Abstract

Increasing focus on sustainability in society forces industrial companies to consider environmental impacts resulting from their activities. Unfortunately, research within the “environmental” domain has to a high degree evolved separately from the “manufacturing” domain, leading to poor understanding regarding how to manage environmental issues in a manufacturing context. To reduce this flaw, this paper takes the starting point in a manufacturing strategy perspective and analyses implications occurring from the inclusion of environmental issues in industrial companies. The paper suggests that concern for environmental issues influence more or less all of the manufacturing strategy decision criteria. Environmental concern may e.g. affect the decision on manufacturing process choice (e.g. new product technology may require new types of manufacturing processes) or on process technology (e.g. new manufacturing equipment are needed). Therefore, the paper concludes that it is paramount to consider environmental issues when formulating and effectuating the manufacturing strategy.

Key words: manufacturing strategy, environmental concern, industrial practice

Introduction

Companies are increasingly facing environmental challenges. Different stakeholders, such as customers, governments, and environmental pressure groups are forcing companies in various sectors of industry, such as the automotive and electrical/electronics sectors, to consider the environmental impacts resulting from their activities. Welford and Gouldson (1993 p. 2) argue that “there is no doubt that we are seeing the beginning of a
change in societies’ attitudes to the environment and industry needs to respond to this.”

A milestone underscoring the role played by industrial companies with respect to environmental problems was the 1992 ‘Earth Summit’ conference in Rio de Janeiro, Brazil. At the conference, government representatives and industrial leaders from all over the world were brought together to discuss environmental issues (van Hemel, 1998). Authorities worldwide have developed different approaches to respond to potential environmental problems. Within the European Union (EU), for example, a number of directives have been targeted towards various types of products. The so-called RoHS (Restriction of Hazardous Substances) directive prescribes that the use of certain substances be prohibited in most electrical/electronics applications. These substances include: lead, mercury, cadmium, hexavalent chromium, polybrominated biphenyls (PBB), and polybrominated diphenyl ethers (PBDE). Such directives, as well as other measures, must be responded to by industry. Hence, both industrial practitioners and research scholars have devoted interest in the management of environmental issues in an industrial context. Researchers have argued for the need to include environmental performance as a new dimension of operations performance (de Burgos Jiménez and Céspedes Lorente, 2001). Unfortunately, research within the “environmental” domain has predominantly evolved separately from the “industrial” domain, leading to poor understanding regarding how to manage environmental issues in industry. This paper therefore takes the starting point in a manufacturing strategy perspective and analyses implications occurring from the inclusion of environmental issues at industrial companies. The paper suggests that concern for environmental issues influence many of the manufacturing strategy decision categories.

Manufacturing strategy

The manufacturing strategy area has been around for many decades, but the development in modern time starts with the seminal article by Skinner (1969). He identified a number of manufacturing outputs that are important to the competitiveness of a company. Marucheck et al (1990) defined manufacturing strategy as

“a collective pattern of coordinated decisions that act upon the formulation, reformulation, and deployment of manufacturing resources and proved a competitive advantage in support of the overall strategic initiative of the firm or the business unit” (Marucheck et al, 1990, p. 93).

The list of manufacturing outputs has been further developed by e.g. Hayes & Wheelwright (1984), who also added a list of decision categories and a grading system for classifying the performance regarding these decision categories. Other researchers have been occupied with the issue of relations between manufacturing strategies and the design of the production system (Hill, 1995; Miltenburg, 1995; Platts & Gregory, 1992). These more recent authors have moved away from the top-down approach to an approach where the strategy formulation process is an interaction between the corporate management’s view and conditions at operational level. They suggest that the process of formulating and implementing manufacturing strategies is a continuous loop involving all operational level strategies as well as corporate level strategies.
Bates et al (2001) state that manufacturing strategies are the processes that companies use to build the resources and the capabilities to create competitive advantages and to align their competitive priorities with the marketing function.

