Can the Six Sigma Method be Applied to the Process of Waste Generation and Treatment?

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Abstract

In this paper an attempt is made to assess the use of instruments commonly applied in quality management systems in the context of environmental management. In the case study described in the paper the six sigma method is applied to waste management. The purpose is twofold. On the hand, the case study should reveal how the six sigma method can be applied to waste management. On the other hand, the case study should reveal how the generation of waste as a by-product should be reassessed on itself. In the first section, a short overview of instruments typically used within the context of environmental management is presented. In the second section, an overview of the six sigma method is given. The third section deals with the application of the six sigma method to the case study of waste management. The last section intends to answer the question whether the six sigma method can be applied to waste management.

Keywords: waste management, quality management, materials flow, six sigma

Introduction

Waste management within the context of a business firm may lead to the achievement of company objectives as stated in an environmental management system or in terms of cost control. It may also lead to a contribution to external objectives. Both viewpoints are illustrated in Figure 1.

Figure 1: External and internal objectives of waste management.
Source: Compilation by the authors.
In Figure 1, the achievement of the overall company goals, the increase of competitiveness, a reduction of environmental liabilities, a reduction of waste management costs and the transparency of the waste streams can be seen as the internal objectives. These objectives are closely linked to external objectives, such as a continual improvement of the environmental performance, as contained within the ISO 14001 standard about environmental management systems, the objectives of waste management legislation and the interests of the community in terms of proper resource management and the protection of environmental compartments, such as air, water and soils.

Broadly speaking, companies have access to a set of instruments which can be used for improving their waste management through the identification of (hidden) weaknesses and (hidden) potentials for improving existing production processes. Table 1 presents a summary of these instruments.

Since all these instruments focus on materials and energy flows, in combination with their environmental impacts, they can be used to investigate production processes or products with a specific focus on the share of the materials which enter the flows within a specific production process but do not become integrated into the product and are separated from it as waste. As an alternative to these instruments which were designed with the objective of improving the environmental performance of a business firm, the issue may be raised that, possibly, other instruments which were not created for that purpose, may also be used.

Since many firms who have put in place some kind of environmental management system, be it according to some (international) standard or in another way, also maintain a specific quality management system, the question may be raised whether instruments from quality management can be used to improve the waste management of a company. One specific set of instruments or, in other words, a dedicated approach to quality management is the so-called six sigma method. In the remainder of this paper, the basic characteristics of the six sigma method will be explained and the application of this method to waste generation and treatment, explicitly defined as a “production” process, will be described, analyzed and assessed.

**Description of the six sigma method**

Six Sigma is a set of practices originally developed by Motorola around 1985 – 1986 to systematically improve the quality of its processes through the identification of potential deficiencies of the company’s products. “Six Sigma” was not the first ever method for quality management as it was inspired by preceding quality improvement methodologies such as quality control, Total Quality Management (TQM) and Zero Defects.

The term “six sigma” refers to the objective of achieving a failure rate for a specific process or a specific product (in a series or a batch) which is equal to that area of a normal distribution probability curve not covered by six times the variance of that probability distribution curve. In other words, the objective of the six sigma method is to practically be in control of a specific production process through the almost absolute avoidance of deficiencies and errors and to secure the output of a product within a given series which meets originally defined specifications to the highest possible extent. Any student of quality management who has to memorize this definition knows that, in theory, this implies that the failure or defects rate is equal to 3.4 parts per million opportunities (DPMO). In this context, a defect is defined as any deviation of a process or a product from the originally set of specifications. In order to put this objective to practice, the implementation of the six sigma method depends on the following three crucial issues:

- A company implementing the six sigma method must be prepared to continuously reduce the variation of the outputs (products) of its processes
- These processes can be measured, analyzed, improved and controlled
- The implementation of the six sigma method requires a commitment from the entire organization and top management must explicitly approve it.

In the context of this commitment, the implementation of the six sigma method takes place within an organizational structure which is briefly described here.

