On manufacturing processes and the environment

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Abstract :
It is tried to obtain a better view on the environmental effects of manufacturing processes, in particular forming. The aim is the introduction of process integrated solutions and the definition of design rules.
Earlier studies showed the difficulties investigating the environmental effects of one main manufacturing process for a general situation. In this study the environmental effects of several products manufactured by representative processes are being investigated, giving an example how the 'life cycle crossing' [1] can be filled in. Because this study is done by a practicable case it was not sufficient to concentrate solely on the environmental aspects. Attention was also paid to the technical and economical constraints. To do this in a systematic way the Manufacturing Environmental Assessment-Method (MEA-method) is proposed. Herewith the goal can be reached step by step. Eventually it becomes possible to propose practical improvements and direct further research, by using the MEA-method. The lack of detailed environmental data is however the restriction to draw quantitative conclusions. Nevertheless it is possible to make well weighted decisions, for example by using the Environmental Cost Model (ECM).

1. Introduction

The ongoing environmental consciousness results in new and higher demands on manufacturing. Stricter laws endanger the continuation of some manufacturing processes and raise production costs, because the use of certain materials will be forbidden or restricted. Another demand is to apply the available potential in manufacturing to enable lower environmental burdens in production and other life cycle phases, for instance in the use- or discard phase. Before these demands can be met, the demands should be shaped for the manufacturing situation by an inventory. In this inventory the processes play a central role, since they cause the burdens. Also because the final target (prevention) is to reach process integrated solutions.
In earlier research [1] it appeared to be very difficult to value processes on their environmental burden for a general situation. The effects of processes are strongly dependent on the manufactured part. Therefore two cases are studied on existing parts, at the press workshop of DAF Trucks NV and at the Automated Presses division of Philips PMF. The DAF-case is an example of how the 'life cycle crossing' [1] can be filled in and must be seen as a pilot study to acquire insight in the demands that are made to

manufacturing. In the Philips-case a verification is made of the basic results from the DAF-case for another range of products. For this a completely different approach is used.

2. The DAF-Case

The objective of this case is to appoint the environmentally most critical material streams in the manufacturing of metal parts. Additionally, possible solutions are formulated to reduce the volume of these streams.

2.1 Introduction

The case is performed at the press work shop of the motor-truck producer DAF Trucks NV. The work shop consists of six hydraulic and nine mechanic presses ranging from 60 to 2000 tons. Here the metal parts of the cabin and the chassis are manufactured. The ingoing material is supplied by the cutting shop and consists of steel plate varying in thickness between 0.8 mm and 13 mm. Part sizes range between 0.01 to 4 m^2. In the workshop approximately 250 different parts are manufactured, all with their own specific set of dies. These dies are designed and maintained by DAF. After the workshop the parts are sent (depending on the part) to be welded, sand blasted, cleaned, painted and/or assembled.
The study is carried out at DAF in the period from 11/94 until 8/95. Starting point was to realise reductions of the environmental load of the press work shop, within the business possibilities. This striving equals the commitments of the management of DAF which underline the importance of environmentally friendly products. For the press work shop itself it was the first confrontation with environmental critics.

2.2 Approach

To establish the environmental load of the manufactured parts the Life Cycle Analysis (LCA) was not used. The principal reason is, besides the not yet reached general agreement on some points (in particular the 'evaluation') within the LCA method [2,3,4], the lack of sufficiently detailed environmental data in the available LCA programs. It was not to be expected that the required data could be acquired within the time limits. However the absence of the required environmental data is a real problem, the reconnoitring character of the case makes lower demands from the availability of data acceptable.

To approach this case the Manufacturing and Environmental Assessment -method (MEA-method) has been introduced. This method is based on research carried out in the Netherlands [5,6] and can be seen as a filling in of the life cycle crossing [1], where parts are produced using production machines. The method is meant to achieve the successful introduction of new and environmentally friendly alternatives in a production situation.
In this domain there is a strong interaction between processes and products. The environmental burden is caused by processes, but it is attached to products.

