Life Cycle Simulation System for Life Cycle Process Planning

S. Takata[1] (1), T. Kimura[1]
[1]Department of Industrial and Management Systems Engineering, Waseda University

Abstract
To realize closed loop manufacturing, it is essential to design product life cycles and to plan life cycle processes properly. Life cycle simulation has been recognized as an effective tool in this direction. In this paper, we present a life cycle simulation system developed as a general tool for life cycle design and management. The system includes functions for modelling and controlling each life cycle process in a flexible manner. The system maintains usage history of products and parts independently taking the reuse of parts into account. Examples of the simulation are shown for both a rapid life cycle scenario and for a part sharing scenario over the product generations.

Keywords:
Life cycle, Simulation, Reuse

1 INTRODUCTION

The realization of environmentally benign manufacturing has become a prime issue in the field of manufacturing systems. The concept of closed loop manufacturing or inverse manufacturing has been proposed as a promising solution [1]. The idea is to redefine the role of manufacturers as service providers, which do not simply provide products, but more importantly functionality by means of products. In this sense, products need not be new as long as they fulfil required function. This perception has brought us the concept of closed loop manufacturing, in which artifacts (products, parts, or material) are circulated by means of reuse and recycling so as to reduce environmental impact, while providing necessary service to users.

In order to circulate artifacts in an efficient way, we need to design and manage their life cycles properly, because artifacts cannot be circulated unless the demand and supply of reclaimed artifacts match each other in reuse and recycling. In designing the life cycle, various factors should be taken into account, such as product features, model change cycles, market characteristics, and users' behaviour. However, it is difficult to find design solutions analytically, because they are interrelated in a complicated manner. Recently, a simulation based approach has been proposed as a promising method to cope with this difficulty [2] [3] [4]. However, so called life cycle simulation systems developed so far have been specific to particular research purposes and had limited functions. It is necessary, therefore, to develop a life cycle simulation system, which is more powerful and can be used as a general tool for life cycle design and management.

In this paper, the requirements for a life cycle simulation system are discussed first. Then the architecture and data structure of the developed life cycle simulation system are explained. Finally, examples of simulations are presented to demonstrate the effectiveness of the system.

2 REQUIREMENTS FOR LIFE CYCLE SIMULATION

In order to be an effective tool for life cycle design and management, which can be adapted to various life cycle scenarios, the life cycle simulation system should have a capability of modelling both products and processes in a flexible manner. The following are important requirements for the life cycle simulation system.

- The system should be able to represent various circulation paths such as repair, product reuse, part reuse and material recycling, and it should have a means to control the material flow in these paths.
- Products and parts should be modelled independently and their relationships should be defined so as to enable various reuse policies.
- Usage histories of parts should be maintained independently of products so as to deal with degradation of reused parts.
- Since processes such as production and disassembly could be operated by different bodies, each process should be modelled as an independent module with its own control system.
- The system should be able to deal with a sufficiently large number of products and parts for the statistical analysis.

3 DEVELOPMENT OF LIFE CYCLE SIMULATION SYSTEM

3.1 System configuration

The life cycle simulation system has been developed in accordance with the requirements mentioned in the previous section. The system simulates the circulation of products and parts as shown in Figure 1 based on discrete simulation techniques. Production, sales, and usage are defined as arterial processes. Repair, reconditioning for product reuse, and disassembly and

