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A user classification method for sharable product focusing on its architecture

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ABSTRACT

Although sharing of products and components is crucial for the increase of the efficiency of product utilization from a life cycle perspective, it is quite difficult to find out promising combinations of components and users among which the components to be shared because various factors (e.g., usage condition and product structure, etc.) are complicatedly interrelated one another. The objective of this study is to propose a user classification method for shared-business that is suitable for a given product architecture, considering the difference in usage conditions and users locations. A simplified case study of a photocopier is also provided.

1. Introduction

Adequate sharing and reuse of products and their components have significant potential to reduce the environmental impact of society [1,2]. Component reuse of automobiles [3], construction machines [4], photocopiers [5] and toner cartridges [6] are typical examples of them.

Recently, a number of studies has analyzed successful reuse and sharing businesses over multiple industries and identified important prerequisites, guidelines, and evaluation criteria for success [for example, 7–11]. Some focused on product (or component) lifetime [7,8], and others dealt with collectability [9], reverse-logistics of post-use products [10,11] and so forth. Life cycle simulation (LCS) method is also proposed to plan economically and environmentally efficient product/component reuse business [12,13]. Reusability of manufacturing equipment is also dealt with in production engineering studies [for example, 14].

This paper defines a sharing business as the business that aims to minimize life cycle cost of products or components by sharing them among multiple users with different usage patterns. Generally speaking, the cost for sharing consists of installation and transportation costs. Products with different architecture have different installation costs and users at different locations need different transportation costs. Although both of these factors significantly influence the profitability of shared-business, installation cost is hardly taken into account in previous studies, partly because they mostly focused on reuse rather than sharing.

The objective of this study is to propose a user classification method for shared-business that is suitable for a given product architecture, considering the difference in installation costs as well as that in users locations and usage conditions. To this end, the study first develops a calculation model of the benefit of and the cost for the sharing business. Then, the study proposes a user classification method for shared-business focusing on installation and transportation cost at the same time. The difference in installation costs caused by the difference in product architecture is also dealt with in this method.

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2. Factors considered in shared-business design

2.1. Potential benefit of sharing

Generally speaking, utilization rate of each product/component is given by the ratio of actual working time to the whole product life. The products/components with low utilization rate (long idle time or longer life than duration of use) have great possibility for sharing across multiple users to reduce the total number of the same model of products/components in society. Products (or components) such as personal automobile, machine tools equipped in machining centre, buckets of construction machines, and so forth are sometimes under-utilized and their utilization rate are low enough to be shared among multiple users.

Theoretically, each product or component can be transferred to the other users' sites and utilized until the summation of its utilization rate over different users reaches 1. Therefore, the potential benefit for its sharing is evaluated as follows:

$$pb_i^j = c\,p_i^j(1-u_i^j) \tag{1}$$

where i, j, pb_i^j, $c\,p_i^j$, and u_i^j denote the index for each component, the index for each user, the potential benefit for sharing the component i of user j with other users, the total of production and end-of-life (EOL) treatment costs of component i of user j, and the utilization rate of component i of user j, respectively.

Assuming that the same products (or components) of different users have the same costs for their production and EOL treatment, potential benefit of component i pb_i is calculated by using the average value of utilization rate over all users as follows:

$$pb_i = c\,p_i(1-u_i) \tag{2}$$

$$u_i = \frac{1}{m}\sum_j u_i^j \tag{3}$$

where cp_i, u_i, and m denotes the total of production and EOL treatment costs for component i, the average utilization rate of component i, and the total numbers of users, respectively.

2.2. Transportation and installation cost

From the technological viewpoint, the cost for sharing a certain component with the other user $cs_i^{j'j}$ consists of transportation and installation costs of corresponding component as follows:

$$cs_i^{j'j} = ct_i^{j'j} + cu_i^{j'j} \tag{4}$$

where $ct_i^{j'j}$ and $cu_i^{j'j}$ denotes the cost for transferring component i of user j to user j', the cost for uninstalling component i of user j and installing the component to the product of user j', respectively.

Assuming that the all users use the same model of product, all users have the same installation cost.

$$cs_i^{j'j} = ct_i^{j'j} + cu_i \tag{5}$$

where cu_i denotes the installation cost for component i.

