Toward the Construction of High-tech Infrastructure for Clean Manufacturing in Japanese Chemical Industry -Challenge of Simple Chemistry Program-

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ABSTRACT : Being confronted with the 21th century at hand, a paradigm shift has been a common topic for development in many fields. Among these, a concept of sustainable development is the most important one to resolve conflicts and nurture mutualism between science/technology(SCI/TEC) and society/environment (SOC/ENV). Looking briefly over the present stats of the chemical industry in Japan, in this paper, we will introduce a research program named simple chemistry as an example for such a challenge.

Introduction

With the time, chemical industry has been supporting the development of Japan since the advent of civilization at the Meiji era. Unfortunately it has created, however variety of nuisances simultaneously at the beginning of the development. In fact, four major pollution cases in Japan were caused by chemicals of related to chemical industry. It is somewhat ironic, however, that the countermeasures have contributed to the progress of technology.

Particularly, efforts paid in 1970s were rewarded by the recovery of environment to a certain extent, and some practically effective engineering that has been succeeding until today. We are proud of such outcome that the amounts of discharge of air pollutants are considerably small among the developed countries as shown in Table 1. To cope with the coming paradigm shift, however, such local or end-of pope technology will be almost helpless due to both economic and technical inefficiencies. Instead, it is necessary to move to a global or in-process technology that enables us to overcome such inefficiencies.

It is not too much to say that we can never expect further progress of chemical industry without elaboration on global environmental problems that are becoming complicated, complex, large-scaled and even more inter-related. With this in mind, in this paper we will introduce an attempt to establish a high-tech infrastructure concerning with clean manufacturing after a brief statement on chemical industry in Japan.

1. Situation of chemical industry in Japan

In Japan, more than 413 thousand people are working at chemical industry that shipped 233 billion dollars products ranking fifth among the Japanese industries in 1993. Its value added amounted to 115 billion dollars (forth place). It is one of the most technology-oriented industries in terms of the weight on the basic research, and research cost for development that has grown up to the 16 billion dollars (second place). Though we have some specific fields esteemed world-widely, however, we are still inferior to the western leading companies from a viewpoint of international competition and global environmental consciousness.

To fight severe competition in future when globalization will proceed rapidly, we need to away with the existing state of things. This is exactly true because the scale of company is rather small compared with the major western one, and because the rate of energy conservation as a result of another elaboration is being saturated recently (See Fig. 1).

Table 1 Discharge of Air Pollutants (1991)

	Canada	USA	France	Germany	Italy	UK	Japan
CO_2(1)	435	5035	406	957	419	608	1079
(2)	16.1	19.9	7.1	12.0	7.3	10.5	8.7
SOx(1)'	3306	20730	1314	5697	1988	3565	879
(2)'	122.3	82.0	23.0	71.4	34.4	61.8	7.1
NOx(1)'	1923	18760	1507	3234	1996	2747	1301
(2)'	71.2	74.2	26.4	40.5	34.5	47.7	10.5

Total = (1) : [million] ; (1)' : [1000t]

per person = (2) : [t] ; (2)' : [kg] Source : OECD

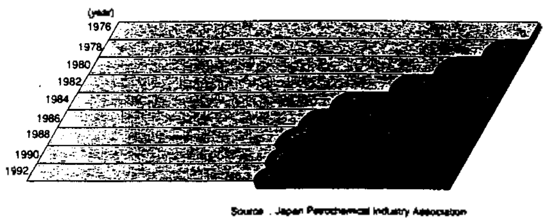

Fig. 1 Transition of the rate energy conservation

In addition, since the proposal of Agenda 21 in 1992, the idea of sustainable development has been recognized as a common basis for the progress of society. That requires us to incorporate the environmental issues into economic activities. Likewise Keidanren of the Japanese federation of economic organization proposed a charter for global environment protection in 1991. It expresses definitely that the next management should attach great importance to the environment problems. Furthermore JCIA (Japan Chemical Industry Association) is taking leadership to promote the responsible care(RC) campaign that is a concrete movement to cope both with human health and environmental protection under the concept of sustainability. (76 companies are members of JRCC by 1995.)

