HOW TO OPTIMIZE THE SPECIFICATION OF BUILT-TO-ORDER TECHNOLOGY SYSTEM: A CASE OF WASTEWATER TREATMENT SYSTEM

Yuji Sato
Graduate School of Business Administration
Chukyo University
Nagoya, Aichi, Japan
E-mail: ysato@mecl.chukyo-u.ac.jp

ABSTRACT

The objectives of this paper are to propose a diagnosis process of user's preference for a new built-to-order technology system, and to subsequently optimize the specification of the system for a manufacturing company. Manufacturing companies, such as chemical products companies, need to take responsibility for reducing plant-based pollutions, given their potentially severe human and environmental consequences. In addition, companies need to investment strategically for their development due to increasing focus on corporate social responsibilities, compliance and sustainability. However, determining the specification of a new built-to-order technology system is a complicated task, because of subjective factors entering into the evaluation of necessary and sufficient specification of the system. Consequently, the choice of appropriate system often lacks transparency and traceability in the process. This paper addressed this issue by combining cost-benefit analysis and the analytic hierarchy process. Wastewater treatment system for a chemical company is considered as one of a built-to-order technology system, and a case study in the company was carried out to demonstrate the applicability of the proposed approach. The results of this paper shows some evidence that the diagnosis process proposed in this paper succeeded in quantifying user's preference for potential systems, and that the specification was optimized successfully.

Keywords: wastewater treatment system, cost-benefit analysis, Analytic Hierarchy Process

1. Introduction

With growing interest in global environmental issues, manufacturing companies need to take responsibility for reducing plant-based pollutions, such as wastewater or gas emissions discharged from the plant, given their potentially severe human and environmental consequences. In addition to taking responsibility, companies need to adopt strategic investments in effluent treatment, which is inseparable from profit generation due to increasing focus on accountability to stakeholders. A certain consent limits, therefore, are set according to a law and industrial emissions must satisfy the limits before discharged into environment.

Decision making for strategic investment in effluent treatment is complicated, particularly in manufacturing companies, where large amounts of hazardous substance are dealt with. In optimizing investment in the treatment system, safety supervisors must evaluate and choose system architectures, which are usually costly and surrounded by uncertainty over the likely effects of the different architectures available. The difficulties arise mainly from intangible factors, such as the safety supervisor's judgment of criteria that enter into the evaluation and choice of appropriate system architecture, given the rapidly changing technological environment. Thus, decision making regarding strategic investment, relying heavily on experience, knowledge, as well as intuition, often lacks transparency and traceability.

Given the need for a necessary and sufficient treatment system within manufacturing plants, a variety of architectures have been proposed. However, the number of studies on strategic investment in the architecture within manufacturing companies is limited due to inherent plant-based risks, which results in a lack of a “standard” framework for the optimization of the system architecture. Manufacturing companies surrounded by uncertainties, such as unexpected losses from disasters and envisaged economic effects from investment in the treatment system, have therefore tried to develop “haute couture” system architecture by, for instance, consulting professional analysts for safety.

This paper proposes to apply the cost-benefit-based evaluation approach as the basis of directing a new built-to-order industrial wastewater treatment system. In the approach, subjective factors in a decision making process are quantified using the Analytic Hierarchy Process (AHP). The approach combining cost-benefit analysis and the AHP consists of a sequence of transparent steps to provide clarity of thought into the evaluation and selection process for safety supervisors of companies. The approach requires supervisors to determine the degree of importance of each criterion by using the AHP which enables supervisors to express their preference for the treatment system quantitatively, and to conduct cost-benefit analysis which enables supervisors to evaluate potential treatment systems systematically. This is desirable since it is possible that supervisors might modify the weighting criteria due to insight gained during the course of a selection process. The result evaluating not only the treatment systems but also the decision criteria, therefore, fully justifies the final decision. An additional benefit of the justification is that the rationale behind each decision is captured and can then be used as the basis of an overall justification.