The MEA-Method consists of the following steps that have to be made:
1. Selection of representative products

2. Description of the process chain of the products
3. Description of the material- and energy streams
4. Detection of environmentally relevant streams
5. Determinationof possible 'improvement options'
6. Decision on the 'feasibility' of the improvement options
7. Decision on the 'desirability' of the improvement options
8. Final choice of the improvement options

The method has been carried out by a team of specialists, employed by the manufacturer and is guided by a conductor who collects the necessary information, takes care of the communication and is controls the progress. It is very important that the team is composed out of all the disciplines that are involved in the manufacturing of the parts.

2.3 Results

In the DAF case the team consisted out of the environmental co-ordinator, a technologist, the involved engineers and the responsible production manager. The conductor was a university researcher.

Step 1: The chosen products should represent the possible processes and process combinations. In this case the representative products are: axle half (13 mm thick, hot rolled, unstained), chassis cross beam (6 mm thick, hot rolled, stained), door outer panel (0.9 mm thick, cold rolled, uncoated), cabin cross beam (1.2 mm thick, cold rolled, thermal zinc coated).

Step 2: In this step the process chains are determined for the different products. Special attention should be paid to determine side borders of the process chains and the detail in which the chains are set up.

A.	The use of lubricants	a) The lubricant must be removed from the part b) The lubricant must be extracted from the earth c) The lubricant is on the material waste
B1.	Cleaning of the axle half	a) High energy use b) Use of hazardous fluids c) Bath fluids have to be treated as chemical waste
B2.	Cleaning of the chassis cross beam	a) Use of hazardous fluids b) Bath fluids have to be treated as chemical waste
C.	Cleaning of the dies, in particular when forming zinc coated or unstained sheet	a) Use of hazardous and/or volatile cleaning fluids
D.	Material waste of outer door panel	a) Over 50% loss of material
E.	Phosphates in degreasing	a) The waste water of the electro coating pre-treatment contain phosphates
F.	Passivating of the chassis cross beam	a) The waste water of the passivating bath contains chromium
G.	Phosphating	a) The waste water of the electro coating pre-treatment contains zinc

Table 1 : recognised environmental loads.

Step 3: The material and energy streams that connect the different processes in the chains are quantified in this step. The quantification requires a lot of information which is sometimes difficult to obtain. For instance the information about the used energy was solely available for the work shop as a whole and over a longer period of time, not for a single press and a specified period. This difficulty was experienced for many quantities. The consequence is that this step takes a lot of time. A 'black box' approach (streams not linked to certain products or processes) would have simplified this step considerably.

<u>Step 4</u>: In close deliberation with the environmental co-ordinator and literature sources the environmentally relevant streams are indicated (see *Table 1*).

<u>Step 5</u>: For the appointed problem areas possible improvement options are suggested. This was done by the entire multi-disciplinary team in a brainstorm-like session and worked out by the conductor. For the results see *Table 2*.

		eco.	tech.	env.	fea.	des.
A.1	Reduction of lubricant quantity	3	4	1	2.4	0.48
A.2	Use of PVD/CVD coatings on dies	4	5	4	4.0	3.20
A.3	Use of unstained sheet	3	3	1	1.8	0.36
B1.1	Reduction of lubricant quantity	3	4	4	2.4	1.92
B1.2	Water cleanable, non-water soluble lubricant	4	4	4	3.2	2.56
B1.3	Alternative cleaning fluid	4	5	4	4.0	3.20
B2.1	Reduction of lubricant quantity	3	4	3	2.4	1.44
B2.2	Phosphating before forming, soap lubricant	3	4	1	2.4	0.48
B2.3	Use of phosphated sheet	4	4	1	3.2	0.64
C.1	Use of PVD/CVD coatings on dies	4	5	4	4.0	3.20
C.2	Use of stained sheet	5	5	2	5.0	2.00
C.3	Protection of zinc coated sheet	3	3	2	1.8	0.72
D.1	Use of 'Tailor Made Blanks'	3	4	4	2.4	1.92
D.2	Re-use of material waste	3	3	3	1.8	1.08
D.3	Hydro forming of door-jamb	2	1	3	0.4	0.24
E.1	Phosphate free degreasing	3	2	5	1.2	1.20
E.2	Neutral degreasing of zinc coated sheets	3	2	4	1.2	0.96
F.1	Cr-free passivating	3	2	5	1.2	1.20
G.1	Re-phosphating	3	2	4	1.2	0.96

Table 2 : Improvement options and their valuations.

