ELSEVIER

Journal of Cleaner Production 9 (2001) 387–394

Journal of Cleaner Production

www.cleanerproduction.net

Using quality function deployment for technique selection for optimum environmental performance improvement

Anthony Halog *, Frank Schultmann, Otto Rentz

Institute for Industrial Production, University of Karlsruhe, Hertzstrasse 16, 76187 Karlsruhe, Germany

Received 16 May 2000; accepted 10 October 2000

Abstract

The paper tackles how a given process or technique can be improved to qualify as an environmentally-conscious one at a given budget constraint. The use of quality function deployment (QFD) for the improvement analysis of selected "Best Available Techniques" is discussed. A modified version of QFD is developed and applied to determine the emissions which need to be analysed further for environmental performance improvement. The critical emitted substances with consideration given to environmental impact potential and cost budget are reported. The target specifications used are the environmental benchmarks obtained from the comparison of emission values of the techniques. Sinter production is used as an illustrative example to apply the proposed House of Ecology and the linear mathematical model. QFD could be applied to the continuous improvement of any process or technique with some modifications. © 2001 Elsevier Science Ltd. All rights reserved.

Keywords: Quality function deployment (QFD); Environmental impact potential; Best available techniques (BATs); House of Ecology (HOE); Mathematical model

1. Introduction

For some years companies and environmental authorities have been increasing their awareness in incorporating environmental issues into their respective systems. Terms such as environmental design, sustainable design, environmentally-conscious processes or products, clean technologies, and green products or systems are now becoming widely important. During the 2000 Seville Conference in Stuttgart, industry representatives proposed that requirements for Best Available Techniques (BATs) (as stated in BAT reference documents) should be descriptive rather than prescriptive. Paragraph 11 in Article 2 of the Integrated Pollution Prevention and Control (IPPC) Directive defines "Best Available Technique" as the most effective and advanced stage in the development of activities and their methods of operation which indicate the practical suitability of particular techniques for providing, in principle, the basis for emission limit values designed to prevent and, where that is not practicable, generally to reduce emissions and the impact on the environment as a whole [1].

In this paper we examine how the environmental requirements of concerned stakeholders can be incorporated into the improvement analysis of BATs. In other words, the authors are interested on how a process/technique can become environmentally friendly assuming that high quality products are still maintained and technologies are available to curb the process emissions. As an example, four selected techniques in sinter production are chosen in this research [1]. It is the purpose of this paper to improve the process regardless of whether it belongs to BATs or non-BATs. However, to limit the study, we concentrate on how the selected four BATs in the said industry can be improved such that the critical emissions of the sinter production process can be effectively reduced. It would be appropriate to advise companies on how to continually improve their processes such that they become more environmentally friendly, taking into account the requirements of environmental agencies or other relevant environmental stakeholders.

With this purpose, this study explores the applicability

---

* Corresponding author. Tel.: +49-721-608-4406; fax: +49-721-758-909.

E-mail address: anthony.halog@wiwi.uni-karlsruhe.de (A. Halog).

PII: S0959-6526(00)00080-9

of quality function deployment (QFD) which is used in the deployment of stakeholders' requirements into the design of products or processes. A modified version of the method is applied to deploy the environmental requirements to the further enhancement of the process such that those substances that critically contribute to the environmental problems are considered closely and economically. The methodology suggested here could encourage further development of BATs or result in innovative environmentally-conscious techniques. Berglund [2] suggested that some of the environmental activities in which QFD can be effectively used are regulatory compliance, emission reduction, pollution and loss prevention programmes, construction or operating permit acquisition, and equipment procurement (equipment leaks).

This paper presents first a short discussion of QFD followed by the modifications made in the methodology to suit the defined environmental requirements and available data. After this, the modified methodology and a mathematical model are applied to a sinter production process. The proposed model is solved to find out which of those emissions have to be deployed for further analysis given a cost budget constraint. The results are then discussed. Finally, conclusions are drawn and suggested recommendations for further research are given.

2. Quality function deployment (QFD)

QFD is a cross-functional planning tool which is used to ensure that the voice of the customer is deployed throughout the product planning and design stages. QFD is used to encourage breakthrough thinking of new concepts and technology. Its use facilitates the process of concurrent engineering and encourages teamwork to work towards a common goal of ensuring customer satisfaction. QFD was first introduced by Akao in 1972 at Mitsubishi's Kobe shipyard site, and then Toyota and its suppliers developed it further for a rust prevention study [3]. After the concept of QFD was introduced in the US through auto manufacturers and parts suppliers [4], many US firms, such as Procter & Gamble, Raychem, Digital Equipment, Hewlett-Packard, AT&T, GM, and Ford, applied QFD to improving communication, product development, and measurement of processes and systems [5].

