Revised extended abstract, AI in Design 98, July 20-23, 1998.

Towards Redesign of Manufacturing Processes based on Functional Understanding

Yoshinobu Kitamura†*, Toshio Ueda†, Masayoshi Fuse‡, and Riichiro Mizoguchi†
† *The Institute of Scientific and Industrial Research, Osaka University,*
‡ *Sumitomo Electric Industries, Ltd.*

Abstracts

This research aims at developing a redesign support system for manufacturing processes. The redesign task requires identifying not only behavior of each process-unit but also relations among them such as "to prevent" and "to allow", because they represent justifications of the existence of each process-unit. In this article, we propose a framework of redesign including functional understanding task to identify functional structure of a target artifact before modification.

1 Introduction

Functionality plays an important role in design problems, because it represents a part of "design rationales" [Chandarasekaran et al. 93, Lee 97]. A lot of research has been carried out on functional representation of artifacts such as [Chandrasekaran et al. 93, Iwasaki et al. 93, Lind 94, Sasajima et al. 95]. Many of them investigate only "to achieve"-type relations among functions. Nevertheless, types of relations among functions are not only the "to achieve" but also others such as "to prevent" and "to allow". For example, an inspection process *P allows* a previous process P_p to produce defective objects, and *prevents* them from flowing into a next process P_n. The former contributes to simplifying the equipment of P_p and hence to saving of costs. The later prevents misbehavior of P_n. We call such dependency among functions *a relational function.*

The relational functions play an important role in redesign, because they represent a part of the justification of the existence of the process. For example, if one removes the inspection process *P* without due consideration for such contributions, the defective objects would cause misbehavior of P_n improperly. In order to remove *P,* we have to change the equipment of P_p for no defective object. Capturing the relational functions enable redesign systems to avoid such side effects and to propose sophisticated redesign solutions.

This research aims at developing a redesign support system for manufacturing processes which consists of the two subtasks, that is, *functional understanding* and *solution generation,* as shown in Figure 1. The former is to identify plausible functional structures from the given behavioral model of the target process. The later is to propose how to change the process (redesign solutions) against the given criteria for redesign.

. We had investigated the following four issues to realize such a system:

(1) To formulate functional structures representing the justification of the process

(2) To build a functional ontology

(3) To formulate functional understanding task

(4) To describe redesign knowledge.

This article outlines the framework of the redesign support system. Section 2 describes functional structure. Section 3 explains the framework of the system. Then, in section 4, the steps of functional understanding and redesign are demonstrated by an example.

2 Functional Models of Manufacturing Processes

2.1 Function of a Process Unit

A manufacturing process can be viewed as a sequence of process units (*P*). The model of a process unit consists of

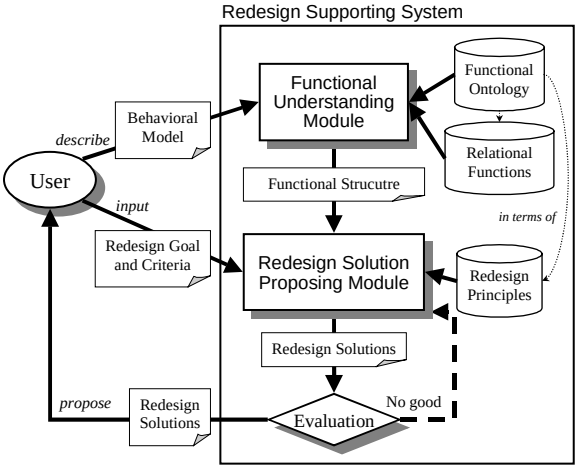

Figure 1: Framework of the Redesign Support System

* *8-1, Mihogaoka, Ibaraki, Osaka 567, Japan*
E-mail: kita@ei.sanken.osaka-u.ac.jp

