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Manuscript Number: IJPE-D-16-00536R1

Title: Investment Performance Analysis of Industrial Products: Case of an Effluent Processing Facility at a Chemical Company

Article Type: SI:Innsbruck 2016

Keywords: Performance analysis; Industrial products; Customer preference; subjective factor; analytic hierarchy process; BOCR analysis

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Abstract: This paper proposes an approach to a multi-criteria investment performance analysis of industrial products. Manufacturers must determine the necessary and sufficient specification of products they use. Such an analysis, however, involves a broad range of factors, including some that are subjective. The performance analysis and decision making for investment thus must often rely heavily on past experience, generalities, and intuition. This paper addresses these issues from a benefit, opportunity, cost and risk (BOCR) perspective, in which the criteria are prioritized and the products are evaluated objectively. Pairwise comparisons among the criteria and quantitative assessments of the performance of products comprise a prioritized BOCR analysis. A case study demonstrating the applicability of the proposed approach is conducted at a chemical company. Results show that the proposed approach succeeds in the multi-criteria performance analysis of industrial products, resulting in a practical proposal of a product specification best suited to this company's case.

29 October 2016

Editor in Chief

INTERNATIONAL JOURNAL OF PRODUCTION ECONOMICS

**Manuscript ID: IJPE-D-16-00536 entitled "Investment Performance Analysis of Industrial Products: Case of an Effluent Processing Facility at a Chemical Company"**

Dear Professor Grubbström,

First, the authors of this paper are glad to learn that reviewers strongly recognize the academic value of this manuscript. This paper shed interesting insights on how managements could cope with both intangible factors, and opportunity and risk factors in addition to benefit and cost factors in the performance analysis of industrial products. On the other hand, the reviewers commented some shortcomings of the paper that need further elaboration.

Please find enclosed the revised version of the manuscript *IJPE-D-16-00536*, whose title has slightly been changed from the original one "Investment Performance Analysis of Industrial Products: a Case of Effluent Processing Facility in a Chemical Company." We have made extensive modifications to the paper in order to address all the suggestions made by the reviewers. We outline the modifications in the following pages.

I do appreciate that you gave me the opportunity to revise my paper. I hope that I have addressed all the issues you raised, and that the revised paper is now suitable for publication in IJPE.

Yours sincerely,

Yuji Sato, Ph.D.

29 October 2016

Special Issue Managing Guest Editor

INTERNATIONAL JOURNAL OF PRODUCTION ECONOMICS

**Manuscript ID: IJPE-D-16-00536 entitled "Investment Performance Analysis of Industrial Products: Case of an Effluent Processing Facility at a Chemical Company"**

Dear Professor Battini,

First, the authors of this paper are glad to learn that reviewers strongly recognize the academic value of this manuscript. This paper shed interesting insights on how managements could cope with both intangible factors, and opportunity and risk factors in addition to benefit and cost factors in the performance analysis of industrial products. On the other hand, the reviewers commented some shortcomings of the paper that need further elaboration.

Please find enclosed the revised version of the manuscript *IJPE-D-16-00536*, whose title has slightly been changed from the original one "Investment Performance Analysis of Industrial Products: a Case of Effluent Processing Facility in a Chemical Company." We have made extensive modifications to the paper in order to address all the suggestions made by the reviewers. We outline the modifications in the following pages.

I do appreciate that you gave me the opportunity to revise my paper. I hope that I have addressed all the issues you raised, and that the revised paper is now suitable for publication in IJPE.

Yours sincerely,

Yuji Sato, Ph.D.

## REVISION NOTE

Red: reviewer's comments

Blue: response to reviewer

Green: revisions made to the original manuscript

● Reviewer #1:

Dear reviewer:

The authors of this paper greatly appreciate your review of our paper "Investment Performance Analysis of Industrial Products: Case of an Effluent Processing Facility at a Chemical Company" (which has slightly been changed from the original title "Performance Analysis of Industrial Products: a Case of Effluent Processing Facility in a Chemical Company"). The comments and suggestions are valuable for helping us in revising the paper. We hope that we have addressed all the issues you raised.

As you kindly commented, the previous version of the manuscript lacked proper explanations of the research design and the contribution of this research, which stood on rather inadequate references. Based on your comments and suggestions, we have carried out substantial revision on the issues of: (a) abstract, (b) details of the case study including the introduction of the expert team, (c) deeper literature review analysis based on recent publications, (d) definitions of decision criteria, (e) presentations of the results with deeper analyses, and (f) contributions of the research in respect to the state of the art.

Abstract has been rewritten, Section 1 has been substantially revised, which focuses on introducing the background of this research and highlights the research questions of this paper. A new section has been added as Section 2 for literature review, in which literature analysis has been extended in order to cover recent AHP, ANP and BOCR analyses. In associate with this revision, the reference list has been updated. Details of the case study have been added to former Section 2 (now Section 3). Former Section 3 (now Section 4) has also been refined, which clarifies the research model, and former Section 4 (now Section 5) has been enriched with limitations of this paper. Furthermore, English presentation has been refined through proof read by professional editor.

Your comments in the report:

*In the present paper authors propose an interesting multi-criteria model based on AHP and BOCR Analysis to optimize performance within a Chemical Company. In general, the manuscript is well done and well organized. The topic of the paper is very promising and nice. I would like to suggest some minor improvements before the publication.*

1. *First of all, I suggest to reconsider the abstract because in the present form it seems too wordy. A more concise and precise description is desirable.*

As you kindly advised, the authors of this paper realized that the abstract in the previous version of the manuscript is rather wordy and includes some promises not discussed in detail.

We rewrote the abstract as follows.

This paper proposes an approach to a multi-criteria investment performance analysis of industrial products. Manufacturers must determine the necessary and sufficient specification of products they use. Such an analysis, however, involves a broad range of factors, including some that are subjective. The performance analysis and decision making for investment thus must often rely heavily on past experience, generalities, and intuition. This paper addresses these issues from a benefit, opportunity, cost and risk (BOCR) perspective, in which the

criteria are prioritized and the products are evaluated objectively. Pairwise comparisons among the criteria and quantitative assessments of the performance of products comprise a prioritized BOCR analysis. A case study demonstrating the applicability of the proposed approach is conducted at a chemical company. Results show that the proposed approach succeeds in the multi-criteria performance analysis of industrial products, resulting in a practical proposal of a product specification best suited to this company's case.

2. *I suggest to add some more lines to introduce the expert team, the role of expert team, and judgments aggregation.*

As you noted, we briefly described the expert team in former subsections 2.1, 3.1 and 3.2 in the previous version of the manuscript. On the other hand, the descriptions of "managers of Co. X" and "managers of Co. Y" in former subsection 3.2 were not accurate, which should be "safety supervisors of Co. X" and "designers of Co. Y" respectively. Furthermore, both the role of the expert team and how the judgments were aggregated were not clear in the form.

In order to clarify the details of the expert team, we revised new subsections 3.1, 4.1 and 4.2 as follows.

new subsection 3.1 (p. 8):

... details of the case study itself and of these safety supervisors and designers, will be introduced in Section ...

new subsection 4.1 (p. 15):

... quantified by the AHP. In determining  $p_c$ , the two executives of Co. X who were in charge of the decision making in the investment conducted pairwise comparisons. In the process, they considered all aspects of the EPS and individually determined the relative importance of each  $c$  among four criteria. Their geometric mean was then assigned to a pairwise comparison matrix, which reflected the degree of importance of the four criteria. As can be seen in Table 2, ...

new subsection 4.2 (p. 20):

... how to promote its products. Retrospective interviews were carried out following the workshop with the safety supervisors of Co. X and the designers of Co. Y. Based on the interviews, ...

3. *Regarding section "1. Introduction", it is desirable a deeper literature review analysis. I would like to suggest to extend literature analysis and to take into account some references on AHP/ANP/BOCR, such as:*

- *De Felice, F., Petrillo, A., Cooper, O., 2013. An integrated conceptual model to promote green policies. International Journal of Innovation and Sustainable Development. Volume 7, Issue 4, 2013, Pages 333-355.*
- *De Felice, F., Petrillo, A., 2014. Proposal of a structured methodology for the measure of intangible criteria and for decision making. International Journal of Simulation and Process Modelling. Volume 9, Issue 3, 2014, Pages 157-166. ISSN: 17402123. DOI: 10.1504/IJSPM.2014.064392.*
- *De Felice, F., Petrillo, A., 2013. Multicriteria approach for process modelling in strategic environmental management planning. International Journal of Simulation and Process Modelling, Volume 8, Issue 1, 2013, Pages 6-16.*

The previous version of the manuscript stood on rather inadequate references. As you kindly advised, it is important to go over progresses in the recent AHP, ANP and BOCR applications.

We added a new section as Section 2 for literature review. The following papers suggested in your comments were added to the reference list, and extended literature analysis.

- De Felice, F., Petrillo, A., Cooper, O., 2013. An integrated conceptual model to promote green policies. *Int. J. Innovation and Sustainable Development*. 7 (4), 333-355.
- De Felice, F., Petrillo, A., 2014. Proposal of a structured methodology for the measure of intangible criteria and for decision making. *Int. J. Simulation and Process Modelling*. 9 (3), 157-166.
- De Felice, F., Petrillo, A., 2013. Multicriteria approach for process modelling in strategic environmental management planning. *Int. J. Simulation and Process Modelling*. 8 (1), 6-16.

In the process of the above-mentioned literature analysis, we found the following papers on the application of AHP, ANP and BOCR analyses. We, therefore, further added these papers to the reference list and enriched literature review in new Section 2.

- Weifeng, Y., Xiaohong, X., Baoliu, P., Chunsheng, G., Jiangang, Y., 2016. The fuzzy comprehensive evaluation of water and sand inrush risk during underground mining. *J. Intell. & Fuzzy Sys*. 30 (4), 2289-2295.
- Mohan, K.K., Srividya, A., Verma, A.K., 2016. Prototype dependability model in software: an application using BOCR models. *Int. J. Sys. Assurance Eng. and Manag*. 7 (2), 167-182.
- Tsai, P-H., Chang, S-C., 2013. Comparing the Apple iPad and non-Apple camp tablet PCs: a multicriteria decision analysis. *Technological and Economic Development of Economy*. 19 (sup 1), S256-S284.
- Chun-Yueh, L., Yih-Chearng, S., 2013. An Application of AHP and Sensitivity Analysis for Measuring the Best Strategy of Reverse Logistics: A Case Study of Photovoltaic Industry Chain. *J. Testing and Evaluation*. 41 (3), 1-12.
- Fouladgar, M.M., Yazdani-Chamzini, A., Zavadskas, E.K., Moini, S.H.H., 2012. A new hybrid model for evaluating the working strategies: case study of construction company. *Technological and Economic Development of Economy*. 18 (1), 164-188.
- Yap, H.Y., Nixon, J.D., 2015. A multi-criteria analysis of options for energy recovery from municipal solid waste in India and the UK. *Waste Management*. 46, 265-277.
- Lee, A.H.I., 2009. A fuzzy AHP evaluation model for buyer-supplier relationships with the consideration of benefits, opportunities, costs and risks. *Int. J. Prod. Res*. 47 (15), 4255-4280.
- Yazdani-Chamzini, A., Shariati, S., Yakhchali, S.H., Zavadskas, E.K., 2014. Proposing a new methodology for prioritising the investment strategies in the private sector of Iran. *Econ. Research-Ekonomska Istraživanja*. 27 (1), 320-345.
- Lee, A.H.I., 2009. A fuzzy supplier selection model with the consideration of benefits, opportunities, costs and risks. *Expert Sys. with Applications*. 36 (2, 2), 2879-2893.
- Cho, S., Kim, J., Heo, E., 2015. Application of fuzzy analytic hierarchy process to select the optimal heating facility for Korean horticulture and stockbreeding sectors. *Renewable and Sustainable Energy Rev*. 49, 1075-1083.
- Bayazit O., Karpak, B., 2007. An analytical network process-based framework for successful total quality management (TQM): An assessment of Turkish manufacturing industry readiness. *Int. J. Prod. Econ*. 105 (1), 79-96.
- Tjader, Y., May, J.H., Shang, J., Vargas, L.G., Ning Gao, N., 2014. Firm-level outsourcing decision making: A balanced scorecard-based analytic network process model. *Int. J. Prod. Econ*. 147 (C), 614-623.
- Bouzarour-Amokrane, Y., Tchangani, A., Peres, F., 2015. Decision evaluation process in end-of-life systems management. *J. Manufacturing Sys*. 37 (3), 715-728.
- Lee, A.H.I., Kang, H-Y., Chang, C-C., 2011. An integrated interpretive structural modeling-fuzzy analytic hierarchy network-benefit, opportunities, cost and risk model for selecting technologies. *Int. J. Information Technology & Decision Making*. 10 (5), 843-871.

Please refer to the new Section 2 of the manuscript.

4. I suggest to improve Figure 1 because it is not clear. Some more details are desirable.

Figure 1 was inserted to illustrate the image of the distribution of potential alternatives. We thought that the figure enabled readers to easily grasp the trade-off between the cost of effluent processing system and the degree of purification of effluent. As you kindly commented, however, the figure is rather confusing than clarifying the trade-off. On the other hand, the trade-off itself is not so complicated to understand if we carefully explain the relationship between the cost of the system and the degree of purification of effluent.

We removed Figure 1, and rewrote the last part of new subsection 3.1 (p. 9) as follows.

Each alternative of EPS must satisfy the requirements defined by the law, such as the cleanliness of discharge or the leakage risk of residuals. Alternatives barely satisfying the regulations would be inexpensive systems but might not be sustainable. On the other hand, alternatives need not err too much on the side of safety, as that would be expensive and might be an over-specification of the system. Customers of EPS must thus resolve this trade-off when selecting a system.

5. I suggest a more rigorous and precise definition of decision criteria.

As you kindly suggested, the definition of decision criteria in the previous version is rather inconsiderate.

We added a table (new Table 1) summarizing the definitions of decision criteria to new subsection 3.1 (p. 9), and rewrote the section to precisely define the criteria.

Table 1  
Criteria for performance analysis

Criteria	Definition
D (Benefit)	The cleanliness of discharge measured by the concentration of leaked BOD in effluent (mg/L), whose reciprocal value is identified as <u>B</u> enefit in BOCR analysis.
F (Opportunity)	Flexibility of the installation of an effluent processing system measured by the area of the installation of the system ( $m^2$ ), whose reciprocal value is identified as <u>O</u> pportunity in BOCR analysis.
C (Cost)	Cost of the system measured by the total amount of initial and running costs (Yen/installation), whose actual value is identified as <u>C</u> ost in BOCR analysis.
L (Risk)	Leakage risk of residuals measured by the total amount of leaked SS (Kg/day), whose actual value is identified as <u>R</u> isk in BOCR analysis.

6. I suggest to improve Formulation of prioritized BOCR analysis.

As for formula (1), since significant differences in variance exist among indicators relating to decision criteria, each parameter,  $c_{s,i}$  is transformed into the T-score of criterion c by this formula. Concerning formula (2), the prioritized BOCR function,  $pBOCR_{s,i}$  defined by this formula calculates each alternative's prioritized performance reflecting customer's preference. Since this formula is based on the above-mentioned formula (1), the prioritized BOCR function can cope with various decision criteria with different units, and can deal with various customers' preferences.

We think that the above-mentioned "T-score transformation" and "prioritization" of the proposed approach makes it possible to deal with various cases of performance analysis, which is practical in real world. We also cover the suggested issue in Section 5 as a future research topic.



7. Please explain better Fig. 2. Results of BOCR analyses.

8. Please explain better Fig. 3. Results of sensitivity analyses of different preference.

As you commented, figures 2 and 3 are rather confusing. Furthermore, even though both figures illustrate similar contents, i.e., the change in the rankings of alternatives, they had different types of presentations, which added to confusion further.

We replaced these two figures with the following ones formatted in common.