The basic concept of QFD is to translate the requirements of the stakeholders into product design or engineering characteristics, and subsequently into process specifications and eventually into production requirements [6]. It is a method that structures the translation of stakeholders' requirements into technical specifications which are mainly understood by engineers. Every translation involves a matrix. Through a series of interactive matrices, QFD can be employed to address almost any business situation requiring decisions involving a multitude of criteria, requirements or demands. This stems from QFD inherently employing and orchestrating many of the Total Quality Management tools and processes in a rigorous and strategic fashion. When used in the evaluation phase of a project, QFD can assure that all relevant issues have been addressed and can provide a new basis for prioritising projects.

The House of Quality (HOQ) is the most important tenet for the QFD concept [4,7–9]. The HOQ consists of seven basic steps: (1) identify the customer's attributes or requirements, (2) identify technical features (counterpart characteristics) of the requirements, (3) relate the customer's requirements to the technical features, (4) conduct and evaluate competing products, (5) relate the technical features identified in step 2 to indicate any correlation, (6) evaluate technical features and develop targets and (7) determine which technical feature to deploy in the remainder of the production process. Fig. 1 shows a typical chart of an HOQ ([10], p. 12).

The labelled parts in Fig. 1 are as follows:

- Stakeholders' requirements include the customer attributes (functional requirements) organised into appropriate classifications. The structure is usually determined by qualitative research. Capturing this "voice of customer" is one of the most important contributions QFD makes to the development of successful products and systems.
- Technical responses identify the technical specifications or engineering characteristics. Going from user requirements to technical specifications involves translating from qualitative requirements to quantitative measurable characteristics.
- Relationship matrix indicates the extent to which each end-user concern has been addressed by a design control parameter. The intersection of each technical specification column and customer requirement row forms a field in the middle of the house. These fields contain the correlations between the pairs. The conventional HOQ employs a rating scale (i.e. weak–medium–strong) to indicate the degree of strength

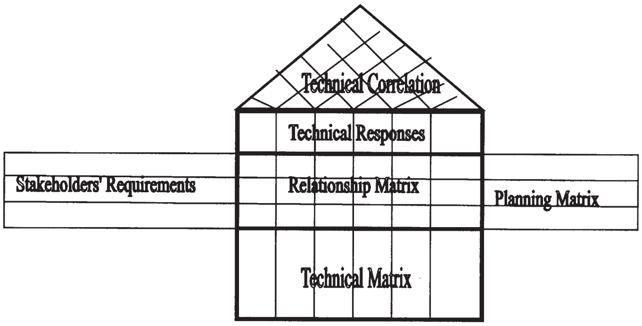

Fig. 1. House of Quality (HOQ) chart.

between stakeholders' requirements and design requirements.

- Planning matrix may contain three main types of information: quantitative data that indicate the relative importance of the wants and needs to the customer; the customer's satisfaction levels with the organisation's and its competition's current offerings; and strategic goal setting for the new product or process.
- Technical correlations, the "roof" of the house, captures the trade-offs between the various engineering parameters. It also employs the rating scale of weak–medium–strong to indicate the degree of strength between design requirements.
- Technical matrix is used for the new design for innovative systems or techniques. Targets are set for all control parameters that determine the new design along with cost, technical difficulty (risk), and relative importance of achieving each target. This provides management with a valuable means to direct resources by showing the experts' best estimates of the costs and benefits of each improvement in the product or current system design. It also allows producers to evaluate their existing product lines against competitors using technical measures (benchmarking).

Since the overall purpose of QFD is to give proper consideration to the voice of the customer in a general sense, specific efforts need to be directed at understanding every interface in which environmental issues might affect a proposed project, and to consider all the stakeholders that might need to be involved in the activity. The initial steps leading to the matrix of stakeholders' requirements versus design requirements are generally applicable to most environmental situations with some modifications, provided they are based on a relevant recognition and understanding of the stakeholders involved in the process.

