

A SURVEY OF TOOLS BEING USED FOR ENVIRONMENTAL MANAGEMENT IN THE PROCESS INDUSTRIES

P.N. Sharratt* and M.S. Ohba+
Environmental Technology Centre, Department of Chemical Engineering, UMIST
+Currently at CETESB, São Paulo, Brazil

Process operating companies increasingly use a range of formal tools and techniques to manage the environmental impacts of their processes. This paper reports a survey of the UK process industries to identify the tools being used. The links between the type of tools used and the nature of the materials handled is examined. This and other reasons underlying the selection of tools are discussed. The choice of tool appears to be related to a number of factors – company size and resource, the nature of the materials processed and the risk of releases to the environment all being important.

Keywords: environmental management; survey; process industry

INTRODUCTION

In the implementation of more thorough and systematic approaches to environmental management, industry is increasingly adopting formal tools and systems to analyse its potential and actual environmental impacts. A great variety of techniques is employed ranging from simple measures of performance to complex environmental management systems. While this is clearly a very important area, little research has been carried out on the reasons for selection and application of the various tools. This paper addresses that issue, and in particular the question what tools are currently being used by the process industry? This may give guidance as to the criteria should be adopted for the selection of appropriate tools to analyse environmental performance.

The question needs to be addressed by investigating current industrial practice. As part of the study reported in this paper, an extensive survey of the UK process industry was carried out with the aim of identifying both the environmental management problems facing industry and the techniques adopted to deal with them. The second question can be answered by comparing the main features of the tools (particularly their inputs and outputs) with the nature of the problems faced by process companies. Clearly, only techniques that produce meaningful and relevant results should be chosen. The available resource and quality of input data are also likely to be important factors in selection.

Many tools and techniques for process industry environmental management have their origins in other areas – safety management, quality systems and environmental assessment for example. Process safety tools developed in the chemical process and nuclear industries have widely been adopted. They are mainly useful for the identification of potential abnormal occurrences and management of the associated risks. Management system standards such as BS5750 and ISO 9001 have long been used as models for documented, controlled systems for manufacturing (and other) industry. Analytical quality management tools have been developed to aid in problem solving – typically the identification of the root cause of problems. Environmental assessment has provided its share of relevant techniques – the life cycle concept for example.

Some of the more popular and important tools are listed in Table 1. Detailed description of the tools is not provided; this is available in the references given.

Table 1 Environmental Management Systems, Tools and Techniques

Method	Abbreviation	Description
Environmental Load Factor[1]	ELF	Screening tool based on waste per unit product
Waste Ratio[2]	WR	Screening tool based on waste per unit product
Modified Weight Measure[3]	MWM	Waste per unit product modified by waste hazard factor
Environment Agency's methodology for BPEO Assessment[4]	BPEO	Suite of tools, concentrating on the contribution of a process to environmental concentrations
Life Cycle Analysis[5]	LCA	Assessment of the resource requirements and impacts of a product throughout its life cycle
BS7750[6]	BS7750	Standard for an Environmental Management System
ISO14001[7]	ISO14001	Standard for an Environmental Management System
EMAS[8]	EMAS	Standard for an Environmental Management System
Activity and Process Flowchart[9,10]	APF	Tool to analyse systems looking for root causes of problems
Checksheets[9,10]	Checksheets	Tool to link occurrence of event with timing or circumstances
Pareto Chart[9,10]	Pareto Chart	Tool to focus effort on most important problems
Cause and Effect Diagram[9,10]	Cause/Effect	Also called Ishikawa or Fish diagram – used to search for root causes
Data Display and Frequency Distribution [9,10]	DDFD	Data representation tool
Scatter Diagram[9,10]	Scatter Diag	Tool to search for patterns in the relationship between variables
Process Control Techniques[9,10]	PCT	Methods of Statistical Process Control
Concept Hazard Analysis	CHA	Hazard assessment tool for use early in process design
Preliminary Process Hazard Analysis	PPHA	Hazard assessment tool for use early in process design
Critical Examination of System Safety	CESS	Safety assessment tool for systems
Hazard and Operability Study	HAZOP	Identification of potential abnormal events by structured brainstorming
Quantitative Risk Assessment	QRA	Quantification of the likelihood of specific abnormal events or outcomes
Failure Mode Effect Analysis	FMEA	Identification of potential abnormal events by consideration of equipment failure modes
	Task Analysis	Safety assessment of tasks
Heat Integration using Pinch Technology	Pinch method	Formal method to search for thermally efficient process options

