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OBJECT-ORIENTED PROTOTYPE SYSTEM FOR EVALUATING LIFE CYCLE OF CHEMICAL PRODUCTS

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Abstract - Associated with realizing clean technology, in this paper, we have developed a prototype system that evaluates life cycle engineering in chemical industry. Thereat we have built a life cycle model on G2 known as object-oriented development environment of intelligent system. Practically it is described by a set of objects arranged into a hierarchical structure in terms of IDEF0 modeling technique to facilitate modular development. In a case study, we compare the superiority between the two kinds of chemical products both from environmental and economical aspects. Just by giving certain values at the menu display as a user interface, we can analyze easily various kinds of scenario, and support our strategic decision making on waste disposal and recycling of the chemical products.

INTRODUCTION

Environmental consciousness is becoming a common concept for process development in the coming world. Accordingly, many interests have been paid to develop effective methods for evaluating environmental management. Nevertheless life cycle assessment (LCA, [Heijungs, 1992]) as such a tool concerns only with the environmental issues, it takes much time and cost to perform it due to the "from cradle to grave" nature. It is desired, therefore to improve the evaluation process, and provide a decision-aid for environmental management under various economic activities. With this point of view, in this paper, we propose a prototype system through the object-oriented approach that enables us to use intelligent applications coupled with information technologies. After presenting a life cycle engineering model (LCE model) built on G2, we will present a case study regarding plastic sheets used for green houses in Japan.

A LIFE CYCLE ENGINEERING MODEL

1. Scope

Associated with the interdisciplinary nature of the problem, our approach will emphasize especially the ever continuing development environment. That is to say, we try to give a framework easy for model expansion/revision, application execution, and data collection/management on the distributed basis of available computer resources. Actually we have adopted G2 software which is known as a development environment for modeling, designing, building, and deploying intelligent applications. Using a variety of interfacing capabilities of G2 besides the object-oriented manner, we can build LCE model realizing the above aspects. After all, the idea whose scheme is shown in **Fig.1** aims at cooperating the local intelligent resources with the distributed object technologies.

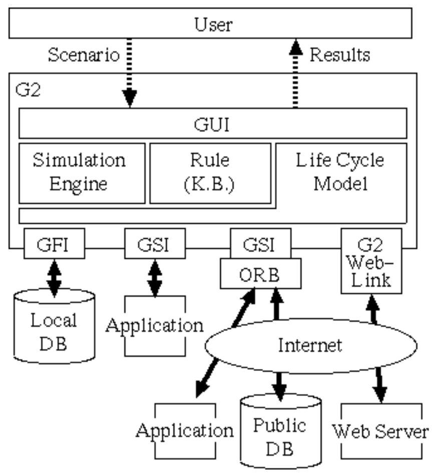

Fig.1 A Scheme of whole system

2. Activity-Based Modeling

We have used a hierarchical activity-based modeling method termed IDEF0 [Marca and McGowan, 1988].

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Here IDEF is known as an outcome from the project of ICAM (Integrated Computer Aided Manufacturing) so that the U.S.A. air force could standardize the order specification of the aircraft. Being viewed as an effective tool for business process reengineering, IDEF is designated to make it be an international standard for functional modeling method.

Its basic structure is simple but definite enough as shown below. It is composed just of one box and four kinds of arrow. There, box represents a certain ACTIVITY such like "produce A" or "consume B", and arrows coming into the box from the left side INPUT, from the top CONTROL, and from the bottom MECHANISM, and leaving to the right OUTPUT respectively. The relation between INPUT and OUTPUT represents what is done through the ACTIVITY while the control describes why it is done, and the MECHANISM how it is done. We can deal even with actual complicated system without using any additional procedures just by decomposing the activity into its sub-activities which inherit the properties at the upper level. (See **Fig.2**. Scheme at each level is called diagram.)

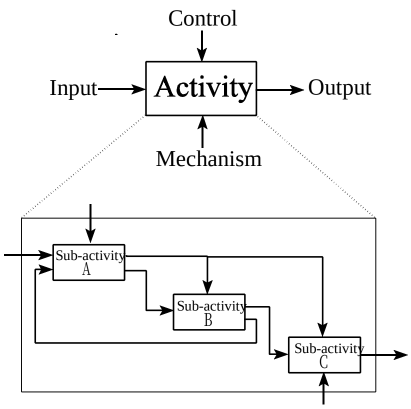

Fig.2 Basic structure of IDEF0 model and its extension

Applying this modeling method, we can achieve the following points that are suitable for our approach.

(1) For elaborate assessment, we often need to modify and/or correct the standard model according to the particular concerns. Therefore, it is desired to facilitate a modular design.

(2) Since the above model management refers to a cooperative work generally, it is vital to obtain the common recognition in model building and scenario definition among the participants.

(3) Besides the relations regarding physical flows, unit process model should involve information regarding controls and resources to set up a proper evaluation scenario.