3. Application of QFD principles in emission reduction

The methodology is adapted to the extent of simplifying it and basing it on the current availability of data. The stakeholders' requirements considered in this paper are non-exhaustive. The modifications introduced in this study are:

1. The stakeholder requirements are defined as impact categories which become popular in Life Cycle Analysis (LCA). Impact categories compile the potential impacts on the environment caused by the individual emissions and consumptions and reflect environmental problems. A list of these impact categories can be found in [11,12,16].
2. The design requirements of a particular technique are expressed in terms of substances that the process emitted which need to be reduced.
3. Instead of using the commonly used 1–3–9 equivalent of the (weak–medium–strong) rating scale for evaluating the relationship of design requirements and stakeholder requirements, the impact potential matrix (relationship matrix) is described as the degree of contribution of a certain substance to a certain impact category. For example, in what degree is the impact of SO_2 to the acidification requirement of the environment. The impact potential (IP) of this substance was used as a measure of the degree of satisfying the requirement of less acidification.
4. The weights of impact categories are based on environmental experts' opinions [1].
5. The triangular top portion of HOQ (technical correlation) was not used in this research because the correlation of the emitted substances have not yet been explored and need to be researched first, and most QFD studies have omitted this portion due to its complexity. The correlation of the emitted substances might give us an idea of possible cost savings from simultaneous implementation of reduction measures between two emitted substances.
6. The target specifications were the results of the environmental benchmarking of emission values for the four techniques being considered but, alternatively, emission limits for water, air, and land as provided by environmental agencies could also be used if available.
7. The design cost is defined here as the cost of implementing the necessary emission reduction for a particular substance to meet the current environmental benchmarks or latest limits. This cost could be attributed to new installations or equipment within the process, changing of raw materials, and changing operating conditions or parameters.
8. The ranking of the emitted substances was based on both cost and environmental impact potential considerations. Cost budget was allocated first to the one that had the greatest impact potential to the environment. The cost budget allocation was demonstrated by the mathematical model discussed below.

The proposed modified HOQ chart for this study is known here as the House of Ecology (HOE) because environmental requirements are being deployed instead of quality requirements as shown in Fig. 2.

4. Mathematical model for cost-effective environmental performance improvement

An emission reduction planning model is used to determine how to optimally allocate the given cost budget to the various emissions to be reduced for a given

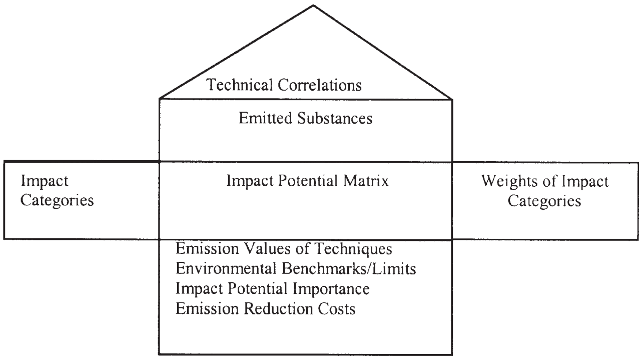

Fig. 2. House of Ecology (HOE) chart.

technique such that effective environmental process improvement is achieved. The greater the impact potential importance of the emitted substance to the environment, the more it is environmentally critical and the greater its chance of being selected and allocated with the budget. The objective function is to maximise the total impact potential importance of selected emitted substances for each technique which is synonymously defined here as the degree of necessary improvements in environmental process performance of each technique. The greater the total impact potential importance of the selected emissions of a technique, the more environmentally unsafe is the technique and thus substantial environmental process improvement is required to achieve acceptable levels of emissions. On the other hand, the less the total impact potential importance of the selected emissions of a technique, the more environmentally safe is the technique and thus minimal environmental process improvement is required to meet the acceptable levels of emissions. The total impact potential importance (Z) of a technique which varies from 0 to 1 (0 to 100%) is referred to as the degree of necessary improvement for the environmental process performance at a given budget.