**Quality Leader/Manager (QL/QM)**

The Quality Leader is at the top of the six sigma organization and he is responsible for the representation of the needs of the customer. Since these needs are at the core of the entire six sigma project, the intention is to improve the operational effectiveness of the company (for the benefit of the customer.)
<table>
<thead>
<tr>
<th>Instrument</th>
<th>Focus</th>
<th>Objectives</th>
<th>Sources</th>
</tr>
</thead>
</table>
| **Company Input**               | Identification of materials and energy flows, which can also be evaluated as costs  
Three levels:  
• entire company  
• specific production process  
• specific product  | - Information instrument to identify weaknesses in company performance  
- Optimization of products and processes  
- Improving decision making in environmental management  
| **Output tables**               |                                                                      |                                                                            |                                              |
| **Analysis of materials flows** | Quantitative and qualitative identification, description and assessment of materials flows and their transformations  
Three levels:  
• specific material  
• specific product  
• specific process  | - Quantitative identification of materials and energy flows throughout a specifically defined process  
- Identification of the causes of the generation of materials and energy flows  
- Reduction or optimization of materials and energy flows within a specifically defined production process  | Jäger, Tobias and Karger, R. Cornelia (2006)                                  |
| **Life Cycle Analysis**         | Scope is the entire life cycle of a product from „cradle to grave“  
In its broadest application, not only environmental but also social and economic impacts are assessed from “cradle to grave”  | - Identification of the environmental impact of a product from „cradle to grave“  
- These aspects may not always be evaluated in monetary terms  | Kaimer, M. and Schade D. (1994).                                            |
| **Environmental controlling**   | Analysis of all materials and energy flows                           | - Identification of all environmental impacts of a company, a production process or a value creating system  
- Improving decision making in environmental management  | Jäger, Tobias and Karger, R. Cornelia (2006)                                  |

Table 1: Instruments for detecting weaknesses and potentials for improving environmental performance. Source: compilation by the authors.
The Quality Leader is typically not directly involved in the actual manufacturing or other processes in order to maintain impartiality. He sits at the top management level of the company.

**Master Black Belt (MBB)**

Master Black Belts are staff members typically assigned to a specific area or function of a business or organization. They can be placed within functional units such as human resources or the legal department or in process specific areas within the actual production units. Master Black Belts are responsible for meeting the quality objectives. Hence, they work closely together with the Process Owners to ensure that quality objectives and targets are set, plans are determined, progress is tracked, and education is provided. In good six sigma organizations, Master Black Belts and Process Owners share information daily.

**Process Owner (PO)**

Process owners are staff members who are responsible for a company process. Process Owners can be found at various levels of a company and, hence, their responsibilities may be broad or dedicated. A Process Owner may be responsible for the entire production process at the top level of the company. Another Process Owner may be responsible for a specific part of that production process at a lower level of a company.

**Black Belt (BB)**

Black Belts are the key persons in six sigma projects. Their main task and responsibility is to lead six sigma quality projects. Normally, during such a project, they spend all their working time on it. Black Belts can typically complete four to six projects per year. They also coach the Green Belts on their projects.

**Green Belt (GB)**

Green Belts are employees trained in six sigma who spend a portion of their time on six sigma projects and who keep their regular work roles and responsibilities. Ultimately, if the six sigma method becomes fully adopted by the company, employees will begin to include the method in their daily activities and the original portion of time will grow to 100%. The iSixSigma website also lists so-called Yellow Belts (YB) who are defined as the helpers of the Green Belts.

A fundamental and basic methodology which must be followed by all participants of the six sigma organizations in any six sigma project is the so-called DMAIC methodology. It consists of five steps which are briefly presented in Box 1. The DMAIC methodology defines the process improvement goals that are consistent with customer demands and the company’s strategy (See Figure 2).

- **Measure** the current process and collect relevant data in order to have a clear understanding of the process and, in particular, its current deficiencies and weaknesses
- **Analyze** the relationship between inputs and outputs of a process and identify the causalities and assure that all inputs and outputs are considered.
- **Improve** or optimize the process based upon the analysis
- **Control** to ensure that any variances are corrected before they result in defects. Set up pilot runs to establish process capability, transition to production and thereafter continuously measure the process and institute control mechanisms

In this paper it is not the intention to present and discuss this methodology in detail, not to compare it with many other six sigma methodologies which have been presented in the literature since there are several websites explaining the DMAIC method and these other methodologies in detail. In the description of the case study of this paper, the use of the DMAIC methodology will be explained.
Case study: application of the six sigma method to waste management for the purpose of the reduction of waste costs

The case study deals with a company in the greater Frankfurt area which is active in the production of automotive components. It has a long tradition as an independent „Mittelstand“ business firm and even after take-over by a global automotive supplier, it is still operated and managed as a „Mittelstand“ firm. At the location, there are several factories which operate independently from each other. This structure has an impact on the generation of waste, the management of waste and the importance which is attached to this issue by each factory. The main problem or objective of the case study consisted in a potential reduction of the costs of waste generation and management or, for short, waste costs.