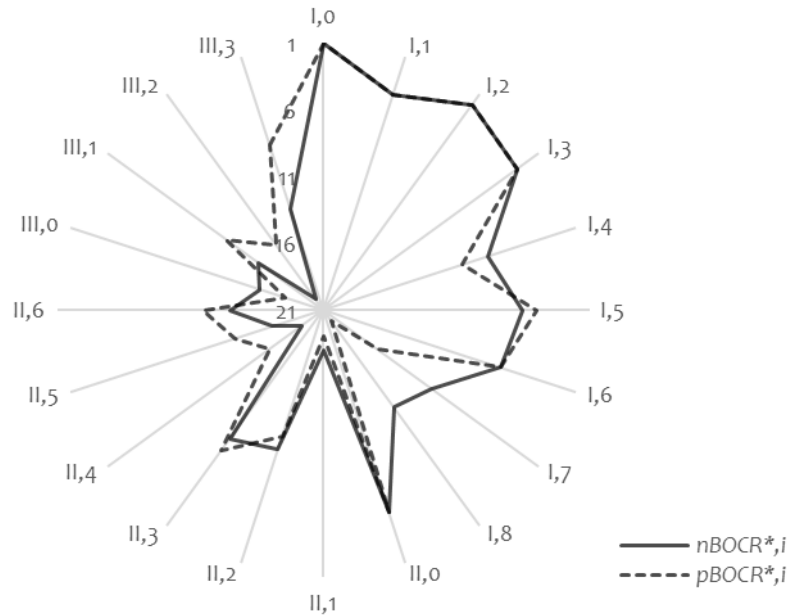


Fig. 2. Results of BOCR analyses (Rankings of potential alternatives).

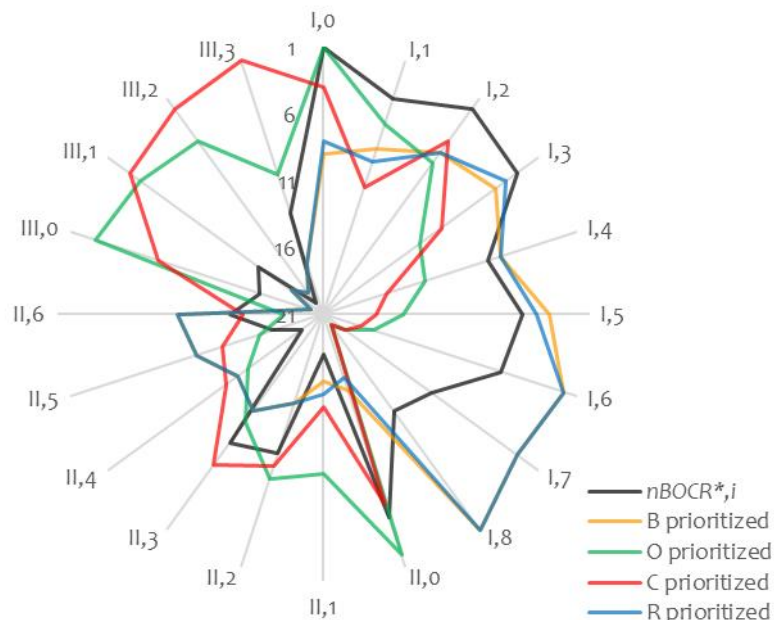


Fig. 3. Results of sensitivity analyses (Rankings of potential alternatives).

9. *It could be useful to show the AHP model.*

As you kindly suggested, a figure illustrating the AHP model helps readers easily understand the approach proposed in this paper.

We added Figure 1 and related explanation to new subsection 3.2 (pp. 11-12).

Figure 1 graphically represents the relationship between the collection of information on customer preference and the quantitative evaluation of potential alternatives otherwise known as an AHP model. As shown in the figure, pairwise comparisons reflected a customer's preference are carried out between the goal of the analyses and the decision criteria, prioritizing the degree of importance of each criterion. Then a quantitative analysis based on the objective data of potential alternatives is conducted between the decision criteria and potential alternatives, evaluating advantages and disadvantages of each potential alternative. This integration of the AHP technique and quantitative analysis followed by a multiple-criteria performance analysis comprises the prioritized BOCR analysis.

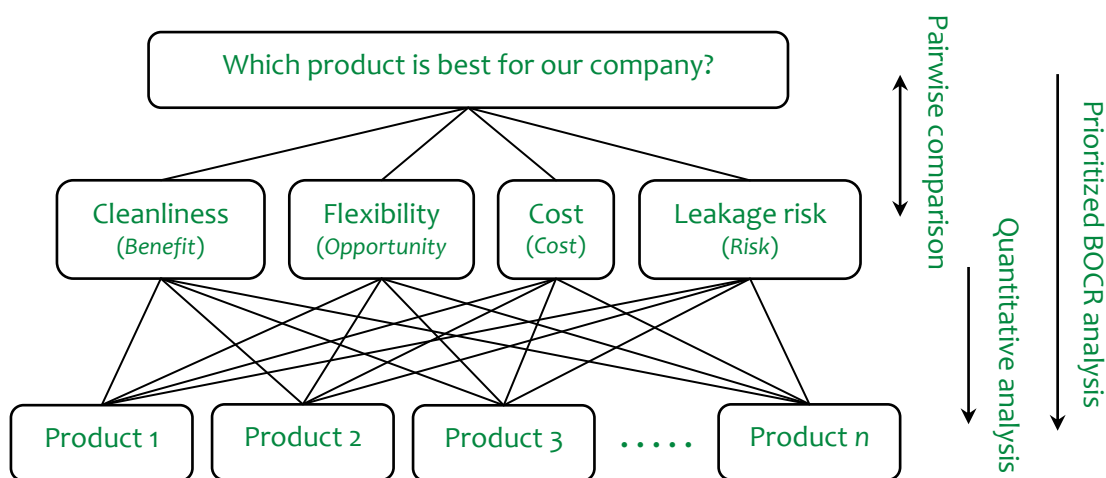


Fig. 1. AHP model.

10. *Please add some more considerations about the managerial implications.*

Based on the retrospective interviews, we described the managerial implications in former subsection 3.2 as follows. From customer's perspective, "... enables the managers of Co. X to gain better insight into the evaluation and selection of new processing system under complicated situation (customer's perspective)." And from supplier's perspective, "... help managers of Co. Y address various customers' requirements (preference) and optimize the design of an EPS with its own technologies in their sales promotion for potential customers (supplier's perspective)." On the other hand, we briefly described the managerial implications from executive's perspective in former Section 4. As you kindly suggested, we need to explore the contributions of this research further.

In order to clarify the managerial implications from executive's perspective, we added further explanations to new Section 5 (pp. 21-22).

... confusion among decision makers. While a number of approaches to the performance analysis of industrial products have been proposed, approaches to the design of an EPS have been limited. In addition, even though many decision-support frameworks have been proposed, little research has provided a systematic model that considers intangible factors. The multi-criteria performance analysis ...

... feel justified in making the purchase. Moreover, the proposed approach allows managers to have a clear decision path that provides traceability, enabling managers to revisit how the decision on an EPS was reached. Even though the proposed approach has been applied to the case of an EPS, it can be tailored and applied to any manufacturer or service company analyzing the performance of products or making investment decisions. This paper demonstrates that ...

11. *Please check English and grammar. Sometimes sentences are not clear. Please pay attention to language.*

We had the revised version of the manuscript proof read by a professional editor.

12. *Please define and clarify the contribution of the research respect the state of art.*

As you kindly suggested, we need to clarify the contribution of the research in respect to the state of the art. We think that the additional explanations in new Section 5 (noted in the above response to your comment #10) could explain a part of the contributions of this research. In addition, we added further explanations to new Section 5 (pp. 22-23).

This paper demonstrates that a new integrated approach to multi-criteria performance analysis is effective. The companies in the case study acknowledged that the approach gave them an overview of the issues affecting EPS performance and provided them with a structured way of seeking to improve. Particularly, the prioritized BOCR and sensitivity analyses allowed them to communicate and make decisions effectively. In short, the BOCR model helps to address the shortcomings of existing approaches (e.g., Weifeng et al., 2016; Tjader et al., 2014; Tsai and Chang, 2013) by giving a clear and systematic approach to analyzing and diagnosing a particular problem. In addition, the proposed approach allows managers to consider various factors that are key to making sound EPS decisions. Specifically, both the positives (benefits and opportunities) and negatives (costs and risks) are quantitatively analyzed, and intangible factors are dealt with in the decision-making process.

13. *A deeper analysis of results is desirable.*

As you kindly advised, we briefly summarized the results of the analyses in former Section 3 in the previous version of the manuscript.

We thus added Table 3 summarizing the results of the BOCR analyses to new subsection 4.1, and carried out a deeper analysis of the results. The explanations of Figures 2 and 3 were revised in accordance with the refinement of the figures.

new subsection 4.1 (pp. 16-17):

... is represented as  $p_c$ . As summarized in the appendix, the score of O (Flexibility) drastically changes in its value in comparison with the other criteria B (Cleanliness), C (Costs) and R (Leakage risk). This difference results in higher scores of alternatives with a greater number of RC, that is, with less volume of FT. As shown in ...

Table 3  
Results of BOCR analyses.

System architecture	$nBOCR_{*,j}$	$pBOCR_{*,j}$
I,0	1.0288	1.0057
I,1	1.0104	1.0019
I,2	1.0208	1.0055

I,3	1.014	1.0037
I,4	1.0021	1.0001
I,5	1.0038	1.0008
I,6	1.0029	1.0004
I,7	0.9951	0.9979
I,8	0.9932	0.997
II,0	1.0077	1.0008
II,1	0.9903	0.9971
II,2	0.9961	0.9991
II,3	0.9979	1.0002
II,4	0.9897	0.9979
II,5	0.9911	0.9984
II,6	0.9926	0.9988
III,0	0.9913	0.9973
III,1	0.9922	0.9988
III,2	0.9884	0.9983
III,3	0.9927	1.0002

**new subsection 4.2 (p. 19):**

As with the analyses in the previous section, significant differences in scores of O (Flexibility) in comparison with the other criteria result in a drastic change in the ranking of alternatives. For instance, a potential alternative (I,8) designed on the newest architecture with more RC is ranked at the top based on B prioritized preference; based on C prioritized preference, however, the alternative is ranked as the worst, where the normal BOCR analysis ranks it 12th among 20 alternatives. This result is considered to be induced by the number of RC that can effectively purify effluent but at great cost. As a result, the rankings of ...

**14. Please add some more details about the case study.**

As you noted, the description of the case study in former Section 3 of the previous version the manuscript is rather inconsiderate. On the other hand, detailed information including the name of the companies cannot be disclosed due to confidentiality agreements.

In addition to the detailed introduction of expert team added to new subsection 4.1, we further added the following information of the case study to new Section 4 (p. 14).

... The case study, which was originally a workshop for the optimization of the specification of an EPS in Co. X, was carried out in Japan. The workshop consisted of two executives from Co. X who were in charge of the decision making in the investment, three safety supervisors of three subsystems of the EPS, and two designers of Co. Y who led the design of the EPS in Co. X. During the course of the workshop, technical aspects of effluent processing, including the parameters defining the performance of the system, were discussed, and the above-mentioned experts conducted the evaluation of the system. Although the companies' names, ...

Again, thank you very much for your patience and interest. We hope that the revised paper is now suitable for publication.

Sincerely yours,

Yuji Sato, Ph.D. (Corresponding author)

● Reviewer #2:

Dear reviewer:

The authors of this paper greatly appreciate your review of our paper “Investment Performance Analysis of Industrial Products: Case of an Effluent Processing Facility at a Chemical Company” (which has slightly been changed from the original title “Performance Analysis of Industrial Products: a Case of Effluent Processing Facility in a Chemical Company”). The comments and suggestions are valuable for helping us in revising the paper. We hope that we have addressed all the issues you raised.

As you kindly commented, the previous version of the manuscript stood on rather inadequate references. Based on your comments and suggestions, we have carried out substantial revision on the issue of the references on the applications of AHP, ANP and BOCR analysis.

Section 1 has been substantially revised, which focuses on the introducing the background of this research and highlights the research questions of this paper. A new section has been added as Section 2 for literature review, in which literature analysis has been extended in order to cover recent AHP, ANP and BOCR analyses. In associate with this revision, the reference list has been updated. Furthermore, English presentation has been refined through proof read by professional editor.

*Your comments in the report:*

*Used old literary sources (1967-2008). Additionally cited:*

- *Int j of prod res 47(15)4255-4280.2009.*
- *ESWA 36(2)2879-2893.*
- *Int J of systems assurance engineering and management 7(2)167-182.*
- *IJITDM41(3)386-397.*
- *Technological and economic development of economy 19:S256-S284 Suppl 1. 2013.*
- *Int J of testing and evaluation 41(3)386-397.2013.*
- *Technological and economic development of economy 18(1)164-188.2012.*
- *Renewable and sust energy reviews 49:1075-1083.2015.*
- *Journal of manufacturing systems 37:715-728, part 3.2015.*
- *Waste management 46:265-245.2015.*
- *Economic research-Ekonomska istrazivanja 27(1)320-345.2014.*
- *J of intell & fuzzy systems 30(4)2283-2396.*

As you kindly advised, the reference of AHP, ANP and BOCR analyses in the previous version is rather old. We added a new section as Section 2 for literature review. The following papers suggested in your comments were added to the reference list, and extended literature review.

- Weifeng, Y., Xiaohong, X., Baoliu, P., Chunsheng,G., Jiangang,Y., 2016. The fuzzy comprehensive evaluation of water and sand inrush risk during underground mining. *J. Intell. & Fuzzy Sys.* 30 (4), 2289-2295.
- Mohan, K.K., Srividya, A., Verma, A.K., 2016. Prototype dependability model in software: an application using BOCR models. *Int. J. Sys. Assurance Eng. and Manag.* 7 (2), 167–182.
- Tsai, P-H., Chang, S-C., 2013. Comparing the Apple iPad and non-Apple camp tablet PCs: a multicriteria decision analysis. *Technological and Economic Development of Economy.* 19 (sup 1), S256-S284.
- Chun-Yueh, L., Yih-Chearng, S., 2013. An Application of AHP and Sensitivity Analysis for Measuring the Best Strategy of Reverse Logistics: A Case Study of Photovoltaic Industry Chain. *J. Testing and Evaluation.* 41 (3), 1-12.
- Fouladgar, M.M., Yazdani-Chamzini, A., Zavadskas, E.K., Moini, S.H.H., 2012. A new hybrid model for evaluating the working strategies: case study of construction company. *Technological and Economic Development of Economy.* 18 (1), 164-188.

- Yap, H.Y., Nixon, J.D., 2015. A multi-criteria analysis of options for energy recovery from municipal solid waste in India and the UK. *Waste Management*. 46, 265-277.
- Lee, A.H.I., 2009. A fuzzy AHP evaluation model for buyer–supplier relationships with the consideration of benefits, opportunities, costs and risks. *Int. J. Prod. Res.* 47 (15), 4255-4280.
- Yazdani-Chamzini, A., Shariati, S., Yakhchali, S.H., Zavadskas, E.K., 2014. Proposing a new methodology for prioritising the investment strategies in the private sector of Iran. *Econ. Research-Ekonomska Istraživanja*. 27 (1), 320-345.
- Lee, A.H.I., 2009. A fuzzy supplier selection model with the consideration of benefits, opportunities, costs and risks. *Expert Sys. with Applications*. 36 (2, 2), 2879-2893.
- Cho, S., Kim, J., Heo, E., 2015. Application of fuzzy analytic hierarchy process to select the optimal heating facility for Korean horticulture and stockbreeding sectors. *Renewable and Sustainable Energy Rev.* 49, 1075–1083.
- Bouzarour-Amokrane, Y., Tchangani, A., Peres, F., 2015. Decision evaluation process in end-of-life systems management. *J. Manufacturing Sys.* 37 (3), 715–728.
- Lee, A.H.I., Kang, H-Y., Chang, C-C., 2011. An integrated interpretive structural modeling-fuzzy analytic hierarchy network-benefit, opportunities, cost and risk model for selecting technologies. *Int. J. Information Technology & Decision Making*. 10 (5), 843-871.

In the process of the above-mentioned literature analysis, we found the following papers on the application of AHP, ANP and BOCR analyses. We, therefore, further added these papers to the reference list and enriched literature review in new Section 2.

