Development of Web-based on-Line Optimization System

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1. Introduction

The study of chemical product design has become an important aspect of chemical engineering. It has been broadly recognized that chemical product design is an essential precondition for the survival and growth of any chemical company in the global market. In the early days, products of the chemical industry were concentrated on commodity chemicals such as ethanol, sulfuric acid, and vinyl chloride monomer. In the past several years, the profit margin of commodity chemicals production has become low due to slow growth and high competition in the chemical industry. Thus, much attention has turned to the development of high value-added chemical products like drugs, blood oxygenator and non-fat cooking oil (Cussler and Moggridge, 2001; Cussler and Wei, 2003; Grossmann, 2004). Since chemical product design can meet both market demand and technological progress, it has been regarded as a remarkable methodology for development and manufacturing of various high value-added chemical products (Westerberg and Subrahmanian, 2000; Charpentier and McKenna, 2004; Gani, 2004; Charpentier, 2005). Chemical product design has been applied to develop high value-added chemical products such as functional shampoo, cosmetics, vitamin C tablets and diaper (Wibowo and Ng, 2001, 2002; Fung and Ng, 2003; Hill, 2004; Siddhaye et al., 2004).

Although there are other kinds of products in the chemical industry, most studies on chemical product design have been limited to material products (Costa, Moggridge and Saraiva, 2006). Fig. 1 shows that chemical products include virtual chemical products as well as material products. Not much attention has been paid to the virtual chemical products, which consist of software. However, virtual products have been regarded as important components of product design in other fields of engineering. Telemedicine, for example, was developed through the methodology of product design. It succeeded in various countries such as the EU, Japan, and Nigeria (Takahashi, 2001; Adewale, 2004). Therefore it is reasonable to pay attention to virtual chemical products developed using chemical product design.

The aim of the present paper is to introduce the development a case of the development of a chemical virtual product and suggest the design procedure for the development of the chemical virtual product. The chemical product design methodology is then applied to the development of a management system for an optimization project. A

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Web-based online system for compressor network optimization is developed as a case study.

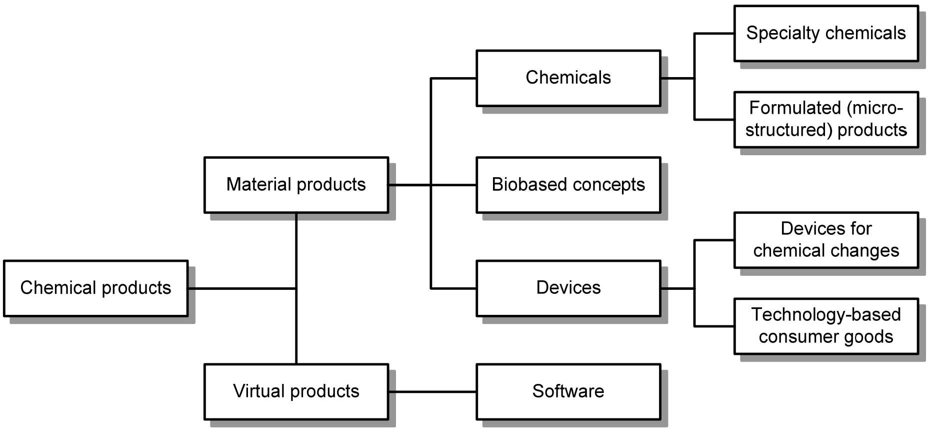


Fig. 1. Classification of chemical products.

2. Procedure

Product design has been widely used in mechanical and industrial engineering. For a long time, research has assisted with progress being made. As a result, procedures of product design have been established to some degree (Paul and Beitz, 1977; Otto and Wood, 2001; Ulrich and Eppinger, 2003). These procedures for product design have been adapted for virtual chemical product design procedure. The design procedure for development of virtual chemical product consists of four steps as seen in Fig. 2.

