Technological Information Infrastructure for Product Lifecycle Engineering

Naka Y [(1)] Hirao M[(2)] Shimizu Y[(3)] Muraki M[(1)*]and Kondo Y [(4)]

(1) Tokyo Institute of Technology, Japan
(2) The University of Tokyo, Japan
(3) Toyohashi University of Technology, Japan
(4) National Institute for Resource and Environment, Japan.

Abstract: For sustainable development, it is requisite not only to assess multi-dimensional items such as environmental impacts, process safety, product safety, and so on, required from human society, environment, and markets, but also to feedback assessment results to product and process design/development. Through the investigation about requirements for manufactures at each stage in product lifecycle, it becomes clear that PDCA (Plan – Do – Check – Action) cycle is necessary to take actions properly from viewpoints of ecosystems, business systems, and society. We clarify required functions of supporting system of PDCA cycle, and then propose material supply chain models of hierarchy structure composed of unit process models. Based on proposed system and models, evaluations of PET bottle recycle system and greenhouse sheet recycle system are implemented as trials. Furthermore, we show the directions of future scope.

Keywords: product lifecycle model, information infrastructure, environmental impacts

Introduction

"Sustainable development for human societies" is a common concept for all human activities in the world, and many interests have been paid to evaluate environmental impacts such as ozone layer depletion, global warming, and acidification through the whole product life cycles, because of the interactions between stages of product lifecycle. Sustainable development is defined to meet the needs of the present under the consideration of future generations' needs, then investigations from viewpoints of business-oriented and societal areas (respectively, micro-economics and technologies concerning business systems, and social issues and macro-economics concerning society) are necessary in addition to that of scientific one (natural and physical sciences concerning ecosystems). From the evaluation results through the product lifecycle and requirements, manufactures, consumers, and policy-makers are required to take actions respectively in production of products and/or services, life style, and policy-making.

To take proper actions under the consideration of these three areas through the product lifecycle, PDCA (Plan – Do – Check – Action) cycle is requisite. It consists of making scenarios (plans) which will be possible solutions for the requirements from environment and human society, forecasting the effects of these scenarios through the product lifecycle, evaluating the effects, and feed-backing them to the decision makers. We propose framework of support systems used in this PDCA cycles for manufactures, of which requirements environmental impacts, material safety, process safety, consumers' satisfaction, production cost and so on, through investigating their PDCA cycle in decision-making on such as product design/development, process design/development, production, purchase, and so on. We show trial works and our scope of technological information infrastructure for lifecycle engineering in future.

*2-12-1 Ookayama, Meguro-ku, Tokyo, Japan 152
Tokyo Institute of Technology
Dep. Industrial Engineering and Management
E-mail mmuraki@me.titech.ac.jp

1. Requirements for manufacturers

As mentioned above, human health, ecological health, and resources become key words according to "sustainable development", and industries, consumers, and policy-makers are required to take proper actions from the evaluation results through product lifecycle. We focus on manufactures supplying products and/or materials to the markets in this study. Firstly, requirements for them from human society and environment, and markets and/or consumers are investigated respectively, and shown in Fig. 1. Human society and environment require them sustainability, environment audit, responsible care, public acceptance, product liability and so on, and targets of these requirements are to realize material safety, process safety, and their environmental conscious behaviors such as minimization of waste, resource consumption, emission, and so on. From the markets and consumers,

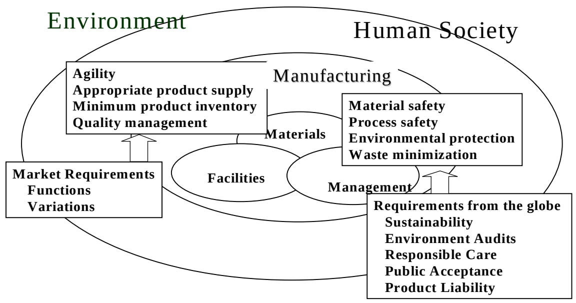

Fig.1 Requirements for Manufactures

product specifications, quality, variety of products, prices, agility, and so on are required as needs. Concrete targets of productivity, economic criteria and so on are also required from manufactures themselves.