- Bayazit O., Karpak, B., 2007. An analytical network process-based framework for successful total quality management (TQM): An assessment of Turkish manufacturing industry readiness. *Int. J. Prod. Econ.* 105 (1), 79-96.
  - Tjader, Y., May, J.H., Shang, J., Vargas, L.G., Ning Gao, N., 2014. Firm-level outsourcing decision making: A balanced scorecard-based analytic network process model. *Int. J. Prod. Econ.* 147 (C), 614-623.
  - De Felice, F., Petrillo, A., Cooper, O., 2013. An integrated conceptual model to promote green policies. *Int. J. Innovation and Sustainable Development*. 7 (4), 333-355.
  - De Felice, F., Petrillo, A., 2014. Proposal of a structured methodology for the measure of intangible criteria and for decision making. *Int. J. Simulation and Process Modelling*. 9 (3), 157-166.
  - De Felice, F., Petrillo, A., 2013. Multicriteria approach for process modelling in strategic environmental management planning. *Int. J. Simulation and Process Modelling*. 8 (1), 6-16.
- Please refer to the new Section 2 of the manuscript.

Again, thank you very much for your patience and interest. We hope that the revised paper is now suitable for publication.

Sincerely yours,  
Yuji Sato, Ph.D. (Corresponding author)

● Reviewer #3:

Dear reviewer:

The authors of this paper greatly appreciate your review of our paper “Investment Performance Analysis of Industrial Products: Case of an Effluent Processing Facility at a Chemical Company” (which has slightly been changed from the original title “Performance Analysis of Industrial Products: a Case of Effluent Processing Facility in a Chemical Company”). The comments and suggestions are valuable for helping us in revising the paper. We hope that we have addressed all the issues you raised.

As you kindly commented, the previous version of the manuscript lacked proper explanations of the research design and the contribution of this research, which stood on rather inadequate references. Based on your comments and suggestions, we have carried out substantial revision on the issues of: (a) research questions, (b) details of the case study including the introduction of the experts—executive, safety supervisors and designers, (c) literature review based on recent publications, and (d) contributions of the research in comparison with past publications.

Section 1 has been substantially revised, which focuses on introducing the background of this research and highlights the research questions of this paper. A new section has been added as Section 2 for literature review, in which literature analysis has been extended in order to cover recent AHP, ANP and BOCR analyses. In associate with this revision, the reference list has been updated that shows the link of this paper with past publications in IJPE. Details of the case study including the information on the experts have been added to former Section 2 (now Section 3). Former Section 4 (now Section 5) has been enriched with limitations of this research. Furthermore, English presentation has been refined through proof read by professional editor.

*Your comments in the report:*

*The paper provides insights into analysis of industrial products and suggests how to optimize specification of a product, requiring substantial investments. Though the research is conducted in a chemical company, the approach is relevant to other industries. The potential usefulness of the research is related to the decision making process of industrial customers. The approach combines objective data and subjective preferences of managers. Hence, suggested approach helps to assure more transparent and solid decision-making path. The methods applied in the research are not new. A novelty of the paper lies in the integration of BOCR analysis and AHP technique followed by multiple criteria performance analysis. The paper is clearly presented. The structure corresponds to the requirements for scientific publications. However, there are some drawbacks which need to be improved.*

*1. The authors are suggested to highlight the research questions in introduction part of the paper.*

As you kindly suggested, introduction part of this paper lacks highlighting the research question.

We thus substantially revised Section 1, which focuses on introducing the background of this research and highlights research questions of this paper (Please refer to new Section 1). In addition, we added the following explanation highlighting the motivation of this research to the last part of new Section 2.

new Section 2 (p. 7):

... must be dealt with. This paper thus focuses on ascertaining the intangible factors in the performance analysis of industrial products from a BOCR perspective, and proposes a systematic approach to performance analysis combining objective data and subjective preference.

2. *In the 2.1 subsection the authors indicate the interviews with the safety supervisors of a chemical company and I have a remark here. Please explain and justify how many supervisors participated in the interview and how they were selected. In the section 3.1 the authors indicated that the executives carried out pairwise comparison. However, the information related to executives is missing. It is not clear how many executives assessed the system. Please explain in detail the information related to managers of company X and designers of company Y.*

As you kindly remarked, we briefly described safety supervisors and executives of a chemical company and designers of a supplier in former subsections 2.1, 3.1 and 3.2 in the previous version of the manuscript. On the other hand, the descriptions of “managers of Co. X” and “managers of Co. Y” in former subsection 3.2 were not accurate, which should be “safety supervisors of Co. X” and “designers of Co. Y” respectively. Furthermore, how many safety supervisors and designers were interviewed, how they were selected, and how many executives conducted pairwise comparison are not clear in the form.

In order to clarify the details of experts who conducted evaluations, we revised new subsections 3.1, 4.1 and 4.2 as follows. In addition, we added the details of the case study to the first part of Section 4.

new subsection 3.1 (p. 8):

... study; details of the case study itself and of these safety supervisors and designers, will be introduced in Section 4.

new Section 4 (p. 14):

...a great many manufacturers. The case study, which was originally a workshop for the optimization of the specification of an EPS in Co. X, was carried out in Japan. The workshop consisted of two executives from Co. X who were in charge of the decision making in the investment, three safety supervisors of three subsystems of the EPS, and two designers of Co. Y who led the design of the EPS in Co. X. During the course of the workshop, technical aspects of effluent processing, including the parameters defining the performance of the system, were discussed, and the above-mentioned experts conducted the evaluation of the system. Although the companies' names, ...

new subsection 4.1 (p. 15):

..., as parameters in subsection 3.3. Three safety supervisors of Co. X are interviewed in order to identify criteria, each one in charge of the safety of one of the three subsystems (i.e., RC, FT and ST). Two designers of Co. Y committed to determining the criteria are the chief and sub-chief of the EPS design. Criteria  $c$  assesses: ...

... quantified by the AHP. In determining  $p_c$ , the two executives of Co. X who were in charge of the decision making in the investment conducted pairwise comparisons. In the process, they considered all aspects of the EPS and individually determined the relative importance of each  $c$  among four criteria. Their geometric mean was then assigned to a pairwise comparison matrix, which reflected the degree of importance of the four criteria. As can be seen in Table 2, ...

new subsection 4.2 (p. 20):

... how to promote its products. Retrospective interviews were carried out following the workshop with the safety supervisors of Co. X and the designers of Co. Y. Based on the interviews, ...



3. *In the last section there is a lack of previous studies for comparison. This section needs to be enriched with limitations.*

As you kindly suggested, we need to clarify the contribution of the research in respect to the previous studies. On the other hand, the limitations of this research (indexing indicators and the selection and definition of parameters) are briefly summarized in the last part of the manuscript.

We thus added further explanations to new Section 5 (pp. 21-23) as follows.

... confusion among decision makers. While a number of approaches to the performance analysis of industrial products have been proposed, approaches to the design of an EPS have been limited. In addition, even though many decision-support frameworks have been proposed, little research has provided a systematic model that considers intangible factors. The multi-criteria performance analysis ...

... find fulfilment in purchasing the product. Moreover, the proposed approach allows managers to have a clear decision path that provides traceability, enabling managers to revisit how the decision on an EPS was reached. Even though the proposed approach has been applied to the case of an EPS, it can be tailored and applied to any manufacturer or service company analyzing the performance of products or making investment decisions.

This paper demonstrates that a new integrated approach to multi-criteria performance analysis is effective. The companies in the case study acknowledged that the approach gave them an overview of the issues affecting EPS performance and provided them with a structured way of seeking to improve. Particularly, the prioritized BOCR and sensitivity analyses allowed them to communicate and make decisions effectively. In short, the BOCR model helps to address the shortcomings of existing approaches (e.g., Weifeng et al., 2016; Tjader et al., 2014; Tsai and Chang, 2013) by giving a clear and systematic approach to analyzing and diagnosing a particular problem. In addition, the proposed approach allows managers to consider various factors that are key to making sound EPS decisions. Specifically, both the positives (benefits and opportunities) and negatives (costs and risks) are quantitatively analyzed, and intangible factors are dealt with in the decision-making process.

Nonetheless, the proposed model has some limitations. Further research needs ...

... is an open ended question. Indeed, identifying a decision maker's utility function of indicators representing the performance of a product is quite challenging. The approximation of the utility in the formulation of analyses may be inevitable, and should be explored in future research.

4. *Considering the fact that some references are old, the authors are suggested to cite more recent publications and also to show the link of this paper with previous published works in IJPE.*

The previous version of the manuscript stood on rather inadequate references. As you kindly suggested, it is important to go over progresses in the recent AHP, ANP and BOCR applications, since we focus on the integration of AHP and BOCR followed by multiple criteria performance analysis of industrial products.

We thus added a new section as Section 2 for literature review. The following papers were added to the reference list, and literature review linked with past publications in IJPE were extended in new Section 2.

- De Felice, F., Petrillo, A., Cooper, O., 2013. An integrated conceptual model to promote green policies. *Int. J. Innovation and Sustainable Development*. 7 (4), 333-355.
- De Felice, F., Petrillo, A., 2014. Proposal of a structured methodology for the measure of intangible criteria and for decision making. *Int. J. Simulation and Process Modelling*. 9 (3), 157-166.

- De Felice, F., Petrillo, A., 2013. Multicriteria approach for process modelling in strategic environmental management planning. *Int. J. Simulation and Process Modelling*. 8 (1), 6-16.
  - Weifeng, Y., Xiaohong, X., Baoliu, P., Chunsheng, G., Jiangang, Y., 2016. The fuzzy comprehensive evaluation of water and sand inrush risk during underground mining. *J. Intell. & Fuzzy Sys.* 30 (4), 2289-2295.
  - Mohan, K.K., Srividya, A., Verma, A.K., 2016. Prototype dependability model in software: an application using BOCR models. *Int. J. Sys. Assurance Eng. and Manag.* 7 (2), 167–182.
  - Tsai, P-H., Chang, S-C., 2013. Comparing the Apple iPad and non-Apple camp tablet PCs: a multicriteria decision analysis. *Technological and Economic Development of Economy*. 19 (sup 1), S256-S284.
  - Chun-Yueh, L., Yih-Chearn, S., 2013. An Application of AHP and Sensitivity Analysis for Measuring the Best Strategy of Reverse Logistics: A Case Study of Photovoltaic Industry Chain. *J. Testing and Evaluation*. 41 (3), 1-12.
  - Fouladgar, M.M., Yazdani-Chamzini, A., Zavadskas, E.K., Moini, S.H.H., 2012. A new hybrid model for evaluating the working strategies: case study of construction company. *Technological and Economic Development of Economy*. 18 (1), 164-188.
  - Yap, H.Y., Nixon, J.D., 2015. A multi-criteria analysis of options for energy recovery from municipal solid waste in India and the UK. *Waste Management*. 46, 265-277.
  - Lee, A.H.I., 2009. A fuzzy AHP evaluation model for buyer–supplier relationships with the consideration of benefits, opportunities, costs and risks. *Int. J. Prod. Res.* 47 (15), 4255-4280.
  - Yazdani-Chamzini, A., Shariati, S., Yakhchali, S.H., Zavadskas, E.K., 2014. Proposing a new methodology for prioritising the investment strategies in the private sector of Iran. *Econ. Research-Ekonomska Istraživanja*. 27 (1), 320-345.
  - Lee, A.H.I., 2009. A fuzzy supplier selection model with the consideration of benefits, opportunities, costs and risks. *Expert Sys. with Applications*. 36 (2, 2), 2879-2893.
  - Cho, S., Kim, J., Heo, E., 2015. Application of fuzzy analytic hierarchy process to select the optimal heating facility for Korean horticulture and stockbreeding sectors. *Renewable and Sustainable Energy Rev.* 49, 1075–1083.
  - Bayazit O., Karpak, B., 2007. An analytical network process-based framework for successful total quality management (TQM): An assessment of Turkish manufacturing industry readiness. *Int. J. Prod. Econ.* 105 (1), 79-96.
  - Tjader, Y., May, J.H., Shang, J., Vargas, L.G., Ning Gao, N., 2014. Firm-level outsourcing decision making: A balanced scorecard-based analytic network process model. *Int. J. Prod. Econ.* 147 (C), 614-623.
  - Bouzarour-Amokrane, Y., Tchangani, A., Peres, F., 2015. Decision evaluation process in end-of-life systems management. *J. Manufacturing Sys.* 37 (3), 715–728.
  - Lee, A.H.I., Kang, H-Y., Chang, C-C., 2011. An integrated interpretive structural modeling-fuzzy analytic hierarchy network-benefit, opportunities, cost and risk model for selecting technologies. *Int. J. Information Technology & Decision Making*. 10 (5), 843-871.
- Please refer to the new Section 2 of the manuscript.

Again, thank you very much for your patience and interest. We hope that the revised paper is now suitable for publication.

Sincerely yours,  
Yuji Sato, Ph.D. (Corresponding author)



29 October 2016

Dear reviewer:

The authors of this paper greatly appreciate your review of our paper “Investment Performance Analysis of Industrial Products: Case of an Effluent Processing Facility at a Chemical Company” (which has slightly been changed from the original title “Performance Analysis of Industrial Products: a Case of Effluent Processing Facility in a Chemical Company”). The comments and suggestions are valuable for helping us in revising the paper. We hope that we have addressed all the issues you raised.

As you kindly commented, the previous version of the manuscript lacked proper explanations of the research design and the contribution of this research, which stood on rather inadequate references. Based on your comments and suggestions, we have carried out substantial revision on the issues of: (a) abstract, (b) details of the case study including the introduction of the expert team, (c) deeper literature review analysis based on recent publications, (d) definitions of decision criteria, (e) presentations of the results with deeper analyses, and (f) contributions of the research in respect to the state of the art.

Abstract has been rewritten, Section 1 has been substantially revised, which focuses on introducing the background of this research and highlights the research questions of this paper. A new section has been added as Section 2 for literature review, in which literature analysis has been extended in order to cover recent AHP, ANP and BOCR analyses. In associate with this revision, the reference list has been updated. Details of the case study have been added to former Section 2 (now Section 3). Former Section 3 (now Section 4) has also been refined, which clarifies the research model, and former Section 4 (now Section 5) has been enriched with limitations of this paper. Furthermore, English presentation has been refined through proof read by professional editor.

*Red: reviewer's comments*

*Blue: response to reviewer*

*Green: revisions made to the original manuscript*

*Your comments in the report:*

*In the present paper authors propose an interesting multi-criteria model based on AHP and BOCR Analysis to optimize performance within a Chemical Company. In general, the manuscript is well done and well organized. The topic of the paper is very promising and nice. I would like to suggest some minor improvements before the publication.*

- 1. First of all, I suggest to reconsider the abstract because in the present form it seems too wordy. A more concise and precise description is desirable.*

*As you kindly advised, the authors of this paper realized that the abstract in the previous version of the manuscript is rather wordy and includes some promises not discussed in detail.*

*We rewrote the abstract as follows.*

*This paper proposes an approach to a multi-criteria investment performance analysis of industrial products. Manufacturers must determine the necessary and sufficient specification of products they use. Such an analysis, however, involves a broad range of factors, including some that are subjective. The performance analysis and decision making for investment thus must often rely heavily on past experience, generalities, and intuition. This paper addresses these issues from a benefit, opportunity, cost and risk (BOCR) perspective, in which the criteria are prioritized and the products are evaluated objectively. Pairwise comparisons among the criteria and quantitative assessments of the performance of products comprise a prioritized BOCR analysis. A case study demonstrating the applicability of the proposed approach is conducted at a chemical company. Results show that the proposed approach succeeds in the multi-criteria performance analysis of industrial products, resulting in a*

practical proposal of a product specification best suited to this company's case.

2. *I suggest to add some more lines to introduce the expert team, the role of expert team, and judgments aggregation.*

As you noted, we briefly described the expert team in former subsections 2.1, 3.1 and 3.2 in the previous version of the manuscript. On the other hand, the descriptions of “managers of Co. X” and “managers of Co. Y” in former subsection 3.2 were not accurate, which should be “safety supervisors of Co. X” and “designers of Co. Y” respectively. Furthermore, both the role of the expert team and how the judgments were aggregated were not clear in the form.