behavior, function, objects (*O*) and agents engaged in the process (*A*). The behavior represents changes in attributes of objects. It is independent of the context. On the other hand, we define function as the interpretation of the behavior under the given context. For example, let's consider a part of a manufacturing process shown in Figure 2. The behavior of the process unit P_2 is "to *assort* inlet objects O_1 into two categories O_2 and O_3 according to the criteria". Because the assorted objects O_3 are discharged by the next process unit P_4, we can interpret the behavior of P_2 as the function that "to *remove* the needless objects O_3". Moreover, if the criteria are the quality of the product, it can be called as "*inspect*". This functional interpretation of P_2 depends on the function of P_4. Therefore, under other contexts, P_2 could achieve different functions such as "*select*". Such definition of function is different from others such as that in [Chandrasekaran et al. 93].

Using our functional representation language named FBRL [Sasajima et al. 95], we can describe a functional model as behavior plus functional toppings (FTs). FTs represent the ways of interpretation. A model of the "inspect" function mentioned above consists of a behavioral model (constraints over attributes of objects) and two FTs "focus on good objects O_2" and "defective objects O_3 are needless". More detail of modeling based on FBRL is shown in [Sasajima et al. 95].

2.2 Relational Functions

A process unit contributes to other process units with specific goals. Keuneke has investigated some types of functions including "ToPrevent" [Keuneke 91]. Bonnet has identified a function type called "ToAllow" [Bonnet 92]. Our aim is to extend such types of functions to relations among functions, because not only the contributing function but also the functions contributed to are important for redesign. We call such relations between functions *relational functions*.

Figure 2 shows the relational functions of the inspection process P_2 mentioned above. It *allows* the paint process P_1 to produce the defective objects, and *prevents* them from flowing into the assembling process P_3. The former contributes to simplifying the equipment of P_1 and hence to saving of costs. The later prevents faults of P_3 and contributes to saving of costs.

Such relational functions represent the justification of the existence of the process units. That of the inspection process P_2 is production of the defective objects by the paint process. Such justification is a part of "design rationale" of the manufacturing process

