



## INTERNATIONAL WORKSHOP ADVANCES IN CLEANER PRODUCTION

"KEY ELEMENTS FOR A SUSTAINABLE WORLD: ENERGY, WATER AND CLIMATE CHANGE"

# Managing I/O Material Flows in Industrial Processes – A Key Step Towards Sustainable Production

P. J. Partidario, J. M. Figueiredo

INETI, Materials and Production Technologies Department, Lisbon, Portugal, [paulo.partidario@ineti.pt](mailto:paulo.partidario@ineti.pt)

---

### Abstract

Industrial wastes consist of unused resources in the production process, which create costs and no added value.

Measuring input-output material flows at a company level is therefore crucial for waste prevention, which is a key path towards higher resources productivity. Waste prevention strategies focus in particular on reducing or eliminating undesired waste streams, and managing by-products within the production process, rather than treatment and disposal approaches. In the long run, prevention strategies are more cost-effective and environmentally sound than conventional pollution control approaches. Waste prevention strategies apply to any manufacturing process and range from relatively easy operational changes and good housekeeping practices to more extensive changes such as replacing input materials, fine tuning or replacing equipment, or even making use of state-of-art technology.

This paper provides insights on the development and testing of a toolbox for the inventory and management of waste flows looking forward to implementing a 'zero waste' strategy. Twelve case studies selected within seven Portuguese industrial branches were explored. The toolbox included an activity based costing methodology, as well as detailed process mapping and material balances used at company level to measure resource flows and undesired waste streams, and thus to fix optimisation targets by integrating waste prevention into business strategies.

In each company, empirical results showed: a) The usefulness of the approach; b) how powerful waste prevention is providing strategic inputs for decision taking (a hierarchy built on a economic and environmental basis); c) how critical operating conditions are, and therein both branch or company's culture, in order to influence the implementation of waste prevention initiatives.

Main conclusions drawn from those case studies enable to propose both: a) at a micro level, new options for strategic improvement; b) at a macro level, hypotheses about how public policies may address waste prevention and about the diffusion of eco-efficiency in those industrial branches in order to pave the way towards sustainable production.

*Keywords: Manufacturing; strategy; performance-measure(s); methodology; innovation.*

---

## 1 Introduction

Industrial wastes consist of unused resources in the production process, which create costs and no added value.

Measuring material flows at a company level is therefore crucial for waste prevention, which is a key path towards higher resources productivity. Waste prevention strategies focus in particular on reducing or eliminating undesired waste

streams, and managing by-products within the production process, rather than treatment and disposal approaches. In the long run, prevention strategies are more cost-effective and environmentally sound than conventional pollution control approaches (Pearce and Turner, 1984).

Waste prevention strategies apply to any manufacturing process and range from relatively easy operational changes and good housekeeping practices to more extensive changes such as replacing input materials, fine tuning or replacing equipment, or even making use of state-of-art technology (Dieleman and De Hoo, 1993).

This paper provides insights on the development and testing of a toolbox for the inventory and management of waste flows looking forward to implementing a 'zero waste' strategy in real industrial conditions.

## **2 Materials and methods**

Twelve case studies selected within seven Portuguese industrial branches were explored. The toolbox included an activity based costing methodology, as well as detailed process mapping and material balances used at company level to measure resource flows and undesired waste streams, and thus to fix optimisation targets by integrating waste prevention into business strategies.

### *2.1 Material Flows*

Material flows were analysed at a process and operations level, and material balances performed and used to monitor resource productivity improvements and the environmental performance, at a company level.

### *2.2 Zero Waste Strategy*

This strategy aims to avoid non-product outputs by integrating resource optimisation targets and waste prevention into business strategy.

### *2.3 Tool Box*

Main complementary tools were used throughout a multistage process (fig. 1), which included process mapping and mass balances, activity based costing, Pareto analysis, cause-effect analysis, and cost-benefit analysis.

### *2.4 A Case Study Approach*

Seven industrial branches were selected on the basis of their waste prevention potential, size (nr. companies) and waste volumes produced. In each of the 12 cases studied, after being previously involved in a cascade training process, actors from each company have been cooperating in practical work looking forward to using a activity based costing methodology to 'zero-waste' activities and to extending their gained experience to new initiatives with the support of a cooperative network.