From these actual conditions, Japanese chemical industry is said to be facing with a new situation which demand an innovative program for further development. In the below, we will introduce an attempt tackling such inevitable concern.

2. Challenge of simple chemistry program

2.1 Prologue

Simple chemistry is a program sponsored by ministry of international trade and industry of Japan (MITI), and members from industry, government-affiliated organization and academia participate in the program. It aimed first to renovate the Japanese chemical industry through realizing highly advanced energy conservation. It was started in 1995 under such a simple idea that reduction of reaction process makes process simple and efficient. Represented by the success of polypropylene process, simplification of the process could really achieve considerable improvements as shown in Fig.2 and Table 2.

To pursue the goal along with this precedent case, the following four projects were set up in the program.

(A) Novel catalyst development
(B) Process renovation in bio-industry
(C) Combined reaction & separation process
(D) Highly advanced technology for energy conservation

However in the preliminary discussion, we noticed that the more global framework is necessary toward the 21th century when the sustainability will become a common keyword for the progress. In another words,

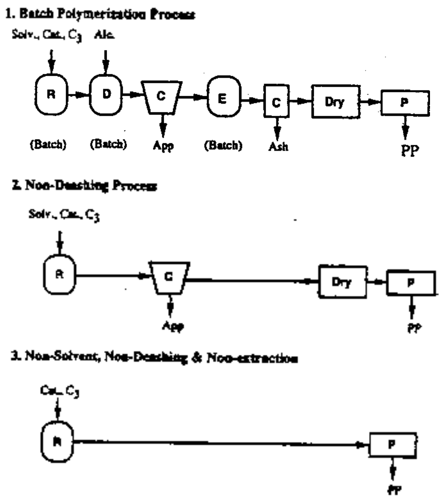

Fig. 2 Transition of improvement in polypropylene process

Table 2 Transition of improvement of polypropylene process

Generation	First	Second	Third
Monomer(ton/ton-PP)	1050-1150	1015	1010
Energy(Gcal/ton PP)	2.5-4.5	1.6	1.3

we should now think over the following 5W1H questions to ourselves.

- Why are we likely unconscious about human and environmental safety? We should take more responsible care for them.
- What is the real energy and/or resources (ENE/RES) conservation while fighting the international competition? We need to focus on the globalization of problem-solving.
- How can we approach the problems? We should consider more comprehensively, and note whole life cycles both product and process.
- Who should take an initiative for such concern, and when and where will it be started? The industrialized countries including Japan are especially responsible for it. Meanwhile worldwide collaboration is also essential. We should start it as soon as possible because the environment protection problems are considered rather urgent in these days.

After all, we have convinced that we should pursue the following two aspects together under the name of clean manufacturing.

- Process/technology innovation
- Life cycle engineering

The first aspect is the end of the preceding projects (A)-(C), and project (D) should be taken place associated with the second one. Furthermore fusion of these aspects is essential to resolve the global environment problems while fighting economical competition. After outlining each project from (A) to (C) one after another, we will elaborate a bit more on project (D).

2.2 Outline of each project

2.2.1 Project (A)-Novel catalyst development

Aim of the project is to develop novel catalysts that can improve industrially important reaction processes. We expect they enable us to find out some better raw materials and/or better catalysts as compared with the currently being used. Here a term better means longer life, higher activity and selectivity besides the soundness against the environment. For the further investigation, we are now paying our attentions on the following five reaction systems.

(1)Selective oxidation of alkane

We have been largely depending on alkene to manufacture many important basic chemicals such as ethylene, methanol, acetate, propylene, acrylate, and much more. Presently those are usually mde form naphtha. We wonder if alkane could deploy alternative technology for producing such basic chemicals because it can improve considerably regarding raw material cost and energy consumption. Besides inventing certain novel catalysts to improve reactivity, we need to reveal the reaction mechanism, optimize the reaction process, and develop a new reactor.

(2)Solid acid catalyst

Since reactions using acid catalysts are popular in industrially important processes, we can get great profits by overcoming such defects as poor selectivity, mass by- and waste- products and some difficulties associated with handling the acids. Taking a few typical cases in alkylation or hydrous reaction, we have briefly reviewed such possibilities.