The binary-type integer programming model for maximising the sum of the impact potential importance of selected emissions (Z) by selecting appropriate substances for reduction within a given budget is proposed as follows, adapted from [13]:

$$Z=\max\{\mathrm{IP}_1x_1+\mathrm{IP}_2x_2+\ldots+\mathrm{IP}_nx_n\} \tag{1}$$

s.t.

$$c_1x_1+c_2x_2+\ldots+c_nx_n\leq B \tag{2}$$

$$x\in\{0,1\}$$

where IP_j is the normalised impact potential importance of an emitted substance j.

$$\mathrm{IP}_j=\sum_{i=1}^{m}w_iR_{ij}^{\mathrm{norm}} \tag{3}$$

R_{ij}^{norm} is the normalised value of impact category i (i=1,2,…,m) and substance j (j=1,2,…,n) in the impact potential matrix in Fig. 2 and w_i is the weight of impact category based on expert opinion. The normalisation procedure of the matrix is referred to [3,13]. The decision variable, x_j, is binary (i.e. if substance j is selected, x_j=1; otherwise, it is 0). The cost coefficients $c_1,c_2,\ldots,c_n$ represent the estimated costs for reducing the said emissions to the desired emission benchmark. B is the available cost budget for improvement. At present, it is assumed that when a particular emitted substance is selected with its corresponding cost, the desired emission limit is achieved after the necessary solution has been made. The cost for reduction is assumed to be constant with respect to percentage of emission reduction. The problem is solved using the well-known "Knapsack" problem approach.

5. Illustrative example and model application

The sinter production process is chosen as an example because its techniques and emissions are relatively well documented. The sintering plant is the main aggregate of an integrated iron and steel works for the preparation of iron ores. This plant essentially consists of a large travelling grate of heat-resistant cast iron. In the sintering process, small particles are sintered into larger pieces (10–50 mm) which can be fed into the blast furnace. Inputs in the sintering plant are fine ores, coke breeze, flux material and recycled substances. An essential output, besides sinter, is the flue gas containing particulate matter and heavy metals. Depending on the kind of flue gas cleaning, waste water can also arise. Normally, since all the remaining products are directly reused in the sintering plant, no solid wastes are disposed of. The three most environmentally relevant groups of emissions for sinter plants are the particulate emissions (coarse and fine dusts), heavy metals (in the form of their oxides), and gaseous emissions (SO_2 and CO). More detailed information on sinter production can be found in the literature, e.g. [14,15].

The four techniques for sintering considered here, which differ mainly in their method of gas cleaning, use an electric separator (Technique A), fabric filter and electric separator (Technique B), cyclone (Technique C), and Airfine-Process (Technique D). In addition to the six impact categories (namely, photochemical oxidation, nutrification of water, acidification, human toxicity, ecotoxicity in air, and protection of the maritime environment) used for Technique A in Table 1, additional ones for Technique D are needed. These are ecotoxicity in water and hazardous wastes. Techniques B and C have the same categories as A. These impact categories are defined in [12,16].

Using the above points as depicted in Fig. 2 and the

Table 1
A simplified HOE chart for the environmental improvement analysis of Technique A (basis: 1 ton of sinter)

	Substance																	Weight
	Dust	CO	SO_2	NO_x	NMVOC	Cl^- as HCl	Fl^- as HF	PCDD/PCDF	As	Cd	Cr	Cu	Hg	Mn	Ni	Pb	Zn	
Environmental impact category																		
Photochemical oxidation[a1]					3.58													0.15
Nutrification of water[a2]				5.32														0.15
Acidification[a3]			83.2	28.7		3.19	5.64											0.15
Human toxicity[b]	1.91	1.73	20.8	8.19														0.15
Ecotoxicity in air[b]	1.90		20.8	8.19						140			0.0451	0.718		0.738		0.15
Protection of the maritime environment[c]								0.00241	5.00	98.2	60.4	177	31.6		48.8	613	0.0012	0.15
	d		e	e	d	d	f	g	h	i	i	i	i	i	i	i	i	
Technique A	7.65	17.3	8.32	4.10	8.61	3.62	35.2	3.45	10	14	12.1	35.4	4.51	71.8	9.76	87.5	240	
Technique B	0.921	31.3	0.131	5.27	4.60	2.86	4.60	1.84	0.368	0.0571	0.442	0.184	1.49	0.203	0.46	0.847	4.602	
Technique C	64.8	23.8	0.135	4.86	30.5	4.54	114	6.48	43.2	13	4.32	13	4.32	54.4	7.46	991	36.7	
Technique D	11	39.6	8.20	4.00	2.50	5.90	12.9	0.446	1.10	0.669	0.446	3.79	2.23	2.01	0.11	9.58	0.223	
Benchmarks	0.921	17.3	8.20	4.00	2.5	2.86	4.60	0.446	0.368	0.0571	0.442	0.184	1.49	0.203	0.11	0.847	0.223	
Emission limits	–	–	0.005	0.005	–	0.003	0.05	–	1	0.02	0.5	0.5	0.02	0.5	0.10	0.5	–	
Impact potential importance[j]	120.0	24.9	2390	2390	1500	41.3	731	0.00162	3.35	2080	40.5	119	21.9	10.3	32.7	422	805	
Fictitious cost ($E+04)	1.80	1.20	1.20	1.20	1.80	4.50	2.50	1.50	1.50	5.00	2.40	2.50	6.60		5.0	1.9		