2. Literature review

There is a significant amount of literature in technology investment and selection (Sriram & Stump, 2004; Debo, et al., 2005; Khouja, 2005; Huang, et al., 2008; Kasikowski, et al., 2008; Wallenius, et al., 2008). However, only a few models have been developed for the design of a wastewater treatment system in the literature, since each manufacturing company has its own preference for the system. Bollinger and Pictet (2008) proposed a multi-criteria decision analysis of treatment technologies for waste incineration residues; however, their approach did not cover the area of industrial wastewater treatment. Freitas et al. (2000) applied an expert system to develop a conceptual design of industrial wastewater treatment process, but the process in the application was a black box; the selection process thus lacked transparency. Therefore, decision makers are unaware of what factors have been considered and what trade-offs have been taken; it is difficult to convince decision makers to trust the expert system’s solution. Some papers adopted optimization methods to solve the problem of wastewater treatment system design (Loucks, et al., 1967; Rossman, 1980; Ellis, et al., 1985; Rossman, 1989; Evenson & Baetz, 1994), which assumed that all information on the system design would be given quantitatively for designers in solving the problem (Noble & Tanchoco, 1995). In designing a complex industrial wastewater treatment system, however, intangible factors in the design process should be taken into account. Data envelopment analysis (Khouja, 2005), the AHP (Lai, et al., 2002), and the ANP (Chen et al., 2009) were applied to solve the problem, while these applications only evaluated a potential system solution in the approved list, and did not include the specific design process of wastewater treatment system. Stehna and Bergströmb (2002) proposed customer-oriented design process of products which could be applied to the design of wastewater treatment system; the approach, however, did not explicitly take user’s subjective preference into design. Safety supervisors in manufacturing companies thus face huge challenges in designing the treatment system and selecting the appropriate technology suppliers.

On the other hand, selecting and designing a sustainable treatment system is vital because this is not a one-off investment; the financial sustainability is also a very important factor. The lower the financial costs are, the more attractive the technology is (Hlemer & Hespanhol, 1997). However, even a low purchasing cost option might not be financially sustainable. A trade-off between purchasing cost and operational cost needs to be resolved in relation to the expected life of the plant (Jianga, et al., 2002). For example, if a wastewater treatment system has lower installation cost, then the operating cost and system stability (it will become a legal issue if the discharging wastewater cannot satisfies the regulated level) become more vital when it would be used for long periods. Thus, it is substantial for safety supervisors to consider how to minimize both the purchase cost for the system components and the operation cost (including the external failure cost, such as warranty cost and repair cost) of the treatment system.

3. Decision support process

This section describes decision support process of designing a built-to-order wastewater treatment system for a manufacturing company by means of a case study. One of the most difficult aspects in designing the treatment system is to determine how to direct design efforts. Design direction is necessary at every decision level, if system designers desire to stay on a path that will lead to consistent decision. Traditionally, making decisions with large amount of investment were mainly made by the central committee of the company; final decision used to be obtained based on the consensus within the committee members. The decision process, however, might be inconsistent, since subjective factors among the members' preference for the treatment system within the committee could affect the outcome of an investment proposal. In order to rectify the weakness of existing approach, the top management of the company keened to adopt an approach which could assist the central committee in making decisions with high transparency.

The treatment system must purify wastewater before discharged into environment so as to satisfy the allowable limits defined by a water pollution prevention law (Hlemer and Hespanhol, 1997). In order to purify wastewater, the treatment system equips several subsystems; Rotating Biological Contactor (RC), Fluid Carrier Tank (FT), and Sedimentation Tank (ST), each of which has different functions and performances. By combining these subsystems, the treatment system satisfies the allowable limits; while, the profile of the combination is not unique. Different combinations have their strengths and weaknesses. For example, a pure RC system is best at cleaning wastewater, but with a higher odor risk, while a pure FT design is with lower initial and maintenance costs but has poor process stability. All possible combinations of subsystems should be reviewed before the final decision would be made.

The regulation set by the legislation has a broad range of items concerning the wastewater treatment, such as concentrations of Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD). These items define the specifications of the treatment systems, each of which can be completely specified as objective information. On the other hand, as a user of the treatment system, the manufacturing company has its own preference for the system, which includes subjective information, such as cost-minimum priority or the sustainability-of-the-system priority in medium-and-long-term perspective. This information relates to each aforementioned specification and is represented as intangible information. Diagnosis procedure of user's preference for a new built-to-order system is thus substantial in optimizing the specification of the system for the manufacturing company.

