Implementation of risk-based life cycle management by decision support tool for small- and medium-sized enterprises

Yasunori Kikuchi[1,]*, Hiroki Matoba[1] and Masahiko Hirao[1]

[1]The University of Tokyo, Department of Chemical System Engineering, Tokyo, Japan

*kikuchi@pse.t.u-tokyo.ac.jp

Abstract At life cycle management (LCM) by industrial decision makers, several evaluation indices should be considered by assessment methodologies. For an appropriate and effective process design, the data required for evaluations must be connected with process design tools such as process models and technical databases. Integrated application of assessment and process design can enhance the practicability of risk-based LCM. In this study, local risk and global environmental impacts are taken into account in process design procedure. This integration is visualized as a business model. A case study is performed on metal cleaning process design, which is the practice in the LCM by small and medium-sized enterprises (SMEs). This case study demonstrates that the visualized integration of assessment and design enables productive discussions on tangible procedures to enhance the practicability and applicability of LCM by SMEs.

1 Introduction

Global environmental impacts and local risks due to the use of chemicals have become issues in decision making in life cycle management (LCM) on process management, which covers planning, design and operation phases of production processes. A decision making in industrial process design is imposed to various constraints. Process managements should focus on the way how to apply and what to be utilized for process chemicals or raw materials under such constraints. For implementing global impacts and local risks into industrial ecology, risk assessment (RA) and life cycle assessment (LCA) have been key technologies to quantify such non-monetary evaluation indices. In RA, chemical risks are categorized as EHS categories: environment, health and safety [1]. RA can consider the critical concerns for decision makers in industry, such as health, and safety issues. LCA has been a strong tool to quantify the potential environmental impacts originating from the life cycles of products within industrial ecology [2]. Based on LCA results, decision makers can identify the life cycle impacts associated with their decisions. For risk-based decision making, integrated application and interpretation of RA and LCA has been discussed with actual case study [3, 4].

Business modeling approach is useful to activate a smooth implementation of such new business activities [5]. Because environmentally-conscious design of processes needs systematically connected activities and information in process evaluation, simulation and optimization [6], effective information technology support is important for process engineers [7] and to activate industrial ecology [8]. Activity model of risk-based decision as a business model should be created for the foundation of adequate software systems development to show system requirements [4, 9].

In this paper, plant-specific risk and life cycle assessments are integrated with sustainable process design. This integration is visualized as business and information models. Activity model represents a method of integrating RA and LCA for a risk-based decision making in industrial process management. Required information structure is visualized by information model. A case study is performed on the design of metal cleaning process, which has been a big issue in Japan on environmental managements by small and medium-sized enterprises (SMEs).

2 METHOD OF INTEGRATING ASSESSMENTS

2.1 Systematic modeling method for business activity and information

The type-zero method of integrated definition language or IDEF0 [10] have widely been used for business process reengineering (BPR) filed [11]. Using IDEF0, all administrations and operation procedures are broken down into "activities" and systematic relationships among them are described by ICOM: Input, Control, Output, and Mechanism. Each activity can be hierarchically decomposed into subactivities. A developed model can make it visible what knowledge, technique and information are actually required for certain activity. IDEF0 has accounted for requirements in software systems development with other modeling languages [12]. In process design field, several authors applied activity and information modeling approach to integrate new or existing engineering methods and tools for environmental protection and EHS risks [13, 14].

Several researches on risk-based decision making have been developed in a couple of decades. They could have solved actual problems based on tactful application of environmental management methodologies by researchers [4]. To enhance the efficiency and practicability of risk-based decision, such research achievements should be generalized and shared systematically enough to implement them into other fields and sectors. Fig. 1 shows the overview of a supporting system for risk-based decision making. This system is composed of the alternative candidate processes generation, process simulation, evaluation modules, and graphical user interface (GUI). Although a decision maker can fulfill the risk-based process design based on assessments by using such supporting system, general system has difficulties to improve individual process design in each industrial sector. The development of suitable software tool should be based on the implementation of supporting mechanisms within actual business models.