In order to clarify the details of the expert team, we revised new subsections 3.1, 4.1 and 4.2 as follows.

new subsection 3.1 (p. 8):

... details of the case study itself and of these safety supervisors and designers, will be introduced in Section ...

new subsection 4.1 (p. 15):

... quantified by the AHP. In determining  $p_c$ , the two executives of Co. X who were in charge of the decision making in the investment conducted pairwise comparisons. In the process, they considered all aspects of the EPS and individually determined the relative importance of each  $c$  among four criteria. Their geometric mean was then assigned to a pairwise comparison matrix, which reflected the degree of importance of the four criteria. As can be seen in Table 2, ...

new subsection 4.2 (p. 20):

... how to promote its products. Retrospective interviews were carried out following the workshop with the safety supervisors of Co. X and the designers of Co. Y. Based on the interviews, ...

3. *Regarding section "1. Introduction", it is desirable a deeper literature review analysis. I would like to suggest to extend literature analysis and to take into account some references on AHP/ANP/BORC, such as:*

- *De Felice, F., Petrillo, A., Cooper, O., 2013. An integrated conceptual model to promote green policies. International Journal of Innovation and Sustainable Development. Volume 7, Issue 4, 2013, Pages 333-355.*
- *De Felice, F., Petrillo, A., 2014. Proposal of a structured methodology for the measure of intangible criteria and for decision making. International Journal of Simulation and Process Modelling. Volume 9, Issue 3, 2014, Pages 157-166. ISSN: 17402123. DOI: 10.1504/IJSPM.2014.064392.*
- *De Felice, F., Petrillo, A., 2013. Multicriteria approach for process modelling in strategic environmental management planning. International Journal of Simulation and Process Modelling, Volume 8, Issue 1, 2013, Pages 6-16.*

The previous version of the manuscript stood on rather inadequate references. As you kindly advised, it is important to go over progresses in the recent AHP, ANP and BOCR applications.

We added a new section as Section 2 for literature review. The following papers suggested in your comments were added to the reference list, and extended literature analysis.

- De Felice, F., Petrillo, A., Cooper, O., 2013. An integrated conceptual model to promote green policies. Int. J. Innovation and Sustainable Development. 7 (4), 333-355.
- De Felice, F., Petrillo, A., 2014. Proposal of a structured methodology for the measure of

intangible criteria and for decision making. *Int. J. Simulation and Process Modelling*. 9 (3), 157-166.

- De Felice, F., Petrillo, A., 2013. Multicriteria approach for process modelling in strategic environmental management planning. *Int. J. Simulation and Process Modelling*. 8 (1), 6-16.

In the process of the above-mentioned literature analysis, we found the following papers on the application of AHP, ANP and BOCR analyses. We, therefore, further added these papers to the reference list and enriched literature review in new Section 2.

- Weifeng, Y., Xiaohong, X., Baoliu, P., Chunsheng, G., Jiangang, Y., 2016. The fuzzy comprehensive evaluation of water and sand inrush risk during underground mining. *J. Intell. & Fuzzy Sys.* 30 (4), 2289-2295.
- Mohan, K.K., Srividya, A., Verma, A.K., 2016. Prototype dependability model in software: an application using BOCR models. *Int. J. Sys. Assurance Eng. and Manag.* 7 (2), 167–182.
- Tsai, P-H., Chang, S-C., 2013. Comparing the Apple iPad and non-Apple camp tablet PCs: a multicriteria decision analysis. *Technological and Economic Development of Economy*. 19 (sup 1), S256-S284.
- Chun-Yueh, L., Yih-Chearng, S., 2013. An Application of AHP and Sensitivity Analysis for Measuring the Best Strategy of Reverse Logistics: A Case Study of Photovoltaic Industry Chain. *J. Testing and Evaluation*. 41 (3), 1-12.
- Fouladgar, M.M., Yazdani-Chamzini, A., Zavadskas, E.K., Moini, S.H.H., 2012. A new hybrid model for evaluating the working strategies: case study of construction company. *Technological and Economic Development of Economy*. 18 (1), 164-188.
- Yap, H.Y., Nixon, J.D., 2015. A multi-criteria analysis of options for energy recovery from municipal solid waste in India and the UK. *Waste Management*. 46, 265-277.
- Lee, A.H.I., 2009. A fuzzy AHP evaluation model for buyer–supplier relationships with the consideration of benefits, opportunities, costs and risks. *Int. J. Prod. Res.* 47 (15), 4255-4280.
- Yazdani-Chamzini, A., Shariati, S., Yakhchali, S.H., Zavadskas, E.K., 2014. Proposing a new methodology for prioritising the investment strategies in the private sector of Iran. *Econ. Research-Ekonomska Istraživanja*. 27 (1), 320-345.
- Lee, A.H.I., 2009. A fuzzy supplier selection model with the consideration of benefits, opportunities, costs and risks. *Expert Sys. with Applications*. 36 (2, 2), 2879-2893.
- Cho, S., Kim, J., Heo, E., 2015. Application of fuzzy analytic hierarchy process to select the optimal heating facility for Korean horticulture and stockbreeding sectors. *Renewable and Sustainable Energy Rev.* 49, 1075–1083.
- Bayazit O., Karpak, B., 2007. An analytical network process-based framework for successful total quality management (TQM): An assessment of Turkish manufacturing industry readiness. *Int. J. Prod. Econ.* 105 (1), 79-96.
- Tjader, Y., May, J.H., Shang, J., Vargas, L.G., Ning Gao, N., 2014. Firm-level outsourcing decision making: A balanced scorecard-based analytic network process model. *Int. J. Prod. Econ.* 147 (C), 614-623.
- Bouzarour-Amokrane, Y., Tchangani, A., Peres, F., 2015. Decision evaluation process in end-of-life systems management. *J. Manufacturing Sys.* 37 (3), 715–728.
- Lee, A.H.I., Kang, H-Y., Chang, C-C., 2011. An integrated interpretive structural modeling-fuzzy analytic hierarchy network-benefit, opportunities, cost and risk model for selecting technologies. *Int. J. Information Technology & Decision Making*. 10 (5), 843-871.

Please refer to the new Section 2 of the manuscript.

4. I suggest to improve Figure 1 because it is not clear. Some more details are desirable.

Figure 1 was inserted to illustrate the image of the distribution of potential alternatives. We thought that the figure enabled readers to easily grasp the trade-off between the cost of effluent processing system and the degree of purification of effluent. As you kindly commented, however, the figure is rather confusing than clarifying the trade-off. On the other hand, the trade-off itself is not so complicated to understand if we carefully explain the relationship between the cost of the system and the degree of purification of effluent.

We removed Figure 1, and rewrote the last part of new subsection 3.1 (p. 9) as follows.

Each alternative of EPS must satisfy the requirements defined by the law, such as the cleanliness of discharge or the leakage risk of residuals. Alternatives barely satisfying the regulations would be inexpensive systems but might not be sustainable. On the other hand, alternatives need not err too much on the side of safety, as that would be expensive and might be an over-specification of the system. Customers of EPS must thus resolve this trade-off when selecting a system.

5. I suggest a more rigorous and precise definition of decision criteria.

As you kindly suggested, the definition of decision criteria in the previous version is rather inconsiderate.

We added a table (new Table 1) summarizing the definitions of decision criteria to new subsection 3.1 (p. 9), and rewrote the section to precisely define the criteria.

Table 1  
Criteria for performance analysis

Criteria	Definition
D (Benefit)	The cleanliness of discharge measured by the concentration of leaked BOD in effluent (mg/L), whose reciprocal value is identified as <u>B</u> enefit in BOCR analysis.
F (Opportunity)	Flexibility of the installation of an effluent processing system measured by the area of the installation of the system (m <sup>2</sup> ), whose reciprocal value is identified as <u>O</u> pportunity in BOCR analysis.
C (Cost)	Cost of the system measured by the total amount of initial and running costs (Yen/installation), whose actual value is identified as <u>C</u> ost in BOCR analysis.
L (Risk)	Leakage risk of residuals measured by the total amount of leaked SS (Kg/day), whose actual value is identified as <u>R</u> isk in BOCR analysis.

6. I suggest to improve Formulation of prioritized BOCR analysis.

As for formula (1), since significant differences in variance exist among indicators relating to decision criteria, each parameter,  $c_{*i}$ , is transformed into the T-score of criterion c by this formula. Concerning formula (2), the prioritized BOCR function,  $pBOCR_{*i}$ , defined by this formula calculates each alternative's prioritized performance reflecting customer's preference. Since this formula is based on the above-mentioned formula (1), the prioritized BOCR function can cope with various decision criteria with different units, and can deal with various customers' preferences.

We think that the above-mentioned "T-score transformation" and "prioritization" of the proposed approach makes it possible to deal with various cases of performance analysis, which is practical in real world. We also cover the suggested issue in Section 5 as a future research topic.

7. Please explain better Fig. 2. Results of BOCR analyses.

8. Please explain better Fig. 3. Results of sensitivity analyses of different preference.

As you commented, figures 2 and 3 are rather confusing. Furthermore, even though both figures illustrate similar contents, i.e., the change in the rankings of alternatives, they had different types of presentations, which added to confusion further.

We replaced these two figures with the following ones formatted in common.

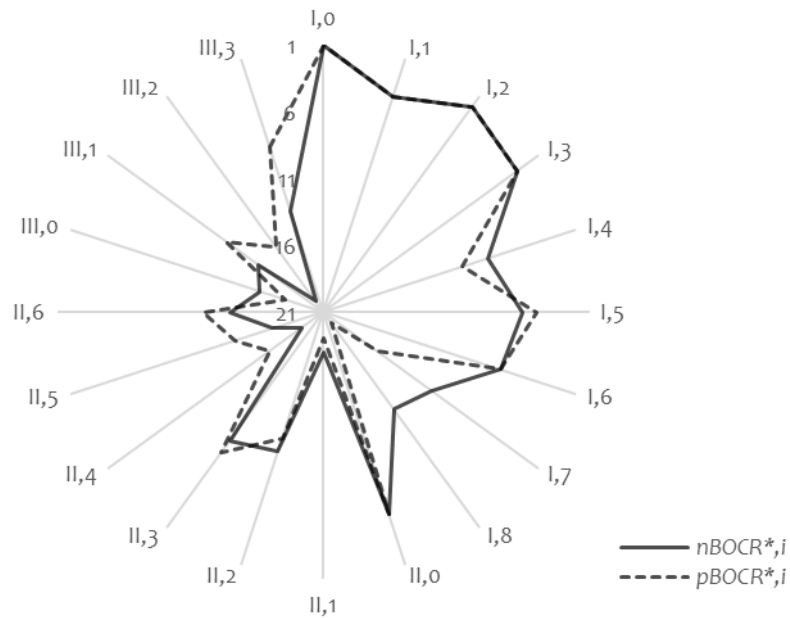


Fig. 2. Results of BOCR analyses (Rankings of potential alternatives).

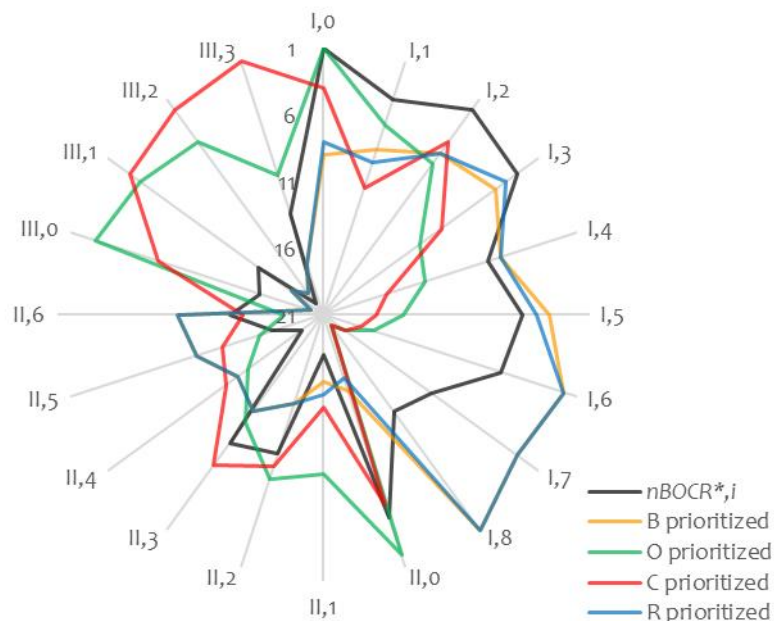


Fig. 3. Results of sensitivity analyses (Rankings of potential alternatives).



9. *It could be useful to show the AHP model.*

As you kindly suggested, a figure illustrating the AHP model helps readers easily understand the approach proposed in this paper.

We added Figure 1 and related explanation to new subsection 3.2 (pp. 11-12).

Figure 1 graphically represents the relationship between the collection of information on customer preference and the quantitative evaluation of potential alternatives otherwise known as an AHP model. As shown in the figure, pairwise comparisons reflected a customer's preference are carried out between the goal of the analyses and the decision criteria, prioritizing the degree of importance of each criterion. Then a quantitative analysis based on the objective data of potential alternatives is conducted between the decision criteria and potential alternatives, evaluating advantages and disadvantages of each potential alternative. This integration of the AHP technique and quantitative analysis followed by a multiple-criteria performance analysis comprises the prioritized BOCR analysis.

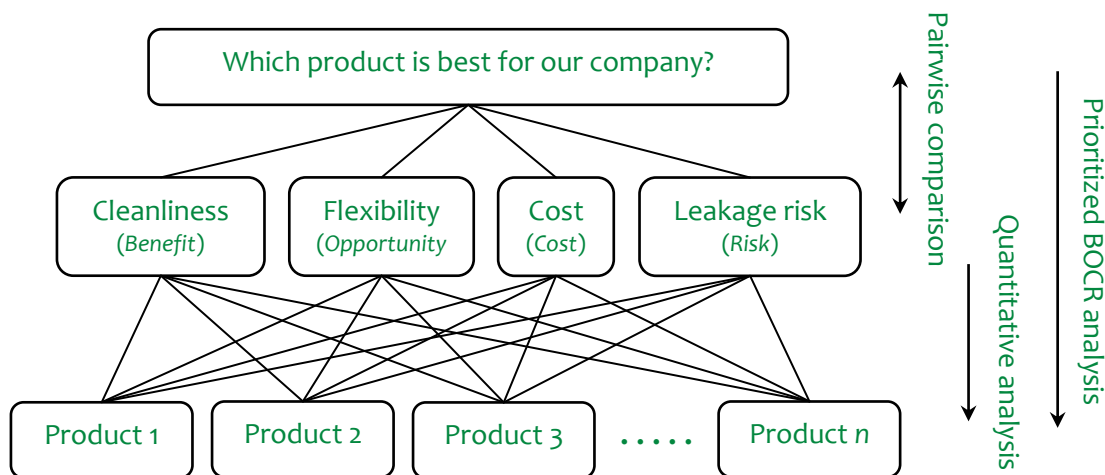


Fig. 1. AHP model.

10. *Please add some more considerations about the managerial implications.*

Based on the retrospective interviews, we described the managerial implications in former subsection 3.2 as follows. From customer's perspective, "... enables the managers of Co. X to gain better insight into the evaluation and selection of new processing system under complicated situation (customer's perspective)." And from supplier's perspective, "... help managers of Co. Y address various customers' requirements (preference) and optimize the design of an EPS with its own technologies in their sales promotion for potential customers (supplier's perspective)." On the other hand, we briefly described the managerial implications from executive's perspective in former Section 4. As you kindly suggested, we need to explore the contributions of this research further.

In order to clarify the managerial implications from executive's perspective, we added further explanations to new Section 5 (pp. 21-22).

... confusion among decision makers. While a number of approaches to the performance analysis of industrial products have been proposed, approaches to the design of an EPS have been limited. In addition, even though many decision-support frameworks have been proposed, little research has provided a systematic model that considers intangible factors. The multi-criteria performance analysis ...