Waste costs are defined as those costs which are the outcome of the multiplication of the quantities of waste generated (measured in tonnes) times the fees to be paid (per tonne or any other unit) to external waste treatment firms. For the case study, these fees are considered to be fixed, although, in theory, it would be possible to (re)negotiate them with the waste management firms or change them through switching to other suppliers of waste management services. Fees vary according to the legally required treatment operations which in turn depend on the “quality” of the waste. If a particular waste stream is actually a mix of several wastes, the fee for the entire stream is set according to the costs for this waste within the waste stream which commands the most complicated required treatment. The quantities of waste are those quantities measured and identified by the waste treatment firms. The identification takes place in accordance to the European Waste Catalogue classification, in which each category of waste has its EWC number. Hence, there are three factors determining the total waste costs: the quantities of the wastes, the fees and the degree to which wastes are separated before delivery to the waste treatment firms. This situation is reflected in Figure 3.

The first step of the case study consisted in a review of the current situation of current waste management practices. Staff members were questioned with respect to their waste management practices. The most important waste stream are so-called domestic (household equivalent) wastes, paper and cardboard, polyethylene (PE) films, and, in some locations, waste oils and metallic scraps. All containers are emptied daily and their contents are being carried to a central waste storage unit by a contracted company. At the central location, the waste is collected, weighed and compacted for delivery to the waste treatment firms. Paper and cardboard waste and so-called domestic (household equivalent) waste from the office units is collected as separated waste streams by an office cleaning company and carried to the central location.

The six sigma method requires a very stringent approach within the organization. With top management being in the position of the Quality Leader, the workload is carried out by the Black Belt and a Green Belt of the company along the steps of the DMAIC cycle. In the case study, the Environmental Management Representative (EMR) can be seen as the Process Owner. Since many instruments exist for Quality Management, a selection must be made for each specific project. Traditionally, this selection is made by the Black Belt who also designed a process improvement plan. The project plan itself is depicted in Table 2.

Define

Within the “Define” stage, obviously, the problem needs to be defined. In the case study, the main issue at stake is the reduction of waste costs, as defined above. One important consequence of using the DMAIC methodology is to consider the activity of waste generation and treatment within the company and by the water treatment firms as a process, similar to any production process. Figure 4 depicts the process of waste management in a simplified form.

![Figure 4: Process of waste management in a simplified form. Source: Compilation by the authors.](image-url)
<table>
<thead>
<tr>
<th>Stages</th>
<th>Milestones</th>
</tr>
</thead>
<tbody>
<tr>
<td>Define</td>
<td>1. Generate and prioritise elements of the project (in the case study the main priority is to reduce waste costs)</td>
</tr>
<tr>
<td></td>
<td>2. Develop a description of the project and the team and draft the initial project plan</td>
</tr>
<tr>
<td></td>
<td>3. Identify the important outputs (in this project these are waste streams and other outputs “y” which are critical to quality CTQ)</td>
</tr>
<tr>
<td></td>
<td>4. Estimation of the outcome of the process</td>
</tr>
<tr>
<td>Measure</td>
<td>5. Detailed description of the process / determination of the inputs and outputs / Preliminary ranking of Key Process Input Variables KIPV</td>
</tr>
<tr>
<td></td>
<td>6. Checking the capability of the measuring system</td>
</tr>
<tr>
<td></td>
<td>7. Collecting data about inputs (x) and outputs (y)</td>
</tr>
<tr>
<td>Analyse</td>
<td>8. Assessing process capability</td>
</tr>
<tr>
<td></td>
<td>9. Identification of the KPIV</td>
</tr>
<tr>
<td>Improve</td>
<td>10. Optimizing the KPIV</td>
</tr>
<tr>
<td></td>
<td>11. Deciding on the best solution</td>
</tr>
<tr>
<td>Control</td>
<td>12. Checking and verifying the improvement in the long run</td>
</tr>
<tr>
<td></td>
<td>13. Identifying the costs savings</td>
</tr>
<tr>
<td></td>
<td>14. Implementing and documenting / Preparing Checking plans / delivery to customer</td>
</tr>
</tbody>
</table>

Table 2: Project plan Source: Compilation by the authors.

Table 2: Project plan Source: Compilation by the authors.

In order to examine this process in more detail, an instrument known as SIPOC can be used. SIPOC stands for Supplier, Input, Process, Output, Customer and the instrument is used to describe the process in detail in order to clarify the problem. Since, in quality management, the basic and overall purpose is to satisfy the needs of the customer(s), the SIPOC instrument is used to determine how these needs can be satisfied. In the case study, the customers are persons or groups of persons with an interest in improving the process of waste generation and treatment. In the case of waste management, there are internal and external customers. The internal customer is the EMR. External customers are the legislator and the general public. Persons and groups with an influence on the inputs of the process are termed Suppliers. From Figure 5, which depicts the SIPOC chart, one can see that the company’s suppliers have an impact on waste generation through the buying department and the logistics department. Moreover, the legislator is not only a customer but also a supplier in the SIPOC sense, since he sets regulations. The Research and Development department has an influence through its work on process and product design. Finally, the EMR has an influence through his instructions for waste management.