3. An Object-Oriented Prototype System

Modeling : The modeling is carried out by viewing every activity in IDEF0 representation as an object. The work space of G2 where every object will be connected and defined its properties is handled so as to correspond to the diagram of IDEF0.

Under these aspects, an activity class is defined to express a set of the activities belonging to the highest class level first. Next the lower classes which inherit the properties of their respective super class are derived consecutively. After all, they are to be expressed as a hierarchical structure. For examples, we can name "production", "consumption", and so on in the upper layer, and likely "collection" and "incineration" in the lower layer.

Also we prepare "control class" and "mechanism class" whose class definitions involve appropriate rules and/or procedures. By doing that, we can awaken any users by showing certain messages when some properties of the activity do not satisfy certain conditions under the present scenario.

Besides these, "transportation class" is added because the inputs of this activity is always equal to the outputs, and some special data such as load factor, transportation distance and so on are necessary on the case by case basis.

Our model ranges from supply of the raw material and production of the original materials in the upstream to recycle and disposal in the down stream, that is to say, over a life cycle of the chemical products. So the input to the system is taken as the amount of crude oil, and the output of the system as recycle products.

Calculation regarding material balances, energy consumption, amount of CO_2 discharge, cost, and much more if necessary are described as the methods in the class definition. They are carried out on the basis of unit consumption, or of linear relation.

For this, data is provided as a set of parameters which are extracted from the linked database located on the sub-work-space of the activity of the lowest layer.

After all, we have constructed a life cycle model on G2 an example of which is shown for PVC sheet at production stage in **Fig.3**.

Interface : For the convenience sake of model builders and users as well, we have designed various interfaces as follows. We develop some user interfaces by merging G2 user interface library to G2 menu system. The former presents a development environment for designing a graphical user interface of the knowledge base (KB) while the latter that for providing a customized menu bar in KB. In **Fig.4**, we show an example of the life cycle model attached the user interfaces mentioned here.

In addition to G2 file interface (GFI) for communicating to the local database (DB), we aim at utilizing G2 standard interface (GSI) and G2 web-link which will play the respective role shown already in Fig.1. Under such an environment, by utilizing new applications and updating/modifying data for the particular problems, we can concern with LCE in the latest manner.

Database : We provide the local DB of the system by collecting various data [Takeshita, 1999, NIRE-LCA, 1997] in EXCEL spreadsheet, and then converting it to ASCII text file all of which field are delimited by the tab character. By using GFI which is possible to exchange data between the local DB and G2, parameters involved in each object are given for the life cycle model.

A CASE STUDY

In Japan, green houses of chemical sheet have been popularly used in farm houses till now. While the share of ply-vinyl chloride (PVC) sheet is overwhelming the others in terms of economy and quality as well, disposal of the spent sheet is calling hot attention associated with what is known as the dioxin problem recently.

In the prototype system, we covered material recycle (MR), thermal recycle (TR), and chemical recycle (CR) as the recycle options. Actually, about 45% of the spent PVC sheet is recycled, and used as a raw material such as floor material and vinyl-sandals (MR). On the other hand, TR, which is carried out demonstratively by mixing with other plastics, has a restriction associated with the dioxin problem, and the corrosion of furnace by HCl, and CR is still at R&D phase. Furthermore, the reuse is presently impossible due to the badly polluted spent sheet. By adding disposal options like landfill and incineration to these, there exist a variety of scenarios to be considered for the downstream management.

It is significant, therefore, to evaluate such scenario from comprehensive point of view, and investigate another possibility including the case of shift from PVC sheet to the others, say ply-ethylene (PE) sheet. To work with such analysis, we have applied the foregoing approach, and carried out some assessments through the developed prototype system. We can choose a variety of downstream scenarios only by giving appropriate values to the production amount of the products, total recycle rates, its breakdown (MR, CR, TR), each processing efficiency and so on. As said before, we provide a user interface as the menu display to set-up these parameters easily.

For an example, we obtain the results shown in **Tables 1-3** for the data we could gather presently, and under several assumptions. As far as interested in the production stage, we can assert that PE sheet is superior to PVC sheet from the aspects both of energy consumption and CO_2 emission from **Table 1**.

However, turning our concern to the downstream management (**Table 2**), we need to reconsider the above result differently depending on the scenario.

If we would not carry out the recycling, and dispose the spent sheet only through landfill and incineration at the equivalent rate, there exists trade-off among the two environmental issues and cost. That is, PVC sheet needs more amount of energy and cost while less emission of CO_2 compared with PE sheet.

On the other hand, under the recycle scenario with the rate like TR 50%, MR 40%, and CR 10%, we know that PVC sheet is more superior to PE sheet from the environmental issues. (The analysis is done under the condition that most of the spent sheet (90%) would be recycled.) By the way, the negative values in the energy column in the table means that the reproduced amount will exceed the necessary amount for the recycling. The results also show that by virtue of conservation of virgin resin and crude oil, in both cases, recycling is quite acceptable from the environmental aspect and cost as well.

