Analysis of the contribution of information management for the implementation of pollution prevention measures into process industries
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Analysis of the contribution of information management for the implementation of pollution prevention measures into process industries

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Abstract

Successful and widespread implementation of existing methodologies for waste minimisation has failed to provide significant benefits for industrial applications because there is not a comprehensive approach that integrates and guides the application of the proper tool depending on the case. Each of these methodologies has been developed for particular stages in the process life cycle and they require different information which may not be available and could result too costly to obtain. The aim of this work is to present the theoretical framework of a tool which integrates these methodologies and provides criteria to select the appropriate structure for the case at hand. The tool explored for this effect is an ontology-based approach for the structured organisation of information aiming to identify significant waste minimisation opportunities.

Keywords: Waste minimisation, information, knowledge, ontology

1. Introduction

Waste generation within a process has to be analysed from the different aspects that cause it. This involves not only the manufacturing process but also other stages of the product lifecycle such as raw material storage and preparation, product distribution and in general, the logistics of the overall supply chain. The modelling of the entire life cycle of the process through the understanding of all the tasks it entails represents an effective way for grouping the necessary information to describe the crucial parts of a process. Mapping and organising this knowledge provides an effective means of reducing losses due to gaps in the understanding of the process and of the signs that point towards waste generation; this translates in an accurate way to identify the areas which need attention for the purpose of pollution prevention and the activities that have to be modified to implement it.

2. Waste minimisation methodologies

Waste minimisation can be defined as: "The reduction or elimination of the generation of waste at source through the efficient use of raw materials, energy and water" (Envirowise 1998) As with any engineering challenge, waste minimisation presents several obstacles for an industry. Waste management costs are higher than many companies realise, however strong resistance against waste minimisation plans or even ignorance about the topic is still found to a great extent (Day 2004). The reasons for this have generally to do with manpower, knowledge, economics, time and technology resources managed in an inadequate way.

An initial summary of the available methodologies shows the important role of information about quantities and causes of waste in the whole process of waste minimisation.

The various methodologies differ in their scope of application. Some are applied for the design or retrofit of the process (understood as the physicochemical transformation). Others consider additional tasks around the core transformation process such as cleaning, storing and transferring of material and even managerial tasks such as customer service. Some methodologies are focused on measuring the environmental/social impacts derived from the transformation.

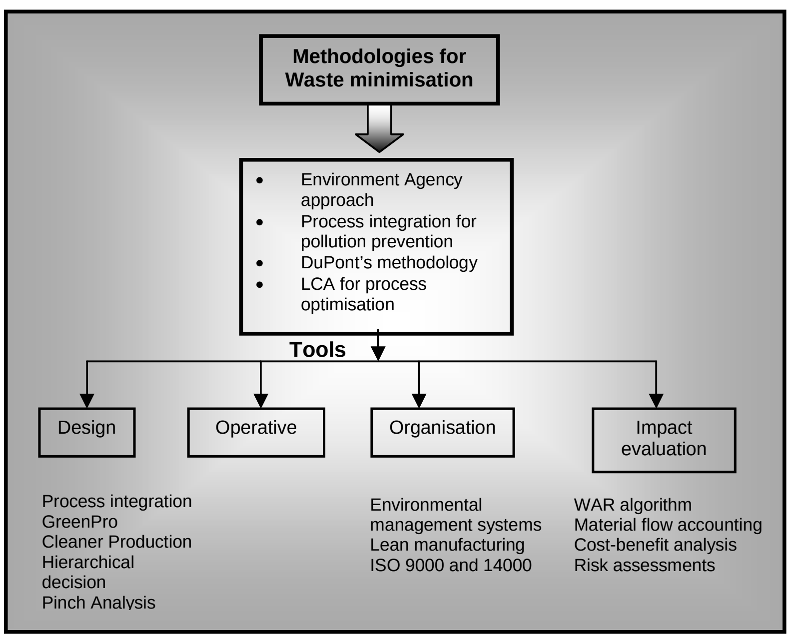

Figure 1. Methodologies for waste minimisation and the tools available for their application

Figure 1 presents an overview of different methodologies available in literature (Douglas 1992; El-Hawagi 1997; Envirowise 1998; Azapagic and Clift 1999; Mulholland 2001; USEPA 2003) and shows a summary of the most important waste minimisation methodologies and tools for their implementation.