The transportation cost of component i from user j to j' $ct_i^{j'j}$ is given as follows:

$$ct_i^{j'j} = wt_i dt^{j'j} \tag{6}$$

where wt_i and $dt^{j'j}$ denotes the component specific weighting factor for transportation (depending on component's volume, weight and so forth) and a distance between a pair of users j and j', respectively.

The installation cost of a certain component depends on the number of its interactions with the other components in a given product. For example, in order to transfer a certain component from one product to another product, unmounting/mounting, adjustment, and modification (and sometimes reprogramming) of system segments that are connected to the component will likely be needed in addition to those of the component itself. These additional necessary operations can be regarded as the main source of difficulty in installation of the component.

Considering such interaction among components, the installation cost is given as follows:

$$cu_i = \sum_{i \in Su_i} wu_i \tag{7}$$

where wu_i and Su_i denotes the cost for installing each individual component and a set of component which should be removed or reconditioned whenever component i is replaced, respectively. Fig. 1 depicts a simplified structure of a photocopier. As shown in this figure, installation of a main body unit also needs the removal and modification of a front and back copying unit. The installation cost for a main body unit is calculated as the total of those for a main body unit and a front and back copying unit.

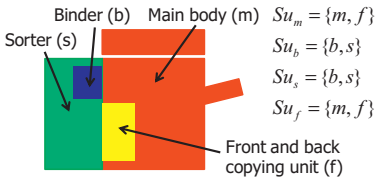

Fig. 1. Structure of a photocopier.

2.3. Estimation of total befit for sharing

Since actual benefit of sharing a certain component cannot be calculated until the groups of users who share the same component are classified as described in Section 4, this study estimates the potential benefit for the sharing to discuss how the difference in product architecture affects the profitability of product or component sharing.

Using potential benefit given by Eq. (2), the total potential benefit of sharing component i tpb_i is estimated as follows:

$$tpb_i = m(1 - u_i)(cp_i - ct_i - cu_i) \tag{8}$$

where ct_i denotes the average transportation cost of component i and given as follows:

$$ct_i = \frac{1}{m^2} \sum_j \sum_{j'} ct_i^{j'j} \tag{9}$$

2.4. Module sharing vs. component sharing

On one hand, it sometimes happens that the simultaneous sharing of multiple components (including product itself) is more profitable than that of a single component because there exists interaction among components. The installation cost of a certain set of components (i.e., module) is sometimes no greater than that of a single component included in the module. In addition, the sharing of product itself needs no installation tasks.

On the other hand, the greater the number of components included in the module increases, the greater the utilization rate becomes because the utilization rate of the module is regarded as the largest one among those of its constituent components. The increase in the utilization rate u_i results in the decrease in total sharing benefit as shown in Eq. (8). There is a trade-off between module sharing and individual component sharing. Therefore, the designer has to find out an adequate set of modules and components for a given product architecture in addition with groups of users among which the modules and the components are to be shared.

3. User classification method for shared business

3.1. Approach

To find out an appropriate set of components and modules with the groups of users among which the corresponding sharing is economically feasible considering the trade-off discussed in Section 2.4, the study subdivided the problem into two sub-problems.

First, a set of modules is generated considering all possible set of components for a given product. For each module or component, groups of users who share the same module or component are classified and the total benefit of its sharing is calculated.

Then, among the set of modules and components, the most profitable set of modules and components are selected by using the index called average sharing benefit.

3.2. User classification procedure

Step 1: Identification of product and users

The designer should first define a group of users among which the constituent components of a given product are to be transferred and shared.

Then, the total cost for each component at production and EOL treatment stages is estimated in addition with its utilization rate. Transportation cost between each pair of users is also estimated considering the location of each individual user.

Step 2: Calculation of utilization rate and initial investment cost for all modules and components

The designer generates a set of modules and components considering all possible subset of components in a given product and calculates the utilization rate and the total of production and EOL treatment cost for each of them.

Regarding as the component set i' as a module, its corresponding cost for production and EOL treatment is given as follows:

$$cp_{i'} = \sum_{i \in i'} cp_i \tag{10}$$

Utilization rate of the module i' is calculated as the largest one among those of all components included in i' as follows:

$$u_{i'} = Max(u_i : i \in i') \tag{11}$$

Installation cost for the module i' is given as follows:

$$cu_{i'} = \sum_{i \in Su^{i'}} wu_i \tag{12}$$