Therefore, the decision support process needs to evaluate all potential alternatives in light of cost and benefit, which integrates objective data and subjective preference for the specification of the treatment system. Thus, the process consists of two following main processes: evaluating potential alternatives in light of cost and benefit based on the objective data on alternatives; collecting information on the preference for the specification of the treatment system.

3.1 Formulation of cost-benefit analysis

A developer of the wastewater treatment system has its own methodologies and techniques for purifying wastewater; therefore, the requirement for the treatment system is determined based on the regulation, once the contamination level of inflow wastewater is fixed. In this paper, the status of the wastewater is supposed to be determined by both the volume and the concentration of BOD of inflow wastewater, and the developer purifies it by the system consisting of three subsystems: RC, FT, and ST. Since the performance of each subsystem is clarified, the regulation can be satisfied by combining the subsystems in several ways. In addition, both the initial and running costs for each subsystem are also given, the specification, in other words, a set of criteria, *c*, evaluating the system, can be defined as follows: "*A*" (Area of installation: m^2); "*I*" (Initial cost: Yen/installation); "*R*" (Running and maintenance costs: Yen/year); "*S*" (Leakage risk of SS: total amount of leaked SS, Kg/day); "*B*" (Leakage risk of BOD: concentration of leaked BOD, mg/L); "*O*" (Odor risk of H_2S: concentration of generated H_2S, ppm*number of RC), where the durable years of the system is set as 20 years. Those criteria, and subsequent indicators defined below were determined based on the discussion with safety supervisors of a chemical products company and designers of a supplier of a wastewater treatment system introduced in Section 4.

In this paper, the following indicators representing the specification of the treatment system are employed in the cost-benefit analysis. Benefits are defined by the reciprocal values of $A_{*,i}$, $S_{*,i}$, $B_{*,i}$, and $O_{*,i}$, and costs are defined by the actual values of $I_{*,i}$ and $R_{*,i}$, where * (*=I: high, II: intermediate, III: low) and *i* (*i*=0, …, 8) respectively denote the BOD load per area of RC in the system, and the number of RC of the treatment system, each of which is indexed using the value when *=I and *i*=0 as a benchmark (set as 1).

Two types of cost-benefit functions are formulated for the analyses: one is "simple" cost-benefit function; the other is "weighted" cost-benefit function. In the functions, each indicator is transformed into T-score. Therefore, the T-score of the criterion $c_{*,i}$ (*c*=*A*, *I*, *R*, *S*, *B*, *O*) is transformed by the following formula and denoted as $c^s_{*,i}$, where $\mu(c_{*,i})$ and $\sigma(c_{*,i})$ are respectively denote the average and the standard deviation of $c_{*,i}$.

$$c^s_{*,i} :=50+10\{c_{*,i} - \mu(c_{*,i})\}/\sigma(c_{*,i}). \tag{1}$$

Based on (1), simple cost-benefit function is defined by the following formula which calculates each alternative's simple performance but does not reflect user's preference.

$$SCB_{*,i} :=\{1/A^s_{*,i}+1/S^s_{*,i}+1/B^s_{*,i}+1/O^s_{*,i}\}/\{I^s_{*,i}+R^s_{*,i}\}. \tag{2}$$

On the other hand, weighted cost-benefit function is defined so as to reflect user's preference for the treatment system to the results. Let w_c denote user's preference for the criterion *c*. Then, the T-score of the criterion $c_{*,i}$ can be represented by the following and denoted as $c^w_{*,i}$.

$$c^w_{*,i} :=50+10\{c_{*,i} - \mu(c_{*,i})\}w_c/\sigma(c_{*,i}). \tag{3}$$

Based on (3), the weighted cost-benefit function can be defined by the following formula which calculates each alternative's weighted performance reflecting user's preference.

$$WCB_{*,i} :=\{1/A^w_{*,i}+1/S^w_{*,i}+1/B^w_{*,i}+1/O^w_{*,i}\}/\{I^w_{*,i}+R^w_{*,i}\}. \tag{4}$$

3.2 Collection of information on user's preference

The user of the wastewater treatment system has its own preference for the treatment system on the premise that the alternatives of the system satisfy the regulation. The user, therefore, would make decisions on which system architecture to order from among the potential alternatives. However, the user is sometimes caught in a dilemma, for example, high flexibility of installation and low running costs. In this paper, user's preference is supposed to be represented upon *A*, *I*, *R*, *S*, *B*, and *O*, each of which determines the specification of the system. User's preference, however, is often expressed as subjective information, such as cost-minimum priority, or the sustainability-of-the-system priority in long-term perspective. Collecting information on user's preference, therefore, should be carried out so as to transform such intangible information into quantitative form.