... feel justified in making the purchase. Moreover, the proposed approach allows managers

to have a clear decision path that provides traceability, enabling managers to revisit how the decision on an EPS was reached. Even though the proposed approach has been applied to the case of an EPS, it can be tailored and applied to any manufacturer or service company analyzing the performance of products or making investment decisions. This paper demonstrates that ...

11. *Please check English and grammar. Sometimes sentences are not clear. Please pay attention to language.*

We had the revised version of the manuscript proof read by a professional editor.

12. *Please define and clarify the contribution of the research respect the state of art.*

As you kindly suggested, we need to clarify the contribution of the research in respect to the state of the art. We think that the additional explanations in new Section 5 (noted in the above response to your comment #10) could explain a part of the contributions of this research. In addition, we added further explanations to new Section 5 (pp. 22-23).

This paper demonstrates that a new integrated approach to multi-criteria performance analysis is effective. The companies in the case study acknowledged that the approach gave them an overview of the issues affecting EPS performance and provided them with a structured way of seeking to improve. Particularly, the prioritized BOCR and sensitivity analyses allowed them to communicate and make decisions effectively. In short, the BOCR model helps to address the shortcomings of existing approaches (e.g., Weifeng et al., 2016; Tjader et al., 2014; Tsai and Chang, 2013) by giving a clear and systematic approach to analyzing and diagnosing a particular problem. In addition, the proposed approach allows managers to consider various factors that are key to making sound EPS decisions. Specifically, both the positives (benefits and opportunities) and negatives (costs and risks) are quantitatively analyzed, and intangible factors are dealt with in the decision-making process.

13. *A deeper analysis of results is desirable.*

As you kindly advised, we briefly summarized the results of the analyses in former Section 3 in the previous version of the manuscript.

We thus added Table 3 summarizing the results of the BOCR analyses to new subsection 4.1, and carried out a deeper analysis of the results. The explanations of Figures 2 and 3 were revised in accordance with the refinement of the figures.

new subsection 4.1 (pp. 16-17):

... is represented as  $p_c$ . As summarized in the appendix, the score of O (Flexibility) drastically changes in its value in comparison with the other criteria B (Cleanliness), C (Costs) and R (Leakage risk). This difference results in higher scores of alternatives with a greater number of RC, that is, with less volume of FT. As shown in ...

Table 3  
Results of BOCR analyses.

System architecture	$nBOCR_{*,i}$	$pBOCR_{*,i}$
l,0	1.0288	1.0057
l,1	1.0104	1.0019
l,2	1.0208	1.0055
l,3	1.014	1.0037

I,4	1.0021	1.0001
I,5	1.0038	1.0008
I,6	1.0029	1.0004
I,7	0.9951	0.9979
I,8	0.9932	0.997
II,0	1.0077	1.0008
II,1	0.9903	0.9971
II,2	0.9961	0.9991
II,3	0.9979	1.0002
II,4	0.9897	0.9979
II,5	0.9911	0.9984
II,6	0.9926	0.9988
III,0	0.9913	0.9973
III,1	0.9922	0.9988
III,2	0.9884	0.9983
III,3	0.9927	1.0002

**new subsection 4.2 (p. 19):**

As with the analyses in the previous section, significant differences in scores of O (Flexibility) in comparison with the other criteria result in a drastic change in the ranking of alternatives. For instance, a potential alternative (I,8) designed on the newest architecture with more RC is ranked at the top based on B prioritized preference; based on C prioritized preference, however, the alternative is ranked as the worst, where the normal BOCR analysis ranks it 12th among 20 alternatives. This result is considered to be induced by the number of RC that can effectively purify effluent but at great cost. As a result, the rankings of ...

**14. Please add some more details about the case study.**

As you noted, the description of the case study in former Section 3 of the previous version the manuscript is rather inconsiderate. On the other hand, detailed information including the name of the companies cannot be disclosed due to confidentiality agreements.

In addition to the detailed introduction of expert team added to new subsection 4.1, we further added the following information of the case study to new Section 4 (p. 14).

... The case study, which was originally a workshop for the optimization of the specification of an EPS in Co. X, was carried out in Japan. The workshop consisted of two executives from Co. X who were in charge of the decision making in the investment, three safety supervisors of three subsystems of the EPS, and two designers of Co. Y who led the design of the EPS in Co. X. During the course of the workshop, technical aspects of effluent processing, including the parameters defining the performance of the system, were discussed, and the above-mentioned experts conducted the evaluation of the system. Although the companies' names, ...

Again, thank you very much for your patience and interest. We hope that the revised paper is now suitable for publication.

Sincerely yours,  
Yuji Sato, Ph.D. (Corresponding author)

29 October 2016

Dear reviewer:

The authors of this paper greatly appreciate your review of our paper “Investment Performance Analysis of Industrial Products: Case of an Effluent Processing Facility at a Chemical Company” (which has slightly been changed from the original title “Performance Analysis of Industrial Products: a Case of Effluent Processing Facility in a Chemical Company”). The comments and suggestions are valuable for helping us in revising the paper. We hope that we have addressed all the issues you raised.

As you kindly commented, the previous version of the manuscript stood on rather inadequate references. Based on your comments and suggestions, we have carried out substantial revision on the issue of the references on the applications of AHP, ANP and BOCR analysis.

Section 1 has been substantially revised, which focuses on the introducing the background of this research and highlights the research questions of this paper. A new section has been added as Section 2 for literature review, in which literature analysis has been extended in order to cover recent AHP, ANP and BOCR analyses. In associate with this revision, the reference list has been updated. Furthermore, English presentation has been refined through proof read by professional editor.

Red: reviewer's comments

Blue: response to reviewer

Green: revisions made to the original manuscript

Your comments in the report:

Used old literary sources (1967-2008). Additionally cited:

- *Int j of prod res* 47(15)4255-4280.2009.
- *ESWA* 36(2)2879-2893.
- *Int J of systems assurance engineering and management* 7(2)167-182.
- *IJITDM*41(3)386-397.
- *Technological and economic development of economy* 19:S256-S284 Suppl 1. 2013.
- *Int J of testing and evaluation* 41(3)386-397.2013.
- *Technological and economic development of economy* 18(1)164-188.2012.
- *Renewable and sust energy reviews* 49:1075-1083.2015.
- *Journal of manufacturing systems* 37:715-728, part 3.2015.
- *Waste management* 46:265-245.2015.
- *Economic research-Ekonomska istrazivanja* 27(1)320-345.2014.
- *J of intell & fuzzy systems* 30(4)2283-2396.

As you kindly advised, the reference of AHP, ANP and BOCR analyses in the previous version is rather old. We added a new section as Section 2 for literature review. The following papers suggested in your comments were added to the reference list, and extended literature review.

- Weifeng, Y., Xiaohong, X., Baoliu, P., Chunsheng,G., Jiangang,Y., 2016. The fuzzy comprehensive evaluation of water and sand inrush risk during underground mining. *J. Intell. & Fuzzy Sys.* 30 (4), 2289-2295.
- Mohan, K.K., Srividya, A., Verma, A.K., 2016. Prototype dependability model in software: an application using BOCR models. *Int. J. Sys. Assurance Eng. and Manag.* 7 (2), 167–182.
- Tsai, P-H., Chang, S-C., 2013. Comparing the Apple iPad and non-Apple camp tablet PCs: a multicriteria decision analysis. *Technological and Economic Development of Economy.* 19 (sup 1), S256-S284.
- Chun-Yueh, L., Yih-Chearnng, S., 2013. An Application of AHP and Sensitivity Analysis for Measuring the Best Strategy of Reverse Logistics: A Case Study of Photovoltaic Industry Chain. *J. Testing and Evaluation.* 41 (3), 1-12.

- Fouladgar, M.M., Yazdani-Chamzini, A., Zavadskas, E.K., Moini, S.H.H., 2012. A new hybrid model for evaluating the working strategies: case study of construction company. *Technological and Economic Development of Economy*. 18 (1), 164-188.
- Yap, H.Y., Nixon, J.D., 2015. A multi-criteria analysis of options for energy recovery from municipal solid waste in India and the UK. *Waste Management*. 46, 265-277.
- Lee, A.H.I., 2009. A fuzzy AHP evaluation model for buyer–supplier relationships with the consideration of benefits, opportunities, costs and risks. *Int. J. Prod. Res.* 47 (15), 4255-4280.
- Yazdani-Chamzini, A., Shariati, S., Yakhchali, S.H., Zavadskas, E.K., 2014. Proposing a new methodology for prioritising the investment strategies in the private sector of Iran. *Econ. Research-Ekonomska Istraživanja*. 27 (1), 320-345.
- Lee, A.H.I., 2009. A fuzzy supplier selection model with the consideration of benefits, opportunities, costs and risks. *Expert Sys. with Applications*. 36 (2, 2), 2879-2893.
- Cho, S., Kim, J., Heo, E., 2015. Application of fuzzy analytic hierarchy process to select the optimal heating facility for Korean horticulture and stockbreeding sectors. *Renewable and Sustainable Energy Rev.* 49, 1075–1083.
- Bouzarour-Amokrane, Y., Tchangani, A., Peres, F., 2015. Decision evaluation process in end-of-life systems management. *J. Manufacturing Sys.* 37 (3), 715–728.
- Lee, A.H.I., Kang, H-Y., Chang, C-C., 2011. An integrated interpretive structural modeling-fuzzy analytic hierarchy network-benefit, opportunities, cost and risk model for selecting technologies. *Int. J. Information Technology & Decision Making*. 10 (5), 843-871.

In the process of the above-mentioned literature analysis, we found the following papers on the application of AHP, ANP and BOCR analyses. We, therefore, further added these papers to the reference list and enriched literature review in new Section 2.

- Bayazit O., Karpak, B., 2007. An analytical network process-based framework for successful total quality management (TQM): An assessment of Turkish manufacturing industry readiness. *Int. J. Prod. Econ.* 105 (1), 79-96.
- Tjader, Y., May, J.H., Shang, J., Vargas, L.G., Ning Gao, N., 2014. Firm-level outsourcing decision making: A balanced scorecard-based analytic network process model. *Int. J. Prod. Econ.* 147 (C), 614-623.
- De Felice, F., Petrillo, A., Cooper, O., 2013. An integrated conceptual model to promote green policies. *Int. J. Innovation and Sustainable Development*. 7 (4), 333-355.
- De Felice, F., Petrillo, A., 2014. Proposal of a structured methodology for the measure of intangible criteria and for decision making. *Int. J. Simulation and Process Modelling*. 9 (3), 157-166.
- De Felice, F., Petrillo, A., 2013. Multicriteria approach for process modelling in strategic environmental management planning. *Int. J. Simulation and Process Modelling*. 8 (1), 6-16.

Please refer to the new Section 2 of the manuscript.

Again, thank you very much for your patience and interest. We hope that the revised paper is now suitable for publication.

Sincerely yours,  
Yuji Sato, Ph.D. (Corresponding author)

29 October 2016

Dear reviewer:

The authors of this paper greatly appreciate your review of our paper “Investment Performance Analysis of Industrial Products: Case of an Effluent Processing Facility at a Chemical Company” (which has slightly been changed from the original title “Performance Analysis of Industrial Products: a Case of Effluent Processing Facility in a Chemical Company”). The comments and suggestions are valuable for helping us in revising the paper. We hope that we have addressed all the issues you raised.

As you kindly commented, the previous version of the manuscript lacked proper explanations of the research design and the contribution of this research, which stood on rather inadequate references. Based on your comments and suggestions, we have carried out substantial revision on the issues of: (a) research questions, (b) details of the case study including the introduction of the experts—executive, safety supervisors and designers, (c) literature review based on recent publications, and (d) contributions of the research in comparison with past publications.

Section 1 has been substantially revised, which focuses on introducing the background of this research and highlights the research questions of this paper. A new section has been added as Section 2 for literature review, in which literature analysis has been extended in order to cover recent AHP, ANP and BOCR analyses. In associate with this revision, the reference list has been updated that shows the link of this paper with past publications in IJPE. Details of the case study including the information on the experts have been added to former Section 2 (now Section 3). Former Section 4 (now Section 5) has been enriched with limitations of this research. Furthermore, English presentation has been refined through proof read by professional editor.

*Red: reviewer’s comments*

*Blue: response to reviewer*

*Green: revisions made to the original manuscript*

*Your comments in the report:*

*The paper provides insights into analysis of industrial products and suggests how to optimize specification of a product, requiring substantial investments. Though the research is conducted in a chemical company, the approach is relevant to other industries. The potential usefulness of the research is related to the decision making process of industrial customers. The approach combines objective data and subjective preferences of managers. Hence, suggested approach helps to assure more transparent and solid decision-making path. The methods applied in the research are not new. A novelty of the paper lies in the integration of BOCR analysis and AHP technique followed by multiple criteria performance analysis. The paper is clearly presented. The structure corresponds to the requirements for scientific publications. However, there are some drawbacks which need to be improved.*

*1. The authors are suggested to highlight the research questions in introduction part of the paper.*

As you kindly suggested, introduction part of this paper lacks highlighting the research question.

We thus substantially revised Section 1, which focuses on introducing the background of this research and highlights research questions of this paper (Please refer to new Section 1). In addition, we added the following explanation highlighting the motivation of this research to the last part of new Section 2.

new Section 2 (p. 7):

... must be dealt with. This paper thus focuses on ascertaining the intangible factors in the performance analysis of industrial products from a BOCR perspective, and proposes a systematic approach to performance analysis combining objective data and subjective

preference.

- In the 2.1 subsection the authors indicate the interviews with the safety supervisors of a chemical company and I have a remark here. Please explain and justify how many supervisors participated in the interview and how they were selected. In the section 3.1 the authors indicated that the executives carried out pairwise comparison. However, the information related to executives is missing. It is not clear how many executives assessed the system. Please explain in detail the information related to managers of company X and designers of company Y.*

As you kindly remarked, we briefly described safety supervisors and executives of a chemical company and designers of a supplier in former subsections 2.1, 3.1 and 3.2 in the previous version of the manuscript. On the other hand, the descriptions of “managers of Co. X” and “managers of Co. Y” in former subsection 3.2 were not accurate, which should be “safety supervisors of Co. X” and “designers of Co. Y” respectively. Furthermore, how many safety supervisors and designers were interviewed, how they were selected, and how many executives conducted pairwise comparison are not clear in the form.

In order to clarify the details of experts who conducted evaluations, we revised new subsections 3.1, 4.1 and 4.2 as follows. In addition, we added the details of the case study to the first part of Section 4.

new subsection 3.1 (p. 8):

... study; details of the case study itself and of these safety supervisors and designers, will be introduced in Section 4.

new Section 4 (p. 14):

... a great many manufacturers. The case study, which was originally a workshop for the optimization of the specification of an EPS in Co. X, was carried out in Japan. The workshop consisted of two executives from Co. X who were in charge of the decision making in the investment, three safety supervisors of three subsystems of the EPS, and two designers of Co. Y who led the design of the EPS in Co. X. During the course of the workshop, technical aspects of effluent processing, including the parameters defining the performance of the system, were discussed, and the above-mentioned experts conducted the evaluation of the system. Although the companies' names, ...

new subsection 4.1 (p. 15):

..., as parameters in subsection 3.3. Three safety supervisors of Co. X are interviewed in order to identify criteria, each one in charge of the safety of one of the three subsystems (i.e., RC, FT and ST). Two designers of Co. Y committed to determining the criteria are the chief and sub-chief of the EPS design. Criteria  $c$  assesses: ...

... quantified by the AHP. In determining  $p_c$ , the two executives of Co. X who were in charge of the decision making in the investment conducted pairwise comparisons. In the process, they considered all aspects of the EPS and individually determined the relative importance of each  $c$  among four criteria. Their geometric mean was then assigned to a pairwise comparison matrix, which reflected the degree of importance of the four criteria. As can be seen in Table 2, ...

new subsection 4.2 (p. 20):

... how to promote its products. Retrospective interviews were carried out following the workshop with the safety supervisors of Co. X and the designers of Co. Y. Based on the interviews, ...

- In the last section there is a lack of previous studies for comparison. This section needs to be*

*enriched with limitations.*

As you kindly suggested, we need to clarify the contribution of the research in respect to the previous studies. On the other hand, the limitations of this research (indexing indicators and the selection and definition of parameters) are briefly summarized in the last part of the manuscript.