Brown (1998) studied the role of manufacturing in the new product development process. As a part of this study he made a distinction between, what he called, enlightened and ordinary companies. Enlightened companies were found to have the following common areas linking business and manufacturing strategies:

a) a degree of vertical integration within the supply chain
b) a specified extent of manufacture, as opposed to assembly, within the plant
c) additions to existing plant capacity
d) new facilities/location decisions
e) increasing volumes of existing products
f) addition of totally new products to existing markets
g) introduction of totally new product markets
h) investment in new process technology

The enlightened company thus contributes to the process of developing new markets, e.g. for exploiting innovations. It also does not hesitate to enter alliances with other companies if needed and it has the ability to learn from such cooperation. One key question is how to establish manufacturing strategies that support the overall objectives and strategies of the company. Several researchers have been occupied with this issue.

Hill (1995) stated that there is no shortcut to success in the process of formulating strategies and designing supportive manufacturing processes. He proposed the following structure of actions in five steps:

1. Define corporate objectives.
2. Determine marketing strategies to meet these objectives.
3. Assess how different products qualify in their respective markets and win orders against competitors.
4. Establish the most appropriate process to manufacture these products (process choice).
5. Provide the manufacturing infrastructure to support production.

This list is however quite top-down and in reality there are iterative loops between all of these steps. Säfsten et al (2007) emphasize the need for both a top-down and a bottom-up perspective, which guarantees that the decisions are well-grounded in the company capabilities.

It is important, according to Hill (1995), to define the importance of each criterion in terms of which criteria are necessary if the manufacturer will be considered as supplier by the customer, i.e. the order qualifiers, and which criteria make the manufacturer really win the orders, i.e. order winners. The distinction between these two categories is often difficult to make, but it is nevertheless very important if the right decisions are to be made. If the company shall provide qualifiers, it will only have to be as good as its competitors, but in order to provide order winners, the company needs to be better than its competitors. There is a third category, the so-called order loosing sensitive qualifier,
which is a very important qualifier. If a company already is a supplier to the market, but
fails to meet this category, it will lose customers. Once the customers develop a bad
impression of a former supplier, they are very reluctant to accept this supplier again.

But what decision criteria are important when making strategic decisions? Hayes &
Wheelwright (1984) presented eight strategic decision criteria, each comprising several
decisions to be considered regarding how to carry out the manufacturing, see Table 1.

<table>
<thead>
<tr>
<th>Decision criteria</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process technology</td>
<td>• flexibility, type of equipment, technology level, layout</td>
</tr>
<tr>
<td>Facilities</td>
<td>• location, size, focus</td>
</tr>
<tr>
<td>Capacity</td>
<td>• amount, acquisition time, type</td>
</tr>
<tr>
<td>Vertical integration</td>
<td>• amount, degree, relations</td>
</tr>
<tr>
<td>Quality management</td>
<td>• definition, responsibility, reporting</td>
</tr>
<tr>
<td>Human resources</td>
<td>• skill level, wage, training and promotion policy, employment security</td>
</tr>
<tr>
<td>Organization structure and control</td>
<td>• relationship between groups, decision</td>
</tr>
<tr>
<td>Production planning and control</td>
<td>• responsibility, rules and systems</td>
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*Table 1. The decision criteria and some of their main characteristics (from Hayes & Wheelwright, 1984).*

Each of these decision categories is important for the success of a manufacturing
organization. The results for the organization are never better than the weakest link and a
bad result in one decision area can obstruct the success of the organization.

The decision criteria should support the different competitive priorities (Swink and Way,
1995; Dangayash and Deshmukh, 2001) as illustrated in table 2. They did however not
include human resources, which is probably one of the most important infrastructural
criteria.

<table>
<thead>
<tr>
<th>Competitive priorities</th>
<th>Decision criteria</th>
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<tbody>
<tr>
<td></td>
<td>Structural</td>
</tr>
<tr>
<td>Cost</td>
<td>Process</td>
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<tr>
<td>Quality</td>
<td>Capacity</td>
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<tr>
<td>Delivery</td>
<td>Facilitates</td>
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<tr>
<td>Flexibility</td>
<td>Vertical integration</td>
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*Table 2 Manufacturing strategy content (Swink and Way, 1995; Dangayash and Deshmukh, 2001)*
Acur et al (2003) described the relations between the process of formulating and implementing manufacturing strategy on the one hand and the content on the other, see figure 1.