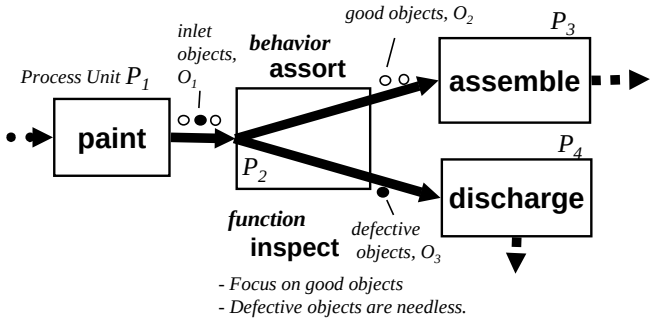

Figure 2: Behavior and Function of a Process

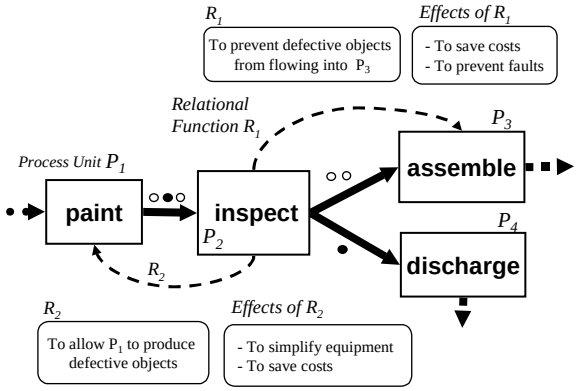

Figure 3: Example of Relational Functions

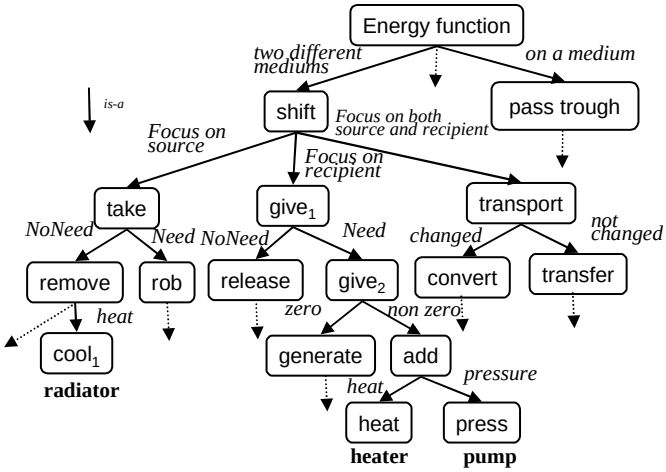

Figure 4: A part of a Functional Ontology

2.3 Functional Ontology

We have built a functional ontology which consists of general functional concepts, which plays a role to specify the functional space. Currently, it includes about 100 concepts for plants and manufacturing processes. Figure 4 shows a part of them organized in is-a hierarchy.

The labels attached the links represent the clues of classifications. More details of the functional ontology are shown in [Kitamura and Mizoguchi 98].

3 Redesign Support System

As Figure 1 shows, the redesign support system consists of the functional understanding module and the redesign solution proposing module.

3.1 Functional Understanding

The former module can generate plausible functional structures from the given behavior models of the target process. Firstly, the module generates all possible functional interpretations of the given behavior. It contains definitions of a number of functional concepts as constraints over FTs. Since the search space over FTs is limited, the functional understanding module generates all tuples of values of FTs and then matches them with definitions in the functional ontology.

Next, relational functions among the generated functions are identified according to a pattern set of relational functions. The set consists of possible patterns of each type in terms of the functional ontology. For each function *F* of a process *P*, the module matches the patterns with *F* and tries to find processes contributed to. It enables the module to identify plausible functional interpretations of *P* from the generated possible functional interpretations, because a functional interpretation that does not contribute to any processes is not plausible. Such contributions cannot be captured by causal relations as pointed out in [Chandarasekaran et al. 93]. More details of the functional understanding are shown in [Kitamura and Mizoguchi, 98].

3.2 Redesign

The later module proposes how to change the manufacturing process (redesign solutions). Then, they are evaluated according to the given criteria. The module uses the redesign principles knowledge representing general improving principles in Industrial Engineering (IE), called ECRS principles. They are highly abstracted in terms of the general functional concepts and hence reusable. Table 1 shows examples of them.

We have also described functional decomposition patterns, which provide alternative ways of achieving a function. Figure 5 shows part of them which are ways to obtain material. Note that Figure 5 shows is-achieved-by relations among the functional concepts, while Figure 4 shows is-a relations as the definitions of them, which are independent of "how to realize them".

Table 1: Examples of the Redesign Principles

Elimination Principle

Goals: Reduction of processing time and/or costs
Targets: A process unit P_1
Conditions: P_1 has no relational function
Changes: To eliminate P_1
Effects: Reduction of processes

Agent Sharing Principle

Goals: Reduction of costs for agents
Targets: Process units P_1,P_2 , Agents A_1,A_2
Conditions: The performance of A_1 is enough to do P_1,P_2
Changes: To remove A_2 and to engage A_1 in P_2
Effects: Reduction of agents

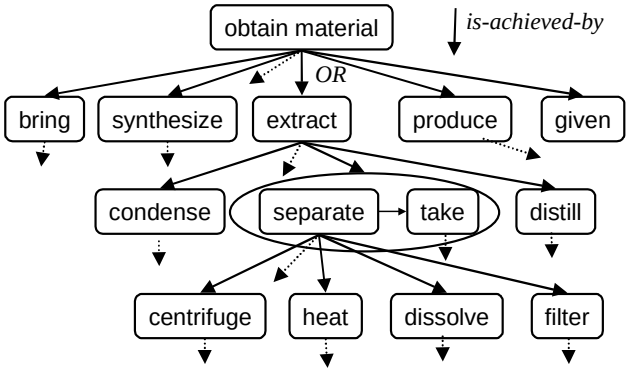

Figure 5. A part of the functional decomposition patterns

4 Example of Redesign

Figure 6 shows an example of redesign of a manufacturing system. Firstly, the redesign system identifies the functions of each process-unit and the relational functions among them as shown in Figure 6a from the given behavioral model. The transportation process unit P_2 allows the two differences between P_1 and P_3, that is, the difference of location (R_1) and the difference of agents (R_2). In other words, the two differences are the justification for the existence of P_2.