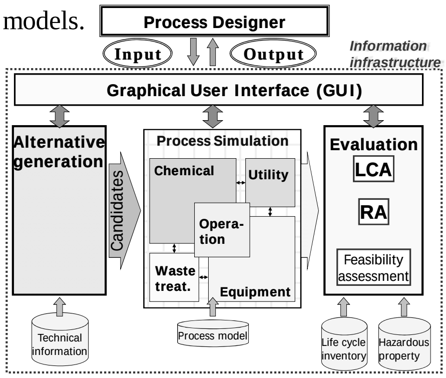


Fig.1: Overview of a supporting system for risk-based decision making

2.2 Business activity model for risk-based LCM

Fig. 2 shows the activities of risk-based decision making. In activity A1 in Fig. 2, external and internal constraints are managed and controls are interpreted and transformed into convenient styles. Based on the specified controls, process in use is assessed in activity A2. This activity includes the main procedures of integrated application of different assessment methodologies. To reduce the evaluated risk, activity A3 generates alternative candidate processes using technical information. Activity A4 assesses the generated alternatives according to the way how process in use is assessed. In activity A5, an alternative process is decided on the basis of analysis and interpretation of all evaluation results. The differentiated interpretations are performed for the results of environmental impacts and local risks. If there are any feedback information including the requirements for more detail evaluations and further improvement of alternative candidates, they are returned from activity A5 to activity A1, and then, internal constraints are updated to reflect the feedbacks.

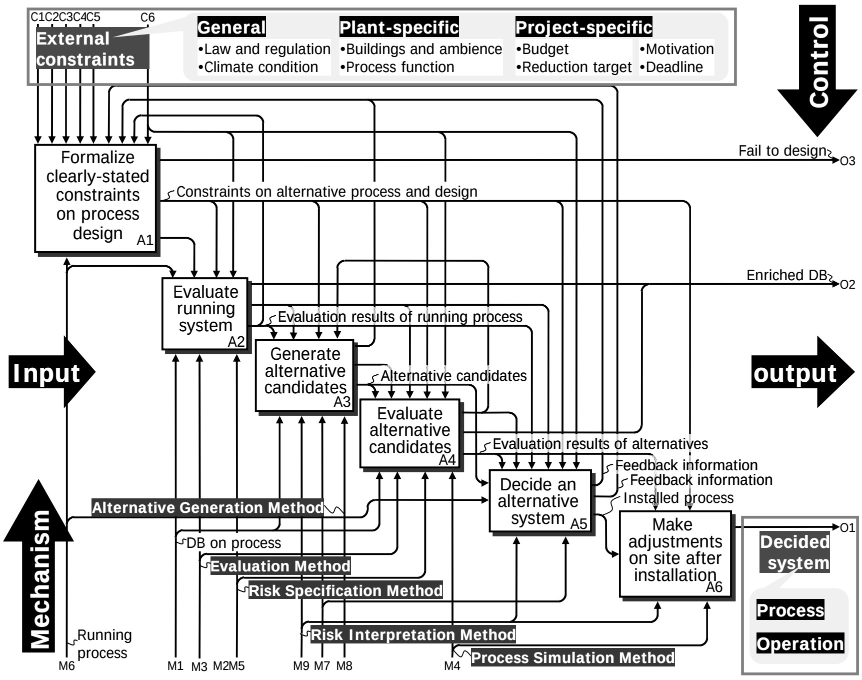


Fig.2: **Risk-based LCM activities described by IDEF0**

3 Case study

3.1 Background

In this case study, an implementation of LCA into actual process design is introduced. Metal parts cleaning and industrial printing have been regarded as major source of volatile organic compounds (VOC) [15]. In addition to VOC, recently, global warming has also become an issue related with carbon footprint [16]. These industrial processes are operated in many SMEs. Because of the lack of resources, they have many difficulties to implement scientific assessment approaches. A software system might be able to play a role of facilitating their implementation of LCA [4].