(3)Formaldehyde

Formaldehyde is one of the most important intermediates for chemical industry. A new separation method using membrane has a great possibility to improve the present dehydration process of methanol in productivity. Developing a new catalyst with high selectivity at low temperature is a key technology besides doing high-tech membrane with durable resistance for temperature and corrosion by formaldehyde.

(4)Dimethyl carbonate

Since toxic phosgene or dimethyl-sulfuric acid are widely used in the present industry, dimethyl carbonate will be a promising substitute for them. If realized, it is possible to establish a simple production route that will bring about cost reduction, improvement in quality of final products, and safety management.

(5)p-Xylene

Shortage of p-Xylene is predicted to continue world-widely as a raw material of PET(Poly-Ethylene Terephthalate) and polyester fabric. Not depending on the variable demands of petrochemical products, a new flexible production of p-Xylene is highly wanted. The new process should be gone into detail of economic factor, safety, and environment impacts.

2.2.2 Project(B)-Process renovation in bio-industry

Bio-process have a great potency to innovate today's technology relying on the peculiar properties compared with the so far chemical processes: (1) its reaction will proceed at normal temperature and pressure; (2) extremely high yield is achievable due to its high selectivity and reaction singularity. The first nature has an effect on advancing energy conservation and safety operation, and second one on reducing by-products and wastes. Conceptually speaking, therefore, we can realize the cleaner production easily through the renovation of bio-processes by applying these synergetic effects. Purpose of project(B) is to reveal bottlenecks for such realization and to develop novel bio-processes. Under this goal, we have reviewed several topics listed below.

- isolation and application of micro-organisms tolerant to organic solvents
- application of enzymatic halogenation reaction
- bioprocess in oil industry
- polymerization reaction started by enzymes
- in vitro protein synthesis process
- bioprocess related to surfactant
- enzymatic peptide synthesis

Among, these we will present below a bit more detail on the above first topic that we think most attractive for the development.

(1)Bio-catalyst tolerant to organic solvents

In spite of the advantages mentioned above, presently it is almost impossible to produce chemical products efficiently using bio-catalysts. This is because most of the chemical processes are composed of the systems using organic solvents. Since the micro-organisms are, in usual, hydrophilic and have no tolerance to organic solvents, they cannot work there at all, or loose their activity rapidly. Consequently making the micro-organisms tolerant to the organic solvent comes first in our concern. We have now a plan to go on the research under the following them.

- to create the organic-resist microbe(child) from the hydrophile parent by applying the mechanism of evolution
- to reveal the mechanism associated with the property of tolerance by identifying the different site of genetics between the parent and child through comparison
- to create the organic-resist microbe through the gene recombination technology
- to evaluate the feasibility of bio-process using the bio-catalyst through simulation

2.2.3 Project(C)-Combined reaction & separation process

Since most reactions are equilibrium limited, conversion of per-pass reactor is not so high. This is why many separators are connected in series for the downstream recovery and purification as shown in Fig.3(a). In addition, a large amount of energy is exhausted for separation since such structure forces us to operate reactor and separator separately.

Purpose of project(C) is to overcome such shortcomings by developing combined process like Fig.3(b).

In such a combined process, we can expect to achieve perfect conversion ideally and to reduce separation energy at the same time if we could make the separation proceed continuously during the reaction. Among the separation technologies such as membrane separation, distillation, extraction, adsorption, or crystallization, we have noted on the membrane separation due to its high selectivity and possibility of continuous operation at high temperature. To make up such combined process, we must decide a structure and find out a medium between the reactor and separator.

As a promising candidate, we are now interested in a reactor with perm-selective membrane, that is, membrane reactor like shown in Fig.4. It can improve the conversion of raw material C through the selective removal of product H. We are trying to apply such a system to de-hydrogeneration reaction using palladium-alloy film or tube as hydrogen permeable membrane.

