1.1 Energy use (set up reduction)

In this project, processes like shear, bond, rivet “auto and manual” have setup times. The setup reduction could be done only to these four processes. The energy calculations are based on the time reduced in setup. The amount of CO\textsubscript{2} emitted for the four processes after setup reduction is shown in table 4.1.

<table>
<thead>
<tr>
<th>Process</th>
<th>Energy used (after setup reduction) in kWh per part</th>
<th>Amount of CO\textsubscript{2} emitted in lbs per part</th>
<th>Amount of CO\textsubscript{2} emission reduced in lbs per part</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shear</td>
<td>25</td>
<td>47.35</td>
<td>5.68</td>
</tr>
<tr>
<td>Bond</td>
<td>26</td>
<td>49.24</td>
<td>7.58</td>
</tr>
<tr>
<td>Rivet &quot;Auto&quot;</td>
<td>17</td>
<td>32.20</td>
<td>5.68</td>
</tr>
<tr>
<td>Rivet &quot;Manual&quot;</td>
<td>8</td>
<td>15.15</td>
<td>3.79</td>
</tr>
</tbody>
</table>
A total of 22.73 lbs (8.8%) of CO₂ emission is reduced from the energy used by setup reduction.

4.1.2 Material use (Reduction of scrap and rework)

In this project, processes like shear, bond, rivet “auto and manual” have scrap rates and the other processes have a rework rate. The materials used calculations are done based on scrap rate and rework rate reduction. According to the ERAP (2007), the amount of CO₂ emitted for producing 1 lb of aluminum is 9.81 lbs of CO₂. The amount of CO₂ emitted for the processes involving reduction of scrap rate or rework rate is shown in table 4.2.

<table>
<thead>
<tr>
<th>Process</th>
<th>Weight of the material used (after reduction of scrap rate and rework rate) in lbs</th>
<th>Total amount of CO₂ emitted in lbs</th>
<th>Total amount of CO₂ emission reduced in lbs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shear</td>
<td>475</td>
<td>4,660</td>
<td>245.25</td>
</tr>
<tr>
<td>Bond</td>
<td>95</td>
<td>932</td>
<td>49.05</td>
</tr>
<tr>
<td>Rivet &quot;Auto&quot;</td>
<td>47.5</td>
<td>466</td>
<td>24.525</td>
</tr>
<tr>
<td>Rivet &quot;Manual&quot;</td>
<td>27</td>
<td>265</td>
<td>29.43</td>
</tr>
<tr>
<td>Build &quot;Tail&quot;</td>
<td>350</td>
<td>3,434</td>
<td>490.5</td>
</tr>
<tr>
<td>Build &quot;Fuselage 1&quot;</td>
<td>1800</td>
<td>17,658</td>
<td>1962</td>
</tr>
<tr>
<td>Build &quot;Fuselage 2&quot;</td>
<td>1425</td>
<td>13,979</td>
<td>735.75</td>
</tr>
<tr>
<td>Build &quot;Wing&quot;</td>
<td>950</td>
<td>9,320</td>
<td>490.5</td>
</tr>
<tr>
<td>Complete &quot;Wing&quot;</td>
<td>47.5</td>
<td>466</td>
<td>24.525</td>
</tr>
<tr>
<td>Complete &quot;Plane&quot;</td>
<td>175</td>
<td>1,717</td>
<td>245.25</td>
</tr>
</tbody>
</table>

A total of 4297 lbs (7.51%) of CO₂ emission is reduced from the materials used by reduction of scrap rate or rework rate. Figure 4.1 shows the future state VSM created based on the recommendations mentioned above.
Figure 4.1: Class project future state VSM

- Reduction of environmental impact opportunities for all processes
- Reduction of energy use by set up reduction and bond
- Scrap rate reduction opportunities for bond and rivet (auto and manual)

Legend:
- VA: Value Added
- NVA: Non-Value Added

Workspace (sq ft) and CO₂ emissions:
- 600 sq ft: CO₂ 1400 lbs
- 1400 sq ft: CO₂ 4707 lbs
- 1700 sq ft: CO₂ 1959 lbs
- 2000 sq ft: CO₂ 3045 lbs
- 700 sq ft: CO₂ 1159 lbs
- 800 sq ft: CO₂ 1497 lbs
- 1000 sq ft: CO₂ 2095 lbs
- 1500 sq ft: CO₂ 2340 lbs
- 2000 sq ft: CO₂ 3200 lbs