SURVEY METHOD

A postal questionnaire survey was chosen for data collection ahead of other techniques such as site interviews, telephone interviews or case study work. Questionnaires can reach a large number of companies at reasonable cost. This would not have been feasible with interviews, for example. Questionnaires have produced good results in similar studies, for example Dale[11] used them in a series of investigations of the implementation of Total Quality Management (TQM). The type of question posed by Dale was similar in style to the present work.

A problem of postal questionnaires is the low response rate. Other similar types of study have been reported with typical response rates in the range 10-20%. A questionnaire about methods and systems of quality management, and views on TQM[12] had a response rate of 17%. A survey made by Green *et al* [13] of how UK companies had been innovating technologically in response to environmental pressures had a 20% response. Low response rates can be expected for broad, general questionnaires and questionnaires sent to a wide range of industries (rather than within a single trade organisation). Surveys on a single technique often give a higher different response, for example a study of the use of Quality Circles in UK[14] had a response rate of 75%; and a study of the use Failure Mode and Effect Analysis[15], obtained a 55.6% response.

The questionnaire comprised 18 separate questions. It was divided into four sections: general information about the company; the operations within the process or manufacturing site; the methods and tools used by the company; and internal programmes and organisation's initiatives related to pollution prevention, waste minimisation, and waste recycling. Space for general comments was also provided. The tools being considered by the survey were listed, so that the respondent could indicate which were used to aid environmental management. Additional space was provided to add further tools not mentioned on the questionnaire. A similar approach was adopted for the identification of the nature of the materials processed and wastes generated.

The majority of company names and the addresses were obtained from a commercial database[16]. This also provided general information about the companies, such as country origin, parent company, statement date, sales and profit, location, trade style and brand names, and details about their line of business. A small number of companies (20 companies) were taken from a list of participants of some graduate courses run at UMIST. For each of the companies, the questionnaires were directed to environmental/ health/ safety groups or departments. Named individuals were possible only within the short list of 20 companies.

Selection of companies from the database took account of two criteria: the line of business, and the number of employees. An approximate proportionality was maintained between the total number of companies listed in the database belonging to a particular industry sector and the number of companies selected from that sector. A balance was also maintained between large companies and small medium-sized enterprises (SMEs). SMEs were defined as having fewer than 250 employees (IEE, 1993). This criterion was preferred to the yearly turnover. Within the SMEs, micro-enterprises (up to 9 employees) were not surveyed. Table 2 summarises the business sectors included in the survey, with the respective percentage of companies in each category.

The selection process was not intended to constitute a rigorous statistical sample from the totality of UK enterprises, which would demand much more extensive work. The results generated can not necessarily be considered statistically representative of whole population of enterprises based in UK. However, statistical analyses were performed on variations within the sample.

The questionnaire survey was conducted over the period April to June 1997. In total, 565 questionnaires were sent by post. Accompanying the questionnaire a letter was sent explaining the purpose of the survey, and suggesting a deadline for answering. Also, it promised that general findings would be sent to the companies that responded. The first batch of 300 questionnaires was sent in early April 1997, and a further 265 were sent in May 1997. Only five questionnaires were returned undelivered, and these were not considered in the analysis. All the responses received were catalogued and identified by a “Identity Number”, which allowed treatment of the respondent’s information on an anonymous and confidential basis