<u>Step 6</u>: The options are valued (by a number between 1 (bad) and 5 (good)) on their technical (tech.) and economical (eco.) possibilities, analogue to the DIN 2225 standard for designers. From here the feasibility (fea.) can be accounted. For the results see *Table 2*.

feasibility [1-5] = economical valuation [1-5] * technical valuation [1-5] / 5

<u>Step 7</u>: The feasibility is then multiplied by a value for the expected environmental improvement (env.). The result is a quantity that can be seen as a measure for the desirability (des.) of the option. The environmental improvement is determined by the heaviness of the environmental load that has to be reduced and by how far it is expected that this load can be reduced. For the results see *Table 2* and *Figure 1*.

Desirability [1-5] = feasibility [1-5] * environmental improvement [1-5] / 5

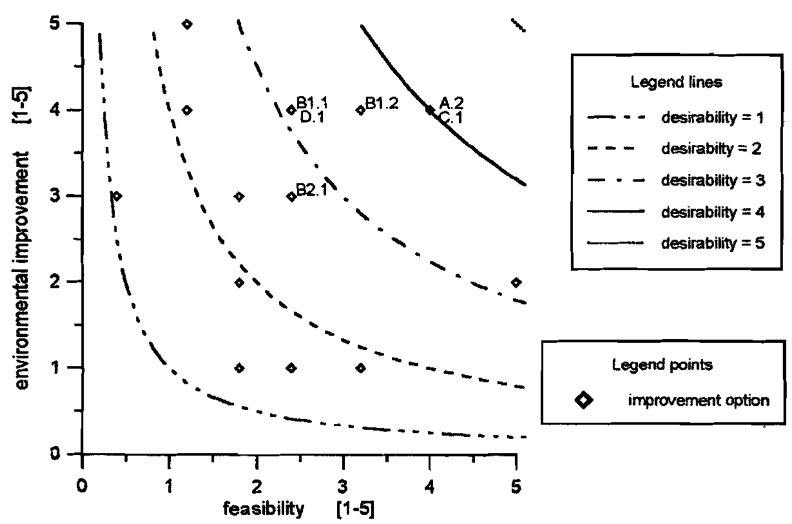

Figure 1: The feasibility and environmental effect of the different improvement options.

Step 8: Finally a decision should be taken, based on the obtained information, about which improvement options can be introduced directly (high feasibility and high environmental effect) and which options are suitable for further research (high environmental effect but low feasibility). In this case it is chosen to change the used lubricant (B1.1, B1.2, B2.1) in combination with a surface coating on some heavily loaded dies (A.2, C.1). Further research is planned to reduce material waste in manufacturing by the introduction of 'Tailor made blanks' (D.1).

2.4 Evaluation

The method: Although the method works satisfactory in a production environment, it is deficient in the valuation. There is no objective environmental unit that values the alternatives. This deficiency is further strengthened, because some improvement options reduce more than one environmental problem. In future this will hopefully be improved by a better availability of data, though the gathering of the required information will always be time consuming.

The DAF situation: On the one hand the chemical content of the streams is important, in particular concerning the auxiliary materials as the lubricant and the cleaning fluid. The lubricant is applied in relativily small quantities compared to the oil consumption in other human activities. But the used lubricant is strongly responsible for polluting the working environment of the workers, because it drips, smells and is volatile. Further the oil sticks to the material waste, including additives, and will be burned during recycling. And it importantly determines the heaviness of the cleaning process and the cleaning fluid. Forming requires a good attachment to product or die, opposite to cleaning that has to separate product and lubricant. Aspects that have to be reviewed are a.o. that the auxiliary materials can be separated and used again, that the cleaning- and recovering processes are energy extensive and that a small quantity of the lubricant that is applied.
On the other hand we can distinguish an other important environmental load type, namely the material waste. This waste stream (mainly steel) is less definable by its chemical content, because there is an almost 100% recycling. This stream is more defined by the energy that is required for the production and recycling (GER, Gross Energy Requirement).