Notes: 1. Full names of chemical substances in Table 3.
2. [a1]values in the row raised to E−02 (kg ethene equivalent); [e]values in the column raised to E−01 (kg/N/m^3);
[a2]values in the row raised to E−02 (kg PO_4^{3-} equivalent); [f]values in the column raised to E−04 (kg/N/m^3);
[a3]values in the row raised to E−02 (kg SO_2 equivalent); [g]values in the column raised to E−09 (kg/N/m^3);
[b]values in the row raised to E+06 (m^3 air); [h]values in the column raised to E−06 (kg/N/m^3);
[c]values in the row raised to E−06 (kg); [i]values in the column raised to E−05 (kg/N/m^3);
[d]values in the column raised to E−02 (kg/N/m^3); [j]values in the row raised to E−04 (kg/N/m^3).

proposed mathematical model, the QFD chart (in the form of matrix) for Technique A is shown in Table 1. Data used except for the artificial costs for reduction are taken from Gelderman et al. [1]. However, substitution of the actual costs using the EXCEL Solver model is easy because the actual values can just be replaced as in a sensitivity analysis. To calculate the actual costs, Schultmann et al. [17] proposed a possible methodology for the economic assessment of best available techniques to determine the cost involved in emission reduction measures. Berglund [18] also suggested the costs for pollution prevention which include the costs for process equipment, process materials, engineering, start-up permitting, training and utilities.

In Table 1, the environmental emission values of all the techniques are presented and can be compared to obtain environmental benchmarks for improvement. In addition, the emission standards or limit values as proposed by environmental agencies are also presented. The intersections of the substance columns and the environmental impact category rows provide the impact potential of each substance on the environment. Using the weights of the impact categories (last column of Table 1), the relationship matrix was normalised to give the impact potential importance of each substance as shown in the second to last row of Table 1.

Next, the mathematical model was solved with the use of Microsoft EXCEL Solver. The use of EXCEL made this study adaptable to company resources rather than using the available specialised QFD and operations research software. By using Solver, an optimal cost allocation of the selected emissions to be reduced is determined for the purpose of improving the environmental performance of technique. Given an annual cost budget limitation of US$200,000, it is shown that the substances to be focused on for Technique A are SO_2, NO_x, cadmium, NMVOC, zinc, lead, dust, chromium, nickel, and carbon monoxide. However, CO can be replaced by another substance because it meets the current emission benchmark. Using a similar procedure for the other techniques, Table 2 shows the ranking of emitted substances for each technique in the sinter production that has to be addressed at the cost budget of US$200,000. The last two rows in Table 2 are the actual total cost for environmental reduction of the substances and the degree of necessary environmental process improvement (Z) respectively at a given budget. Table 3 lists the chemical formulas and symbols used. Fig. 3 portrays the sensitivity analyses for the degree of necessary environmental process improvement over budget constraints.

6. Discussion of results

In Table 2, for all the techniques, SO_2 and NO_x should be addressed first, because of their high impact potential on the environment. Except for Technique B, cadmium should also be considered critically. Besides SO_2 and NO_x, the other critical substances which are common to the four techniques are NMVOC, Pb, and CO. The reduction of dusts is only important for Techniques A and C. Techniques B and D have a better dust collector system. Filter cake is only relevant in Technique D because it is the only process that produces hazardous substances. This verifies that technical and environmental improvement efforts in the design of a process or technique should be focused on the reduction of these substances. Knowing these substances, firms' environmental design resources can be directed to continually improve their processes or systems. Improvements such as introducing equipment within the process, or changing the raw materials to meet the proposed emission values or to attain the ideal objective of zero emission are some of the possible solutions.