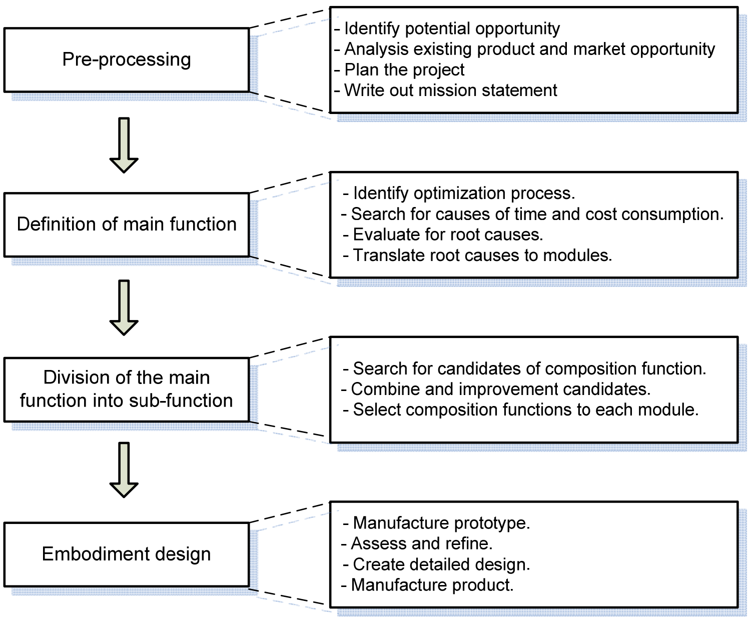
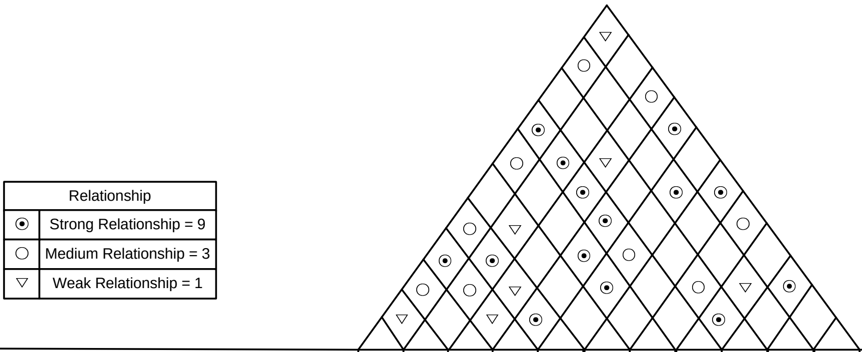


Fig. 2. Design procedure for development of virtual chemical product.

2.1. Pre-processing

First, the project team prepared a process of design. In this step, the team identified the potential opportunity. The opportunities were discovered by considering dissatisfaction with existing products, changes in trends, deepening of competition, and discovery of new technology.

Process optimization at a chemical plant has been shown to be very helpful for saving costs (Li et al., 2000). However, optimization required too much time and cost because of the geographical distance between the chemical plants and the group of experts. Thus, chemical companies have hesitated to perform optimization projects in spite of their effect. A management system for an optimization project can be presented as a clue.