To get proper solutions for the requirements, it is necessary for manufactures to make clear relations between product lifecycle and plant lifecycle. Figure 2 depicts the relation between plant lifecycle to the stage of material production in product lifecycle. These relations of other stages in product lifecycle such as parts production, final product manufacturing, used product treatment, are similar. Implementation of the PDCA cycle from the viewpoints of product lifecycle and/or plant lifecycle enable decision-makers to take proper actions in proper positions of the business flow. From the evaluation results, target activities are made clear, and proper action plans are determined. PDCA cycle mentioned above and its required functions are depicted in Fig. 3. This cycle usually starts as a new project such as a market demand, a business need, a customer request, a technological advance, legal

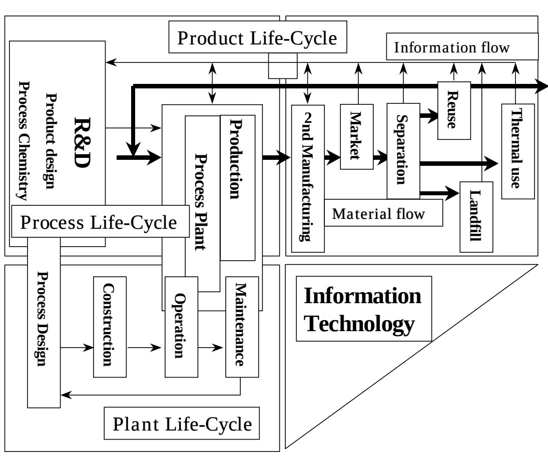

Fig.2 Relations between Product Lifecycle and Plant Lifecycle

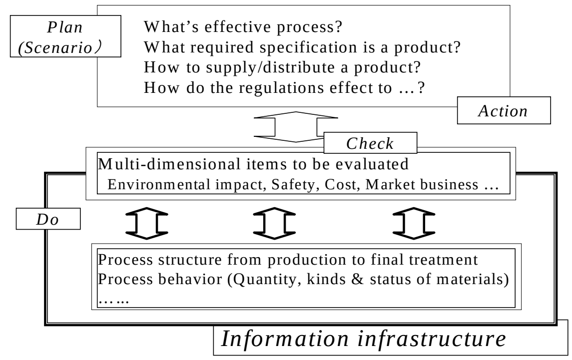

Fig.3 PDCA Cycle in Decision-Making

requirement and so on.

Next step is to foresee the effects of the scenarios through simulations based on individual scenarios. In this step, databases of environmental and cost inventories, simulation models are requisite. Check step is to evaluate the multi-dimensional items such as environmental impacts, process safety, product safety, and so on, required from human society and environment, and markets as mentioned above. Actions are taken if necessary. It is desirable to get trigger information from the check step to modify and/or improve the scenario properly. We call an infrastructure supporting do and check steps as "information platform".

2. Framework

Any actions at any stages effect on the multi-dimensional items through the whole product lifecycle, and it indicates necessity of consideration of many (multi-dimensional) items simultaneously through the whole product lifecycle because of different effects on the same items at different stages. Actions at some stage may create new restrictions and/or constraints at the other stages. The decision-making process on some stages are investigated in some detail.