Just differing in the consideration of certain steps, these four methodologies consider specific tools shown in the third level of the figure to complete the waste minimisation study. In order to select of any of the existing tools it is important to understand their goals and field of applicability. The applicability of the methodologies presented has been classified and summarised in Table 1 which provides guidance on which waste minimisation tool or methodology can be used in a specific stage within the pollution prevention plan. The methodologies presented may sometimes be insufficient for a specific industry or process with characteristics different to the standard; this is the reason for the present analysis.

Table 1. Tools and methodologies applicable for waste minimisation plans

Stage in waste minimisation plan	**Technical tools or methodologies for development of the step**	**Feature for its applicability**
Assessment	P-graph, Digraphs	Identification of relationships between streams, operations and tasks
Commitment of management	Cost benefit analysis	Identification of project tradeoffs
Data collection	Process flow diagrams	Map of material flows through the process
	Process integration	The analysis stage in this methodology allows identification of the constituent elements of the whole process
	ISO 9000	Identification of the requirements of information for efficient performance of the process
Analysis of the true cost of waste	DuPont's methodology	Consideration of part of the wastes obtained as saleable products
	P-graph	Identification of useful and useless products
Prioritisation	Onion diagram, waste reduction algorithm	Weighing of different issues in process waste minimisation to determine in which order they have to be tackled
Generation of options for improvement	DuPont's methodology	Complete understanding of the process to eliminate or reduce sources of waste
	Hierarchical decision	Clear and organised list of different factors related to the process and their relationships
Opportunity assessment and feasibility analysis	Optimum application of LCA	Generation of optimisation models taking into account economic and environmental criteria
	Process integration	Evaluation to understand if design objectives are met along with the optimal solution for the problem
	Hierarchical decision	Evaluation of alternatives from the relationships identified in previous stages
Project implementation	Optimum application of LCA ISO 9000	Identification of areas in which action has to be taken and procedures for taking action

The applicability of waste minimisation methodologies is limited by the availability of the required information. Existing methodologies rely on the existence of detailed process information. The barriers found in the implementation of these methodologies are hence related to difficulties in the collection of the required information. This situation forces the application of the methodologies to use inaccurate, uncertain or incomplete information. It has been recognised that the selection of appropriate measures for environmental performance of a process involves an understanding of the nature of environmental concerns, the kind of information available and its accuracy (Sharratt 1999).

Knowledge found in systems with several different variables and dimensions such as waste minimisation has been usually dealt with only by the use of keywords. To manage this kind of information in an effective way adequate descriptions of content and capabilities of knowledge resources are needed. This means proper descriptions of the syntax and semantics of the data being managed (W3C 2004), which can be achieved by employing ontologies.

The term ontology is an adaptation from philosophy and refers to the science of describing the kinds of entities in the world and how they are related (Smith 2003). In the field of information management it has been described as "formal specifications of the terms in a domain and the relations amongst them" (Gruber 1995). Ontologies are used to enable communication between different subjects interested in a same topic.

3. Theoretical framework for a new waste minimisation tool

The proposed approach starts with the definition of the environmental requirements or benefits of a plan for waste minimisation. It then follows taking into account that effective gathering, representation and modelling of information from all the staff levels within the process is essential to ensure integration and success of the different waste minimisation actions. The methodology divides knowledge about a process into five main classes which contribute in different levels to the successful application of waste minimisation tools.

Process information and knowledge is divided into five classes shown in Figure 2:

- *Crucial* information is the one responsible for the initial description of the process.
- *Prior* information refers to the information obtained previously about objects, actors and actions needed to perform a task.
- *Subordinate or secondary* information is the one that does not define the process but without which, the performance might be unsatisfactory or unsuccessful.
- *Contextual* information refers to the contribution of any situation affecting the perception of the actors or performance of the objects, such as psychological or environmental restrictions.
- *Causal* information is identified in the form of relationships between objects and variables.