Concluding, it can be said that the registered environmental loads can be divided into two main kinds, the chemical content, in particular of the auxiliary materials and the energy consumption, in particular of the material waste.
Besides this some other interesting issues are established that need to be examined. These are the environmental relevance of the production and maintenance of dies and the possible potential of manufacturing to reduce the environmental loads in other life cycle phases, for instance by the introduction of Tailor Made Blanks.

3. The PHILIPS-Case

This case is set up to check the results of the DAF-case in a different situation and to try to solve one of the problematic points of the MEA-method, viz. the lack of possibilities to measure the environmental load. The solution of this problem is sought in assigning environmentally loaded streams to costs and to use this unit (environmental costs) as a first indicator for the size of the environmental loads.

3.1 Introduction

In the Philips PMF Automated Presses metal parts are manufactured for the electronic industry, for Philips as well for other producers. The parts are manufactured in mass production, series range from 10^5 and 10^7 per year. The sizes of the parts range from 10^{-4} to 10^{-2} m². The entrance material consists of rolls of metal strips that are previously sized, thickness' range from 0.1 mm to 2 mm. After deforming the parts are cleaned and dried depending on the used lubricant and the requirements of the purchaser.

3.2 Approach

To assign the environmentally loaded streams to costs the Environmental Cost Model (ECM) is introduced. The model is based on the idea that the government stimulates and discourages the industry in an environmentally friendly direction by subsidies and levies. Environmentally unfriendly actions will, in this picture, have negative financial effects and increase the manufacturing costs of a product. The size of the financial effect is taken as a measure for the unfriendliness of the action. An other assumption is that the costs that are made to recycle a certain material to its original state can be qualified as environmental costs. To make this model effective a clear difference has to be made between environment related costs (env. costs) and not-environment or production related costs. So the processes and efforts in production have to be divided in two parts, processes to produce the required products and processes to fulfil the environmental regulations. As a measure for the processes and efforts to recycle production waste to the original state the difference between buy and sell prices are taken. Further are costs for energy fully accounted as environment related.

3.3 Results

The ECM-method is applied to a small metal part, a brace. This brace is produced in a process chain of punching, bending, PER-cleaning and drying. The part is ±2.5 10^{-3} m² and irregularly shaped, the batch size is approximately 10^7 parts.