2.3 Project(D)-Life cycle engineering for clean manufacturing

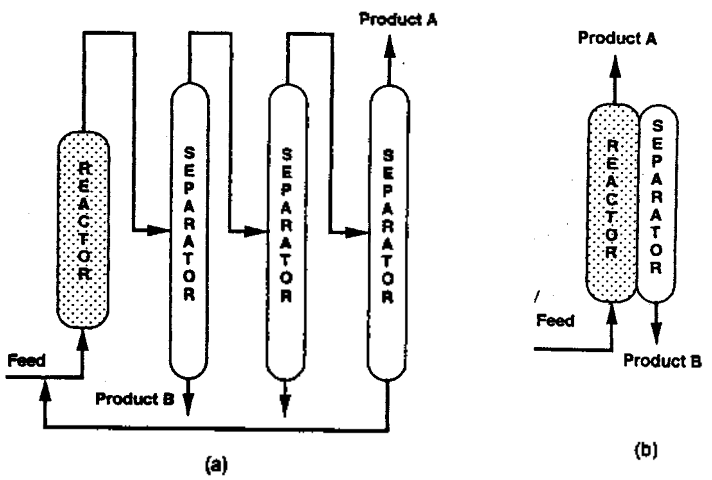

Fig. 3 Combined reactor and separator process (a) Current, (b)Future

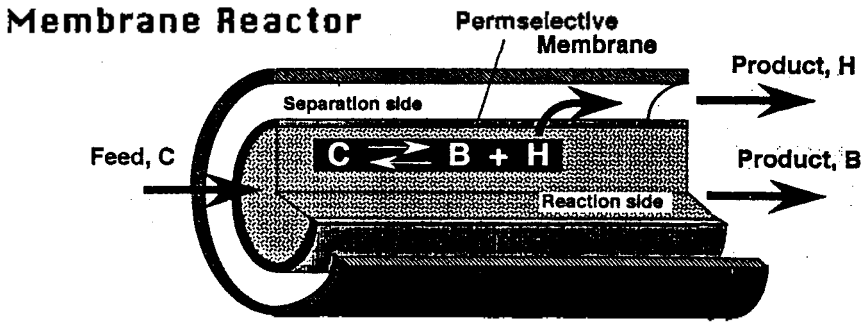

Fig. 4 Concept of membrane reactor

2.3.1 Back ground

As mentioned already, we must have a global viewpoint to achieve the highly advanced ENE/RES conservation. It will eventually result in reducing environmental impacts while being internationally competitive. Such a stance will become one of the most important aspects in the coming century. On the other hand, we cannot expect further development in the so far framework due to the shortcomings intrinsic to

- evaluation of efficiency only at the end of process, or plant-size ENE/RES conservation.
- idea attaining at the goal is important.
- performance index neglecting social cost.

Instead, we need another framework to

- evaluate through the process (life cycle assessment(LCA)).
- know process attaining at the goal is more important.
- involve social cost in the performance index (full cost accounting).