### *2.5 Actors*

INETI, INR-National Institute for Wastes, Branch Associations (8), Technologic Infrastructures (7), and the following 12 Portuguese companies: Acatel, SA; Erofio, SA; Fitcom, Lda; Hydro A. Portalex, SA; Irmade, SA; JSL, Lda; Malhas Sonicarla, SA; Olegário Fernandes, SA; Offsetlis, Lda; Peltéci, SA; Tintas Dyrup, SA; Toyota Caetano, SA



Fig. 1. The PreResi method

### 3 Results and Discussion

#### 3.1 Cascade Training

The aim of performing a cascade training process was twofold: expert training on industrial waste prevention, eco-efficiency and on the zero waste strategy in particular, was provided to a wide group of actors (Industry, Branch associations, Government, University, Technological Centres, Consultants) considering their key role in value chains (Partidário and Vergragt, 2000; Partidário, 2002); next, selected experts from the previous group, provided branch oriented training to companies on the pre-selected industrial branches enabling a previous contact both with the method and the toolbox, before getting involved in practical work in the companies.

This step provided a 70 hours training program to 244 participants, 100 companies included (Fig. 2).

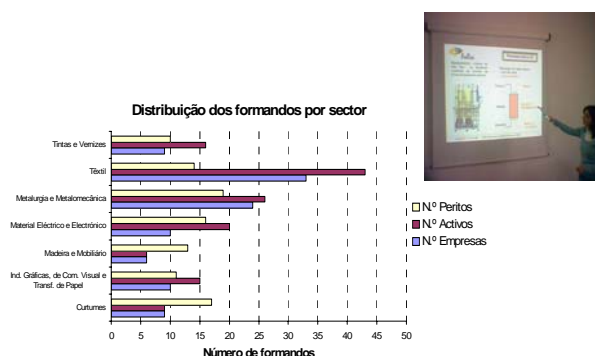


Fig. 2. Training provided to seven industrial branches

#### 3.2 Implementing the Method

In real industrial conditions, twelve case studies were performed from April '06 to April '07 following the different steps of the PreResi method, as represented in fig. 1.

In each case studied, process analysis was performed on an activity basis, including auxiliary activities, with the identification and quantification of both the used resources (raw materials, auxiliary materials, water, energy and manpower), and the effluents & residues generated in each step.

Taking, for instance, the case of truck manufacturing (Ribeiro et al, 2007) and a process step in particular, consisting of a primary and a enamel or metallic painting, as represented in fig. 3.

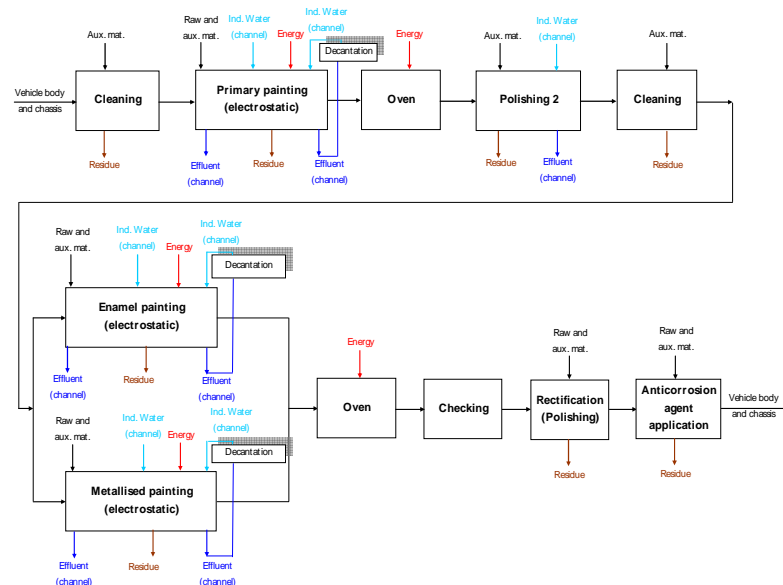


Fig. 3. Example of a painting process step within a case study approach

For a given process step, accountings of material flows and costs on a year basis regarding resources, effluents & wastes, such as the one represented in fig. 4, enables to put in evidence the relative meaning of non-product outputs.