WS: Workspace, CO₂: Amount of Carbon dioxide emissions (lbs) - square feet

Steel use of Resources

Notes:
- Demand: 5 planes/week
- Week: 5 days
- Day: 8 Hrs
- Hour: 60 min
The total amount of CO\textsubscript{2} that could be reduced from reducing energy and material usage based on the recommendations provided is 4320 lbs of CO\textsubscript{2}. Based on yearly demand, the total amount of CO\textsubscript{2} that could be reduced per year is 1,123,200 lbs (8%).

4.2 Case study 2: Sheet metal shop in company X

All the activities involved in machining a bracket in this case study are explained in section 3.6. The recommendations given below are based on assumptions. The recommendations are given only for energy used and materials used in router machine. A kaizen event can be organized for reducing the non-value added workspace involved.

4.2.1 Energy use (set up reduction)

The setup time involves the time taken for setting the program and fixing an aluminum sheet on the machine bed. The aluminum sheet is taped as the vacuum pump does not work efficiently. If the vacuum pump is replaced, the time taken for taping the aluminum sheet could be reduced which is about three minutes. 3.35 kWh of energy could be reduced by changing the vacuum pump. So, 6.5 lbs (12.47%) of CO\textsubscript{2} emission could be reduced for every part.

4.2.2 Material use (Aluminum sheet size reduction)

An aluminum sheet of 60x18.5x0.063 is used for machining. The dimensions of the machined part are 43x17.5. If an aluminum sheet of 50x18.5 is purchased then the amount of CO\textsubscript{2} emitted for producing the aluminum sheet could be reduced. So, 10.98 lbs (15.98%) of CO\textsubscript{2} emission could be reduced for every part.

The total amount of CO\textsubscript{2} that could be reduced by altering energy and material usage based on the recommendations provided is 17.5 lbs of CO\textsubscript{2} per part. Based on yearly demand, the total amount of CO\textsubscript{2} that could be reduced per year is 215325 lbs (15%).
Figure 4.2 shows the future state VSM created based on the recommendations previously mentioned.

![VSM Diagram]

Figure 4.2: Sheet metal shop future state VSM

As shown in figure 4.2, a kaizen event can also be organized to reduce the energy used for router.

4.3 Case study 3: Clip manufacturing in company Y

All the activities involved in manufacturing a clip in this case study are explained in section 3.7. The recommendations given below are based on assumptions since the data was
given by the company. The recommendations are given only for energy used and materials used in different machines. A kaizen event can be organized for reducing the non-value added workspace involved.

4.3.1 Energy use (set up reduction)

For this case study, the set up reduction time is given based on the assumptions. The energy used recommendations are given for router, punch and brake press.

4.3.1.1 Router

Energy used for machining an aluminum sheet in this machine is 45.6 kWh. The setup time for this machine is ten minutes. If the setup time is reduced by three minutes, then 13.02 kWh of energy could be reduced. So, 24.6 lbs (28.4%) of CO₂ emission could be reduced for every part.

4.3.1.2 Punch

Energy used for machining an aluminum sheet in punching machine is 26.5 kWh. The setup time for this machine is ten minutes. If the setup time is reduced by three minutes, then 7.23 kWh of energy could be reduced. So, 13.69 (27.2%) lbs of CO₂ emission could be reduced for every part.

4.3.1.3 Brake press

Energy used in this machine is 18.66 kWh. The setup time for this machine is fifteen minutes. If the setup time is reduced by three minutes, then 3.4 kWh of energy could be reduced. So, 6.44 lbs (18.1%) of CO₂ emission could be reduced for every part.

4.3.2 Material use (Reduction of unused material)

Materials used recommendations are given for router and punch as there is no defect rate
involved in all the processes.