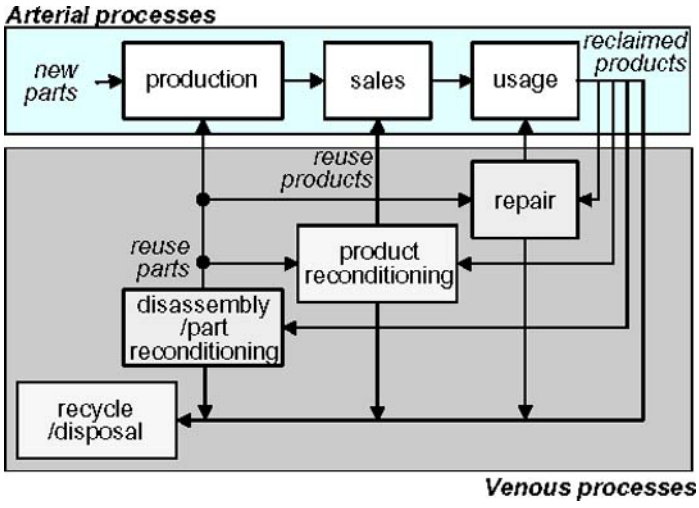

Figure 1 : Life cycle processes defined in the life cycle simulation system

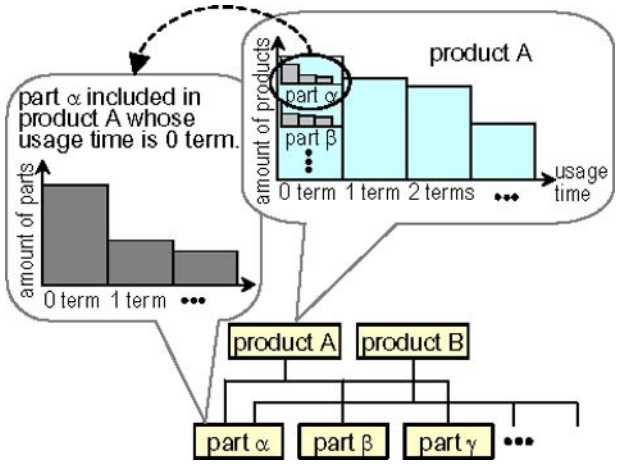

Figure 2 : Data structure of products and parts

reconditioning for part reuse are defined as venous processes. Since the current system has been developed mainly for the evaluation of reuse scenarios, it does not deal with the flow of recycled material back to the production for the present.

The simulation system consists of 3 subsystems: a parameter setting subsystem, an execution subsystem, and an output subsystem. In the parameter setting subsystem, product configurations are specified. This includes such factors as periods of sales of each product, product-part relations, and part reuse policies. Parts may be reused in a product family within the same generation or across several generations. For each type of parts, a failure rate function is defined in terms of a Weibull distribution for simulating occurrences of failures. Obsolescence rate functions are defined for the product to represent the extent of discard because of user's dissatisfaction with functions of the products. The obsolescence rate function is also represented in terms of a Weibull distribution. In addition, the obsolescence rate could be changed stepwise when a period of sales terminates or a new model is put on the market.

The execution subsystem consists of two modules; a simulation engine module and a process control module. The simulation engine module realizes the flow of products and parts through the life cycle processes, while the process control module controls the flow of each process. Users can implement various control algorithms in the process control module.

3.2 Data structures of products and parts

In the case of the part reuse scenario, parts may be reused more than once and assembled into different products each time. Therefore, usage time should be maintained for each part independently of the products. However, this requires an enormous amount of memory, if the statistically meaningful number of products and parts are processed.

To overcome this problem, the system maintains a usage history in the form of histogram as shown in Figure 2. The histogram shows frequency distribution of products or parts used for a period of i terms. The term can be defined arbitrary on the condition that its values are integral multiples of simulation time interval. The histogram is maintained for the set of each product type existing in each process. The histograms for the parts are nested in those of the products as shown in Figure 2. Namely, usage history of each type of parts is maintained corresponding to each class of histogram of the products. When a set of products or parts move from one process to another, the histograms for this product set are constructed from those of the products in the source process, and added to those of the products in the destination process.

3.3 Process control

There are two types of processes in the system. The first type has an input and output inventory as well as processing, such as production, repair, product reconditioning, and part reconditioning process. The second one has only one inventory, such as sales, usage, and recycling & disposal. The control of each inventory is based on the algorithm specified in a corresponding unit of the control module. The processing is characterized by the capacity and the lead time.

Arterial processes

In each simulation time interval, the order to the sales process is generated according to a given demand pattern. In response to this order, the sales process delivers products to the usage process, and places an order to the production process.

In the production process, production is executed according to the order placed by the output inventory. Parts to be assembled could be both newly manufactured ones and reused ones, which are supplied by the part manufacture and the part reconditioning process respectively. The ratio of the order of the new parts to that of the reuse parts can be specified in the control algorithm for the input inventory.

In the usage process, the usage histories of the products and parts are updated depending on the period of their stay in the process. Termination of usage of products is determined by two factors: obsolescence of products and failures of parts. It is assumed that failure of any part cause the termination of the product usage. In each simulation time interval, the number of products to be discarded is calculated based on the specified obsolescence rate functions and failure rate functions.

Venous processes

The discarded products in the usage process are sent to the repair process, the product reconditioning process, the disassembly and part reconditioning process, or recycling and disposal process according to the rules specified in the control module.

In the repair process, all the products sent from the usage process are repaired and returned to the usage process except that a certain ratio of products are sent to