In this paper, the AHP is adopted in quantifying user's preference. The user is required to conduct pair-wise comparisons over all possible combinations of criteria in order to represent his/her preference for the specifications of the treatment system. In the process, the user represents his/her preference by comparing each specification pair-wisely over all possible combinations of specifications, such as "Which specification of the treatment system do you think is more important for the treatment system of your plant, Flexibility or Initial cost?" The results of this process quantify the user's preference for the treatment system.

4. Case study

This section introduces the procedure and the result of the case study verifying the approach proposed in this paper. A chemical company X (Co.X) is a major chemical products company in Japan, whose wide array of products is highly esteemed and ranges from basic materials to fine chemicals. A wastewater treatment system company Y (Co.Y) is a supplier of a wastewater treatment system, whose technology in RC is highly rated in the field. Co.Y develops various types of the treatment system combining RC and FT, meeting the demands from great many manufacturing companies. Both companies' name, X and Y, cannot be disclosed due to confidentiality obligation; on the other hand, every data and information employed in this case study is the real in the companies.

On the occasion of the renewal of the wastewater treatment system in Co.X, the management team of the company has to make decision on the investment in a new built-to-order industrial wastewater treatment system. As noted in the previous section, there are three major indicators for the wastewater treatment: (*i*) total amount of leaked BOD, (*ii*) concentration of leaked SS, and (*iii*) concentration of generated H_2S. Safety supervisors and designers in the companies X and Y need to design the treatment system to purify the wastewater to meet the required legislation level. There are three core subsystems in the wastewater treatment system: RC, FT, and ST, where ST is designed to be configured at the final phase of the treatment system, and the requirement for the contamination level of wastewater inflowing to ST is fixed for all potential alternatives in this case.

The decision process is complicated as it requires selecting the most appropriate combination of subsystems and deciding the architecture of the treatment system. Based on the approach proposed in this paper, safety supervisors of Co.X and designers of Co.Y identify a set of criteria for the new built-to-order treatment system, which are listed as indicators in subsection 3.1. The criteria assess the potential benefits of the new system, its alignment with the company's strategy, its impact on identified objectives, and its failure risks. With this approach, a number of alternatives of the treatment system are designed and evaluated by the set of criteria. The alternatives with high prioritization scores are finally approved.

Co.Y first proposes some alternatives of the wastewater treatment system each of which meets required level of Co.X.; the details of the alternatives, i.e. the specifications of the potential treatment systems, are given in the appendix. Co.X, then represents its preference for the wastewater treatment system; Table 1 summarizes Co.X's preference for the system quantified by the AHP. As shown in the table, Co.X emphasizes the degree of importance of initial cost, $I_{*,i}$, as the highest, and the safeness of BOD leakage, $1/B_{*,i}$, as the second highest, and so on. These degrees of importance can be interpreted as the company's preference for the treatment system, which should be reflected in designing the new system.

Table 1. Chemical company X's preference for the treatment system.

Specifications	Flexibility	Initial cost	Running cost	SS safeness	BOD safeness	Odor safeness
Degree of importance	0.096	0.247	0.187	0.110	0.236	0.124

The results of "simple" cost-benefit analyses based on the specifications of the alternatives are shown in $SCB_{*,i}$ and its ranking columns of Table 2 whose values are calculated by (2). As shown in the table, the cost-benefit scores, $SCB_{\mathrm{III},5}$, $SCB_{\mathrm{I},0}$ and $SCB_{\mathrm{II},8}$ are the top three. While, the results of "weighted" cost-benefit analyses are shown in $WCB_{*,i}$ and its ranking columns of Table 2 whose values are calculated by (4). As shown in the table, the scores and its ranking of $WCB_{*,i}$ has slightly changed from those of $SCB_{*,i}$; $WCB_{\mathrm{III},5}$, $WCB_{\mathrm{I},0}$ and $WCB_{\mathrm{III},3}$ are the top three. The results of the weighted cost-benefit analyses reflecting user's preference imply that safety supervisors of Co.X judge the requirement for the new treatment system to be almost the same as that of "simple" cost-benefit analyses suggest.