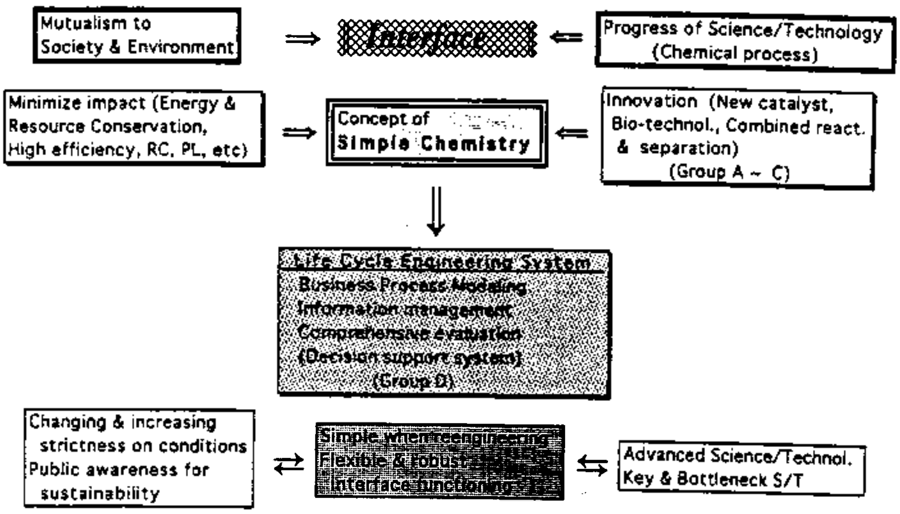

Fig. 5 Scope that the simple chemistry program will pursue

We think such a framework will be consistent to the sustainable development, and be economical from full cost accounting. For example, with the environmental disaster known as Minamata disease, Chisso corporation has been compensating the patients greatly, and much money was also prepared for Superfund in USA. It is easily supposed such great expenses were unnecessary if appropriate prevention had been taken beforehand.

This suggests that as whole society, we need first of all a revolution of way-of-thinking which has been expressed by the following phrases. Japan has not taken as initiative for the environmental problems because we

- are easy to flush with water (forgive and forget).
- believe water & safety is free of charge.
- are conscious enough and making efforts, but do not dare to say it aloud.

We must change such recognition so that the following aspects will be viewed as key issues for each society, that is,

- for people-creation of new culture or reconsideration of our life style(green consumer)
- for the government-policy-making addressing and supporting the sustainability
- for industries-clean manufacturing (green producer)
- for scholars and engineers-efforts to integrate synergetic scholarship and technology for pursuing the sustainability

2.3.2 Our scope

Besides pointing out the revolution of way-of-thinking, we need also a scope for the problem solving that will be described as Fig.5. It claims schematically that our approach should act as an interface to realize mutualism between the progress of SOC/ENV and the development of SCI/TEC. That is to say, the approach must minimize the undesirable impacts on SOC/ENV through the innovation of SCI/TEC while achieving ENE/RES conservation or high efficiency. It must also cope with the response care, product liability and so on appearing associated with human behaviors. Eventually, it will establish a life cycle engineering composed of several element technology.

In other words, using advanced SCI/TEC, we must provide a simple and easy procedure for reengineering under various changes and increasing severeness of circumstances. Furthermore, it will help awaken public concerns on the sustainability, and point out the key or bottleneck technologies necessary for the further development. Therefore, it should have a flexible and robust interface to work with the idea.

2.3.3 Our approach

To put our scope into definite shape, we have called attention on two types of the life cycle, that is, the product life cycle, and the plant life cycle shown in Fig.6. The product life cycle concerns with the industrial activities directly associated with the material flows. On the other hand, the plant life cycle is a cycle of engineering itself. In the figure, each box stands for the activity, manufacturing concerns task. Arrows with solid line show information flows, and broken ones material flows.

As mentioned already, our goal is to establish the life cycle engineering fusing the environmental issues into the economical ones. Therefore we need pay special attentions on the down-streams of the cycle where so far engineering has never noted seriously. They correspond to such boxes as discrimination, reuse and disposal in the product life cycle, and decommissioning in the plant life cycle. We should also note the recycle flows fed back from these regions. Then we move to model each activity or function of engineering task through an appropriate general technique managing information and material flows together.