We thus added further explanations to new Section 5 (pp. 21-23) as follows.

... confusion among decision makers. While a number of approaches to the performance analysis of industrial products have been proposed, approaches to the design of an EPS have been limited. In addition, even though many decision-support frameworks have been proposed, little research has provided a systematic model that considers intangible factors. The multi-criteria performance analysis ...

... find fulfilment in purchasing the product. Moreover, the proposed approach allows managers to have a clear decision path that provides traceability, enabling managers to revisit how the decision on an EPS was reached. Even though the proposed approach has been applied to the case of an EPS, it can be tailored and applied to any manufacturer or service company analyzing the performance of products or making investment decisions.

This paper demonstrates that a new integrated approach to multi-criteria performance analysis is effective. The companies in the case study acknowledged that the approach gave them an overview of the issues affecting EPS performance and provided them with a structured way of seeking to improve. Particularly, the prioritized BOCR and sensitivity analyses allowed them to communicate and make decisions effectively. In short, the BOCR model helps to address the shortcomings of existing approaches (e.g., Weifeng et al., 2016; Tjader et al., 2014; Tsai and Chang, 2013) by giving a clear and systematic approach to analyzing and diagnosing a particular problem. In addition, the proposed approach allows managers to consider various factors that are key to making sound EPS decisions. Specifically, both the positives (benefits and opportunities) and negatives (costs and risks) are quantitatively analyzed, and intangible factors are dealt with in the decision-making process.

Nonetheless, the proposed model has some limitations. Further research needs ...

... is an open ended question. Indeed, identifying a decision maker's utility function of indicators representing the performance of a product is quite challenging. The approximation of the utility in the formulation of analyses may be inevitable, and should be explored in future research.

*4. Considering the fact that some references are old, the authors are suggested to cite more recent publications and also to show the link of this paper with previous published works in IJPE.*

The previous version of the manuscript stood on rather inadequate references. As you kindly suggested, it is important to go over progresses in the recent AHP, ANP and BOCR applications, since we focus on the integration of AHP and BOCR followed by multiple criteria performance analysis of industrial products.

We thus added a new section as Section 2 for literature review. The following papers were added to the reference list, and literature review linked with past publications in IJPE were extended in new Section 2.

- De Felice, F., Petrillo, A., Cooper, O., 2013. An integrated conceptual model to promote green policies. *Int. J. Innovation and Sustainable Development*. 7 (4), 333-355.
- De Felice, F., Petrillo, A., 2014. Proposal of a structured methodology for the measure of intangible criteria and for decision making. *Int. J. Simulation and Process Modelling*. 9 (3), 157-166.
- De Felice, F., Petrillo, A., 2013. Multicriteria approach for process modelling in strategic environmental management planning. *Int. J. Simulation and Process Modelling*. 8 (1), 6-16.



- Weifeng, Y., Xiaohong, X., Baoliu, P., Chunsheng, G., Jiangang, Y., 2016. The fuzzy comprehensive evaluation of water and sand inrush risk during underground mining. *J. Intell. & Fuzzy Sys.* 30 (4), 2289-2295.
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- Fouladgar, M.M., Yazdani-Chamzini, A., Zavadskas, E.K., Moini, S.H.H., 2012. A new hybrid model for evaluating the working strategies: case study of construction company. *Technological and Economic Development of Economy.* 18 (1), 164-188.
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- Yazdani-Chamzini, A., Shariati, S., Yakhchali, S.H., Zavadskas, E.K., 2014. Proposing a new methodology for prioritising the investment strategies in the private sector of Iran. *Econ. Research-Ekonomska Istraživanja.* 27 (1), 320-345.
- Lee, A.H.I., 2009. A fuzzy supplier selection model with the consideration of benefits, opportunities, costs and risks. *Expert Sys. with Applications.* 36 (2, 2), 2879-2893.
- Cho, S., Kim, J., Heo, E., 2015. Application of fuzzy analytic hierarchy process to select the optimal heating facility for Korean horticulture and stockbreeding sectors. *Renewable and Sustainable Energy Rev.* 49, 1075–1083.
- Bayazit O., Karpak, B., 2007. An analytical network process-based framework for successful total quality management (TQM): An assessment of Turkish manufacturing industry readiness. *Int. J. Prod. Econ.* 105 (1), 79-96.
- Tjader, Y., May, J.H., Shang, J., Vargas, L.G., Ning Gao, N., 2014. Firm-level outsourcing decision making: A balanced scorecard-based analytic network process model. *Int. J. Prod. Econ.* 147 (C), 614-623.
- Bouzarour-Amokrane, Y., Tchangani, A., Peres, F., 2015. Decision evaluation process in end-of-life systems management. *J. Manufacturing Sys.* 37 (3), 715–728.
- Lee, A.H.I., Kang, H-Y., Chang, C-C., 2011. An integrated interpretive structural modeling-fuzzy analytic hierarchy network-benefit, opportunities, cost and risk model for selecting technologies. *Int. J. Information Technology & Decision Making.* 10 (5), 843-871.

Please refer to the new Section 2 of the manuscript.

Again, thank you very much for your patience and interest. We hope that the revised paper is now suitable for publication.

Sincerely yours,  
Yuji Sato, Ph.D. (Corresponding author)

**Title:**

Investment Performance Analysis of Industrial Products: Case of an Effluent Processing Facility at a Chemical Company

**Authors:**

Yuji Sato<sup>1\*</sup>

Kim Hua Tan<sup>2</sup>

Ying Kei Tse<sup>3</sup>

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**Highlights of this paper:**

- This paper proposes a multi-criteria performance analysis of industrial products.
- The analysis integrates benefit-opportunity-cost-risk (BOCR) analysis and the AHP.
- Outputs of the analysis are more compatible than those of the original BOCR.
- A case study verifies the effectiveness of the proposed approach of analysis.
- The approach can be applied to any manufacturer analyzing product's performance.

# Investment Performance Analysis of Industrial Products: Case of an Effluent Processing Facility at a Chemical Company

Yuji Sato<sup>1\*</sup>, Kim Hua Tan<sup>2</sup>, Ying Kei Tse<sup>3</sup>

<sup>1</sup> Graduate School of Management, Chukyo University,

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## Abstract

This paper proposes an approach to a multi-criteria investment performance analysis of industrial products. Manufacturers must determine the necessary and sufficient specification of products they use. Such an analysis, however, involves a broad range of factors, including some that are subjective. The performance analysis and decision making for investment thus must often rely heavily on past experience, generalities, and intuition. This paper addresses these issues from a benefit, opportunity, cost and risk (BOCR) perspective, in which the criteria are prioritized and the products are evaluated objectively. Pairwise comparisons among the criteria and quantitative assessments of the performance of products comprise a prioritized BOCR analysis. A case study demonstrating the applicability of the proposed approach is conducted at a chemical company. Results show that the proposed approach succeeds in the multi-criteria performance analysis of industrial products, resulting in a practical proposal of a product specification best suited to this company's case.

**Keywords:** Performance analysis; Industrial products; Customer preference; subjective factor; analytic hierarchy process; BOCR analysis

## 1. Introduction

Making investment decisions for industrial products costing large sums of money can be quite complicated. Customers must analyze the performance of potential alternatives, and then determine the architecture and specifications of the product, all while being

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1 mindful of rapid changes taking place in the technological environment. The difficulties  
2 arise primarily from intangible factors, such as customer judgment on criteria that enters  
3 into the evaluation and the need to select an appropriate alternative. Confounding the  
4 decision-making process is that preferences for products are often subjective. As such,  
5 the performance analysis relies heavily on experience, generalities, and intuition, all of  
6 which lack transparency and traceability (Tan et al. 2006).  
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15 One industry that would benefit from a more objective decision-making process is  
16 that dealing with effluent process systems (EPS). Stehna and Bergströmb (2002)  
17 proposed a customer-oriented approach to the design of industrial products that could  
18 be applied to the performance analysis of an EPS. Their approach, however, did not  
19 explicitly incorporate customers' subjective preferences into the design. Because  
20 customers were unaware of the factors that were taken into account or how trade-offs  
21 were resolved, they were wary of accepting the solution. As a customer of an EPS, a  
22 manufacturer faces tremendous challenges in designing the processing system and  
23 selecting the appropriate technologies. While many decision-support frameworks have  
24 been proposed in the literature (e.g., Tan, et al. 2006; De Felice and Petrillo 2014;  
25 Bouzarour-Amokrane, et al. 2015), only a few studies have provided systematic models  
26 that consider intangible factors such as the customer's judgment of decision criteria.  
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46 What is available, though, is objective data, which can provide a quantitative analysis  
47 of the specifications of potential alternatives underlying the process in the performance  
48 analysis. For example, traditional methodologies for quantitative analysis, such as cost-  
49 benefit analysis, are often used to evaluate alternatives. To date, a number of approaches  
50 to the performance analysis of industrial products have been proposed. A workable  
51 approach to the design of an EPS has been limited, however, as each manufacturer  
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1 demands its “haute-couture” design of the system, whose details range from the ease of  
2 risk management to the green image of the company. Consequently, if we are to include  
3  
4 other factors (e.g., opportunities and risks) in the analysis, then performance-analysis  
5  
6 approaches that take into consideration only benefits and costs of alternatives do not  
7  
8 fulfill the requirements.  
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11  
12 To carry out a more robust analysis that optimizes the specification of products for a  
13 manufacturer, this paper proposes an approach to a multi-criteria performance analysis  
14  
15 of industrial products by combining the Analytic Hierarchy Process (AHP) and a benefit,  
16  
17 opportunity, cost and risk analysis (BOCR analysis). The AHP is the measurement method  
18  
19 of human perception proposed by Saaty (1980), and has since been disseminated with  
20  
21 the development of software (e.g., expertchoice®). Along with the refinement, the AHP  
22  
23 has been widely used in a variety of fields because of its user-friendly interface and its  
24  
25 compatibility with problems in the real world. The BOCR analysis was developed in the  
26  
27 AHP literature as one of evolved cost-benefit analysis (e.g., Saaty 2001; Saaty and  
28  
29 Ozdemir 2004), which precisely analyzes both pros (benefits and opportunities) and cons  
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31 (costs and risks) quantitatively. The series of steps of quantification and evaluation in the  
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33 procedure introduce clarity of thought into the decision-making process.  
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43 The multi-criteria performance analysis of industrial products proposed in this paper  
44 first requires customers of an EPS to determine the degree of importance of each  
45  
46 criterion for the analysis by using the AHP, in which subjective factors in the analysis are  
47  
48 quantified. This quantitative information then allows customers to systematically  
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50 evaluate potential alternatives by conducting a quantitative evaluation followed by the  
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52 prioritized BOCR analysis proposed in this paper. Note that a refined “rescaled quotient  
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54 with sum” form is employed as a BOCR function in this paper based on the critique made  
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1 by Wijnmalen (2007). The results evaluating not only potential alternatives but also  
2 criteria for the analysis thus fully justify the final outputs of the analysis. An additional  
3 benefit of the revised formulation is that the rationale behind each process of the analysis  
4 is captured and can then be used as the basis for a final judgment.  
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10 Neither of the methodologies, that is, the AHP or the BOCR analysis, employed here is  
11 new. Integrating them, however, provides new insight into industrial problems, thus  
12 improving industrial practice and supporting sound decision making. Furthermore, the  
13 outcome of this integrated approach suggests the best architecture and specification for  
14 a product, which satisfies the industrial requirement and its managerial and economic  
15 consequences. Based on traditional analytical methodologies, the performance analysis  
16 proposed here provides practical value in industrial applications, as confirmed by the  
17 retrospective survey carried out following the case study. Although the proposed  
18 approach has been designed for a chemical company, it can be tailored and applied to any  
19 manufacturer that desires to analyze the performance of products or investment  
20 decisions.  
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38 Section 3 describes the research design: outline of effluent processing; the  
39 methodology for collecting information on customer preference; and the formulation of  
40 the prioritized BOCR analysis. In Section 4, a case study verifying the proposed approach  
41 is introduced, in which the architecture and specification of a new EPS is optimized. The  
42 implications for a product's supplier in its sales promotion for potential customers are  
43 also explored. Section 5 concludes this paper and discusses its limitations and future  
44 research directions.  
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## 59 **2. Literature review**

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2 Much has been written about the technology investment and selection problem,  
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4 which can be applied to the performance analysis of industrial products (e.g., Sriram and  
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6 Stump 2004; Debo, et al. 2005; Kasikowski, et al. 2008). One of the typical papers on  
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8 hazardous waste treatment processes, by Evenson and Baetz (1994), adopted  
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10 optimization methods to solve the selection problem of system design, under the  
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12 assumption that all information for the system design is quantitatively given for  
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14 customers in solving the problem. Few models, however, have been developed for the  
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16 design of an EPS. In EPS design decisions, managers face difficulties selecting the right  
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18 criteria, as each customer/manufacturer has its unique preference for the system, often  
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20 expressed as subjective information. In order to cope with such subjective information,  
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22 many researchers have resorted to the AHP. For example, De Felice and Petrillo (2014)  
23  
24 evaluated Italian racecourse performance, and Weifeng, et al. (2016) quantitatively  
25  
26 analyzed the dangers of water and sand inrush caused by underground mining using the  
27  
28 AHP. In addition, Bayazit and Karpak (2007) assessed the readiness of the Turkish  
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30 manufacturing industry, De Felice and Petrillo (2013) assessed environment, and Tjader, et  
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32 al. (2014) built a cohesive decision model for determining firm level IT outsourcing  
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34 strategy using the Analytic Network Process (ANP). These approaches explicitly cope  
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36 with factors considered intangible in evaluations and assessments.  
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48 To evaluate trade-offs among BOCR factors, other research employed the AHP or  
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50 fuzzy AHP, along with a BOCR analysis when evaluating subjects that tend to involve  
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52 intangibility or uncertainty. Lee (2009a and 2009b), respectively, evaluated the buyer-  
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54 supplier relationship between manufacturer and supplier, and proposed an analytical  
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56 approach to the selection of suppliers under a fuzzy environment. Chun-Yueh and Yih-  
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Chearng (2013) presented the model of reverse logistics of the Taiwan photovoltaic industry supply chain, and Tsai and Chang (2013) evaluated the performance of tablet personal computers. Yazdani-Chamzini, et al. (2014) and Bouzarour-Amokrane, et al. (2015), respectively, proposed a hybrid model to prioritize strategies of investing, and an evaluation and optimization approach for the withdrawal location process in the field of aircraft dismantling. Cho, et al. (2015) selected an optimal heating facility for the horticulture and stockbreeding sectors in Korea, and Yap and Nixon (2015) developed multi-criteria decision-making methodology and produced a preference ranking of alternative technologies. The integration of ANP or Fuzzy ANP along with a BOCR analysis were also proposed to evaluate various technologies for new product development (Lee, et al., 2011); proper working strategy in a fuzzy environment (Fouladgar, et al., 2012); supply chain environmental performance (De Felice, et al., 2013); and prototype dependability in software (Mohan, et al., 2016).