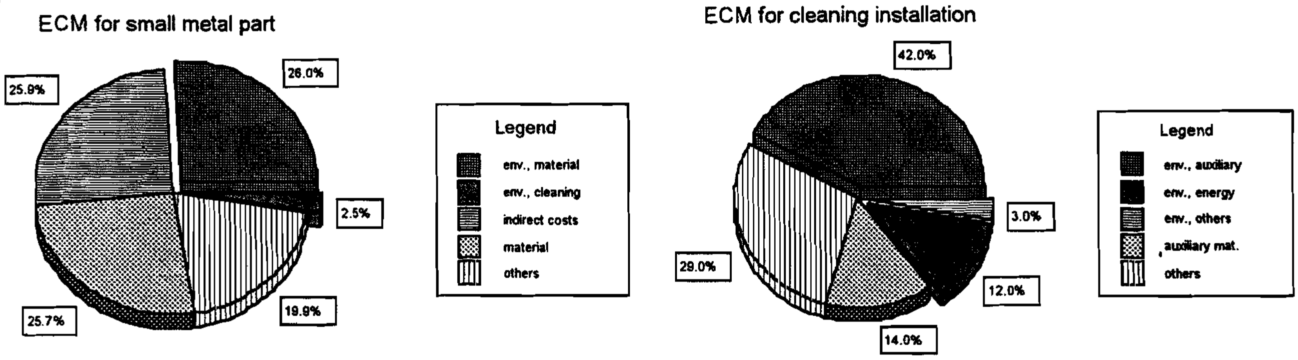

Figure 2: Environmental Cost Model for a small metal part

Approximately a fourth part (28.5%) of the total costs can be related to environmental issues. This is for the major part (26%) a result of the material waste. This is appr. equal to the costs of the material that actual is contained in the part. The other 2.8% of the env. costs are caused by the cleaning process. If the cleaning process is enlarged it appears that more than half of the costs (57%) of this process can be accounted as environmentally related. The biggest portion (42%) is caused by the cleaning fluid that has to be carried of after use. This has to be done according to environmental laws and regulations. Another substantial part (12%) is caused by the considerable amount of energy that is consumed to heat the process. Another 3% of the environmental costs are made for fluid proof floors, research and personnel.

3.4 Evaluation

Method: It is possible to indicate the material streams that have the highest environmental impact on basis of the costs that have to be made to deal with these streams according to the environmental regulations.

In some cases it is difficult to decide whether costs are made in relation with the environment or not. This concerns in particular materials. The difference between the buy price of the virgin material and the sell price of the waste is used as an indicator for the environmental load of the materials recycling process. This indicator is of course clouded by the market influences. But if the price of the waste is high it means that it is wanted by the market and that it probably will be used again, which is environmentally positive. This is in agreement with the lower accounted environmental costs, so the market influences do not work into the wrong direction. Besides, for rare or energy intensive virgin materials (like aluminium), where recycling is the better alternative, material waste prices are relatively high, which agrees with lower calculated environmental costs.

The Philips results: Even with the completely different kind of production (product - and series size) compared to the DAF case, the Philips case leads to the similar results. There are two main environmental burdens related to forming processes a) material waste and b) cleaning fluid in relation to the used lubricant. The environmental costs (mainly material waste) are approximately a quarter of the total costs needed to manufacture a metal part. The costs of the cleaning process are more than half related to the environment.

4. Conclusions

- The MEA-method is proposed as a practicable, unpretentious method, that is helpful to obtain commercially acceptable and environmentally friendly developments in production and to direct necessary research to meet future environmental restrictions.

- The ECM-method is a rough indicator to indicate environmentally relevant material streams, although it needs more research to prove the relation between the costs and the environmental loads.

- In forming two kinds of environmental loads can be distinguished.
  Energy
  This is mainly attached to materials. The materials can be seen as carriers of energy. The production scrap is in this perspective a loss of energy. The press and the cleaning installation are only additional energy consumers.
  Chemical content
  The used auxiliary materials can contain environmentally hostile elements. Both in lubricants and cleaning fluids.

  This has been found in both the truck - and the electronic part manufacturing and can be seen as a general item for sheet metal forming processes.

- The environmental load of the production and maintenance of dies requires further research. It appeared to be a relevant factor, but it is not yet clear how important this factor is compared to other factors.

- In addition to process integrated solutions within the 'Life Cycle Crossing', there is also a potential to reduce environmental loads in other life cycle phases by developing and introducing new manufacturing processes, e.g. Tailor Made Blanks.

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References:

[1] De Winter, A., Kals, J.A.G., 'A methodic approach to the environmnetal effects of manufacturing, RECY'94, 2. International Seminar on Life Cycle Engineering, Erlangen, Germany, Oktober 1994.
[2] Goedkoop, M., Braam, J., 'Eco-indicator gaat verder dan levenscyclus analyse', E&M, nov. '95.
[3] Kaniut,C., Kohler, H., 'Life Cycle Assessment (LCA)- A supporting tool for vehicle design?', Life Cycle modelling for innovative products and processes, IFIP WG5.3-conference, Berlin, Germany nov./dec. 1995.
[4] Zürn, J., Diener, J., 'Ecological assessment of products and processes challenge and opportunity', RECY'94, 2. International Seminar on Life Cycle Engineering Erlangen, Germany, Oktober1994.
[5] Cramer, J., Quakernaat, J., et al., 'Theorie en praktijk van integraal ketenbeheer', NOVEM, RIVM, Apeldoorn, 1993
[6] 'Handboek voor preventie van afval en emissies in de metaalproduktenindustrie', Ministerie van VROM en Ministerie van economische zaken, Den Haag, 1992.