In Table 2 it is shown that Technique D is the best among the techniques considered because it requires less necessary improvements to make it more environmentally friendly as compared to the other techniques at a given budget. Fig. 3 further depicts that Technique D is superior to the other techniques across different cost budgets. Technique B is considered the worst among the techniques at a budget lower than or equal to US$125,000 because it requires the most necessary environmental process improvements. However, as the budget increases, it appears that Technique C requires the most necessary environmental improvements. In terms of ranking the techniques, A precedes C, B precedes C, and finally D precedes B. Although the present study confirms the ranking as proposed by a multi-criteria approach by Geldermann et al. [1], the methodology used here allows the ranking of techniques by their degree of necessary improvement as a consequence of the prioritisation of emitted substances which is based on their impact potentials and cost budget allocation.

This study also suggests that every technique or process can be improved depending on which substances should be focused on first with respect to its environmental impact potential. However, the ranking of emitted substances might change depending on the degree of economic and technological considerations. With respect to economic consideration, the cost could be balanced with the environmental benefit of a cleaner production system. Small- or medium-sized firms that do not have the financial resources to completely overhaul their processes would find the concept proposed here useful. They can improve their processes based on their yearly budget given that the technology needed to reduce the emitted substances is available.

Table 2
Ranking of emitted substances for each technique in sinter production

Technique A	Technique B	Technique C	Technique D
SO_2	SO_2	SO_2	SO_2
NO_x	NO_x	NO_x	NO_x
Cd	NMVOC	Cd	NMVOC
NMVOC	Zn	NMVOC	Cd
Zn	Hg	Ni	Filter cake
Pb	Pb	Dust	Pb
Dust	CO	Pb	Cr
Cr	Cl^- as HCl	CO	CO
Ni		F^- as HF	
CO			
US$200,000	US$200,000	US$186,000	US$200,000
[a]97.97%	97.49%	99.61%	89.37%

Notes: Budget constraint US$200,000.
Full name of chemical substances in Table 3.
[a]Represents the maximum sum of the impact potential importance (*Z*).

Table 3
Chemical formulas and symbols used

Full name	Formulas and symbols
Carbon monoxide	CO
Sulfur dioxide	SO_2
Nitrogen oxides	NO_x
Non-methane volatile organic compounds	NMVOC
Chloride ions	Cl^-
Hydrogen chloride	HCl
Hydrogen fluoride	HF
Polychlorinated dibenzo-dioxins	PCDD
Polychlorinated dibenzo-furans	PCDF
Arsenic	As
Cadmium	Cd
Chromium	Cr
Mercury	Hg
Manganese	Mn
Nickel	Ni
Lead	Pb
Zinc	Zn
Fluoride ions	F^-

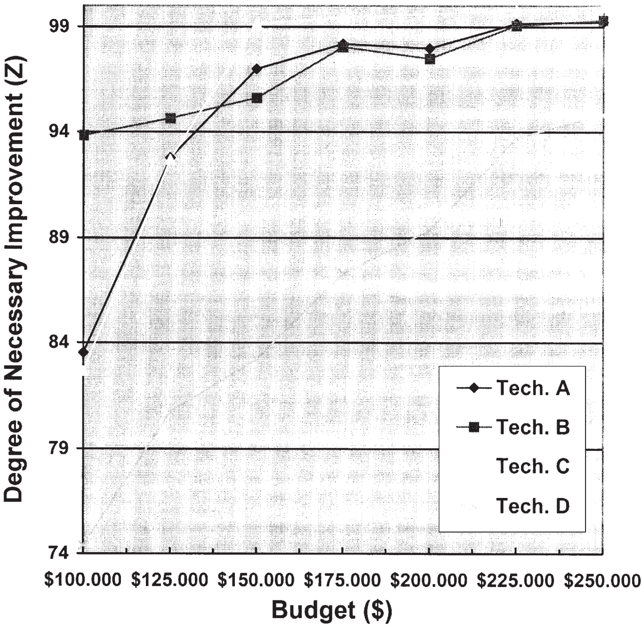

Fig. 3. Sensitivity analysis for the degree of environmental process improvement over budget constraint.

7. Conclusion and future work

This study demonstrates that it is better to address the substances that contribute critically to the deterioration of the environment based on their impact potentials. Knowing these most critical emitted substances, the cost budget could be allocated effectively. Also, financial resources for environmental improvements can be allocated first to those substances that do not meet the initial benchmarks. Additionally, it is verified that QFD principles can be applied in considering the environmental requirements of the stakeholders for environmental process improvement. This statement agrees that QFD can be a critical tool for environmental decision making, as suggested previously by Berglund [2].