Figure 4 shows a simplified material supply chain model because of rough decomposition of product lifecycle. At MP (material production) stage where materials are produced from raw materials (resources), there may exist many requirements from a customer request from environmental impact consideration, a market demand from consumers' satisfaction, a business need from cost reduction, and so on. For these requirements, scenarios such as change of raw materials, change of production processes, change of material specifications and so on may be considered. Effects of scenarios such as competition with other materials, production cost, process safety, productivity of this stage, and items such as environmental impacts, lifecycle (total) cost, material and product safety, and flexibility through the whole product lifecycle must be

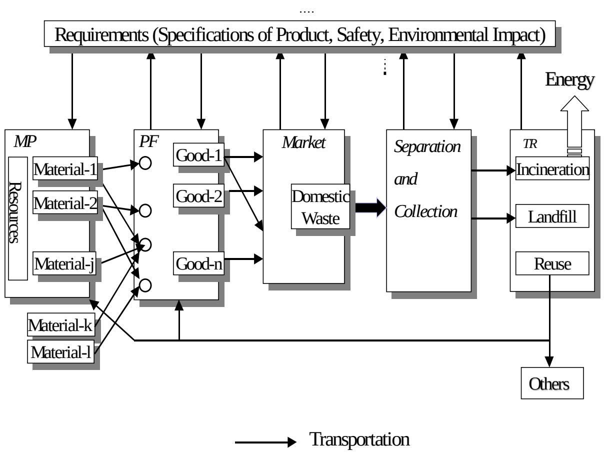

Fig.4 An Example of Material Supply Chain Model

investigated simultaneously. At PF (product fabrication) stage, products are manufactured from fabricating of materials and/or assembling of parts. Change of materials from legal requirement concerning to restrictions on use of materials and/or a customer request, change of products specifications from market demand, and so on may be considered, and many items mentioned above must be investigated simultaneously in like manner of MP stage. At Market and collection stage, treatment stage, and transportation stage, change of supply/delivery systems, change of collection systems, change of sorting processes, change of treatment systems and processes, change of recycling systems may be considered to reduce environmental impacts, minimize the waste, reduce lifecycle cost, and so on.

It is useful for development of PDCA support system for manufactures to clarify its objectives, then we analyze three type of scenarios in this study; problems of individual technologies, integrated technologies, and legal systems. Problems of individual technologies are simplest ones. If material production process innovation is much effective, there may be possibility of influencing product manufacturing. If target product can be manufactured from various kinds of materials by innovation of product manufacturing technology, it may effects on material production, market, and collecting and recycling system. In these cases, engineers are interested to compare their technologies with others. A linkage of material production technology and product manufacturing technologies is one integrated technology problems, and it may effects on possibility of new materials, or simplification of material grades. An extreme case may be integration of all technologies from material production to used product treatment. Engineers are interested to evaluate the technology integration. Engineers are also interested to investigate the effects of existing and/or planning legal systems on material production, product manufacturing, treatment systems and so on. This is one of legal systems. Cost allocation of waste treatment is one example of this category. In Fig. 5, triggers of each scenario and its scope are shown. Dotted and solid arrows indicate the scopes respectively of possible and necessary investigations.