Optimization Procedure	Time / Cost Consumption	Site Verification	Questionnaire	Explanation of Technique & Knowledge	Site Visit	Collection of Empirical Knowledge	Output Arrangement	Discussion	Collection of Information and Data	Verification of Literature	Adjustment of Discussion Schedule	Midterm Assessment	Weighting Factor	Relative Time Consumption	Absolute Time Consumption
Step1. Understanding of Compressor System	Collection of Process, Equipment, and Sensor's Information	○	⦿		⦿	⦿	○		⦿		○	▽	**0.13**	5.59	0.058
	Collection of Compressor System Events Data	○			○	⦿	▽		⦿		▽			3.25	0.034
	Understanding of Compressor system	▽			▽			▽				⦿		1.56	0.016
Step2. Data Collection and Reconcillation	Selection of Sensor for Modeling	⦿	⦿	▽	○	○	▽	⦿	○	○	▽	▽	**0.13**	5.33	0.056
	Preparation of Tag List for Site Logging		▽		▽			○						0.65	0.007
	Collection of Operation Data and Process Events	⦿			○		○	○	⦿		▽			3.51	0.037
	Sensor validation Data reconciliation			○	○	▽	○	⦿				⦿		3.64	0.038
Step3. Compressor System Modeling and Analysis	Compressor System Modeling and Explanation of Modeling Tools			⦿	▽		○			○	▽	▽	**0.16**	3.52	0.037
	Analysis of Compressor and Expansor Design Data and Discussion				▽	▽	○	⦿	⦿			▽		5.12	0.053
	Analysis of Compressor Performance based on Operation				▽	▽	○	⦿	▽			▽		3.84	0.040
	Analysis of Compressor Performance based on Model				▽	▽	○	⦿				▽		3.68	0.038
	Arrangement of Compressor System Characteristic			▽	▽		⦿	⦿				⦿		5.28	0.055
Step4. Optimization	Definition of Optimization Parameter and Boundary Condition	⦿	⦿	▽	⦿	⦿	⦿	⦿	⦿	○	▽	⦿	**0.21**	15.33	0.160
	Definite form of Optimization		▽		▽			▽	○					1.26	0.013
Step5. Refinement and Test	Off-line Optimization Simulation and Refinement		○	▽	⦿	○	○	⦿			▽	⦿	**0.26**	10.14	0.106
	Adjustment of Test Schedule	⦿	○		○	○	▽	⦿			▽	▽		9.10	0.095
	Test	⦿			○									4.68	0.049
Step6. Analysis and Training	Collection of Data after Optimization	○	○		▽		▽		○		▽		**0.11**	1.43	0.015
	Analysis of Efficiency and Discussion			▽		○	⦿	⦿	○		▽	⦿		3.96	0.041
	Training of Compressor Operation			⦿	⦿		⦿	⦿			▽	⦿		4.95	0.052
Importance Weight	Absolute	10.15	6.46	3.69	10.89	7.12	9.81	17.77	8.68	1.50	2.00	11.15			
	Relative	0.114	0.072	0.041	0.122	0.050	0.010	0.199	0.097	0.017	0.022	0.125			
Technical Rank		4	8	9	3	7	5	1	6	11	10	2			

Fig. 3. House of quality for cost and time of process optimization.

2.2. Definition of main function

To design the management system for an optimization project, the main function had to be identified. To identify the main function, the process of the optimization project was identified. The process generally consisted of twenty steps, and each step consisted of eleven individual activities. In order to find the relationship between the steps and the activities, a "house of quality" was introduced (Karlsson, 1997; Barad and Gien, 2001). For identifying the degree of the relationship, several experts who have performed the optimization were interviewed. The experts responded to a questionnaire, which included questions on the importance of each step and the relationships between them. Fig. 3 shows the resulting house of quality. In this table, the causes of time and cost consumption were identified.

However, since there were many causes, they were evaluated to root causes through a roof correlation matrix (Trappey et al., 1996). The analysis identified three root causes. This result was translated into a module to solve the time and cost consumption. Researched as benchmarks, telemedicine and fishery diagnosis Web-based systems were known the successive service system products that transcend distance (Adewale, 2004; Li, 2002). Therefore, the modules were suggested as a form of the Web-based system. Three modules corresponding to the root causes were suggested: Table 1 shows the root causes and the suggested modules extracted from the house of quality.

Table 1. Grouping of consuming time cause into root cause and module.

Consuming time causes	Root cause	Module
- Site visit - Discussion. - Collection of empirical knowledge. - Explanation of technique and knowledge.	Activity with visit of site	Communication module
- Midterm assessment. - Output arrangement.	Assessment	Project management module
- Questionnaire. - Verification of site. - Collection of information and data.	Collection of scattered information	Information interaction module

2.3. Division of main function into sub-functions

The suggested modules needed detailed sub-functions. Ten candidates were generated in the communication module. These candidates were sorted into three conceptual modules: the synchronous module, the asynchronous module, and the computer-supported cooperative work module. Fig. 4 shows the classification tree for the candidates. The synchronous module helped the users to communicate concurrently. The asynchronous module helped the users to work without regard to time. The computer-supported cooperative work module allowed users to cooperate more effectively and to hold information in common (Kamel and Davison, 1998).