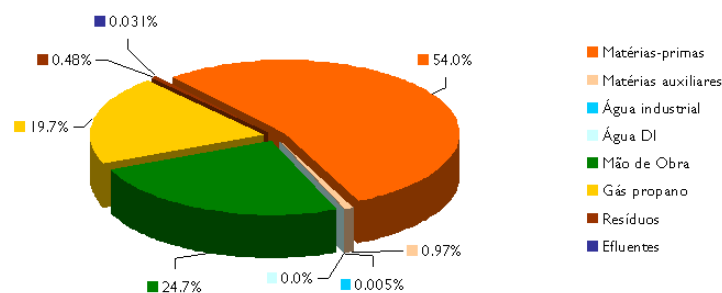


Fig. 4. Annual costs distribution in the painting process, focusing on a given booth

Activity after activity, having gathered detailed data throughout the whole process, in particular about the different non-product outputs occurring in each operation, it enabled to proceed with problem definition. In order to manage a wide variety of improvement opportunities, an effective approach consists in applying the Pareto principle and representing the hierarchy of waste costs quantified in those operations (fig. 5).

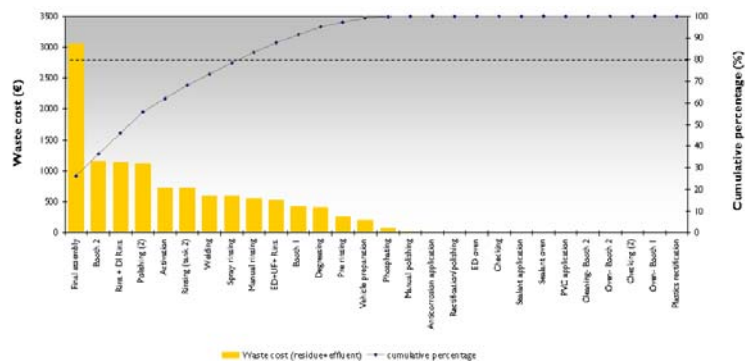


Fig. 5. Hierarchy of costs for waste prevention purposes

After using the Pareto's 80:20 rule it is time then to focus on the 20% of causes that are corresponding to the 80% of total costs. As a rule of thumb, each lost resource means an improvement opportunity to prevent such loss. This step enables therefore to define priority improvement opportunities on a costs basis. Other priorities and criteria may be considered (e.g. company's auditing issues) at this stage, before performing root-cause analysis focusing on each particular waste problem.

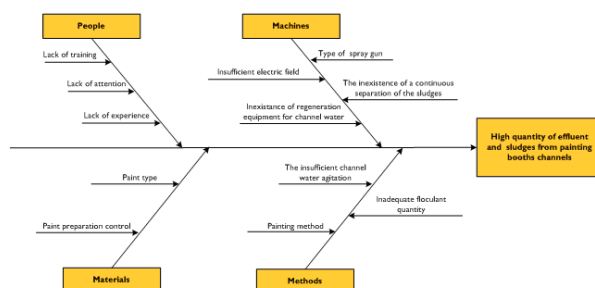


Fig. 6. Root-cause analysis: The case of painting wastes in booths channels

Taking for instance the painting booths and in particular the painting booth for the coating of metal parts. That particular booth includes a water channel for the collection of paint droplets that result from the overspray. In booth operations the main occurring wastes consist of sludge from booth channels cleaning and from the liquid effluent also generated in that operation (i.e. channel water). Taking four root-cause classes, the Ishikawa diagram in figure 6 represents the analysis performed focusing on the painting operation including the channel cleaning. The identification of root-causes in this particular case enabled to emphasize two main issues:

- The inexistence of a continuous sludge separation;
- Non sufficient water mixing in the channel, and inadequate amount of flocculating agent, which results in the existence of a solids layer (paint particles) on top of the water.

Having concluded this analysis, it was possible to explore improvement alternatives for each of the priority issues.

In the particular context of the painting process a deeper analysis was performed focusing on the amount of sludge and effluent that result from the channels in the painting booth.