In terms of outputs, one can see that there are two broad categories of waste which are labelled non-hazardous and hazardous wastes respectively. Moreover, another characteristic of the outputs is the degree of waste separation. These three characteristics or factors of the outputs are critical to quality (CTQ).

**Measure**

The purpose of the Measure Stage is to identify the inputs $x_j$ which influence the interests of the customers as identified with SIPOC and to link them with CTQ. Based upon the SIPOC chart, a so-called Process Map is created. For each step in the process, all relevant inputs and all outputs are determined. The outcome is a flow chart as shown in Figure 6.

For each stage of the process, the main waste streams are identified. In Figure 6, these are mentioned for stage 1. Since they remain the same throughout the process, for the other stages, the general denomination “all waste streams” is used. Stage 2 is important for the ultimate purpose of the project (reduction of waste costs), since it consist of the (separate) collection at the decentralised container units. Stage 3 consists in the internal determination of the quantities and their allocation to the various factories and other units. This stage does not contribute to the generation nor reduction of waste costs. The delivery of the waste to the waste management firms and transportation constitutes the last stage and it also contributes to the generation of waste costs. Once the wastes of the stages and their impact on the generation and reduction of waste costs (i.e., the outputs) have been identified, it is important to determine which inputs, together with elements of the production processes, determine these outputs. In the upper part of Figure 6, these inputs and process elements are characterised and grouped with symbols. The input categories “process and engineering” and “materials” clearly have an impact on the generation and reduction of wastes and on the “quality” of these wastes in terms of their environmental risks. The input category „instructions“...
relates to documents, such as work instructions, technical specifications and related documents from which parameters are derived that have a controlling influence on the outputs. They can be referred to as controlling parameters. Using the input “waste category” may be confusing, since wastes are outputs of the process, but it should be kept in mind that these waste categories, as generated in stage 1, constitute inputs for the consecutive stages. Lastly, the input category “disturbance inputs” is mentioned. They are somewhat like the opposite of the controlling parameters since their influence on the outputs is very difficult to control. Inspecting this Process Map one can see that the number of disturbance inputs is larger than the number of controlling parameters. This seems to imply that the process of waste generation and management is complex and difficult to control. Moreover, some materials such as packaging, office papers and operating and auxiliary supplies materials eventually will become waste. In order to find out how to improve process control in the sense of establishing process capability, it is necessary to determine the relative importance of each influencing input. With this prioritization it becomes possible to identify the Key Input Process Variables (KIPV) of the process of waste generation and management. For this prioritization, the Black Belt of the project selected the so-called the instrument of the Cause and Effect Matrix (C & E Matrix) within the six sigma method. Figure 7 shows the structure of the C & E Matrix. The columns (1) document the method to evaluate and assess the outputs in terms of their importance for the customer of the process. In the context of the case study, it is assumed that the EMR, also as a representative of the legislator and the general public, is the customer. The rows (3) contain the process inputs taken from the Process Map.

<table>
<thead>
<tr>
<th>Supplier (products)</th>
<th>Input</th>
<th>Process</th>
<th>Output</th>
<th>Customer</th>
</tr>
</thead>
<tbody>
<tr>
<td>supplier (products)</td>
<td>logistics</td>
<td>waste development</td>
<td>waste amounts and costs according to waste sort</td>
<td>internal officer</td>
</tr>
<tr>
<td>supplier (products)</td>
<td>=&gt; packaging ordinance</td>
<td>=&gt; packaging - multi-pack - paper - foil - wood</td>
<td>- non-dangerous waste</td>
<td>publicity</td>
</tr>
<tr>
<td>supplier (products)</td>
<td>=&gt; packaging</td>
<td>=&gt; packaging - multi-pack - paper - foil - wood</td>
<td>- dangerous waste</td>
<td>lawmaker</td>
</tr>
<tr>
<td>laws</td>
<td>guidelines</td>
<td>=&gt; laws</td>
<td>=&gt; customer</td>
<td>=&gt; internal guidelines</td>
</tr>
<tr>
<td>design</td>
<td>production technology</td>
<td>=&gt; machine</td>
<td>=&gt; process</td>
<td>=&gt; product design</td>
</tr>
<tr>
<td>human being</td>
<td>=&gt; consumer</td>
<td>=&gt; employee</td>
<td></td>
<td></td>
</tr>
<tr>
<td>internal officer (environmental officer)</td>
<td>internal standards</td>
<td>waste development and management</td>
<td>waste development</td>
<td>collection of waste on specific places</td>
</tr>
</tbody>
</table>
Figure 6: Process map. Source: Compilation by the authors.
The very top row (2) lists the importance of the outputs for the customer (in our case the Environmental Management Representative) for which he uses a grading scale between 0 (not important) to 10 (very important).