Figure 1. Issues in formulation and implementation as well as content in manufacturing strategy. Questionnaire presented by Acur et al (2003).

Implications from introducing environmental issues in manufacturing strategies

As a result of the increased environmental pressure that manufacturing companies face, they have to respond in a way that support long term business goals. All functional areas within a company must therefore contribute by developing and implementing consistent functional strategies (Gupta, 1995). In the literature it has been claimed that the manufacturing function will play a key role in a company’s efforts in managing environmental issues as illustrated in a model presented by Sarkis (2001). The model shows the linkages between manufacturing organization functions and environmental influences; see figure 2. This model indicates that different company elements, including strategic, operational, and support elements, are involved in meeting the external environmental demands. The model also indicates that various practices are available to the companies. Even though manufacturing function is essential for meeting the environmental challenges, manufacturing strategy has not traditionally included any environmental issues. What will be the implications for a company if such issues are included?
Environmental issues may influence the competitive priorities. A company should analyze to decide to which degree environmental performance contributes to the long term business goals, i.e. whether environmental performance is a competitive priority or not. Companies’ possibilities to strategically position themselves relative to their competitors, in terms of environmental performance, have increased (IVA, 1995) and companies can adopt different positions (Roome, 1992; Azzone et al, 1998; Brockhoff et al, 1999). The positions range on a continuum from re-active to pro-active environmental strategic positions (Aragón-Correra, 1998). A company adopting a re-active position seeks to respond to minimal environmental demands, whereas a pro-active company strives to exceed the demands or even set a new standard. The strategic position adopted is based on the potential competitive advantage envisaged for each position, respectively. At least three different perspectives may be included when a company analyses if environmental performance is a competitive priority: scientific, government, and consumer perspectives (Boks and Stevels, 2007). The scientific perspective is based on the Life Cycle Assessment (LCA) approach to determine the environmental impacts of the company activities. The government perspective relates to a number of different factors, including population density, availability of energy sources, geographical

Figure 2. Manufacturing organization functions and environmental influences (Sarkis, 2001).
location, status of the economy, etc. These factors affect how governments prioritize among various environmental issues and do not always correspond to the same order if based solely on scientific arguments. The consumer perspective concerns the willingness on the market to buy “green” products and is strongly related to emotions and the general debate in society on toxicity, CO₂ emission levels, global warming, etc. What is considered relevant environmental issues from these three perspectives and how companies respond affects the competitive situation. Including all these three perspectives therefore seems relevant in order for a company to have a sound basis for a decision on whether or not environmental performance should be considered a competitive priority.

The competitive priorities should be supported by the decision criteria (Swink and Way, 1995; Dangayash and Deshmukh, 2001). If environmental performance is considered a competitive priority, a number of implications for the decision criteria can be identified.

**Process technology:** The efforts of achieving high environmental performance may require new process technology. An example from the electronic and electrical equipment (EEE) industry can serve as an illustration. Traditionally, SnPb solder alloys have been used in the assembly of modern electronic circuits (Suganuma, 2001). The popularity of alloys including Pb is that it lowers the surface and interfacial energies of the solder, among other things (Zeng and Tu, 2002). The earlier mentioned RoHS-directive forces, however, companies to reduce hazardous substances, including e.g. lead. The shift to lead-free soldering has had implications for the soldering process. Even though several alternative solder alloys exist, few meet all standards such as the required material properties (e.g. low melting temperature, wettability, metal integrity), good manufacturability, and reasonable costs (Suganuma, 2001). Furthermore, current processing equipment and conditions for electronics assembly are optimized for SnPb solders. A critical parameter for the quality of soldered joints is soldering temperature. A common characteristic of lead-free solder alloys is higher melting temperature, which makes the process window narrower (Suganuma, 2001; Zeng and Tu, 2002). Several electronic components cannot withstand an increase in reflow temperature and as a result there is a need to modify or develop the processing conditions to incorporate heat-resistant components (Suganuma, 2001).