Because of over-spraying effects occurring in that booth, the channel currently needs cleaning every 3 months. Such cleaning includes removing the sludge collected and sending the aqueous solution to the wastewater treatment plant (WWTP). The amount of sludge removed from the channels (about 5 ton/ y), and its management cost, justifies this analysis. In addition, even though the effluent volume (about 320 m<sup>3</sup>/ y) sent to the WWTP and its costs are not a priority issue, it was considered an opportunity to be integrating such evaluation as potential was identified to reduce cleaning operations. Having decided that, the following issues were discussed:

- a) Electrostatic painting - the existence of insufficient electric fields can originate a higher paint dispersion. There is, consequently, a sludge amount increase that accumulates in the channel. It is thus convenient to periodically implement a check plan focusing on that equipment in use.
- b) Flocculating/coagulant agent concentration - its optimization enhances paint particles precipitation. Therefore, the remaining water contains less paint in suspension, and consequently the cleaning cycles can be reduced.
- c) Sludge and water consumption – Effective water/sludge separation is not a reality, thus resulting into a greater sludge quantity than technically feasible, as well as on greater transportation costs due to their higher water content. In addition, makeup water has to be introduced frequently. If an effective water mixing system could be installed, water would run in a closed loop circuit. It could thus move through a solid-liquid separation system (decanter; filter), enabling continuous particle removal. The effectiveness of sludge separation would consequently increase, and wastewater discharges would be less frequent. Adding to that, if water mixing could be installed, it would provide a sufficient air flow to prevent odour releases.

In brief, solutions identified and proposed after this stage, within the scope of the painting booth, were the following:

- Perform regular checking of electric fields in the electrostatic painting;
- Optimize the flocculating agent concentration;
- Set up an effective mixing system for the aqueous effluent;
- Implement water recycling in a closed loop circuit, running through a decanter/filter system, looking forward to solid particles removal and to the reduction of water consumption.

Finally, the solution evaluation stage provided an interesting discussion about competing technical alternatives, e.g. vacuum evaporation against flocculation and separation. After a first economic assessment, which lead to the conclusion that vacuum evaporation would require an 50 kEuros initial investment approximately, plus energy costs around 3.2 kEuros per year, then tests were performed focusing on a flocculation combined with a 200 µm filtration option. Main conclusion was that investments required would be about 20 kEuros, plus operating costs around 1.5 Euros per hour, which includes air injection in order to promote mixing effects. Within this option, equipment adjustments might be expected due to the variation of contaminants concentration along time. Following this path, the company may expect as well a longer effluent discharge period (1 year approx.) in the WWTP service, i.e. lower effluent volumes and treatment costs. This is a key input for the very final stage of the method: implementation and monitoring, which will have necessarily to match with company's own investment planning.

Extending this approach to the whole production process/ company, it enables the organisation to creatively enrol its staff within different departments, and to identify and evaluate improvement alternatives to solve the previously selected priority problems (fig. 7). In each one of the cases studied (Figueiredo and Partidário, 2007), empirical results showed:

a) The usefulness of the approach. Different statements from companies reflect that:

- "Value creation, by quantifying and analyzing graphically the resources involved, and thus preventing in the exact process stage that a given resource (e.g. raw-materials, energy, human power) might result into non-product outcomes and waste";
- "Immediate implementation of low cost solutions, and the definition of actions for continuous improvement" (resources; wastes);
- "Better insights on each process and operation in the production line"; "Measure to enable a better management"; "To focus and be very objective about existing problems, and have an hierarchy for action planning";
- "Integrate waste management into total quality management" (...through continuous improvements, in practices, equipment and processes taking a zero-waste direction);
- "Using new tools" and "Doing better with less";
- "Involving workers in company's problems"; "Creating (...or improving) Environmental Management Systems"; "Look at environmental management as an opportunity to stimulate productivity improvements, and other less succeeded issues".

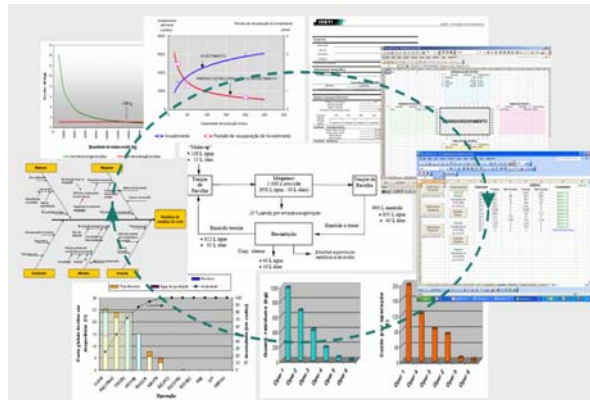


Fig.7. The method after implementation

b) How powerful waste prevention is. It provides strategic inputs for decision making, and a hierarchy built on an economic and environmental basis. In whole, improvement solutions types as proposed to companies had in a aggregated form a distribution as represented in fig. 8. This shows in particular the key importance and the direct role workers have in waste prevention, together with the improvement opportunities regarding raw material selection and process changes as well.

c) How critical operating conditions are, and therein both branch or company's culture, in order to influence the implementation of waste prevention initiatives.