However, more work has to be done to prove the robustness of the House of Ecology (HOE) in environmental decision making. Costs for implementing an appropriate solution for reducing the emissions should be identified and calculated. Another improvement would be to integrate the costs in proportion to the percentage of emission reduction. For the HOE chart, the stakeholders' requirements should be better defined by gathering adequate data and doing industrial case studies. Research should also be geared to determining the correlation of the emitted substances such that possible cost savings can be incorporated into the mathematical model. The technical difficulty involved in reducing the emissions is another limitation that could be introduced into the model. The interplay of quality, environmental, and safety issues could also be considered.

Moreover, investigation can now be undertaken of the next lower level of the QFD matrix, where the critical emitted substances with respect to the stakeholders' requirements and the appropriate equipment or installations or other technical solutions with regard to the design requirements can be determined. The creation of this matrix might result in innovative solutions, such as the discovery of alternative raw materials that could be substituted for the materials used in the present process, process retrofitting, or even the development of a new environmentally conscious technique or process.

Finally, a word of caution is in order. The illustrative example which is introduced should not be regarded as an absolute template for the use of QFD. Each QFD effort must be customised for the application.

References

[1] Geldermann J, Chan Ch, Spengler T, Rentz O. Proposal for an integrated approach for the assessment of cross-media aspects relevant for the determination of Best Available Techniques (BAT) in the European Union. French–German Institute for Environmental Research, University of Karlsruhe (Report), 1998.

[2] Berglund R. QFD: a critical tool for environmental decision making. ASQC Qual Congr Trans 1993;593–9.

[3] Wasserman GS. On how to prioritise design requirements during the QFD planning process. IIE Trans 1993;25(3):59–65.

[4] Sullivan LP. Quality function deployment (QFD): the beginning, the end, and the problem in between. A collection of presentations and QFD case studies. American Supplier Institute, 1987.

[5] Ansari A, Modaress B. Quality function deployment: the role of suppliers. Int J Purchas Mater Manage 1994;30(4):28–35.

[6] Akao Y. Quality function deployment: integrating customer requirements into product design. Cambridge: Productivity Press, 1990.

[7] Graessel B, Zeidler P. Using quality function deployment to improve customer service. Qual Prog 1993;26(11):59–63.

[8] Rijsenbrij DB, Bauer AB. A quality system for a software house. J Syst Software 1993;23:211–24.

[9] Tottie M, Lager T. QFD—linking the customer to the product development process as a part of the TQM concept. R&D Manage 1995;25(3):257–67.

[10] Cohen L. QFD: how to make QFD work for you. New York: Addison-Wesley, 1995.

[11] Klöpfer W, Renner I. UBA-Texte 23/95. Methodik der Wirkungsbilanz in Rahmen von Produkt-Ökobilanzen unter Berücksichtigung nicht oder nur schwer quantifizierbarer Umwelt-Ökobilanzen—Wirkungsbilanz und Bewertung. Berlin, 1995.

[12] Schmitz S, Oels HJ, Tiedemann A. UBA-Texte 52/95. Ökobilanz für Getrankeverpackungen. Berlin, 1995. [English trans.; UBA-Texte 19/96. Life-cycle assessment for drinks packaging system.]

[13] Park T, Kim K. Determination of an optimal set of design requirements using House of Quality. J Operat Manage 1998;16:569–81.

[14] Bothe, R. Umweltpolitik bei der Eisenerzsinterung. Dissertation. Aachen, 1993.

[15] Cappel F, Wendeborn H. Sintern von Eisenerzen. Stahleisenbücher Band 19. Düsseldorf: Verlag Stahleisen m.b.H., 1973.

[16] Heijungs R, Guinee JB, Udo De Haes HA, Wegener Sleeswijk A, Ansems AM, Eggels PG et al. Environmental life cycle assessment of products; guide and backgrounds. Leiden: Centre of Environmental Science, 1992.

[17] Schultmann F, Jochum R, Rentz O. A methodology for the economic assessment of Best Available Techniques—demonstrated for the case study electric steelmaking. In: Proceedings for International Workshop on Economic Aspects of BAT (Brussels, Belgium), February 10–11, 2000.

[18] Berglund R. Quality costs and pollution prevention: a CPI imperative. ASQC Qual Cong Trans 1991;602–9.