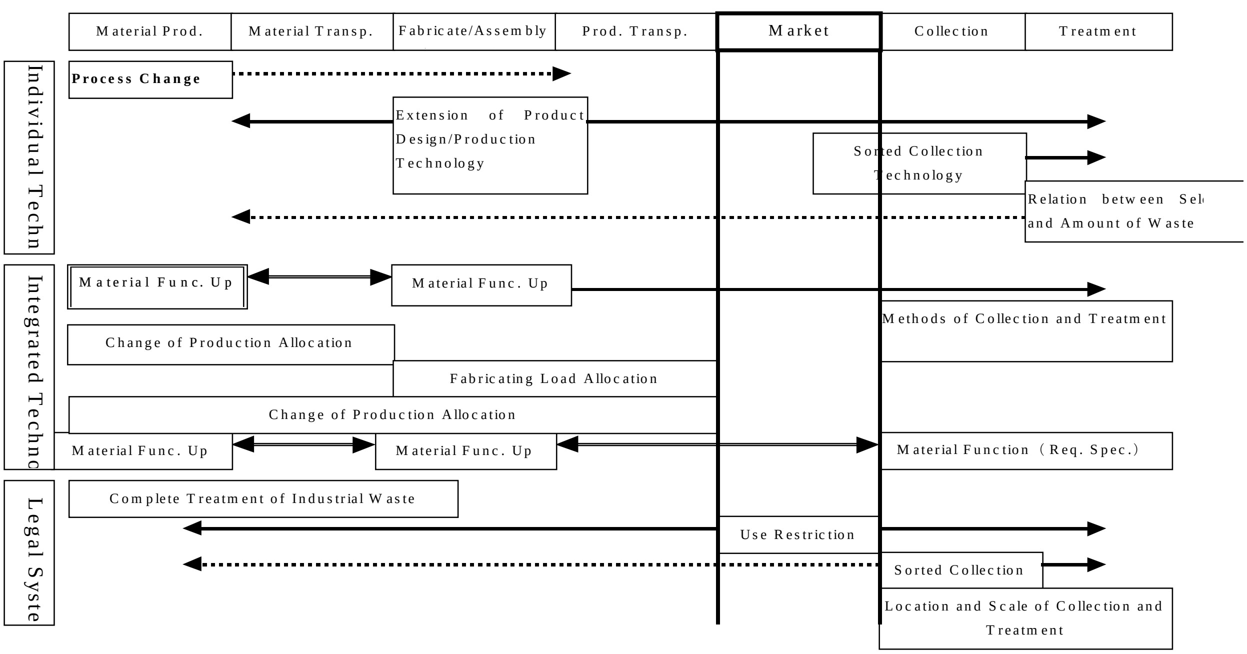

Fig.5 Scopes and Triggers in Scenarios

3. Proposed system

We propose a hierarchy structure of material supply chain model as shown in Fig. 6, in which material supply chain models are composed of sector models, and sector models are composed of unit process models. In this study, we basically prepare two types of sector and unit process models, which are average and user defined models. Sector model can be used to define the investigation scope, and then we distinguish this material supply chain model by a standard material or product name and its flow. This name is corresponding to an output of some unit process model, then it is possible to automatically calculate material flows in downstream and upstream unit process models.

Each unit process model must have its own name to distinguish from the others, and static models are normally used in this study. For the case of more than two products produced simultaneously from one unit process, one main product is used as a standard, and allocation problems are solved in like manner of LCA (Life Cycle Assessment). We also prepare unit process models considering the local distribution of inputs and/or outputs to investigate the local collection, transportation, and distribution processes. The prepared four types of unit process models are explained briefly;

1) Average unit process model based on production

This is a standard model of ISO14000, and data used in this model are averaged based on amounts of productions. In addition its name, as attributes, product names, raw material names, used energy names, names of emissions, their amounts of consumption per main product production, and lower upper limits of production, and so on are prepared. Relationships between inputs and output are linear.

2) Average unit process model based on production processes

This is also standard model of ISO14000, and data used in this model are averaged based on amounts of productions of individual processes. As attributes, the same items of above model are prepared. Relationships between inputs and output are linear.

3) Nonlinear unit process model based on production processes

This model is prepared by use of information from flow sheets. Process simulation is possible based on this unit process model. Relationships between inputs and output are normally nonlinear. As attributes, the same items of above model are prepared.

4) Unit process model based on the Input Output Table

This model is prepared from analysis of the Input Output Table. Relationships between inputs and output are linear. As attributes, the same items of above model are prepared. Many assumptions are