Table 2 Business Sectors Surveyed and Response Rates

Business Grouping	Business Sector	Number of companies surveyed	Number of respondents	Response rate (%)
Chemical	Chemical process	82	25	30.5
Chemical	Fertiliser, pesticides	8	1	12.5
Chemical	Petrochemical process	12	3	25.0
Chemical	Pharmaceutical process	27	7	25.9
Food, Cosmetic, Paper	Cosmetic industry	18	2	11.1
Food, Cosmetic, Paper	Food and beverage	34	2	5.9
Food, Cosmetic, Paper	Paper industry	32	6	18.8
Manufacture	Car manufacturer	17	2	11.8
Manufacture	Electric and electronic	45	6	13.3
Manufacture	Leather industry	13	1	7.7
Manufacture	Machine manufacturer	29	1	3.4
Manufacture	Textile industry	24	1	4.2
Metals	Foundry (iron, steel)	14	4	28.6
Metals	Galvanising	18	1	5.6
Metals	Non- ferrous	41	5	12.2
Pack/mix/blend	Bulk storage, mix-blend	13	4	30.8
Pack/mix/blend	Packing	28	3	10.7
Primary	Cement industry	9	0	0.0
Primary	Mining	21	3	14.3
Primary	Power supplier	22	2	9.1
Service	Civil engineering	23	4	17.4
Service	Waste recycle/ treatment/ disposal	30	6	20.0
	Total	560	89	15.9

RESULTS AND DATA ANALYSIS

Where possible and useful, statistical analysis of the data was carried out using either the statistical software SPSS (Version 6.1.3 for Windows) or a spreadsheet (Excel97). Despite the reasonable size of the sample it was difficult to draw a large number statistically significant conclusions. Furthermore, it must be borne in mind that the respondents may not constitute a truly random sample. Not only were they chosen from a selected subset of companies, but also the respondents may not be representative (perhaps being those more interested in the environment or with more time available to complete questionnaires).

ANALYSIS OF THE RESPONSE

From the 560 delivered questionnaires a response rate of about 17% (97 questionnaires) was obtained. This is considered a good result for postal questionnaires, and it is comparable with other published studies. Not only were the questions diverse, but also the survey was not on behalf of an official body or trade organisation, so a high response would not be expected. The response rate does indicate a significant interest in environmental matters in the UK process industries. Some respondents did not complete the questionnaire but either sent generic corporate information, or apologised for being unable to respond. The remaining "valid" response is broken down by business sector in Table 2.

Differences between response rates from the various business sectors were analysed statistically. The null hypothesis was that the responses were random and independent of the business sector, so the variation could be accounted for by chance. Under this assumption, the number of responses would be expected to follow a binomial distribution. At the 95% significance level machine manufacturing had a lower that average response rate (3.4% against an average valid response rate of 15.9%). Other sectors gave low responses, notably food, textiles, leather, galvanising and cement, but the samples are too small to be significant. The chemicals sector had a significantly higher than average response rate (30.5%), as did the grouping of chemical process industries when taken together (pharmaceuticals, petrochemicals, agrochemicals and chemicals) with an average response of 27.9%. These results would be consistent with the view that the chemicals sector leads the process industries in concern about environmental matters.

ANALYSIS OF THE TOOLS USED BY BUSINESS SECTOR

In order to manage the very large dataset and to draw conclusions about the patterns of tool use by the business sectors they were grouped into six "business groupings". The allocation was based on similarities in products and/or processes and is summarised in Table 2. The tools used by the respondents in each of the business groupings are given in Table 3.

Statistical analysis of the results is complicated because the underlying distribution of number of tools used is not known. As a null hypothesis the distribution of use of each tool was assumed to be random, with a probability of use equal to the observed number of uses divided by the total number of companies. Thus, for example, the probability of use of HAZOP by any company was taken to be 31/89 = 0.35. By this means the number instances of tool use observed in a grouping could be compared with the expected number for the number of companies. Again, the distribution assumed was binomial.

Overall the chemicals grouping used significantly more tools per company that the average, while the manufacturing sector used fewer. Other sectors were not significantly different from the mean. For individual tools there was significantly more (95% confidence) use of Scatter Diagrams, Preliminary Process Hazard Analysis, Concept Hazard Analysis, Critical Evaluation of Safety Systems, Task Analysis, HAZOP and FMEA by the chemicals sector. This probably reflects the safety management background of companies and respondents.

While the use of analytical tools is greatest in the chemicals group, the takeup of environmental management standards (EMAS, BS7750[a] and ISO14001) is widespread, with 41 of the respondents using one of BS7750 or ISO14001. Checksheets were also reported across all business groupings. The use of the Environment Agency's BPEO methodology by 15 companies is interesting – takeup of the method is significant despite industry resistance to the concept.