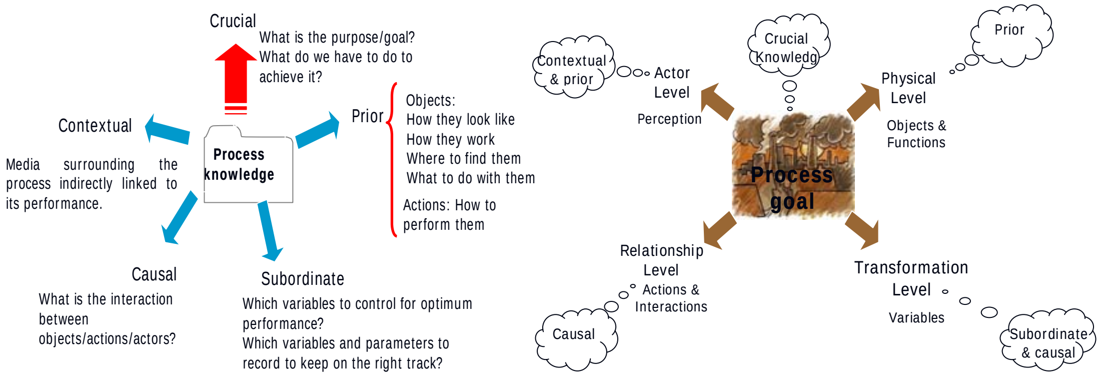

Figure 2. Five classes of process knowledge and their interaction with the process goal.

The different categories of information and knowledge are considered as components of one knowledge block; which, by interaction with several others along the process results in a network of knowledge that can be then analysed through its different parts.

Thus the whole process is analysed parting from a general approach such as the one given in Figure 3(Cano-Ruiz and McRae 1998), exploring any crucial information that dictates the overall objective of the process and the different tasks and subtasks that have to be performed to achieve it. After that any subordinate, previous and causal information is defined. This leads to the identification of the subsequent sub processes which involve routines and steps in a similar way as a functional decomposition (Kitamura and Riichiro 2004; Halim and Srinivasan 2006)

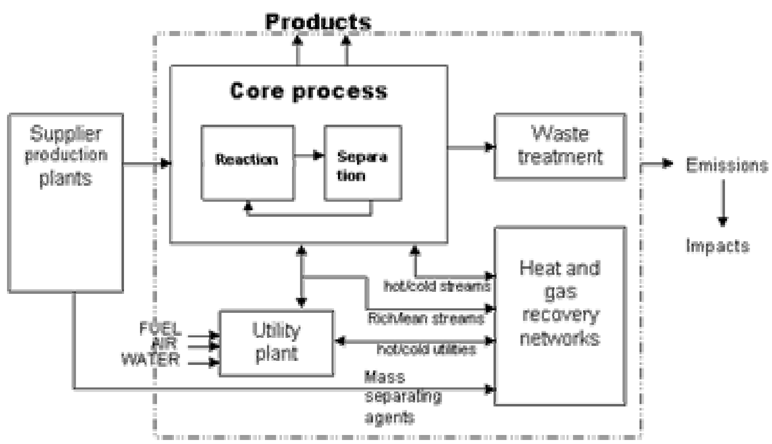

Figure 3. General overview of a process.

Transferring the analysis done to a more complex process, different levels of information and knowledge needed can be identified as well as the interactions between each of the objects, actors and activities involved in the whole process as shown in Figure 4.

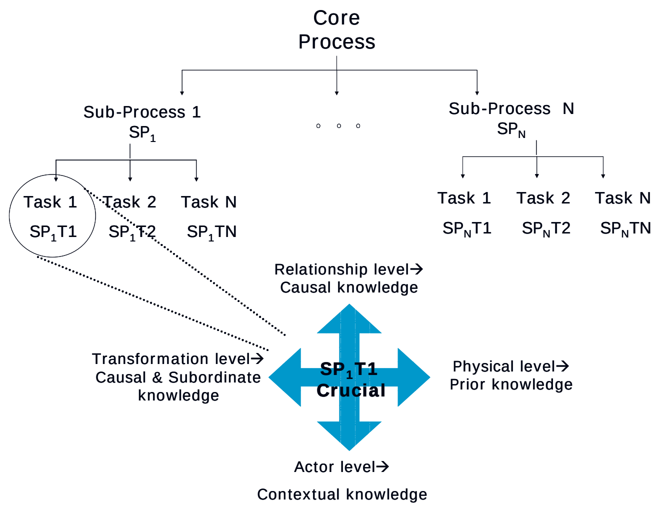

Figure 4. Task separation and analysis of knowledge contribution.

The next part of the methodology is based on the link between ontology development and functional knowledge modelling explored by Kitamura which helps to provide structure to the concepts of existence and contribution into a system of devices and components (Kitamura and Riichiro 2004). According to the latter it is concluded that ontologies coupled with the description of existing functions are able to provide the information necessary to describe a system. After the description, all information relevant for its correct performance is detected and leads to the identification of all crucial information which must be managed in order to control the performance of the system.