Table 1 Evaluation at production stage

Kind	Energy [10^8kJ/km^2]	CO_2 [t/km^2]
PVC	70.0	246.8
PE	14.4	199.0

Table 2 Evaluation of scenarios at downstream

Scenario	Kind	Energy [10^6kJ/km^2]	CO_2 [t/km^2]	Cost [10^6¥/km^2]
Landfill 50%, Incineration 50%	PVC	20.9	68.2	7.52
	PE	16.3	154.0	5.87
TR50%, MR40%, CR10%	PVC	-1056.6	41.1	6.73
	PE	-716.4	174.4	4.69

In developing the life cycle model, we emphasize the importance to evaluate the system totally, and derive a final judgement based on it. In **Table 3**, we present a result which is evaluated over the life cycle of the products. It describes a different picture from the foregoing limited extent of concern. The results show that since most of the energy consumption and CO_2 emission occur at the production stage, recycle as material (MR) or reuse is very effective as far as PVC sheet is concerned. Also, if we would shift to PE sheet from PVC sheet, we could considerably reduce the energy consumption at the expense of a little increase in CO_2 emission regardless of recycling or not.

To realize the above recycle scheme, however, we need to pioneer new markets utilizing the recycled resin actually, and change our value system to make more conscious about the environment at the same time.

Table 3 Evaluation of scenarios over life cycle

Scenario	Kind	Energy [10^8kJ/km^2]	CO_2 [t/km^2]
Landfill 50%, Incineration 50%	PVC	70.5	322.5
	PE	14.8	358.9
TR50%, MR40%, CR10%	PVC	59.7	295.4
	PE	7.43	379.3

CONCLUSIONS

In this paper, we have developed a prototype of decision-aid for LCE. There we have built the life cycle model on G2 in compliance with the IDEF0 modeling method. Running the system under a variety of scenarios, we can calculate energy consumption, CO_2 emission and even cost over the life cycle of the chemical products.

Applying the system, in a case study, we compared the superiority between the two kinds of chemical sheet used for green houses in Japan. Just by giving several values in the scenario menu, it has been shown that we can analyze the scenario, and carry out the assessment for strategic decision making for LCE.

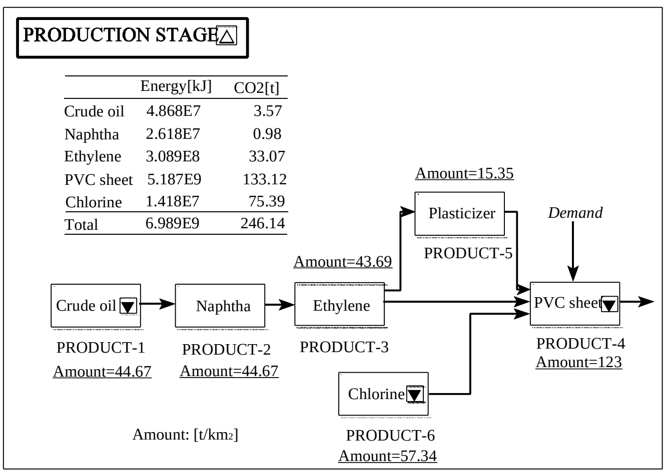

Fig.3 Life cycle model at the production stage (PVC sheet)

However, to deal with a more general concern, and also to derive a more reliable conclusion, lack of reliable data is considered to be a bottleneck. It is quite natural to emphasize the importance of collaborative effort to collect and adjust various data for LCE. Besides the standardization of data specification, therefore, it is desired to apply an object-oriented DB from the aspect of easy DB management in future study.

Even under such a recognition, we can honor the potentiality of our systems from a continuous and self-awaken structure which improves itself according to collection of available activity models, applications and data appearing in future studies.

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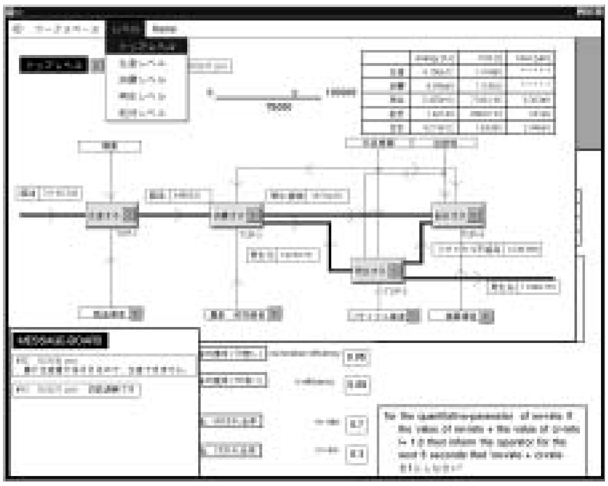

Fig.4 Life cycle model attached with Japanese user interface

ワークスペース: Work space, レベル: Level
生産: Production, 消費: Consumption,
再生: Recycle, 処分: Disposal,
原油: Crude oil, 製品: Product,
再生品 : Recycle product