The above research explicitly took both intangible and BOCR factors into account by integrating multi-criteria decision-making methodologies with a BOCR analysis, which helped promote transparent and traceable decision making. Although a broad range of subjects has been covered, an EPS has not yet been an object of evaluation. Designing a sustainable EPS for manufacturers is essential, as the human and environmental consequences in case of an accident can be catastrophic. In addition, it is not a “one-off” investment necessitating no further investment due to the need to balance the initial costs with the costs of running the system. The system requires a certain amount of margin to be on the safe side, but financial sustainability associated with the life expectancy of the system is also required. The problem, however, is that neither “a certain amount” nor “sustainability” can be uniquely determined because both are a

1 subjective matter for each manufacturer based on its unique preference. Therefore,  
2 manufacturers must consider how to resolve “trade-offs” where intangible factors must  
3  
4 be dealt with. This paper thus focuses on ascertaining the intangible factors in the  
5 performance analysis of industrial products from a BOCR perspective, and proposes a  
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7 systematic approach to performance analysis combining objective data and subjective  
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9 preference.  
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18 **3. Research Design**

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22 This section outlines effluent processing and details the process of performance  
23 analysis of an industrial product. The example used is an EPS in a chemical company that  
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25 needs massive amounts of capital investment. How to collect information on customer  
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27 preference for the EPS is then introduced, and a prioritized BOCR is proposed.  
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35 **3.1 Outline of effluent processing of a manufacturer**

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40 An EPS is required in order to purify industrial effluent in accordance with thresholds  
41 defined by the law governing effluent processing before being discharged into the  
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43 environment. The regulations set by the law contain a broad range of items concerning  
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45 effluent processing, viz. concentrations of Biological Oxygen Demand (BOD), Chemical  
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47 Oxygen Demand (COD) and Suspended Soil (SS). These items relate to the architecture  
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49 and specifications of processing systems and can be specified as objective data. To purify  
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51 effluent, an EPS includes several subsystems, usually a Rotating Biological Contactor (RC),  
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54 a Fluid Carrier Tank (FT) and a Sedimentation Tank (ST), each of which performs a  
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1 different function. When all these subsystems are incorporated, an EPS satisfies the  
2 regulations. On the other hand, the configuration of these subsystems is not unique, and  
3  
4 each different combination has its own advantages and disadvantages. For example, a  
5  
6 pure RC system is best at purifying effluent but costs more, while a pure FT design entails  
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8 lower initial and maintenance costs but has poor process stability. All possible  
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10 combinations of subsystems must be reviewed for the performance analysis.  
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15 Suppliers of an EPS have their own methodologies and techniques for purifying  
16  
17 effluent. Thus, once the contamination level of effluent flowing into an EPS is given,  
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19 requirements for the processing system is specified based on the regulations. According  
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21 to an interview with the safety supervisors of the chemical company where the case  
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23 study was carried out for this research, the status of the industrial effluent can be  
24  
25 specified by both the volume and the concentration of BOD of inflowing effluent. An EPS  
26  
27 then purifies effluent using the three above-mentioned subsystems—RC, FT, and ST.  
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29 Since the performance of each subsystem is clarified based on its specification,  
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31 requirements for the system can be satisfied by combining the subsystems in various  
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33 ways. In addition, both the initial costs and the costs of running each subsystem are also  
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35 specified. The parameters, that is, a set of criteria for the performance analysis (c)  
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37 evaluating the system, can be defined as shown in Table 1, where the expected life of the  
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39 system is 20 years. The four indicators summarized in the table were identified based on  
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41 discussion with safety supervisors of a manufacturer (customer) and with designers of  
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43 the EPS (supplier) from a case study; details of the case study itself and of these safety  
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45 supervisors and designers, will be introduced in Section 4.  
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Criteria for performance analysis

Criteria	Definition
D (Benefit)	The cleanliness of discharge measured by the concentration of leaked BOD in effluent (mg/L), whose reciprocal value is identified as <u>B</u> enefit in BOCR analysis.
F (Opportunity)	Flexibility of the installation of an effluent processing system measured by the area of the installation of the system (m <sup>2</sup> ), whose reciprocal value is identified as <u>O</u> ppportunity in BOCR analysis.
C (Cost)	Cost of the system measured by the total amount of initial and running costs (Yen/installation), whose actual value is identified as <u>C</u> ost in BOCR analysis.
L (Risk)	Leakage risk of residuals measured by the total amount of leaked SS (Kg/day), whose actual value is identified as <u>R</u> isk in BOCR analysis.

Each alternative of EPS must satisfy the requirements defined by the law, such as the cleanliness of discharge or the leakage risk of residuals. Alternatives barely satisfying the regulations would be inexpensive systems but might not be sustainable. On the other hand, alternatives need not err too much on the side of safety, as that would be expensive and might be an over-specification of the system. Customers of EPS must thus resolve this trade-off when selecting a system.

3.2 *Process of performance analysis of a product*

One of the most difficult tasks in the performance analysis of an EPS is how to direct design efforts. Decisions about massive amounts of capital investment are traditionally made by the executive committee of a manufacturer, with the final decision made by consensus. The decision-making process might be inconsistent, however, since subjective factors of the members' preferences for the EPS could affect the outcome of an investment proposal. To rectify the limitations of the existing approach, management

1 would be keen to adopt an approach that could help the executives make decisions that  
2 were transparent.  
3

4  
5 Assuming that the alternatives of the processing system satisfy the regulations, a  
6  
7 manufacturer must select one alternative based on its unique preference for the system,  
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9 such as “cost-saving and robust over the long-term.” As the cost and robustness of a  
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11 system often results in a trade-off, the manufacturer is faced with a dilemma. The  
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13 manufacturer must therefore accurately analyze the performance of potential  
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15 alternatives and make decisions on which architecture and specifications of the system to  
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17 select when the manufacturer’s various requirements for the system conflict with each  
18  
19 other. Furthermore, the requirements often includes subjective information, such as  
20  
21 “flexibility of system at installation,” which relates to each aforementioned specification.  
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23 Quantifying the customer’s requirements when analyzing the performance of the system  
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25 is essential. Thus, the decision-making process must first integrate objective data and  
26  
27 subjective requirements (customer preference) for the specification of an EPS, and then  
28  
29 evaluate all potential alternatives in light of their advantages and disadvantages. In short,  
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31 the process thus consists of two main steps: collecting information on the customer  
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33 preference, and evaluating potential alternatives quantitatively.  
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46 *3.2.1 Collection of information on customer preference for EPS*  
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49 In the first step of the performance analysis, a customer’s preference is represented  
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51 by four criteria—*D* (cleanliness), *F* (flexibility), *C* (cost), and *L* (risk) defined in subsection  
52  
53 3.1—each of which relates to a specification of the processing system. Information must  
54  
55 be collected on a customer’s preference in order to convert intangible information into  
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57 quantitative form. The AHP is ideally suited to quantifying customer preference. The  
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1 customer must conduct pairwise comparisons of all possible combinations of criteria in  
2 order to represent his/her final preference for the specification of an EPS. For example,  
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4 *All the following alternatives of EPS satisfy the regulations of effluent processing in*  
5 *your plant but have different features with different architectures. If you compare four*  
6 *criteria c (D, F, C, and L) pair-wise in selecting the best alternative, which criterion do*  
7 *you consider more important for the EPS of your plant, cleanliness of discharge (D) or*  
8 *flexibility of the processing system (F)?*  
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10 The results of this process quantify the customer's preference for the processing system.  
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### 18 3.2.2 Quantitative evaluation of potential alternatives

19 In the second step of the performance analysis , a quantitative evaluation of potential  
20 alternatives in light of advantages and disadvantages can be carried out systematically,  
21 since all data representing the status of effluent and the specification of the subsystem  
22 (e.g., the concentration of BOD of inflowing effluent into an EPS, and the performance of  
23 RC removing BOD) is specified as objective data. Figure 1 graphically represents the  
24 relationship between the collection of information on customer preference and the  
25 quantitative evaluation of potential alternatives otherwise known as an AHP model. As  
26 shown in the figure, pairwise comparisons reflected a customer's preference are carried  
27 out between the goal of the analyses and the decision criteria, prioritizing the degree of  
28 importance of each criterion. Then a quantitative analysis based on the objective data of  
29 potential alternatives is conducted between the decision criteria and potential  
30 alternatives, evaluating advantages and disadvantages of each potential alternative. This  
31 integration of the AHP technique and quantitative analysis followed by a multiple-criteria  
32 performance analysis comprises the prioritized BOCR analysis.  
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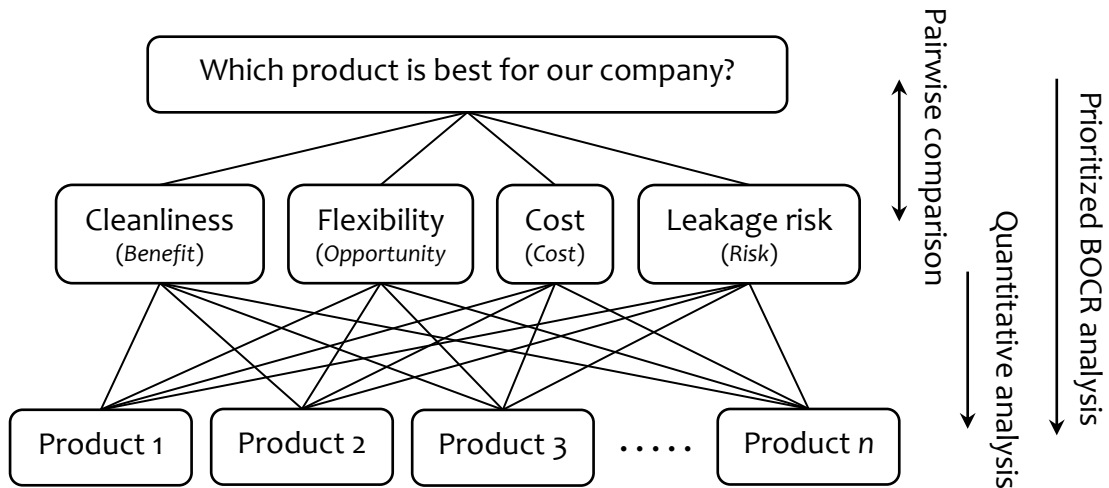


Fig. 1. AHP model.

### 3.3 Formulation of prioritized BOCR analysis

The following parameters,  $c_{*,i}$  ( $c=D, F, C, L$ ), representing the specification of an EPS are employed in the BOCR analysis, where  $*$  ( $=I$ : newest,  $II$ : contemporary,  $III$ : conventional) and  $i$  ( $i=0, \dots, 8$ ), respectively, denote the architecture of the processing system and the number of RCs of the system, each of which is indexed using the value, where  $*$ = $I$  and  $i=0$ , as a benchmark (set as 1). In this paper, a potential alternative is denoted as  $*,i$ . For the merit factors, benefit is defined by the reciprocal value of  $D_{*,i}$  (cleanliness of discharge), and opportunity is defined by the reciprocal value of  $F_{*,i}$  (flexibility of the system installation).  $1/D_{*,i}$  represents the cleanliness of discharge, which enhances the “green” image of the manufacturer and would benefit its future corporate activities.  $1/F_{*,i}$  indicates the degrees of freedom of the system installation, particularly in

1 laying out the processing system, which increases the opportunity to expand business by  
 2 using the surplus space of the manufacturer. For the demerit factors, cost is defined by  
 3 the actual values of  $C_{*i}$  (initial and running costs), and risk is defined by the actual value  
 4 of  $L_{*i}$  (leakage risk of residuals), both of which can be naturally interpreted as cost and  
 5 risk in defining a BOCR function.  
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14 A BOCR function is then formulated for performance analyses, where  $p_c$  ( $c=D, F, C, L$ )  
 15 denotes a customer's preference for criterion  $c$  derived from the application of the AHP,  
 16 explained in subsection 3.2. Since significant differences in variance exist among  
 17 indicators, each indexed parameter,  $c_{*i}$ , is transformed into a T-score of criterion  $c$  by the  
 18 following formula and denoted by  $c_{*i}^p$   
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$$31 \quad c_{*i}^p := 50 + 10 \{ c_{*i} - \mu(c_{*i}) \} p_c / \sigma(c_{*i}) \quad (1)$$

32 where  $\mu(c_{*i})$  and  $\sigma(c_{*i})$ , respectively, denote the average and the standard deviation of  
 33  $c_{*i}$  ( $c=D, F, C, L$ ). Based on (1), the prioritized BOCR function,  $pBOCR_{*i}$ , can be defined by  
 34 the following formula, which calculates each alternative's prioritized performance  
 35 reflecting a customer's preference.  
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$$48 \quad pBOCR_{*i} := (1/D_{*i}^p + 1/F_{*i}^p) / (C_{*i}^p + L_{*i}^p) \quad (2)$$

49  $c_{*i}^p$  with  $p_c=1$  corresponds to a normal BOCR function,  $nBOCR_{*i}$ , which does not take the  
 50 customer's preference for criteria into account.  
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#### 4. Model analyses

This section introduces the procedure and the results of a case study verifying the multi-criteria performance analysis approach proposed in this paper. 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. Company Y (Co. Y) is a supplier of an EPS, whose technology in RC is highly rated in the field. Co. Y develops various types of the processing system combining RC and FT, meeting demands from a great many manufacturers. The case study, which was originally a workshop for the optimization of the specification of an EPS in Co. X, was carried out in Japan. The workshop consisted of two executives from Co. X who were in charge of the decision making in the investment, three safety supervisors of three subsystems of the EPS, and two designers of Co. Y who led the design of the EPS in Co. X. During the course of the workshop, technical aspects of effluent processing, including the parameters defining the performance of the system, were discussed, and the above-mentioned experts conducted the evaluation of the system. Although the companies' names, X and Y, cannot be disclosed due to confidentiality agreements, all data presented in this case study are real data from the companies.

##### 4.1 *A case study at a chemical company: performance analysis of EPS*

Upon the renewal of the EPS in Co. X, the management of the company has to decide which alternative of a new EPS to invest in, a decision that would be greatly facilitated by a multi-criteria performance analysis of the products. As noted in the previous section,

1 there are two major factors in effluent processing: (i) the total amount of leaked BOD and  
2 (ii) the concentration of leaked SS. Safety supervisors of Co. X and designers of Co. Y  
3  
4 need to design a processing system that satisfies the required level. There are three core  
5  
6 subsystems in the EPS—RC, FT, and ST, where ST is designed to be configured at the final  
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8 phase of the effluent processing. The requirement for the contamination level of effluent  
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10 into ST is set at the fixed level that Co. X designates. The design of the EPS is thus  
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12 equivalent to determining the configuration of the remaining subsystems e.g., the  
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14 number of RC, and the volume of FT.  
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20 The performance analysis of EPS is complicated, as it requires selecting the most  
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22 appropriate combination of subsystems and deciding on the architecture of the EPS from  
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24 among a great many potential alternatives. Based on the prioritized BOCR analysis  
25  
26 approach proposed in this paper, the safety supervisors of Co. X and the designers of Co.  
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28 Y identify a set of criteria for the new EPS, which are listed as parameters in subsection  
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30 3.3. Three safety supervisors of Co. X are interviewed in order to identify criteria, each  
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32 one in charge of the safety of one of the three subsystems (i.e., RC, FT and ST). Two  
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34 designers of Co. Y committed to determining the criteria are the chief and sub-chief of the  
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36 EPS design. Criterion *c* assesses the potential benefits of the new system (benefit:  $1/D$ );  
37  
38 its alignment with the company's strategy (opportunity:  $1/F$ ); its costs for identified  
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40 objectives (cost: *C*); and its failure risks (risk: *L*). In this approach, potential alternatives of  
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42 the processing system are evaluated by the set of criteria, *c*. The alternative with the  
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44 highest BOCR scores is then approved as the new EPS.  
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55 Co. Y first proposes some alternatives of the EPS, each of which satisfies the required  
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57 level of Co. X. Leaving out the actual raw data regarding the specifications of EPS here,  
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the indexed details of the alternatives, that is, the specifications of the potential processing systems, are summarized in the appendix. Co. X then represents its preference for the processing system; Table 2 summarizes Co. X's preference for the system quantified by the AHP. In determining  $p_c$ , the two executives of Co. X who were in charge of the decision making in the investment conducted pairwise comparisons. In the process, they considered all aspects of the EPS and individually determined the relative importance of each  $c$  among four criteria. Their geometric mean was then assigned to a pairwise comparison matrix, which reflected the degree of importance of the four criteria. As can be seen in Table 2, Co. X emphasizes the degree of importance of the initial cost,  $C_{*,i}$ , as the highest, and cleanliness of discharge,  $1/D_{*,i}$ , as the second highest, and so on. The set of the degrees of importance can be interpreted as Co. X's preference for the EPS, which needs be reflected in the design of the new processing system.