4. Construction of an ontology for waste minimisation

The proposed methodology follows the structure shown in Figure 5. It aims to provide answers to questions such as which are the environmental requirements not being complied, what kind of information is needed to describe the non-compliance, how is this information obtained, what kinds of waste minimisation options are available and which resources are needed to implement them.

The approach developed considers the construction of an ontology that addresses simultaneously four key aspects shown in Figure 6: the matters that define *environmental compliance* for the case under study; a *description of the process* including the different objects and activities that have to be performed to achieve the specific goal of the process; the *resources* available for the company; and the specific steps to be followed for *waste minimisation* plans.

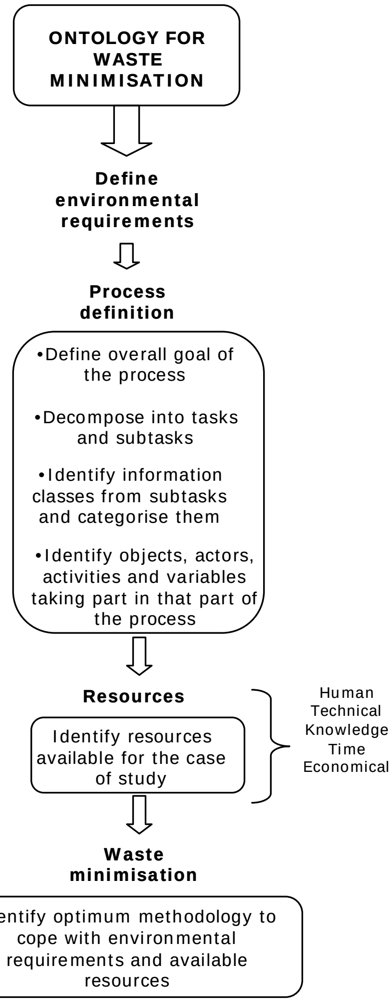

Figure 5. Structure of the waste minimisation ontology

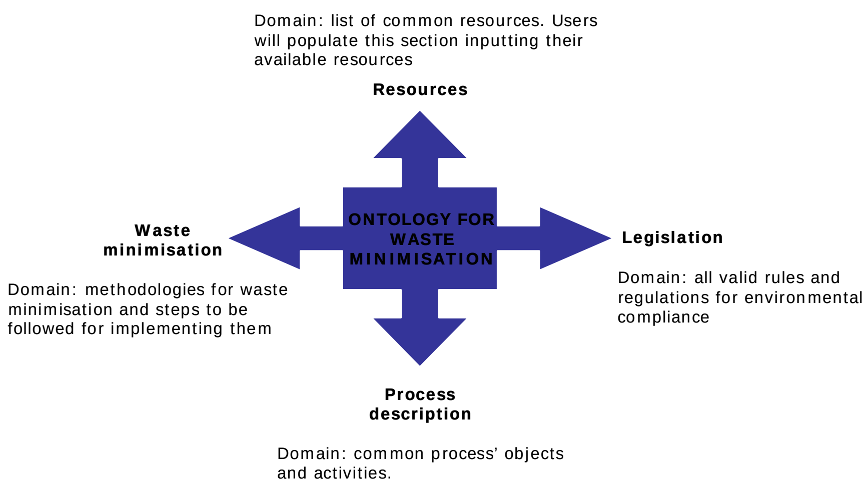

Figure 6. Key aspects for the ontology for waste minimisation and their domains

Environmental compliance

To obtain awareness of an industry's environmental load it is needed first to understand its environmental requirements. The presented approach includes a part of the ontology in which all the knowledge needed about environmental rules, regulations and requirements is embedded.

Description of the process

As discussed previously methodologies for waste minimisation often rely on the availability and accuracy of information about the process. However, this information might not be linked between different sources. Knowledge about an isolated part of the process might be in an abstract format which is not compatible with other information sources.

A proper ordering of relevant process information has been presented by Morbach et al (2007) in the form of an ontology called OntoCAPE. It is constructed for the domain of chemical process engineering and includes design, construction and operations. The ontology is composed of three types of structural elements: layers, modules and partial models (Yang et al. 2001). Embedded within these elements are the chemical process system and materials modules.

A fraction of the OntoCAPE ontology is reused as a platform for the process description phase (Gruber 1995; Noy and McGuinness 2001; Gómez-Pérez et al. 2004). As the approach tries to tackle the difficulty of interpreting complex information to solve practical problems, the only modules considered from the previously mentioned ontology are the ones that include objects, variables or activities dealing directly with the process which are the ones responsible for everyday decision making. The focus is on the information requirements for the process, the physical plant, the materials occupied and the costs involved.