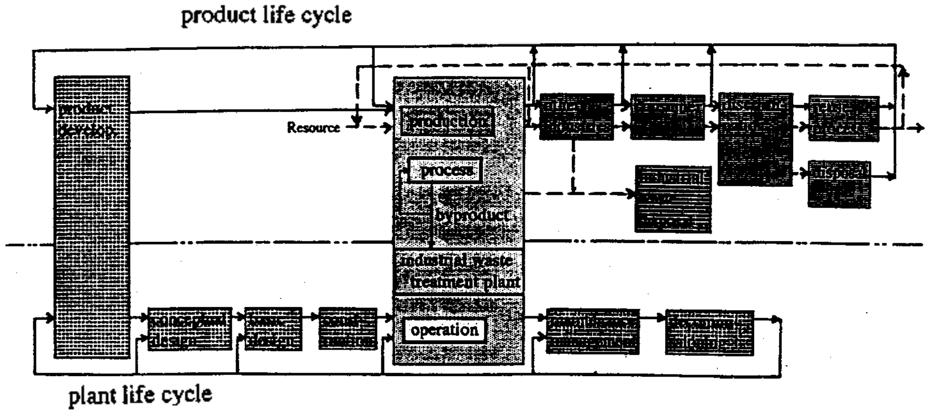

Fig. 6 Scheme of product and plant life cycles

Using such model, we can concern with the clean manufacturing generally. For example, to increase certain convenience at the reuse or disposal stage, we will utilize information fed back from the down-stream, and reengineer the stage of product development or production. Also according to the changes of requirements associated with ENE/RES conservation, raw material modification or various restrictions of law, revamping of plants should be often taken place at every stage of the plant life cycle. However it has been very time-consuming to cope with the new situation since so far engineering is not made based on the sufficient information-driven or intelligent structure.

We can improve such inconvenience through the information supported approach. For this purpose, it is necessary to incorporate with the outcome of international standardization like what is known as STEP (Standard for Exchange of Product model data) or CALS (Commerce At Light Speed).

Generally speaking, real world engineering must consider complicated inter-relationship among the elements both along the material and information flows, and variety of restrictions for the development. Furthermore we have to make appropriate evaluation amenable to decision making. Therefore, it is very important to adopt a transparent approach that enables

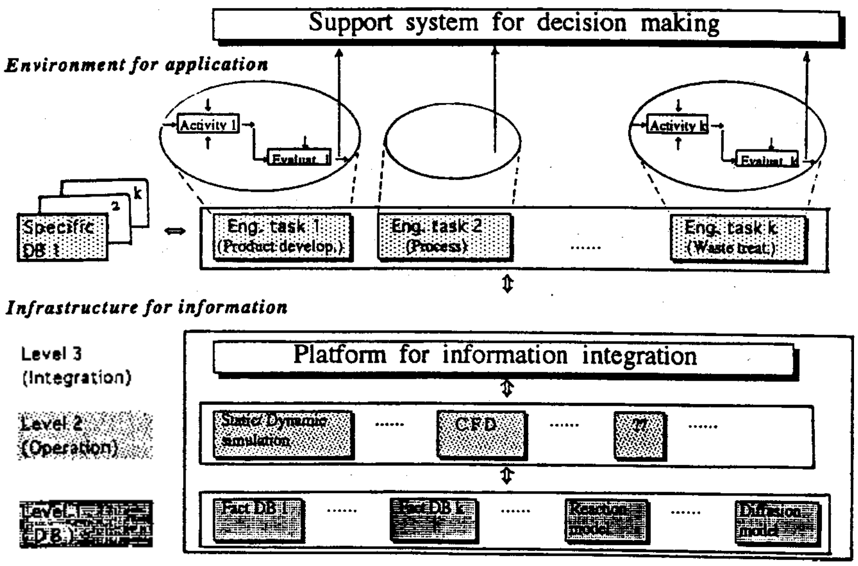

Fig. 7 Overview of the approach of simple chemistry program(Project D)