3.2 Evaluation activities and software system design

Required activities for integrated assessments in process design are shown in Fig. 3, which are the sub-activities of activities A2 and A4 in Fig. 2. Each activity needs somewhat technical knowledge on LCA and RA. Through several case studies of evaluation [4, 17, 18] and investigations on engineers, available information on site and practical activities for them could be specified. Because data required for LCA and RA cannot be always available on site, the estimations of them are needed as shown in Fig. 4.

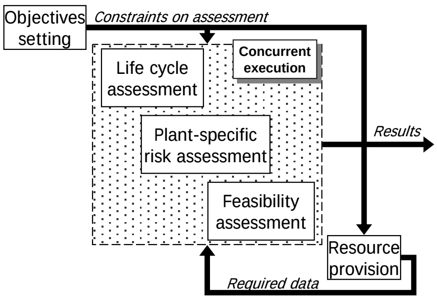


Fig.3: Activities of integrated evaluation

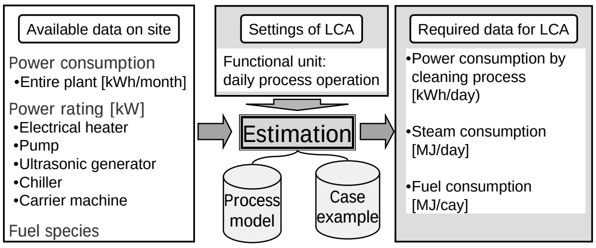


Fig.4: Estimation of process data required for LCA

3.3 Evaluation for alternative generation and interpretation

Fig. 5 shows the schema of process simulation in the tool. In process simulation module, two models were constructed. One is a process model of cleaning device, and another is process model of local ventilation. The model of cleaning device evaluates the amount of agent emission of alternatives, and the model of local ventilation evaluates the amount of agent emitted to the inside and the outside of sites.

Concerning agent emission, process parameters which mainly influence on emission of cleansing agent were identified by the analysis of heuristics and experiments with actual metal cleaning machine. Experiments were performed to quantify the relationship between the amount of agent emission and process parameters. Based on these analysis including experiments, several mathematical models were developed as process model of cleaning devices for evaluating the behavior of agent emission by implementing alternative processes.

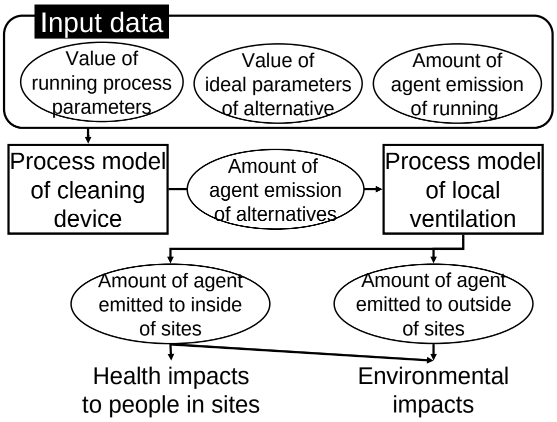
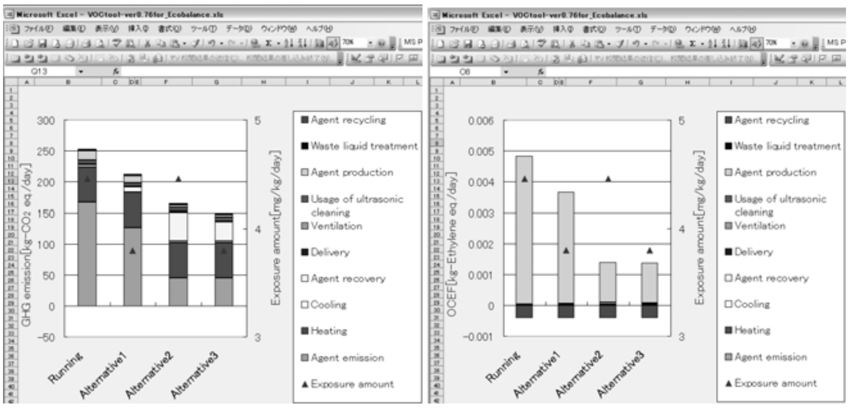