These modules were not useful for individual work. However, when they were combined, synergy effects occured. For example, the audio/video module was not effective for explaining complex information such as process modeling. However, taken with the shared documents/files editing and the electronic whiteboard, the combined modules helped the users explain complex information. With the asynchronous module, the time limitations of the other modules were reduced. With the previous audio/video conference confirmation module, users who were absent from the discussion could confirm the result of the discussion.

The result of selecting and combining sub-modules was that the combination of the audio/video conference, chat, Web-alarm, confirmation of the previous audio/video conference, shared documents/files editing and the electronic white board. Therefore, the suggested six modules were used as sub-modules of the communication module.

In the case of the project management module, the process management module and the decision and change management module were suggested as sub-modules. For the management of process and output, the process management module was suggested. There were many project management module candidates. From these candidates, a Gantt chart was chosen. A Gantt chart was an effective tool for scheduling the total process and for representing information about schedule and sub-process output (Wilson et al., 2003). The decision and change management module was suggested for discussion with absent users. To impart information about decisions and changes in a project, this module represented information about the project with a Gantt chart.

The information interaction module consisted of two sub-modules, the information/ knowledge request module and the questionnaire module. Total information and knowledge requests were represented on Web by the information/knowledge request module, so collection of information was more convenient. Through a feedback function in this module, project delay was reduced. The questionnaire module was able to help the optimization experts collect the opinions of many operators and engineers. Through this module, opinions were collected more quickly and the cost of the off-line questionnaire was reduced.

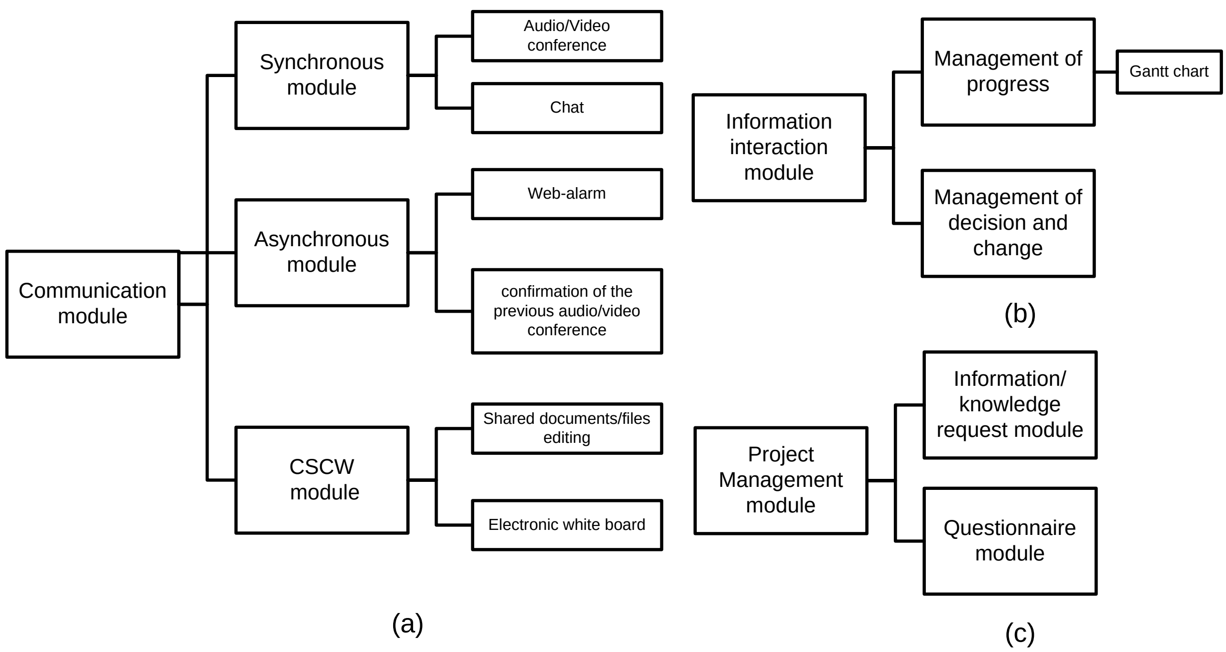


Fig. 4. Suggested sub-module of each module: (a) communication module, (b) project management module, (c) information interaction module.