**Facilities:** The location, size and focus of manufacturing facilities are based on different points of origin. The need for short delivery times may require facilities to be located closely to customers. Estimated production volume and the number of product variants affect the facility size and focus. Including environmental performance as a concern may add to the complexity regarding the decision on where to locate a manufacturing facility (Sarkis, 2001). This can also be exemplified with an example from the EEE industry. An analysis of printed board manufacturing should address a number of different environmental load elements: material use, amount of auxiliary compounds, water consumption, energy consumption, air emissions discharge, waste flows, and packaging materials. According to Nagel (2003) a manufacturing facility’s policy related to these elements is affected by local and regional regulations and agreements regarding noise, emissions, wastewater, landfill, nuisance, and quality of the soil around the
manufacturing facility. Furthermore, Nagel stresses that environmental performance is interconnected with the cost structure of the manufacturing facility in terms of costs for materials, water and energy use. Hence, the analysis of where to locate a manufacturing facility must include additional issues when environmental performance is considered. Concern for environmental issues may also have implications for the cost structure of the facility and this is partly related to where the facility is located.

Capacity: When choosing the appropriate manufacturing capacity, considerations need to be made regarding two contradictive demands, Just-In-Time delivery to demanding customers and minimal environmental load from transportation. This trade-off may seem difficult to handle, but some issues could be to choose suppliers who are located closely to environmentally sound means of transport such as railroads and to create efficient reloading routines to enable as short truck transportations as possible. This also requires load carriers that are suitable both for reloading and different modes of transport. By introducing consignation stocks, either at the supplier or at the customer, transportation becomes even more efficient. This causes however longer lead times to changes, larger difficulties to make late changes, and higher cost for tie-up of assets.

Vertical integration: The environmental impacts associated with business activities are not isolated to a single company. On the contrary, environmental impacts occur in the entire supply chain. That is, the different actors and processes in the supply chain generate environmental impacts. Managing manufacturing process inputs and outputs, which affect a company’s environmental performance, is central to supply chain management (Sarkis, 2001). The degree to which vertically integrate may hence include consideration for environmental issues and customer-supplier relationships plays a role in the environmental performance of the business activities (Nagel, 2003). Sharing and integrating ideas for environmental improvements across organizational boundaries will support the abilities for a manufacturing facility to achieve high environmental performance. Sourcing process inputs from suppliers close to the manufacturing facility may also contribute to environmental performance. Whether high environmental performance can be achieved via cooperative settings involving different supply chain actors or whether a company should integrate vertically in order to get better control of the various processes should be included in the decision regarding vertical integration.

Quality management: Similar to one of the basic rules in lean philosophy, the worst form of waste is to over-produce and to make faulty products. Thus, the most important issue from an environmental point of view would be to create stable processes and routines, which minimize re-work, transportation of rejected goods etc. It is also essential that companies adapt a life-cycle approach to quality and environmental management in order to minimize the total environmental load during the entire product life-cycle. It has also been stated that organizations that are familiar with quality management systems such as the ISO 9000 will identify similarities with the environmental management system ISO 14000 (Poksinska et al, 2003). The ISO 14000 system has been developed purposely to be well-matched with ISO 9000 in terms of language, approach and certification methods. The different ISO management systems have certain core elements in common, whether focused on quality, environment or safety. When comparing the two
management systems (i.e. ISO 9000 and ISO 14000) based on a survey among Swedish companies, Poksinska et al (2003) found that ISO14000 certified organizations experienced significantly more in terms of stakeholders’ satisfaction than ISO 9000 certified organizations.

**Human resources:** In order to handle the complex issues of environmental management, all employees need to be trained, both regarding their own work tasks but also in the total environmental consciousness of the company. Similar to some successful examples of lean implementation, it is advisable that this training starts at the top management in order to create company commitment for these issues.