The table is now filled out (4) by entering the influence of each input on the outputs. This influence is assessed with the help of the following grading scheme:

- 0 - no influence,
- 1 - little influence
- 3 - moderate influence
- 6 - significant influence
- 10 - strong influence

Clearly, the grading depends upon a good understanding of the process by the EMR and the other team members (Black Belt and Green Belt) who need to study the process in detail. Hence, expertise is necessary at this stage. Exchange of knowledge and experience among the team members may lead to a situation in which subjective judgements can be identified as such. In this way, the grading itself can be improved and lead to realistic outcomes. The marks indicating the influence of each input on each output are entered in the respective cells of the C & E Matrix. For each input, each mark is then multiplied with the grading of the output for the customer and the resulting outcomes are added up to form the cumulative sum of multiplications (5). The formula is as follows:

\[
m_i(y_1) \cdot s(y_1) + m_i(y_2) \cdot s(y_2) + m_i(y_3) \cdot s(y_3)
\]

Hence, each input is assessed in a similar way as shown in the following formula:

\[
\{(m_i(y_1) \cdot s(y_1) + m_i(y_2) \cdot s(y_2) + m_i(y_3) \cdot s(y_3)) \cdot w(C)\}
\]

It is now possible to multiply both gradings

\[
\{(m_i(y_1) \cdot s(y_1) + m_i(y_2) \cdot s(y_2) + m_i(y_3) \cdot s(y_3)) \cdot w(C)\}
\]

in order to obtain the combined influence of an input on the outputs taken together in terms of their importance and their controllability. These indicators can be referred to as the overall effects of the inputs. Hence, an input with a high importance and a lack of controllability will score higher than an input with the same importance but a better controllability etc. The information about these overall indicators can be transformed into relative indicators across the inputs in a separate column. This is not shown in Figure 7.

The C & E Matrix for the case study is shown in Appendix 1. Since it is difficult to interpret such a table, the information contained in it can be visualised graphically with a so-called Pareto Diagramme. A Pareto Diagramme, named after Vilfredo Pareto, an Italian sociologist and economist, who invented this method of information presentation toward the end of the 19th century, is a chart containing information about properties or factors which all relate to a particular issue.

In the case of quality management, the issue is to find the causes of quality failures in terms of deficiencies, deviations from technical specifications and the like. These causes are listed in a bar chart in descending order of frequency or importance. Simultaneously, the cumulative frequency or “cumulative importance” is drawn as an increasing curve. Since all causes together represent the totality, the maximum value for that curve is 100 %. Hence, the Pareto Diagramme permits to see how causes are responsible for the first 20 %, the first 40 % etc. of quality failure. Vilfredo Pareto observed income and wealth distributions in the early 19th century and he found that about 20 % of the population owned about 80 %
of all wealth and income. From this empirical finding, a more general principle of the "significant few versus the trivial many" was derived. The principle is based on the unequal distribution of things in the universe, stating that "the significant few things will generally make up 80% of the whole, while the trivial many will make up about 20%". This 20% - 80% principle was eventually applied to quality management, where it was found that about 20% of the causes explain about 80% of the quality problem. Hence, in a Pareto Diagramme on can observe which share of causes contributes to quality failure for a certain majority of the totality. Clearly, concentrating on the elimination of these "major causes" will then result in the most cost-effective improvement scheme. Figure 8 represents the Pareto Diagramme for the process of waste management in the case study and it can be seen that it does not support the Pareto principle. For the sake of clarity, the denominations of the inputs are not printed below the overall effect indicators.

In order to illustrate this more clearly, a horizontal line is drawn at the 80% level and its intersection with the cumulative importance curve is shown. One can easily see that about 50% (and not 20%) of all factors cause about 80% of the problem of the process. This may be due to the fact that this process is complex, diffuse and difficult to control, as already suggested above.

Since the C & E Matrix did not result in a dominating set of factors in the sense of the Pareto Diagramme, the cut-off point for selecting these set of factors for further investigations was done more or less arbitrarily. The number was set at fourteen in order to concentrate on them in the further work. The factors kept for further analysis are the following:

- Availability of swap containers
- Staff in unit a

Figure 7: C&E Matrix. Source: Internal company documentation.