Table 2. Results of cost-benefit analyses.

BOD load per area of RC	RC	$SCB_{*,i}$	Ranking	$WCB_{*,i}$	Ranking
I (High)	0	2.04436	2	2.00699	2
	1	1.99842	12	2.00003	13
	2	2.01569	8	2.00406	7
	3	1.99734	13	2.00046	12
	4	1.96948	21	1.99533	21
	5	1.97342	20	1.99557	20
	6	1.96748	22	1.99398	22
	7	1.94938	23	1.99006	23
	8	1.94194	24	1.98780	24
II (Intermediate)	0	2.03476	4	2.00466	6
	1	1.97742	19	1.99637	18
	2	1.99115	14	1.99968	14
	3	1.99851	11	2.00094	11
	4	1.98113	18	1.99741	17
	5	1.98481	17	1.99748	16
	6	1.99043	15	1.99770	15
	7	1.98750	16	1.99617	19
	8	2.03697	3	2.00495	5
III (Low)	0	2.03081	5	2.00352	8
	1	2.01220	9	2.00277	9
	2	2.00802	10	2.00260	10
	3	2.02428	7	2.00521	3
	4	2.02874	6	2.00508	4
	5	2.06515	1	2.01157	1

On the other hand, by using the "weighted" cost-benefit analysis, we can conduct sensitivity analyses; how user's preference would affect the result of the selection of the treatment system. The analysis can also be applied to the diagnosis procedure for customers of Co.Y. Table 3 shows the results of the analyses, which summarizes the rankings of the same alternatives shown in Table 2 with different users' preference, such as Flexibility prioritized, Initial cost prioritized, and so on. In the analyses, by changing the values of pairwise comparisons so as to emphasize the degree of the importance of a criterion, abovementioned priorities are artificially generated. For example, Flexibility prioritized preference is generated as follows; the relative importance of Flexibility to all the other criteria, such as Initial cost and BOD safeness, are set to "9" in pairwise comparisons, and in all other pairwise comparisons, the relative importance between the remaining criteria are set to "1". As shown in the table, the rankings of alternatives change drastically based on the user's preference, which leads to the different choice of the architecture of the treatment system.

Table 3. Results of sensitivity analyses.

BOD load per area of RC	RC	Flexibility	Initial cost	Running cost	SS safeness	BOD safeness	Odor safeness
I (High)	0	1	2	13	17	8	1
	1	9	12	20	22	10	4
	2	7	9	9	13	5	5
	3	14	15	14	11	4	7
	4	18	16	22	21	9	14
	5	20	18	18	12	6	15
	6	22	21	21	9	2	20
	7	23	23	23	10	7	23
	8	24	24	24	7	3	24
II (Intermediate)	0	2	4	15	19	15	2
	1	11	13	19	24	21	18
	2	6	7	17	23	19	16
	3	12	10	11	14	16	13
	4	15	14	16	16	18	22
	5	17	17	10	8	14	21
	6	19	19	6	5	13	17
	7	21	22	5	4	11	19
	8	16	20	2	1	1	8
III (Low)	0	3	5	12	18	22	3
	1	4	3	7	15	23	11
	2	5	1	8	20	24	12
	3	8	6	4	6	20	10
	4	13	11	3	3	17	9
	5	10	8	1	2	12	6

Traditional approaches could not address the wastewater treatment system selection problem with taking subjective factors into consideration. Questions such as why the component and architecture of the system was selected, nor what the benefit of the selected alternative to the performance of wastewater treatment was, were not easily answered. The approach combining cost-benefit analysis and the AHP proposed in this paper provides a framework for considering the impact of each trade-off decision on the criteria, and develops a justification path for the management team of the company.