Fig.5: Schema of process simulation

A prototype tool was implemented on Microsoft® ExcelTM. This tool has GUI to develop a user-friendly system. This GUI enables on-site engieers to easily identify which data should be inputted. Using the prototype tool, case study was performed to demonstrate the applicability of developed system for process improvement on site. In this case study, developed system was used by on-site engineers, managers, and experts in metal parts cleaning. Fig. 6 shows the example of GUI for the results of LCA and RA. Figs. 6(a, b) shows the impact of global warming and photochemical oxidant creation associated with running and alternative processes, respectively. Both assessments are for the actual process. In alternative 1, the temparature of cooling water is adjusted. Alternatives 2 is the case installing agent recovery. And in alternaitve 3, both of alternating approaches addressed in alternatives 1 and 2 are applied. As shown in Fig.6, by using recovery system, the impact of photochemical oxidant is decreased while greenhouse gas (GHG) emission is increased due to its utility. According to the result of alternative 2, agent recovery system cannot decrease local risk as indicated by exposure amount. This is because the agent recovery is an end-of-pipe technology. As mentioned above, developed tool can facilitate the recognition of local risk and global impact with thier trade-off relationship.



(a) Global warming **(b) Photochemical oxidant creation**

Fig.6: GUI for evaluation result

3.4 Verification of the applicability of developed tool

The availability of input data and the applicability of the developed tool were verified through hearings and interviews to expected users, who are the on-site engineers or experts in industries. It is demonstrated that the system enables them to perform LCA and RA. At the same time, with the survey for several sites, following points to be discussed were extracted. These points might be an important suggestion for highly-applicable decision suppot tool for SMEs.

- Regarding managers' priority, payback time is the most important constraint in process design phase. In a case of one SME operating cleaning process, if payback time is more than 2 years, the alternative might not be feasible.
- Initial cost is also an important constraint. There is a limitation of possible investment. Even if payback time is short, an alternative with high initial cost cannot be selected.
- Engineers do not understand mechanism of whole metal cleaning process. Therefore, they are worried about the reduction in cleaning quality by process improvement.
- The engineers cannot implement alternatives into practice only by the evaluation results based on LCA and RA. Concrete instruction of implementation might be helpful for thier actions.

4 Conclusion

This paper proposed a method of integrating assessment and process design for risk-based LCM by utilizing business activity modeling. For a practical application of LCA and RA, these should be implemented into a business model, especially in process design for industrial ecology. Because not all engineers in industries can apply such highly developed scientific assessments, supporting system should be maintained to enhance their practicability. The important players to accomplish systems development must be system users, developers, and researchers on risk-based LCM. The first two players are necessary for implementing software systems into actual business activities. The last one is the key player to achieve the implementation of risk-based decision into practice. This means that the role of customizing scientific assessment methods should be assigned to the researchers. Business activity model can behave interfaces among players.

Actual case study of developing supporting system for process design in LCM was conducted on metal cleaning process. Required activities of on-site engineers were developed and defined by IDEF0. A prototype software system was developed. In this tool, graphical requirements on evaluation results can be considered and outputted for alternative candidate processes generation and interpretation in decision making. This tool was used by potential users for the reduction in local chemical risks and global environmental impacts. Through the interviews and hearings to them, the devloped tool can be understandable to perform LCA and RA. The importance and applicability of developed tool was verified. For enhancing the user-friendly aspects of developed system, GUI and contents should be revised considering the situation of the use of software tool on site.