Figure 8: Pareto Diagramme for the process of waste generation and management. Source: Compilation by the authors.
- Staff in unit b
- Staff in unit c
- Staff in unit d
- Staff of the office cleaning company
- Paper for printers
- Buying department
- Logistics
- Use of cleaning paper
- Exchange of test liquids
- Production order
- Labelling of containers in offices
- Containers in production lines

To this set, an instrument known as **Failure Mode Effects Analysis (FMEA)** was applied. In addition to the **C&E-Matrix**, the FMEA allows for a prioritization of the factors on the basis of three criteria, which are assessed by knowledgeable experts of the process – in this case the generation and treatment of waste. A **FMEA** is a procedure for the analysis of potential failure modes within a system for the classification by severity or determination of the failure's effect upon the system.

Doing a **FMEA** involves taking several steps which include the identification of the way in which the potential failure can occur, the consequences of the failure and a comparison of current practices with potential improved practices in order to avoid the failure in the future. Normally, a **FMEA** worksheet is used. Factors in this case study are related to the fourteen inputs and are seen as drivers or contributors to the waste costs as defined at the outset of this section. Each factor is assessed according to the following criteria:

- the probability or likelihood that the failure will occur – **O (occurrence)**
- the consequences or the severity of the failure – **S (severity)**
- the probability or likelihood that the failure will be detected before the product (D) - in our case the undiscovered extra waste costs - reaches the customer, in our case the Environment Management Representative (EMR).

A quantitative assessment of the importance of each factor or failure can be obtained through the calculation of the product of the three ratings:

\[
\text{RPN} = \text{Severity} \times \text{Occurrence} \times \text{Detection}
\]

The outcome RPN is referred to as the Risk Priority Number (RPN). Since, in the process of waste generation and treatment, it was not possible to avoid a strong subjective component in a reliable estimation of the likelihood of the failure detection (D), an alternative indicator which omits D and known as the **RP** was also used. It is simply defined as follows:

\[
\text{RP} = \text{Severity} \times \text{Occurrence}
\]

Since all three criteria, S, O and D, are assessed on a scale ranking from 1 to 10, the RPN indicator has a span between 1 and 1000 and the RP indicator ranks between 1 and 100. Figure 9 shows the outcome for the selected fourteen factors kept for further analysis.

![Evaluation of the input causes (from FMEA)](image)

**Figure 9**: Outcome – RPN and RP – of the FMEA for the selected fourteen factors kept for further analysis. Source: Compilation by the authors.

At the end of the **Measure Stage** it became clear that the factors which are contributing to the generation of waste can be grouped into a set of Key Process Input Variables (KPIV). They can be identified as: **Purchasing and Logistics**, **Staff** of the various departments, **Waste collection containers**, the use of **Printing paper** and the lack of available **Swap containers**. Table 3 contains a description of these KPIV and their relevance for the generation of waste and waste costs. The results from the **Measure Stage** are now transferred to the **Analyse Stage**.

**Analyse**

Quantities of waste, waste categories and the total waste costs and costs per tonne (2006) are shown in Figure 10.
Table 3: KPIV and their relevance for the generation of waste and waste costs. Source: Compilation by the authors.

<table>
<thead>
<tr>
<th>KPIV</th>
<th>Relevance for the generation of waste and waste costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Purchasing</td>
<td>- Purchase of materials and products and (not) taking into account that these may (partially) become wastes</td>
</tr>
<tr>
<td>Logistics</td>
<td>- Identification and verification of packaging (not) taking into account that this may (partially) become wastes</td>
</tr>
<tr>
<td>Staff</td>
<td>- Generation of waste</td>
</tr>
<tr>
<td>- Waste handling</td>
<td></td>
</tr>
<tr>
<td>Waste containers</td>
<td>- Waste containers allow for the separation of wastes</td>
</tr>
<tr>
<td>Printing paper</td>
<td>- Printing paper becomes waste</td>
</tr>
<tr>
<td>Swap containers</td>
<td>- Lack of swap containers implies the use of packaging which may become waste</td>
</tr>
</tbody>
</table>

Since the data are proprietary, the actual costs and the denominations of the categories of waste are not shown. The three charts show large varieties in quantities, total costs and costs per tonne.

For waste category 2, the costs are negative which implies that the waste is actually sold as recycled material. One general tendency shows that the costs per tonne tend to be higher with small quantities of waste. The reason for this tendency is the hazardous character of these wastes. One should, however, not totally neglect the first category in the respect. This outcome suggests that waste separation has an impact on waste cost, since mixed wastes which contain a category of hazardous waste cause the costs which are required to treat the hazardous portion of that mixed waste stream. Moreover, if a staff member sorts a waste of a specific category into a stream which commands higher costs, he will contribute to an increase of the overall waste costs.