Once the available process knowledge has been organised within an ontology-based framework, the information categories are compared with the resources needed and available for the adequate analysis that generates options for the optimal performance of the actual process being studied.

Available resources

As with any engineering challenge, waste minimisation presents several obstacles for an industry. Economic resources are amongst the bigger problems perceived when trying to implement waste minimisation, not only referring to the lack of budget for getting state of the art equipment that can cope with the task but also in the form of less resources to put into employees training and education on how to minimise waste. Focus on short term economical survival can be determining for small and medium enterprises which do not have the infrastructure or the resources to plan in a bigger scale neither to add environmental issues directly to their agenda.

A company's attitude represents a major issue to address when trying to implement waste minimisation; many of the methodologies involve commitment from people in high management levels for this matter. These people, mostly involved in managerial activities, might only be convinced with plans that represent major economical benefits for the company in a short period of time. Other concern is the presence of a reactive attitude towards environmental issues this refers to the implementation of new waste minimisation technologies only when the company is required by external organisations and not as part of an improvement plan.

Availability of technology plays a major role for the implementation of waste minimisation plans. Lack of economically feasible equipment for this effect makes the company to decide for less expensive and more polluting equipment. Time scales will present problems for pollution prevention implementation. Projects may take longer than expected and therefore be regarded as losses in productivity.

Available knowledge and information can restrict or limit what can be done for environmental protection in a company. The organisation might not know their pollution load in order to determine whether it is significant and able to address the environmental problem in a more specialised way.

The proposed approach links all resources available with the different information levels they are connected with. In this way, all actors, objects and activities within a knowledge block are identified as shown in Figure 7. The next step is to couple these available resources with the relationships already structured in the previous steps.

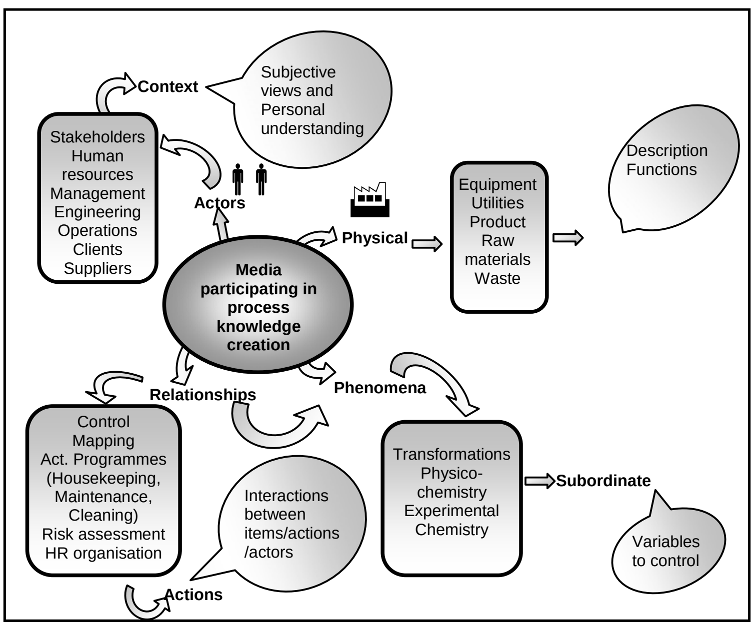

Figure 7. Actors, objects and activities within a knowledge block

Waste minimisation

Finally, the waste minimisation methodologies studied previously are organised in a section of the ontology which provides a step-by-step guidance about each of them. A format similar to the guidelines approach proposed by Venkatasubramanian et al (2006) has been followed to some extent in order to provide a structured overview of the guidelines to follow. These are translated in specific knowledge to guide decision making for structuring waste minimisation plans tailored for the specific company under study.

Conclusions

The methodology presented in this paper provides tools to identify and manage key required information to analyse specific processes and derive waste minimisation strategies based on the application of the adequate methodology according to the information requirements. Effective organisation of available information and knowledge is the key for the proper application of waste minimisation methodologies.

The role of informatics for decision making has quickly increased its participation in several aspects of industrial life. The methodology presented uses ontologies to model the information in order to analyse and manage information from various sources. The methodology will provide a more adequate evaluation of the completeness and accuracy of existing information and generate unambiguous waste minimisation options which adapt to specific situations for a given process.

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