4.3.2.1 Router

Materials used calculations are based on an assumption of 70% usage of the sheet for the current state environmental VSM. If 80% of the aluminum sheet is used, then a total of 0.07 lbs (15.5%) of CO$_2$ could be reduced per part.

4.3.2.2 Punch

For this process also materials used calculations are done based on an assumption of 70% usage of the sheet for the current state environmental VSM. If 80% of the aluminum sheet is used, then a total of 0.23 lbs (16.4%) of CO$_2$ could be reduced per part.

The total amount of CO$_2$ that could be reduced from reducing energy and material usage based on the recommendations provided is 46.66 lbs of CO$_2$ for two different clips. Based on yearly demand, the total amount of CO$_2$ that could be reduced per year is 129808 lbs (28%).

Figure 4.3 shows the future state VSM created based on the recommendations mentioned above.
As shown in figure 4.3 a kaizen event can also be organized to reduce the environmental impacts for router and punch machine and the energy used for the brake press.
4.4 Summary

This chapter discussed the recommendations for reducing CO$_2$ emissions for each case study. The recommendations were given to reduce energy and materials used so as to reduce CO$_2$ emissions. The recommendations were based on reduction of setup time, unused material, scrap rate, and rework rate. The amount of CO$_2$ that could be reduced for each process is also discussed. Then the future state VSM is also shown for each case study.
CHAPTER 5

CONCLUSION AND FUTURE WORK

In today’s competitive world, companies are focusing on eliminating environmental wastes to increase their profits and ensuring customer satisfaction. Companies are required to follow the rules and regulations framed by the government towards environmental benign manufacturing. The objective of this thesis is to assess environmental impacts and add these impacts as values in a VSM. The proposed method helps in identifying basic environmental factors obtained from EPA and adding it to a VSM. This chapter discusses the conclusion, achievements, and the possible future work of this research.

5.1 Summary

The main objective of this thesis was to determine and incorporate the environmental factors in a VSM. In order to achieve the objective, initially a hierarchy was developed for the environmental factors of the manufacturing sector. Based on the hierarchy, three major environmental factors were considered. A method was developed to measure the environmental factors like energy use, materials use, and workspace use. Then a method for incorporating the measured environmental factors in a VSM was also described. The proposed method was tested at two different local aircraft companies and a class project. A current state VSM was prepared for each case study. The processes and the activities involved in the case studies were explained in detail. The environmental factors for each workstation was identified and incorporated in the current state environmental VSM. After an analysis, recommendations were provided for reducing the environmental impacts. Future state VSM’s were prepared for each case study based on the recommendations provided.
5.2 Achievements

1. Identified the major environmental factors affecting a manufacturing organization and developed a hierarchy.

2. Developed a method to determine and incorporate environmental factors in a VSM.

3. Tested the method with two real world case studies and one class project case study.

4. Provided recommendations for reducing the environmental impacts and prepared future state VSM’s based on the recommendations provided.

5.3 Future work

The goal of determining and incorporating the environmental factors was achieved successfully, but some improvements can be added to the existing model. The activities that can be added to this model are described as follows:

1. To assess and incorporate other environmental factors mentioned in the hierarchy in a VSM based on the requirements of the organization.

2. To determine the height of the workspace and include the workspace measurement as a volume. In this thesis, the workspace measurement was taken in terms of length and width.

3. To implement the proposed model in a large scale to extensively reduce the environmental impacts. This model was implemented in only one production line for two different companies.

4. To determine the carbon dioxide emissions for other materials as used. Since aluminum was the material used in all the case studies, carbon dioxide emissions were given only
for aluminum.

5. To include carbon dioxide emissions involved in the transportation of the material for the materials used calculation. Carbon dioxide emissions only for the production of aluminum were considered for this thesis.

6. To show the environmental factors in the VSM in terms of dollars for better understanding.
REFERENCES


Azzone, G., Bertele, U., & Nuci, G. Bare, C. J., Norris, G. A., Pennington, D. W., & Mckone, T. (2008). At last we are creating environmental strategies which work; Long range planning, 30, 562 - 571.


Class project user’s manual (2002). Wichita State University, Department of Industrial and Manufacturing Engineering.


U.S. Environmental Protection Agency (EPA), Green house gas emission factors for primary