Co.X management is satisfied with the insight gained from the approach, based on which the trade-off among various criteria can be quantified and the decision can be made with high transparency. Moreover, the approach provides a flexible decision framework that can take a new focus on the assessment into consideration when different preference for the wastewater treatment design would be expressed. On the other hand, Co.Y management is also satisfied with the diagnosis procedure that can address different users' preference. By using this procedure, the company would be able to address various users' preference and to optimize the architecture of the treatment system with its own technologies combined. Based on the retrospective interview focusing on the differences between the actual choice of Co.X and its clarified preference following the analyses, both the quantification of the user's preference shown in Table 1, and the results of the cost-benefit analyses summarized in Table 2, are persuasive, resulting in the consensus of the "next" selection of system architecture for the company. The results of the sensitivity analyses shown in Table 3 are also significant for Co.Y, which helps its promotion of the treatment system to potential customers.

5. Concluding remarks

This paper proposes a diagnosis procedure of user's preference for a new built-to-order industrial wastewater treatment system and subsequently optimizes the specification of the system for a manufacturing company, which integrates both objective and subjective information on the system. The approach not only satisfies the required legislation level, but also reflects user's preference to the design of the system, which makes decision path more transparent than before. The case study demonstrates the applicability of the approach that supports safety supervisors in designing a built-to-order industrial wastewater treatment system. A cost-benefit analysis is a systematic approach to evaluate the system performance, while the application of the AHP is a simple approach to transform the subjective information into objective information. The proposed approach, therefore, enables safety supervisors to deal with this information on the same horizon. By providing clarity to the analysis process, the decision making results in transparent and traceable.

Further research is needed to explore design improvement and technology selection in more complex industrial wastewater treatment systems. In addition, how to define the indices of the specifications of the system, such as the reciprocal values for the benefits of Flexibility, is an open-ended question.

REFERENCES

Bollinger, D. & Pictet, J. (2008). Multiple criteria decision analysis of treatment and land-filling technologies for waste incineration residues. *Omega, 36,* 418-428.

Chen, C.C., Shih, H.S., Wu, K.S. & Shyur, H.J. (2009). Using ANP for the Selection of Green Supply Chain Management Strategies. *Proceedings of the Tenth International Symposium on the Analytic Hierarchy/Network Process*.

Debo, L.G., Toktay, L.B. & Van Wassenhove, L.N. (2005). Market Segmentation and Product Technology Selection for Remanufacturable Products. *Management Science, 51(8),* 1193-1205.

Ellis, J.H., McBean, E.A. & Farquhar, G.J. (1985). Stochastic optimization/simulation of centralized liquid industrial waste treatment. *Journal of Environmental Engineering (ASCE), 1(II),* 804-821.

Evenson, E.J. & Baetz, B.W. (1994). Selection and sequencing of hazardous waste treatment processes: a knowledge-based systems approach. *Waste Management, 14,* 161-165.

Freitas, I.F.S., Costa, C.A.V. & Boaventura, R.A.R. (2000). Conceptual design of industrial wastewater treatment processes: primary treatment. *Computers and chemical Engineering, 24,* 1725-1730.

Hlemer, R. & Hespanhol, I. (1997). Water Pollution Control—A guide to the use of water quality management principles. In WHO (Ed.).

Huang, C.C., Chu, P.Y. & Chiang, Y-H. (2008). A fuzzy AHP application in government-sponsored R&D project selection. *Omega, 36,* 1038-1052.

Jianga, R., Zhangb, W.J. & Jia, P. (2004). Selecting the best alternative based on life-cycle cost distributions of alternatives. *International Journal of Production Economics, 89(1),* 69-75.

Kasikowski, T., Buczkowski, R. & Cichosz, M. (2008). Utilisation of synthetic soda-ash industry by-products. *International Journal of Production Economics, 112(2),* 971-984.

Khouja, M. (2005). Joint inventory and technology selection decisions. *Omega, 33,* 47-53.

Loucks, D.P., Revelle, C.S. & Lynn, W.R. (1967). Linear Programming Models for Water Pollution Control. *Management Science, 14(4),* 166-181.