2.4. Embodiment design

To test the selected module, the prototype was made. Then, an expert group and operator/engineer assessed the prototype. There were some refinement targets that were mainly raised as problems. Analysis of problems provided the solution for improving the product. For example, some operators felt uncomfortable using the communication module because of insufficient experience. Thus, the suggested solution was to apply a comfortable graphical user interface to the module. Lack of understanding of the project management module and communication modules was solved. The solution was applied to the problem of the information interaction module limits in the presentation of information.

Then, the final specification of each module was set. The programmer designed the product in more detail. In the communication module, the audio/video conference and the chat module were organized with the shared documents/files editing and the electronic white board on one screen. The previous audio/video conference confirmation helped absent users. The project management module was constituted by the Gantt chart and management of decision and change. All of these sub-modules were placed in one chart, so users could understand the optimization process more easily. Also, the information interaction module was named I-Map, which unified all the information and knowledge about process. Therefore, users could collect various information and knowledge more conveniently. All of the modules were coupled, so that the weaknesses of the modules were offset and the effects of synergy resulted. Fig. 5 shows the final product, a Web-based online optimization system.

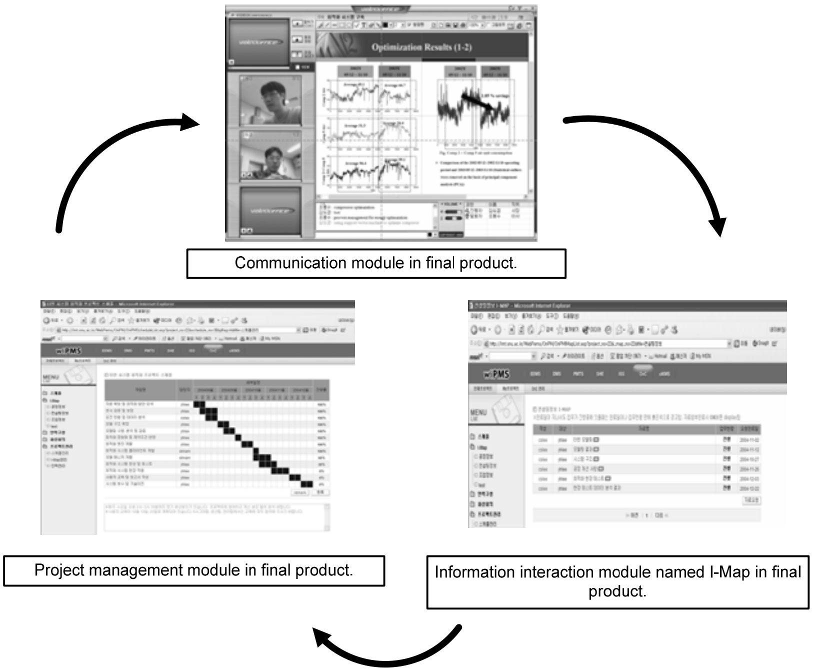


Fig. 5. Final product of Web-based online optimization system.

3. Case study: optimization of plant-wide compressor network

Using the proposed procedure, a Web-based online optimization system was developed. A plant-wide compressor network system optimization was selected as a case study. Plant-wide compressor network optimization has been very useful for saving energy and reducing costs. Since most electric power is consumed in the compressor network, network optimization is important to economizing energy (Han and Han, 2003; Han et al., 2004). However, a typical problem of the optimization project arose: time and cost. Therefore, the Web-based optimization system for reducing time and cost was needed. Analysis of the optimization process result showed that 150 days and $192,000 were needed for the optimization project.

The Web-based online optimization system was successfully implemented. The suggested product reduced both time and cost of the project: 85 days and $109,000 were needed for the optimization project to be carried out using the Web-based online optimization system. In other words, the cost and the time of the project were reduced by 43.5% and 43.3%, respectively.

4. Conclusions

In this paper, the design procedure for development of virtual chemical products was proposed. The proposed procedure was applied to the Web-based online optimization of a plant-wide compressor network. The developed system reduced both the time and cost, which means that the Web-based optimization system is expected to be cost-effective for optimization of various processes. Moreover, the proposed software design procedure could be applied extensively to developing chemical process improvements for different kinds of virtual chemical products.

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