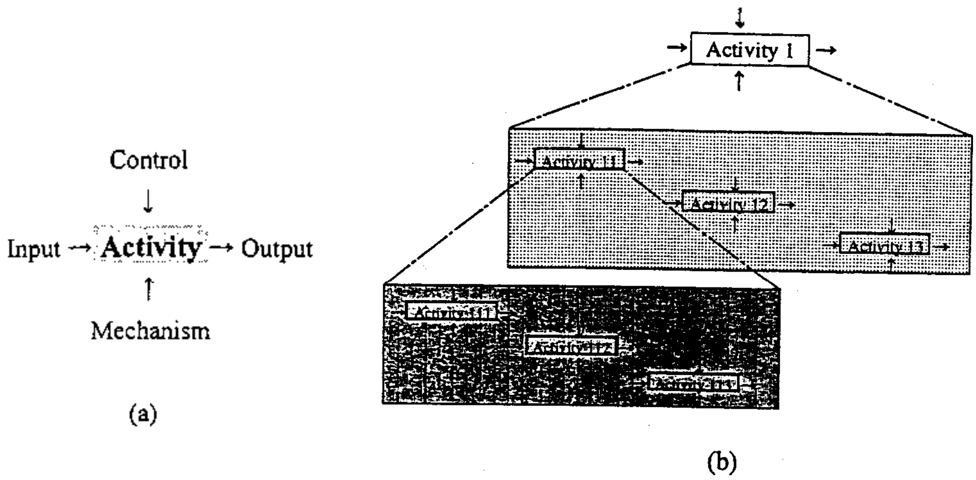

Fig. 8 Structure of the activity model (a) basic, (b) General

us to keep correspondence between what we think and what we should perform in element-wise. It is also inevitable to grasp definite relationship among the elements, and each element to the whole system. Such requirements require us to establish a framework supported by the information integrated infra-structure shown in Fig.7

To cope with a variety of engineering for the clean manufacturing, we think it convenient to decompose the framework into a few layers each of which can be developed independently. Accordingly, it was divided into the three layers, that is, a life cycle model layer, and infrastructure for information management, and a decision support system layer. Furthermore we think it practical to decompose the information management infrastructure into a hierarchy locating an individual database at the low level, and at the middle level operation module-bas such as simulation or computer fluid dynamics (CFD), and so on. They will be run using the appropriate databases at the lower level. Meanwhile, top level works as a platform to arrange and integrate the information. There communicates directly with the life cycle model layer, that is to say, a set of activity models describing the engineering tasks, and must provide any information necessary for simulating the activity models.

In such a structure, it is of special importance to have a harmonized communication protocol realized by holding consistency of information all over the layers while keeping the independence of each at the same time. This means that we should take an object-oriented approach controlled by application programming interface and object management. Thus, we can cope with the complicated and multi-dimensional engineering tasks individually and effectively. In another words, we cam give a high modularity, reusability, and encapsulation to the approach.

2.3.4 Our tools

In this section, we will refer only to modeling method known as the activity model. It was developed as a structured modeling technique for requirement definition. The requirement definition is a careful assessment of the needs that the system is to fulfill. It is also known as IDEF0(7) (Integrated Computer Aided Modeling DEFinition), and has a basic structure like Fig.8 (a). It describes an activity or an engineering task by a set of input, output, control, and mechanism. After all, the life cycle model will be developed by an appropriate linkage of each activity. The relation between input and output represents what is done through the activity. On the other hand, the control and mechanism describe why it is done, and how it is done respectively.

The basic structure will de decomposed into sub-structures until the derived one is concrete and definite enough to explain the original activity. Therefore it will be usually described as a hierarchy like shown in Fig.8 (b). Transforming a conceptual/fuzzy structure into a logical/definitive one, the activity model can provide more clear answers for 5W1H questions regarding the engineering tasks, and can assign appropriate resources according to such dialog. Even more since it is possible to reveal necessary information for evaluation, we are easy to make a rational decision making.

To complete the approach, we should provide and develop some technological element bases that are being investigated presently. They are for example, object-oriented modeling technology(2), methods for comprehensive evaluation (LCA(3), Risk communication(1),...), decision support system(8), and much more.

Conclusion

All over the world, there continues such an inclination that people do not necessarily give whole-hearted support to the progress of SCI/TEC. The situation is very different from the one a few decades ago when it was believed to bring about the welfare for all people. This may partly come from the daily reports that criticize SCI/TEC regarding the destructions of global environment represented by the acid rain, the ozone depletion, the greenhouse gases effect on the earth warming, wild-life extermination, and so on. Though it is not clear to what degree the progress of the SCI/TEC may hold responsibility for these destructions, it is quite certain that their remediations will also owe to SCI/TEC.

In the simple chemistry program, we are going to take an initiative to tackle this challenging problem. Through the research and development thereupon, we hope the foregoing statements in §2.3.1 will be restated as follows. Japan has become a country where people

- recycle ENE/RES, and minimize pollutant emission as much as possible.
- obtain water and safety at low costs using high technology.
- are proud of efforts on the sustainable development. Moreover they can say it aloud, and communicate internationally.

Acknowledgements

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