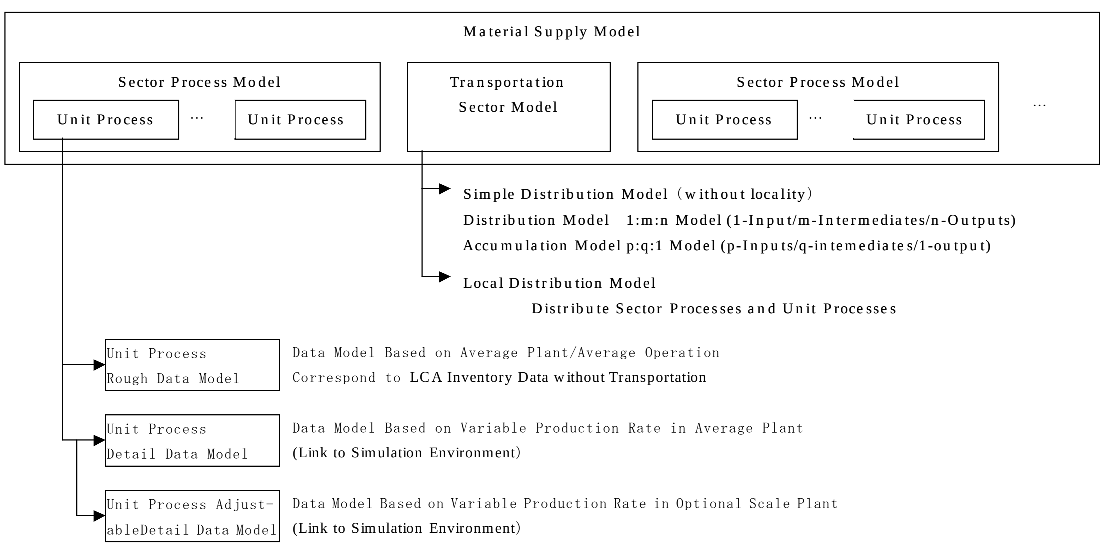

Fig.6 Models of Material Supply Chains

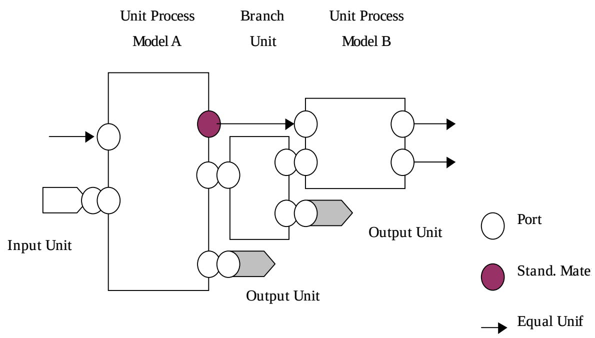

Fig.7 Linkage of Unit Process Models

necessary in use this model, and then normally we do not use this model.

In addition to the unit process models mentioned above, units of input-output and branch-juncture are necessary to define the scope of investigation. Figure 7 shows the linkage of unit process model, input-output units, and branch-juncture units. The painted circles (ports) and arrows are respectively standard materials, and flows from downstream and upstream units. In addition of material names, each input unit has input flow, energies, emissions, and upper and lower limits of supply flow as variables. Each output unit has same information of the upstream port automatically. We consider two types of juncture units; one is to mix flows of different materials, the other is to join flows of the same materials. In the former, it is possible to change the name of materials. In both units, values of attributes must be calculated again because each flow has different source process. It becomes possible to investigate the scenarios mentioned above by these preparations.

In addition to unit process models, input-output units, and branch-juncture unit models, simulators and database, which are mainly environmental inventory and cost inventory, are necessary. Based on the scenario, a proper material

Based on this proposed system, we have two trials of evaluations of PET bottle recycle system and greenhouse sheet recycle system (Hirao *et al*.,1999, Shimizu *et al*., 1999) where average unit process model based on production are used, but their explanations are omitted here.

4. Future scope

We propose PDCA support systems for manufactures through investigation Product lifecycle and plant lifecycle. In this chapter directions of our research are explained briefly.

Based on the scenario, proper material supply chains models and databases are to be prepared. It becomes clear that required information is objective process structure corresponding to material supply chain models, set and given conditions corresponding to assumptions or constraints such as demand, process functions and so on, and parameters, then it becomes important how to define scenarios. Use interface interactively supporting to provide required information based on scenarios is significant.