Data about the distribution of waste streams and waste costs by departments are shown in Figures 11 and 12. The names of the departments, the quantities and the actual costs are not shown because the information is proprietary. The left hand side of both figures shows production units. The right hand sides show the office area (second bar from the right), unknown origins (third bar from the right) and the incoming goods and storage department (bar on the far right), where packaging waste is generated. The waste stream marked in red is sold as recyclable materials.

It is interesting to note that the highest quantity of this recyclable material is generated in Production Department 5, but this has no effect on the ranking of this department in terms of overall waste costs. It is also remarkable to note...
that the office area ranks second in terms of the generation of waste costs, ahead of four out of five production departments. This is due to the fact that most of its waste is composed of a mixed waste stream, the remainder being paper waste. It also confirms the experience that the extent to which wastes are separated contributes to the lowering of the waste costs.

In order to investigate this waste stream in more detail, samples should be taken and a detailed analysis about their composition should be made, specifically in order to find out if their contents are parts of other waste streams which are supposed to be generated by separation. In other words, the samples should reveal to what an extent instructions to separate waste are carried out. A representative sampling of these wastes is very complex and costly and fluctuations in production volumes must be taken into account. This means that the sampling period should cover at least one year. At the time of performing the case study, such an intensive experiment was not seen as feasible, even though casual observations revealed that parts of the mixed waste stream should have been collected separately and allocated to such waste streams. Another difficulty refers to the lack of information about inputs which end up as wastes. Whilst the Buying Department registers the inputs, there are no data about the shares of these inputs becoming wastes.

**Improve**

In the *Improve stage* measures are formulated with the intention to modify or eliminate the factors contributing to the process of the generation of waste and of waste costs. Once again, similarly to the construction of the *C&E Matrix*, these measures must be assessed in a priority table.

Hence, every measure is given a score between 1 and 10 for each of the following five criteria:

- Required investment costs - I (8)
- Simplicity S - (3)
- Speed of implementation – SI (5)
- Technical requirements - T (8)
- Effect upon an improvement of waste separation – WS (6)

Each of the five criteria is also weighed on scale between 1 and 10 by the six sigma team. In the enumeration above, these weights are mentioned in brackets. The overall assessment of a measure consists in the summed products of the scores times the weights of the criteria, as follows:

\[
[m(I) \times 8] + [m(S) \times 3] + [m(SI) \times 5] + [m(T) \times 5] + [m(WS) \times 6]
\]

with \(m(.)\) indicating the respective score. The summed products can be ranked and, in this way, one obtains a list of measures ranked by importance or adequacy. The higher the sum of products of a measure, the easier it can be implemented or the more successful it will be. Similarly to the prioritization of the factors, the measures can be graphically represented according to their importance, as seen in Figure 13. The prioritization table is shown in Appendix 2.

Of the sixteen measures shown, the first eight were considered as having top priority. The other eight measures stayed on the list for documentation purposes and for future consideration. The prioritization shows that the measures in the list tend to improve the separation of waste (e.g. better identification of containers and training of staff) and to reduce the waste volumes. One such waste stream for which reduction measures are implemented is packaging. The distinction between local and global suppliers serves this purpose as it relates to the packaging used by them. Local suppliers will now be obliged to use swap containers travelling back and forth between them and the company and global suppliers should be encouraged, wherever possible, to do the same. The so-called Packaging Manual will be written more specific and explicit and outline clearly which packaging must be used by suppliers. Packaging which does not meet specifications will be identified and suppliers will be charged the extra costs of their waste treatment. Packaging from suppliers should be used, if possible, for packaging goods to customers.
Figure 13: Measures for the reduction of waste costs according to their prioritization

The assessment of paper use by departments does not in itself constitute a measure to reduce waste but information about paper use may lead to further measures such as the investment in duplex printers. For that reason, the measure of using duplex printers is in the second part of the list. [An estimation of paper use of one year based upon actual paper use during one week revealed that, if such duplex printers are used, paper consumption can be decreased by about 30%.

For this company, this saving implies several tonnes of paper.] In order to implement the eight top priority measures, a planning and communication strategy has been worked out.

**Control**

In the final stage of the six sigma method is dedicated to the monitoring of the entire project. It is important to check whether the factors (causes) of the failure are eliminated and whether the (new) measures are appropriate for fulfilling the objectives. The Control Stage also constitutes the transition into a new round of the DMAIC Cycle. During the time of completing the project, the Control Stage could not be put to practice, since the Improve Stage requires an adequate time period for results to appear. Hence, one can only suggest how this Control Stage should be structured.