**Organizational structure and control:** Precious studies on integration of environmental issues in business activities indicate that environmental specialists primarily work with environmental issues *per se* (e.g. producing the company’s annual environmental report) and hence are seldom involved in the “conventional” activities within a manufacturing company (Johansson and Magnusson, 2006). They are therefore not part of the contact network within the development and manufacturing organizations in a company. Aspects related to that problem may include the approach to foster involvement of environmental specialists in product development projects as well as manufacturing improvement projects and to delegate authority and responsibility to the project team level on making necessary decisions related to environmental issues. Furthermore, “to be able to integrate environmental considerations effectively, it is not sufficient that various project team members (e.g. electronics engineers, purchasers, etc.) learn from the environmental specialists about environmental issues; the specialists also have to learn [...] from the other project team members in a mutual learning process” (Johansson and Magnusson, 2006 p. 1375). This requires a flat organizational structure which enables decisions to be made when and where they are needed, but also that senior management provides support and guidance by expressing how environmental issues constitute part of the business activities and by establishing clear goals and directions for the activities (Johansson, 2002).

**Production planning and control:** Including environmental concern may induce a need for new or modified production processes and perhaps investment in new production equipment. At a first glance, these changes of production processes and need for investments may seem unnecessary cost increases not leading to commercial benefits. However, the changes and investments can, in fact, be positive if one adopts a slightly broader perspective and not just focus on the initial cost increases. The following example from Japan EEE manufacturers illustrates that environmental concern can trigger a company to capture improvements potentials in the operations. The example shows that the introduction of lead-free soldering manufacturing processes, which in many cases is considered being a problematic and expensive endeavor, actually can contribute to companies getting better understanding of their processes and hence enhances their output. “The requirements of lead-free processing (e.g. higher process temperatures) have led to the Japanese getting a greater understanding of their surface mount processes and consequently they have much better control over the process”
(Electronics Manufacturing & Test Magazine, 2001 p. 3). Hence, concern for environmental issues may have implications for the production planning and control.

<table>
<thead>
<tr>
<th>Decision criteria</th>
<th>Environmental characteristics (examples)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process technology</td>
<td>• Waste and pollution reduction/elimination</td>
</tr>
<tr>
<td></td>
<td>• Reuse of equipment</td>
</tr>
<tr>
<td></td>
<td>• Recycling when reuse is not possible</td>
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<tr>
<td>Facilities</td>
<td>• Remanufacturing instead of creating waste</td>
</tr>
<tr>
<td></td>
<td>• Location (near customer or resources) to minimize transportation</td>
</tr>
<tr>
<td></td>
<td>• Re-use of energy, such as process heat</td>
</tr>
<tr>
<td>Capacity</td>
<td>• Chose the best combination of economy of scale and manufacturing near customer</td>
</tr>
<tr>
<td></td>
<td>• Trade-off JIT manufacturing and delivery vs transportation</td>
</tr>
<tr>
<td>Vertical integration</td>
<td>• Source from suppliers near the respective plants</td>
</tr>
<tr>
<td></td>
<td>• Many suppliers when acting on a global market</td>
</tr>
<tr>
<td>Quality management</td>
<td>• ISO 14000</td>
</tr>
<tr>
<td></td>
<td>• Life cycle assessment</td>
</tr>
<tr>
<td>Human resources</td>
<td>• Train personnel in environmental consciousness</td>
</tr>
<tr>
<td>Organization structure</td>
<td>• Delegate authority and responsibility to team level on making necessary decisions related to</td>
</tr>
<tr>
<td>and control</td>
<td>environmentally related issues</td>
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<tr>
<td></td>
<td>• Senior management support and guidance</td>
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<td></td>
<td>• Project team member learning</td>
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<tr>
<td>Production planning and</td>
<td>• Relate planning decisions to consequences for environment, such as small batches vs extra cleaning</td>
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<tr>
<td>control</td>
<td>of surface treatment equipment</td>
</tr>
</tbody>
</table>

Table 3 Development of manufacturing strategy decision criteria by adding environmental characteristics (based on Hayes & Wheelwright, 1984).

The environmental characteristics of the decision criteria are exemplified in table 3.

**Discussion and concluding remarks**

This paper has shown that including environmental issues, as part of the manufacturing strategy content, i.e. as a competitive criterion, do have an impact on the various decision areas in a manufacturing strategy. For example, environmental concern may affect the decision on manufacturing process choice (e.g. new product technology may require new types of manufacturing processes) or on process technology (e.g. new manufacturing equipment are needed). Therefore, we conclude that it is paramount to consider environmental issues when formulating and effectuating the manufacturing strategy.

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