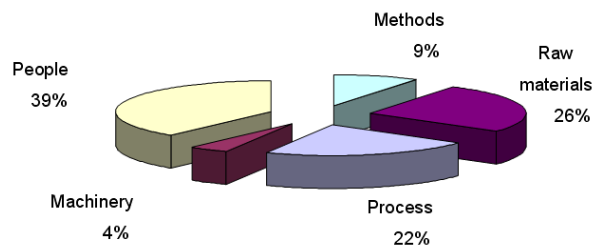


Fig. 8. Solutions aggregation by types to feed-in the improvement process

## 4 Main Conclusions

Experimental data enables to have insights on:

- Companies' opportunities since they began involved in the program till their individual case study was over.
- The benefits of waste prevention approaches, as described in literature.
- The importance of operational conditions (company, sector), as well as of key actors enrolment inside each company, to make progresses in such kind of initiatives.
- The opportunity each industrial branch has to discuss conclusions achieved in each case study, and the potential they have, in particular when considering the EU Thematic Strategy on the Prevention and Recycling of Waste, the Portuguese National Plan on Prevention of Industrial Wastes – PNAPRI (Figueiredo, 2001), as well as the EU Strategy on Sustainable Use of Natural Resources.
- In case a particular waste type cannot be avoided, a key primary step consists on its reduction (quantity, danger) as far as it is technically possible, following the waste hierarchy (EC, 2008) and a life cycle perspective.

Main conclusions drawn from those case studies enable to propose both at a:

- Micro level - new options for process and product improvement.
- Meso level - a chance to enrol companies within a given industrial branch and/ or a given region, to contribute for the mapping of wastes (quantity, quality). Those wastes might be addressed as resources eventually useful within other value chains beyond the boundaries of the original industrial branch.
- Macro level - hypotheses about how public policies may address waste prevention, and about the diffusion of eco-efficiency in those industrial branches, in order to pave the way towards sustainable production.

## 5 References

- [1] Pearce, D.W. & Turner, R.K., 1984. The economic evaluation of low and non-waste technologies. *Resources and Conservation*. 11: 27-43.
- [2] Dieleman, H. and De Hoo, S. 1993. Towards a Tailor-made Process of Pollution Prevention and Cleaner Production: Results and implications of the Prisma Project. In: Fisher K. and Schot J. (Eds), *Environmental Strategies for Industry – International perspectives on research needs and policy implications*. Washington D.C.: Island Press, pp. 245-275.



- [3] Partidário, P. & Vergragt, Ph.J, 2000. Shaping Sustainable Technology Development in the Coatings Chain. Defining boundaries, environmental problems and main players. *Journal of Cleaner Production* **8**, 3: 201-214.
- [4] Partidário, P., 2002. "What-If": From path dependency to path creation in a coatings chain; A methodology for strategies towards sustainable innovation, PhD Thesis, Delft University of Technology. Delft (NL): Druk Tan Heck.
- [5] Ribeiro C., Pedrosa F., Gonçalves L., Cardoso S., Vale E & Ferreira S., 2007. Manual para a Prevenção de Resíduos – Estudo de caso para o sector da metalurgia e metalomecânica: Toyota Caetano Portugal SA, J. Figueiredo e P. Partidário, Editores. Lisboa: INETI.
- [6] Figueiredo J e Partidário P. (Eds), 2007. Manuais para a Prevenção de Resíduos – Estudos de caso, <http://preresi.ineti.pt>
- [7] Figueiredo J (Ed), 2001. PNAPRI – Plano Nacional de Prevenção de Resíduos Industriais. Lisboa: INETI
- [8] EC (2008) The EU Waste Directive 2008/98/EC, Nov. 19.