**Table 2**  
Company X's preference for the EPS.

Parameter	$1/D_{*,i}$ (Cleanliness)	$1/F_{*,i}$ (Flexibility)	$C_{*,i}$ (Costs)	$L_{*,i}$ (Leakage risk)
$p_c$	0.352	0.149	0.365	0.134

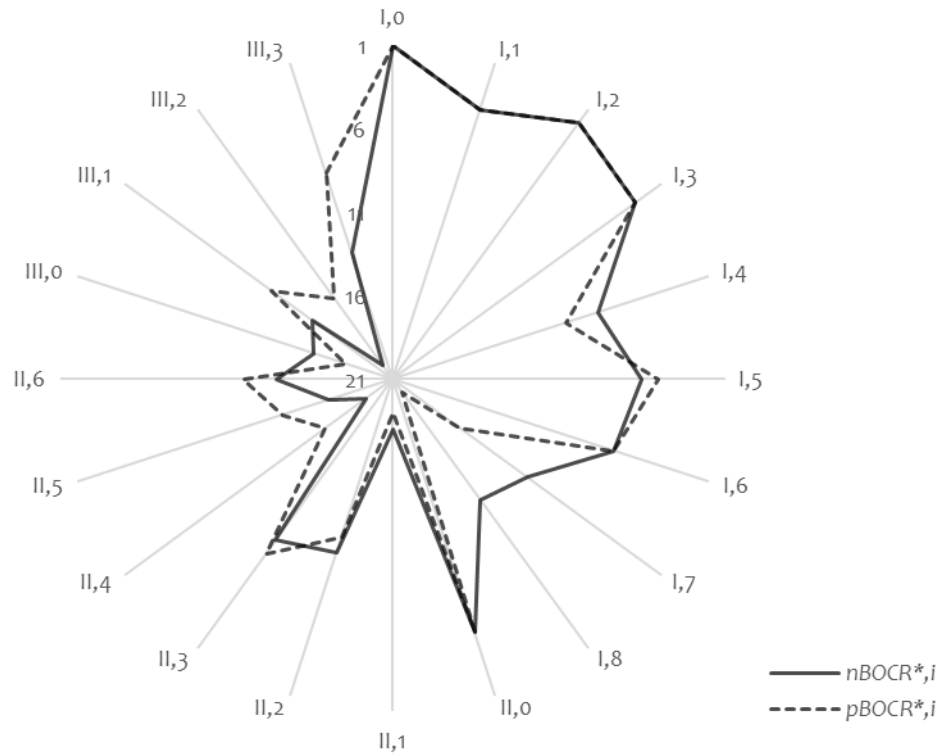
Table 3 summarizes the results of the BOCR scores, and Figure 2 illustrates the rankings of the alternatives shown in the table. A normal BOCR score of a potential alternative  $(*,i)$ ,  $nBOCR_{*,i}$  calculated by (2) with  $p_c = 1$ , is shown by a solid line. A prioritized BOCR score of a potential alternative  $(*,i)$ ,  $pBOCR_{*,i}$  calculated by (2), is shown by a dashed line, in which

Co. X's preference shown in Table 2 is represented as  $p_c$ . As summarized in the appendix, the score of O (Flexibility) drastically changes in its value in comparison with the other criteria B (Cleanliness), C (Costs) and R (Leakage risk). This difference results in higher scores of alternatives with a greater number of RC, that is, with less volume of FT. As shown in Table 3, the normal BOCR scores of  $nBOCR_{1,0}$ ,  $nBOCR_{1,2}$  and  $nBOCR_{1,3}$  are the top three, while the rank order of these alternatives based on  $pBOCR_{*,i}$  is exactly the same as that of  $nBOCR_{*,i}$ . Therefore, the primary results of the prioritized BOCR analysis are almost identical to those of a normal BOCR analysis, which means that the judgment of the executives of Co. X falls in almost the same direction as the normal BOCR analysis implies.

**Table 3** Results of BOCR analyses.

System architecture	$nBOCR_{*,i}$	$pBOCR_{*,i}$
I,0	1.0288	1.0057
I,1	1.0104	1.0019
I,2	1.0208	1.0055
I,3	1.014	1.0037
I,4	1.0021	1.0001
I,5	1.0038	1.0008
I,6	1.0029	1.0004
I,7	0.9951	0.9979
I,8	0.9932	0.997
II,0	1.0077	1.0008
II,1	0.9903	0.9971
II,2	0.9961	0.9991
II,3	0.9979	1.0002
II,4	0.9897	0.9979
II,5	0.9911	0.9984
II,6	0.9926	0.9988
III,0	0.9913	0.9973
III,1	0.9922	0.9988

III,2	0.9884	0.9983
III,3	0.9927	1.0002

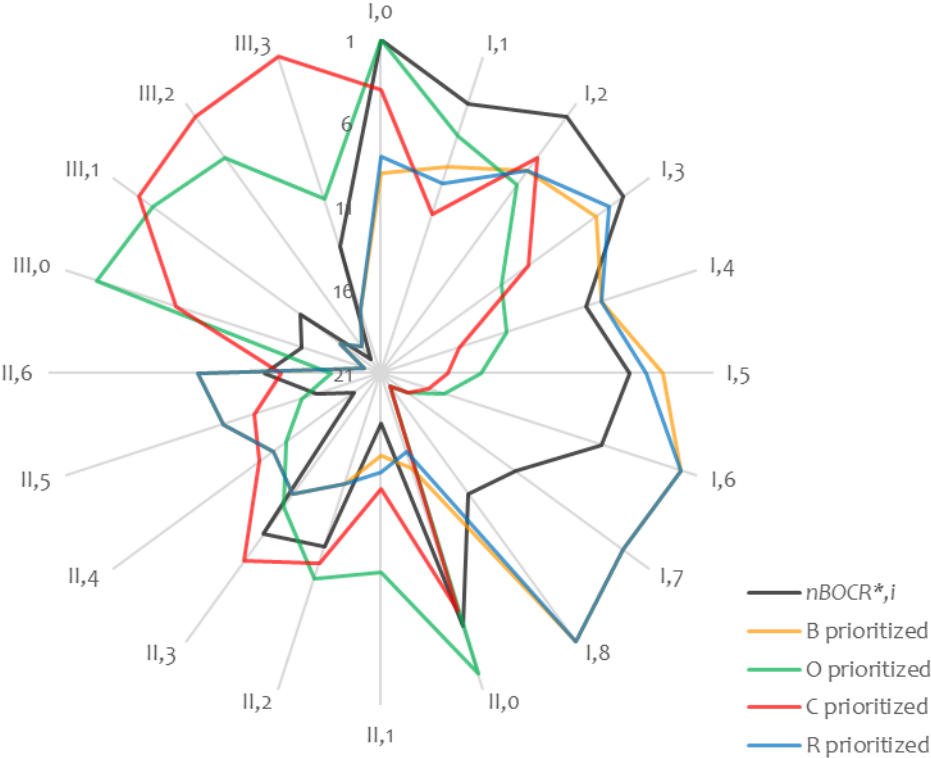


**Fig. 2.** Results of BOCR analyses (Rankings of alternatives).

#### 4.2 Implications for the sales promotion of a supplier for potential customers

By using the prioritized BOCR analysis, sensitivity analyses of customers' preferences can be conducted, and how preferences for a product would affect the results of the selection would be clarified. The results from the analyses hint at how Co. Y might promote its product to potential customers. Leaving aside the details of prioritized BOCR scores, Figure 3 shows the results from the sensitivity analyses of different preferences, summarizing the rankings of the potential alternatives, as shown in Figure 2. Figure 3 shows the rankings of alternatives based on prioritized preferences, such as opportunity

(flexibility of the system installation) prioritized, cost (initial and running costs) prioritized. In the analyses, each preference is artificially generated by perturbing the values of pairwise comparisons so as to emphasize the degree of importance of a criterion. For example, opportunity prioritized preference, O prioritized, is generated by setting the relative importance of opportunity as “9” (absolutely important) to all the remaining criteria in pairwise comparisons, and fixing the relative importance among the remaining criteria as “1” (equivalent) in all remaining pairwise comparisons.



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3 **Fig. 3.** Results of sensitivity analyses (Rankings of alternatives).  
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7 As with the analyses in the previous section, significant differences in scores of O  
8 (Flexibility) in comparison with the other criteria result in a drastic change in the ranking  
9 of alternatives. For instance, a potential alternative (1,8) designed on the newest  
10 architecture with more RC is ranked at the top based on B prioritized preference; based  
11 on C prioritized preference, however, the alternative is ranked as the worst, where the  
12 normal BOCR analysis ranks it 12th among 20 alternatives. This result is considered to be  
13 induced by the number of RC that can effectively purify effluent but at great cost. As a  
14 result, the rankings of alternatives change drastically according to the preferences,  
15 suggesting a different selection of effluent processing system for the customer.  
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17 Furthermore, the sensitivity analysis clarifies the pros and cons of each alternative based  
18 on a customer's preference, thus suggesting to the supplier how to promote its products.  
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36 Retrospective interviews were carried out following the workshop with the safety  
37 supervisors of Co. X and the designers of Co. Y. Based on the interviews, the proposed  
38 multi-criteria performance analysis succeeded in enhancing managerial decision making  
39 by improving transparency and traceability. In the analysis, trade-offs among various  
40 criteria could be quantified using the AHP (Table 2) and the decision could be made with  
41 high transparency (Figure 2). Moreover, the approach provided a flexible decision-making  
42 framework that could take different focuses on evaluation into consideration when  
43 another preference for the processing system would be expressed. The prioritized BOCR  
44 analysis thus enabled the safety supervisors of Co. X to gain better insight into the  
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1 evaluation and selection of a new processing system in a complicated situation  
2 (customer's perspective).  
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5 Co. Y's designers were also satisfied with the prioritized BOCR analysis that could  
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7 address different customers' preferences (Figure 3). The approach proposed in this paper  
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9 clarified the pros and cons of each potential alternative based on a customer's preference,  
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11 which could, in turn, help designers of Co. Y address various customers' requirements  
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13 (preferences) and optimize the design of an EPS with its own technologies in their sales  
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15 promotion for potential customers (supplier's perspective).  
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21 In contrast to the approach proposed in this paper, existing approaches to  
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23 performance analysis could never sufficiently address the EPS selection problem while  
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25 taking subjective factors into account. Neither questions such as why the component and  
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27 architecture of the processing system was selected nor what the benefit of the selected  
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29 system was could be easily answered. The multi-criteria performance analysis combining  
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31 the AHP and the BOCR analysis proposed in this paper provides a framework for  
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33 considering the impact of each trade-off decision on the criteria, and develops a clear  
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35 decision path for a manufacturer that justifies massive investment in an EPS.  
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## 43 **5. Concluding remarks and future research**

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49 This paper proposes an approach to multi-criteria performance analysis of industrial  
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51 products and subsequently optimizes the specification of a product for a manufacturer in  
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53 which an EPS is employed as one of the industrial products requiring massive amounts of  
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55 capital investment. The performance analysis integrates objective data and subjective  
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57 preference for products, and not only satisfies the legal requirement, but also takes  
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1 customer preference into account in the design of the product. The approach contributes  
2 to making the decision path more transparent and solid than traditional approach could  
3 do. The case study demonstrates the applicability of the approach that supports  
4 customers in designing an EPS, in which the best architecture and specifications for the  
5 product were identified. The application of the AHP is a simple approach to transforming  
6 subjective information into objective data, while the BOCR analysis is a systematic  
7 approach to evaluating the performance of the system. The proposed approach,  
8 therefore, allows a manufacturer to deal with these objective data and subjective  
9 information on the same horizon. By providing clarity to the process of the performance  
10 analysis, the decision-making results are transparent and traceable.

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26 Since an EPS requires massive amounts of capital investment, many company  
27 executives will face this decision-making process. Such as the case of group decision  
28 making, diverse ideas and opinions affect the decision-making process, which sometimes  
29 results in confusion among decision makers. While a number of approaches to the  
30 performance analysis of industrial products have been proposed, approaches to the  
31 design of an EPS have been limited. In addition, even though many decision-support  
32 frameworks have been proposed, little research has provided a systematic model that  
33 considers intangible factors. The multi-criteria performance analysis proposed in this  
34 paper is thus significant, as each decision criterion and evaluation result can be clarified at  
35 each decision-making step. The approach can be applied to more general supply chain  
36 management, such as for build-to-order products ranging from personal computers to  
37 custom-built homes. The approach also provides potential customers of such industrial  
38 products with a good opportunity to reflect on their preferences for the product. This  
39 process supports their decision making and makes them feel justified in making the  
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1 purchase. Moreover, the proposed approach allows managers to have a clear decision  
2 path that provides traceability, enabling managers to revisit how the decision on an EPS  
3 was reached. Even though the proposed approach has been applied to the case of an EPS,  
4 it can be tailored and applied to any manufacturer or service company analyzing the  
5 performance of products or making investment decisions.  
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12 This paper demonstrates that a new integrated approach to multi-criteria  
13 performance analysis is effective. The companies in the case study acknowledged that  
14 the approach gave them an overview of the issues affecting EPS performance and  
15 provided them with a structured way of seeking to improve. Particularly, the prioritized  
16 BOCR and sensitivity analyses allowed them to communicate and make decisions  
17 effectively. In short, the BOCR model helps to address the shortcomings of existing  
18 approaches (e.g., Weifeng et al., 2016; Tjader et al., 2014; Tsai and Chang, 2013) by giving a  
19 clear and systematic approach to analyzing and diagnosing a particular problem. In  
20 addition, the proposed approach allows managers to consider various factors that are  
21 key to making sound EPS decisions. Specifically, both the positives (benefits and  
22 opportunities) and negatives (costs and risks) are quantitatively analyzed, and intangible  
23 factors are dealt with in the decision-making process.  
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43 Nonetheless, the proposed model has some limitations. Further research needs to  
44 explore the following issues: the pros and cons of indexing indicators, and the selection  
45 and definition of parameters. In this paper, all indicators are indexed by a benchmarking  
46 alternative, since each indicator has a different unit. In addition, those indexed indicators  
47 are transformed into a T-score due to their significant differences in variance. This  
48 indexing and transformation of indicators for the prioritized BOCR analysis should be  
49 explored further. As for the selection and definition of parameters that relate to the  
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1 specifications of industrial products, experts in the design of products discussed and  
2 determined parameters, which was plausible for the case study. On the other hand, how  
3 to define parameters identifying specifications of the system, such as the reciprocal value  
4 of  $D_{*,i}$  for the benefits of cleanliness of discharge, is an open-ended question. Indeed,  
5 identifying a decision maker's utility function of indicators representing the performance  
6 of a product is quite challenging. The approximation of the utility in the formulation of  
7 analyses may be inevitable, and should be explored in future research.  
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**Appendix:** Specifications of potential alternatives of EPS proposed by Company Y.

System architecture	Number of RC	Volume of FT	B (Cleanliness)	O (Flexibility)	C (Costs)	R (Leakage risk)
I (Newest)	0	791	<b>1.00000</b>	<b>1.00000</b>	<b>1.00000</b>	<b>1.00000</b>
	1	791	1.04163	0.64602	1.08541	0.96003
	2	528	1.09188	0.60036	0.99951	0.91585
	3	528	1.14298	0.47837	1.07353	0.87490
	4	396	1.11957	0.42740	1.16206	0.89320
	5	396	1.17484	0.36173	1.16762	0.85118
	6	317	1.23012	0.32242	1.21763	0.81293
	7	264	1.22934	0.28716	1.29140	0.81345
	8	264	1.28730	0.25594	1.35788	0.77682
II (Contemporary)	0	791	0.81613	1.00000	0.99688	1.22530
	1	791	0.84944	0.64602	1.07318	1.17725
	2	396	0.84374	0.67104	1.00732	1.18520
	3	317	0.89027	0.54727	0.98887	1.12325
	4	264	0.90237	0.45287	1.05562	1.10819
	5	226	0.95167	0.38624	1.07010	1.05078
	6	226	0.99800	0.33181	1.08269	1.00200
III (Conventional)	0	791	0.69364	1.00000	0.98750	1.44167
	1	528	0.72016	0.80585	0.92477	1.38859
	2	264	0.71048	0.73602	0.91752	1.40751
	3	226	0.76628	0.57486	0.87811	0.00500

Each criterion is indexed by the specification of an alternative, (I,0) as a benchmark (shown in bold).