ANALYSIS OF THE TOOLS USED VERSUS THE HAZARD OF MATERIALS HANDLED

As part of the survey a link was sought between degree of hazard involved in operations and the tools used to assess environmental impacts. The questionnaire replies identified the types of substances handled, processed, or produced, by the companies surveyed. This information was correlated with the use of specific methods or tools.

In order to simplify analysis and try to produce statistically significant results it was necessary to group the materials present in operations into various (arbitrary) levels of hazard. New variables (HAZ1 to HAZ5) were defined, crudely representing the level of hazard posed by the materials. The ranking system was as follows.

- HAZ1: <u>either</u> radioactive material <u>or</u> {any of (aromatic compounds, organic halogenated compounds, pesticides, asbestos) <u>together with</u> heavy metals}.
- HAZ2: no radioactive material and no heavy metals, but with any of (aromatic compounds, organic halogenated compounds, pesticides, asbestos).
- HAZ3: no radioactive material and none of (aromatic compounds, organic halogenated compounds, pesticides, asbestos), but with heavy metals.
- HAZ4: no radioactive material, aromatic compounds, organic halogenated compounds, pesticides, asbestos or heavy metals but <u>with</u> {volatile organic compounds, mineral oils and hydrocarbons (HCs)} <u>as well as</u> (inorganic salts, acids and base, ceramics, minerals, biological, and other low-hazard substances}.
- HAZ5: inorganic salts, acids and base, ceramics, minerals, biological, as well as non-hazardous substances.

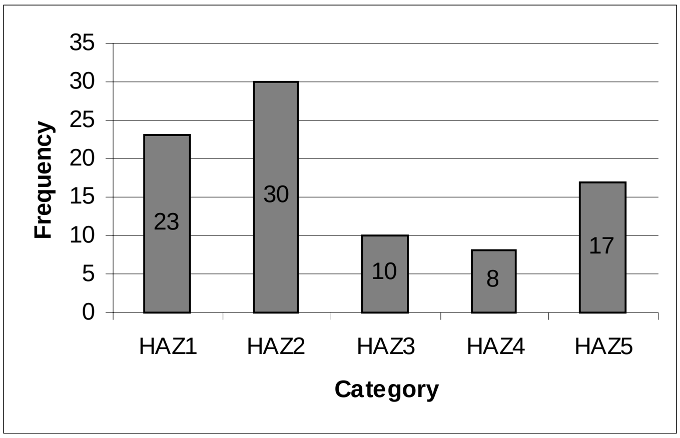
The new groups above rank the companies broadly by the type and degree of hazard, with the highest degree of hazard as HAZ1 to the lowest HAZ5. The two intermediate groups HAZ2 and HAZ3 can be thought of having a similar degree of hazard, but with differences between the nature of the substances. Each company was allocated to only one of the categories based on materials handled. The numbers falling into the groups are illustrated in Figure 1.

[a] BS7750 has ceased to be used since completion of the survey.

Table 3 Tools and Techniques used by Business Grouping

Methods and tools	Chemical	Manufacture	Food, Cosmetic, Paper	Metals	Primary	Service	Pack/Mix/ Blend	Total
ELF	6	-	1	-	-	-	1	**8**
WR	5	-	-	1	-	-	1	**7**
MWM	1	-	-	-	-	-	-	**1**
BPEO	10	1	1	1	1	1	-	**15**
LCA	7	1	2	1	1	-	-	**12**
BS7750	11	2	-	-	3	4	1	**21**
ISO14001	15	4	5	2	3	2	2	**33**
EMAS	5	1	1	1	1	1	-	**10**
APF	9	2	2	1	1	4	2	**21**
Checksheets	14	1	5	1	2	5	2	**30**
Pareto Chart	9	1	1	1	-	1	1	**14**
Cause/Effect	7	1	2	-	-	-	1	**11**
DDFD	7	2	1	-	1	1	1	**13**
Scatter Diag	8	-	1	-	-	1	-	**10**
PCT	17	5	2	1	3	1	2	**31**
CHA	8	-	-	-	-	1	-	**9**
PPHA	10	-	-	-	2	-	-	**12**
CESS	6	-	-	-	-	-	-	**6**
HAZOP	23	2	2	-	1	2	1	**31**
QRA	12	3	2	-	-	1	1	**19**
FMEA	11	1	-	-	1	-	1	**14**
Task Analysis	12	2	1	-	-	1	1	**17**
Pinch method	4	-	-	-	-	-	-	**4**
Other methods	7	2	2	1	-	2	-	**14**
Total number of tools	**224**	**31**	**31**	**11**	**20**	**28**	**18**	**363**
Total number of companies	**36**	**16**	**10**	**5**	**5**	**10**	**7**	**89**
Average	**6.2**	**1.9**	**3.1**	**2.2**	**4**	**2.8**	**2.6**	**4.1**