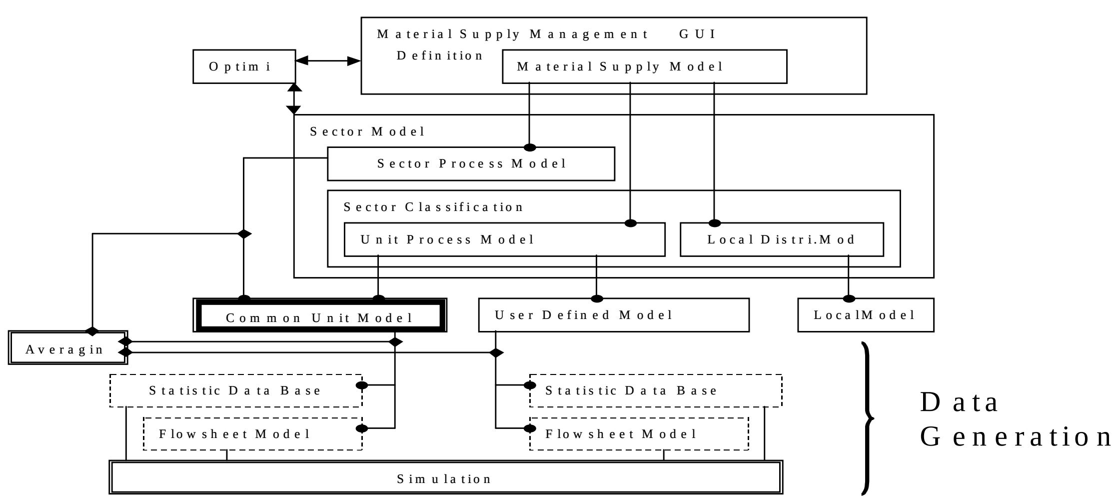

Fig.8 Relations between Models

Changes of data structure and attributes are often required to cope with new knowledge and different scenarios. Furthermore, there exist many stages in the product lifecycle, many kind of production processes, national models or local models, a large number of materials *et al.,* then it is impossible to store all inventory database and process models in one site. It is necessary to exchange process models and data between outside ones because of collaboration and/or sharing. Data model definition including standardization and distributed information technologies including agents become important. It is natural to determine data model standards like STEP.

To foresee the effects of scenarios through product lifecycle, it is possible to adopt models of various levels. For example, it is possible to use user defined unit process models at some focused sectors, and average unit process models at others. Investigation about fidelity is necessary.

It is suitable not only to evaluate the estimation results about multi-dimensional items, but also to get trigger information about actions and/or positions from check step of PDCA cycle.

Conclusions and discussion

Through the investigation about requirements for decision-makers, it makes clear that PDCA cycle is requisite to take proper actions in from viewpoints of ecosystems, business systems, and society. To support this PDCA cycle, we clarify required functions of supporting system of PDCA cycle, and then propose material supply chain models with hierarchical structure composed of unit process models and the relations between models. Based on proposed system, evaluations of PET bottle recycle system and greenhouse sheet recycle system are implemented as trials. Furthermore, we show the directions of future scope.

We think that realization of societies with material recycle systems is expected through these investigations in near future, then it is necessary to consider how to manage material supply chains after that. In these societies, new mechanisms and/or systems are necessary to recycle most of the used products. Used products are indicated by “product name” and “product structure”, and quality (composition) and quantity are included in attributes of the latter. Parts and materials disassembled from used products must be sorted into reuse part, recycle material, and disposal by comparing the values of these attributes with standard ones, then new standardization and definition of material flows are necessary.

To maintain and keep transparency and accuracy of data, it is important to establish proper database management systems in the distributed environment, in other words, consensus about 4W1H (who, when, what, where, how) in data maintenance is important.

Acknowledgment – This work is partially supported by Japan Chemical Innovation Institute.

References

Hirao M. and Y. Fukushima, Evaluation of Environmental Impacts of Product Lifecycle for Process Design. ESCAPE-9Butapest, Hungary (1999)

Shimize Y. *et al*., Object-oriented prototype system for evaluating life cycle of chemical product, APCChE Congress, Seoul, Korea (1999)