Lai, V.S., Wong, B.K. & Cheung, W. (2002). Group decision making in a multiple criteria environment: A case using the AHP in software selection. *European Journal of Operational Research, 137(1),* 134-144.

Lin H.W., Nagalingam, S.V., Kuik, S.S. & Murata, T. (2012). Design of a Global Decision Support System for a manufacturing SME: Towards participating in Collaborative Manufacturing. *International Journal of Production Economics, 136(1),* 1-12.

Noble, J.S. & Tanchoco, J.M.A. (1995). Marginal Analysis Guided Design Justification: A Material Handling Example. *International Journal of Production Research,* 33(12), 3439-3454.

Rossman, L.A., 1980. Synthesis of waste treatment systems by implicit enumeration. *Journal of the Water Pollution Control Federation, 52,* 147-160.

Rossman, L.A. (1989). A hybrid knowledge-based/algorithmic approach to the design of waste treatment systems. *Proceedings of ASCE Sixth Conference on Computing in Civil Engineering*. Atlanta, GA., 162-169.

Sriram, V. & Stump, R. (2004). Information technology investments in purchasing: an empirical investigation of communications, relationship and performance outcomes. *Omega, 32,* 41-55.

Stehna, L. & Bergströmb, M. (2002). Integrated design and production of multi-storey timber frame houses – production effects caused by customer-oriented design. *International Journal of Production Economics, 77(3),* 259-269.

Wallenius, J., Dyer, J.S., Fishburn, P.C., Steuer, R.E., Zionts, S. & Deb, K. (2008). Multiple Criteria Decision Making, Multiattribute Utility Theory: Recent Accomplishments and What Lies Ahead. *Management Science, 54(7),* 1336-1349.

Appendix. The specifications of the alternatives of wastewater treatment systems proposed by the wastewater treatment system company Y.

BOD load per area of RC	Number of RC	Volume of FT	Flexibility	Initial cost	Running cost	SS safeness	BOD safeness	Odor safeness
I (High)	0	791	**1.00000**	**1.00000**	**1.00000**	**1.00000**	**1.00000**	**1.00000**
	1	791	0.64602	1.23484	1.03807	1.07986	1.04163	0.50000
	2	528	0.60036	1.16485	0.94713	1.18441	1.09188	0.25000
	3	528	0.47837	1.39969	0.97020	1.30117	1.14298	0.16667
	4	396	0.42740	1.46128	1.06726	1.24628	1.11957	0.12500
	5	396	0.36173	1.68568	1.00349	1.38000	1.17484	0.10000
	6	317	0.32242	1.83641	1.02160	1.52935	1.23012	0.08333
	7	264	0.28716	2.02919	1.05766	1.52711	1.22934	0.07143
	8	264	0.25594	2.26403	1.07080	1.70340	1.28730	0.06250
II (Intermediate)	0	791	1.00000	1.00000	0.99589	1.00833	0.81613	1.00000
	1	791	0.64602	1.23484	1.02197	1.10762	0.84944	0.05000
	2	396	0.67104	0.99160	1.01229	1.08986	0.84374	0.02500
	3	317	0.54727	1.13189	0.94356	1.24546	0.89027	0.01667
	4	264	0.45287	1.32468	0.97038	1.29023	0.90237	0.01250
	5	226	0.38624	1.51746	0.92838	1.49514	0.95167	0.01000
	6	226	0.33181	1.74187	0.87386	1.72839	0.99800	0.00833
	7	226	0.29082	1.97670	0.86601	1.98306	1.03967	0.00714
	8	0	0.28119	1.87870	0.71344	2.42000	1.09573	0.00625
III (Low)	0	791	1.00000	1.00000	0.98354	1.03419	0.69364	1.00000
	1	528	0.80585	0.93002	0.92311	1.15110	0.72016	0.02500
	2	264	0.73602	0.85500	0.93732	1.10652	0.71048	0.01250
	3	226	0.57486	1.03735	0.82766	1.40040	0.76628	0.00833
	4	226	0.46205	1.27219	0.78855	1.79746	0.81984	0.00625
	5	0	0.43821	1.17419	0.67486	2.06838	0.84719	0.00500

Every criterion is indexed by using values when *=I and *i*=0 as a benchmark (shown in bold).