Figure 1 Distribution of Companies Surveyed by Hazard of Materials Processed.



The methods and tools used by the companies were correlated with this distribution of ranked groups and the results are shown in Table 4. Note that the total number is 88 companies because one company did not answer this specific question.

Table 4 Frequency of use of Tools According to Materials Hazard

Methods and tools	HAZ1	HAZ2	HAZ3	HAZ4	HAZ5
ELF	3	4	0	0	1
WR	2	3	1	0	1
MWM	0	1	0	0	0
BPEO	7	5	1	2	0
LCA	2	5	1	2	1
BS7750	5	10	1	2	3
ISO14001	7	14	4	3	5
EMAS	2	2	1	2	2
APF	5	10	1	1	4
Checksheets	5	14	1	4	6
Pareto Chart	2	7	2	2	1
Cause and Effect	0	7	1	1	2
DDFD	3	6	1	1	2
Scatter Diagram	4	5	0	1	0
PCT	7	14	3	3	5
CHA	2	5	0	2	0
PPHA	3	6	0	2	1
CESS	1	3	0	2	0
HAZOP	10	14	1	4	2
QRA	4	8	1	3	3
FMEA	5	6	0	2	1
Task Analysis	4	8	1	2	1
Pinch method	0	4	0	0	0
Other methods	8	2	1	1	2
Total number of tools	91	163	22	42	43
Total number of companies	23	30	10	8	17
Average per company	4.0	5.4	2.2	5.3	2.5

The overall number of methods and tools used, as well as the average number of methods used per company is higher among the groups HAZ1, HAZ2, and HAZ4, compared to groups HAZ3 and HAZ5. None of the companies from HAZ5 use the BPEO method and particular methods from quality and safety management systems such as Scatter Diagram, CHA and CESS; and only a low percentage of them use LCA, HAZOP, and FMEA.

Within the HAZ3 group, some methods from the quality and safety management systems are not used at all; and some of the important and more frequently used methods, such as the BPEO method, LCA, HAZOP, and FMEA, only appear infrequently. It is reasonable to expect such behaviour from the fifth group. However, the third group has some potentially harmful substances and materials. Some techniques from the quality management systems are used, such as PCT and Pareto Charts, and the EMS standard ISO 14001. However, the general pattern is a limited use of methods and tools, compared to the HAZ4 group. That group, even having a low number of companies (8), employs a high number of methods and tools. The average is more than twice that in HAZ3.

The first group (HAZ1), that represent the companies with the highest degree of hazard in their operations use methods like BPEO, HAZOP, and all the tools from the safety management systems. Many of the techniques from the quality management systems are also well used. EMS standards are used as frequently as in other groups.

The pattern observed in HAZ1 has similarities in the HAZ2 and HAZ4 groups, except regarding the BPEO method, LCA, and the environmental performance indices. All the safety tools had high degrees of use within these three groups, perhaps related to the presence of volatile compounds and organic compounds in general. HAZOP for instance, is widely used within all three groups (almost 50% of the companies). Some other particular methods from safety management systems have a lower percentage within HAZ1 compared to the other two groups, possibly influenced by the service company which did not identify any methods.

DISCUSSION AND CONCLUSIONS

As with all questionnaires of this type it is dangerous to draw conclusions as to the mechanisms by which the results occur – to investigate the reasons for selection would require further work. Nevertheless, some conclusions can be drawn and interesting results highlighted. The results of indicate that a very wide range of assessment and management tools is used by the process industries. There is evidence that the use of tools is not uniform. The chemicals sector uses more and a greater range of tools than other sectors. The manufacturing and metals industries use fewer.