Next, the system tries to generate redesign solutions. The goal (criteria) of redesign here is reduction of the processing time. Thus, the system tries to omit P_2 according to the elimination principle shown in Table 1.

In order to satisfy its condition, that is, no relational function, the redesign system has to remove R_1 and R_2 by changing P_1 and/or P_3.

The relational function R_1, that is, to allow the difference of location, can be removed by changing the layout. On the other hand, for the relational function R_2, that is, to allow the difference of agents, the system tries to apply the agent sharing principle shown in Table 1. In the cases where the performances of the agent A_1 and A_2 are not enough to do so, the system also applies the agent replacement principle. Then the two process-units share an agent A_3 (Figure 6b). At this point, there is no relational function of P_2 . Then, the process-unit can be eliminated (Figure 6c).

Lastly, the redesign solution is evaluated. Its effects are saving of the processing time by eliminating the transportation and reduction of costs for an agent. The side effect is costs for replacing the agents.

5 Summary

In summary, this research attempts to model the design rationale of manufacturing processes. It enables the redesign system to consider the justifications of the existence of the process. Towards the goals, up to now, relational functions have been categorized and conceptual level design of the system has been finished. Future plan includes incorporating Value Engineering (VE) results into the redesign module to realize creative redesign as well as implementation of the system.

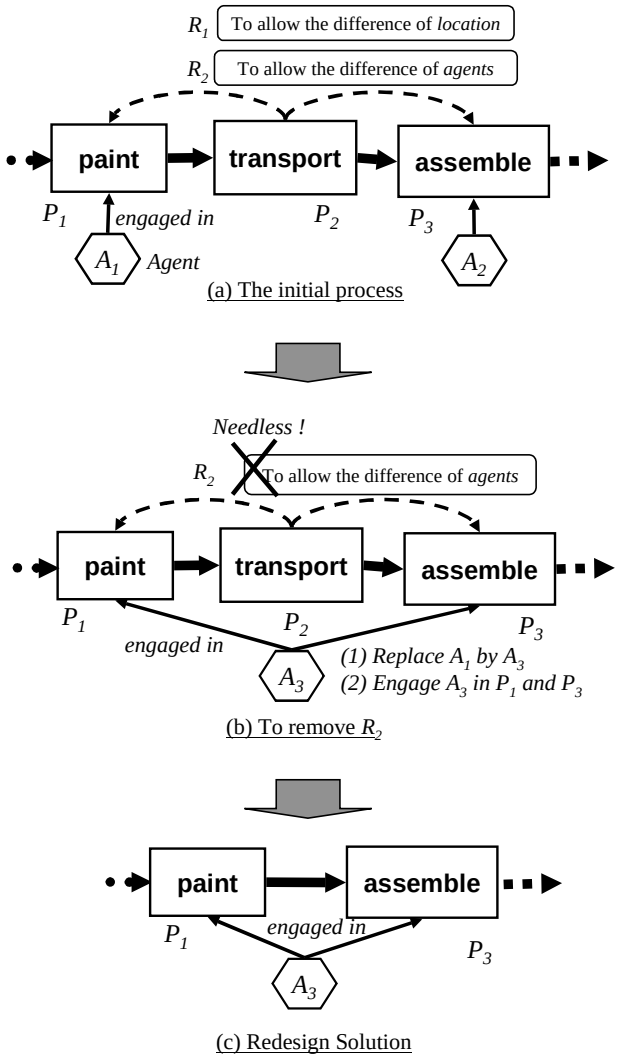

Figure 6: Example of Redesign

Acknowledgments

The authors would like to thank Mitsuru Ikeda and Kwang-Mong Sim for their valuable comments.

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