The first and foremost instrument to be used is an Audit of the waste generation and management process and the trends in the waste costs. In that way, attempts should be made to improve knowledge about the impact of the various factors (using RPN and RP indicators) and of the KPIV. This knowledge can be used to improve the outcomes of the C&E Matrix and the FMEA. If no progress is being measured, it will
become unavoidable to suggest and introduce other measures, e.g. the bottom part of Figure 12 or any other measures the six sigma team may propose. If progress is measured, a similar approach can be taken in order to speed up or improve this progress.

Can the Six Sigma method be applied to the process of waste generation and treatment?

In section 3, it became obvious that, at least to a certain extent, this question can be positively answered. In this last section, a closer look is taken at this issue. First, one can ask whether the Project Plan, can be carried out to the very end.

<table>
<thead>
<tr>
<th>Stages</th>
<th>Milestones</th>
<th>Instruments / Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Define</td>
<td>1. Generate and prioritise elements of the project (in the case study the main priority is to reduce waste costs)</td>
<td>Definition of waste costs / Identifying drivers of waste costs</td>
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<td></td>
<td>2. Develop a description of the project and the team and draft the initial project plan</td>
<td>Project Charter (not discussed in this paper)</td>
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<td></td>
<td>3. Identify the important outputs (in this project these are waste streams and KIPV (Key Process Input Variables))</td>
<td>SIPOC</td>
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<td></td>
<td>4. Estimation of the outcome of the process</td>
<td>Waste statistics, Waste classification number</td>
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<tr>
<td>Measure</td>
<td>5. Detailed description of the process / determination of the inputs and outputs / Preliminary ranking of Key Process Input Variables KIPV</td>
<td>C&amp;E-Matrix, FMEA, Pareto Diagramme, RPN and RP – of the FMEA for the selected fourteen factors, KIPV and their relevance for the generation of waste and waste costs</td>
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<td>6. Checking the capability of the measuring system</td>
<td>Quantities of waste, waste categories and the total waste costs and costs per tonne</td>
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<td></td>
<td>7. Collecting data about inputs (x) and outputs (y)</td>
<td>Distribution of waste streams and waste costs by departments</td>
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<td></td>
<td>8. Assessing process capability</td>
<td>Data about the quantities of waste and the waste costs</td>
</tr>
<tr>
<td>Analyse</td>
<td>9. Identification of the KPIV</td>
<td>FMEA, Pareto Diagramme (not discussed in this paper)</td>
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<tr>
<td>Improve Control</td>
<td>10. Optimizing the KPIV</td>
<td>Brainstorming, FMEA</td>
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<td>11. Deciding on the best solution</td>
<td>Priority table</td>
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<td>12. Checking and verifying the improvement in the long run</td>
<td>Audits,</td>
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<td>13. Identifying the costs savings</td>
<td>Data on waste and on waste costs (not discussed in this paper)</td>
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<td>14. Implementing and documenting / Preparing Checking plans / delivery to customer</td>
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From Table 4 it can be seen that, for most Steps of the project plan, appropriate instruments and outcomes can be identified. Hence, from the methodological point of view, the six sigma method seems to be applicable. This is also confirmed by the fact that all stages of the DMAIC Cycle can actually be performed and completed.

From a content point of view, the question needs to be raised whether the instruments lead to satisfactory outcomes. In this context, it should be known that the six sigma method is very much dependent on the availability of (ample) data. The strength of the method consists in the generation of quantitative outcomes according to mathematically formulated instructions from possible large data sets.

Table 4: Project Plan for the case study. Source: Compilation by the authors.
Examples are the instruments for prioritization shown in the paper. Since the company does not keep and maintain such an ample data set about the generation and the treatment of waste and about the waste costs, the applicability of the six sigma method remains limited in terms of obtaining satisfactory outcomes. The shading of the cells in Table 4 relates to this in the sense that green stands for “satisfactory” and red represents an “unsatisfactory” outcome, with yellow as an in-between result. The strength of the six sigma method is to identify failures in a process at the location where they occur and, hence, offer an opportunity for improvement. For the case study of improving the process of generating and managing waste and of reducing the waste costs, this strength is not given to the full extent.

References


Further references


### Appendix 1

**Prozess Outputs (Y)**

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<tr>
<th>Prozess Outputs (Y)</th>
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**Ranking der Wichtigkeit des Outputs für den Kunden (Proz. L.)**

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**Wichtigkeit des Outputs für den Kunden (Proz. L.)**

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**Prozessinputs**

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**Produktursumme prozentuale Stärke aller Einflüsse auf Outputs**

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**Ranking der Stärke aller Einflüsse auf Outputs**

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## Appendix 2

### Wichtigkeit des Kriteriums zur Umsetzung der Lösungen

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