There is some link between the degree of hazard of materials handled and the tools selected, though the metals industry, for example, which handles some particularly dangerous materials, uses few tools. While it would be easy to suggest that this is because the sector is relatively backward, this may be unfair. The limited use of tools may also reflect the lack of likelihood of release compared with chemicals production, or the restricted range of events that can lead to accidental releases. The chemicals sector uses volatile and flammable materials may give greater risk or number of possible events that could lead to catastrophic loss of containment through fire and explosion.

While few statistically significant conclusions can be drawn it is interesting to note the apparently rational basis for tool selection. The results suggest that the criteria that tend to be used for tool selection include

- Degree of hazard of the materials handled;
- Likelihood of escape of the materials handled through accidents.

Nevertheless, the great range of tools used suggests that the mechanisms for tool selection may involve chance, company culture and history as well.

The widespread use of quality-based tools is worthy of comment. These are often most useful for the identification and analysis of operating problems and undesired events that have not been foreseen during design. This may indicate that the environmental performance of many companies is not under complete operational control.

The good response, particularly from the chemicals and related sectors indicates clearly significant interest in environmental matters. This interest appears not yet to have spread to the food and manufacturing sector, for example.

ACKNOWLEDGEMENTS

The British Council is thanked for its support of Ms Ohba. The students of the IPM Masters programme at UMIST are thanked for their helpful comments and discussions.

REFERENCES

1. Perriman, R.,1995, Environmental Management – An example from the fine chemicals sector, *from Sharratt PN (Ed) Environmental Management Systems, IChemE, Rugby*

2. Benforado, D.M., Ridlehoover, G., and Gores, M.D., 1991, Pollution Prevention: One firm's experience, *Chemical Engineering*, Sept, 1991.
3. Rhone-Poulenc, 1993, From *Wastewater Management for Industry*. IBC Conference, Manchester, UK
4. HMIP (1996) Environmental, Economic and BPEO Assessment Principles for Integrated Pollution Control, E1, Her Majesty's Inspectorate of Pollution, HMSO
5. US EPA (1993). *Life-Cycle Assessment: Inventory Guidelines and Principles* (EPA/600/R92/245), by Batelle and Franklin Associates, Ltd. for the Risk Reduction Engineering Laboratory, Office of Research and Development, Cincinnati, OH, USA.
6. BSI (1994) *British Standard 7750: Specification for Environmental Management Systems.* British Standards Institute, London, UK.
7. Hortensius and Barthel, 1997, Beyond 14001- an Introduction to the ISO 14000 Series. In *ISO 14001 and Beyond*, Sheldon, C. (Ed.), Greenleaf Publishing, Sheffield, UK, 19-28.
8. EC, 1993, Council Regulation Allowing Voluntary Participation by Companies in the Industrial Sector in a Community Eco-Management and Audit Scheme, EEC no. 183/93. *Official Journal of the European Communities, No. L168/1, July 93.*
9. Juran, J.M., 1988, Juran's Quality Control Handbook, 4th Edn., McGraw-Hill, New York
10. Ishikawa, K., 1982, Guide to Quality Control, Unipub, Asian Productivity Organisation, Tokyo
11. Dale, B. D., 1997, Methods Used to Research Total Quality Management: a Critique. *Research in Practice - Operations Management. Manchester School of Management, UMIST, Manchester, UK.*
12. Lascelles, D.M. and Dale, B.G., 1988, A Study of Chief Executives: Awareness, Attitudes and Methods of Quality Management, *A Report to the DTI*, Manchester School of Management, UMIST.
13. Green, K., McMeekin, A. and Irwin, A., 1994, Technological Trajectories and R&D for Environmental Innovation in UK Firms, *Futures*, vol. 26, no. 10, pp1047-1059.
14. Dale, B. D., and Ball T., 1983, A Study of Quality Circles in UK Manufacturing Organisations, *Occasional Paper 8306*, Manchester School of Management, UMIST, UK.
15. Dale, B.G. and Shaw, P., 1989, Failure Mode and Effects Analysis: A Study of its Use in the Motor Industry, *Occasional Paper 8904*, Manchester School of Management, UMIST, UK.
16. Dun & Bradstreet, 1997, Key British Enterprises Database, *CD Answer Retrieval Software*, Dataware Technology, Inc.