5 Acknowledgement

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6 References

[1] Kolluru R. V., Bartell S. M., Pitblado R. M., and Stricoff R. S., *InteRisk assessment and management handbook for environmental, health, and safety professionals*, New York: McGraw-Hill, 1996

[2] Matthews H.S., and Lifset R., The Life-Cycle Assessment and Industrial Ecology Communities: Expanding Boundaries Together, *Journal of Industrial Ecology*, Vol.11, No.4, 2007, pp. 1-4.

[3] Kikuchi Y., Hirao M., Practical Method of Assessing Local and Global Impacts for Risk-Based Decision Making: A Case Study of Metal Degreasing Process, *Environmental Science & Technology*, Vol.42, No.12, 2008, pp. 4527-4533.

[4] Kikuchi Y., Hirao M., Hierarchical Activity Model for Risk-Based Decision Making Integrating Life Cycle and Plant-Specific Risk Assessments, *Jounal of Industrial Ecology*, Vol. 13, No. 6, 2009, pp. 945-964

[5] Naka Y., *Introduction to Integration Engineering (original title in Japanses)* , Tokyo: Kogyo Chosakai, 2006

[6] Chen H., Shonnard D.R. Systematic framework for environmentally conscious chemical process design: Early and detailed design stages, *Industrial & Engineering Chemistry Research*, Vol.43, 2004, pp. 525-552.

[7] Schneider R., Marquardt W., Information technology support in the chemical process design life cycle, *Chemical Engineering Science*, Vol. 57, No. 10, 2002, pp. 1763-1792.

[8] Heijungs R., de Koning A., Suh S., Huppes G., Toward an information tool for integrated product policy: Requirements for data and computation, *Journal of Industrial Ecology*, Vol. 10, No. 3, 2006, pp. 147-158.

[9] Ajisaka T., *Computer Science Library-16-Introduction to Software Engineering*, Tokyo: Science, 2008

[10] Ross D.T., Application and Extensions of SADT, *Computer*, Vol. 18, 1985, pp. 25-34.

[11] Killich S., Luczak H., Schlick C., Weissenbach M., Wiedenmaier S., Ziegler J., *Task modelling for cooperative work, Behaviour & Information Technology*, Vol. 18, 1999, pp. 325-338.

[12] Kim C. H., Weston R. H., Hodgson A., Lee K. H., The Complementary Use of IDEF and UML Modelling Approaches, *Computers in Industry*, Vol. 50, 2003, pp. 35-56.

[13] Gabber H. A., Aoyama A., Naka Y. Model-Based Computer-Aided Design Environment for Operational Design, *Computers & Industrial Engineering*, 46, 2004, pp.413–430.

[14] Sugiyama H., Hirao M., Mendivil R., Fischer U. Hungerbühler K., A Hierarchical Methodology for Chemical Process Design Based on Life Cycle Assessment, *Process Safety and Environmental Protection*, Vol. 84, 2006, pp. 63–74.

[15] Ministry of the Environment, Japan: Manual for self-management on discharge control of volatile organic compounds (VOC). (Original title in Japanese) http://www.env.go.jp/air/osen/voc/manual1/index.html. (2007) Accessed September 2008.

[16] Japan Federation of Printing Industries, Investigation research on the calculation of carbon footprint for publication and commertial printings, 2010 http://www.jfpi.or.jp/publication/report/h21/file/h21_1.pdf (Accessed 17.Aug.2010)

[17] Kikuchi, Y., Hirao M., Local Risks and Global Impacts Considering Plant-Specific Functions and Constraints: A Case Study of Metal Parts Cleaning, *International Journal of Life Cycle Assessment*, Vol. 15, No. 1, 2010, pp. 17-31.

[18] Kikuchi E., Kikuchi Y., and Hirao M., Analysis of risk trade-off relationships between organic solvents and aqueous agents: Case study of metal cleaning processes, *Journal of Cleaner Production*, Vol. 19, No. 5, 2011, pp. 310-326