Development of Environmental Evaluation Method and System Construction in Manufacture

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Preface

The business environment which surrounds companies, such as development of information technology, economic globalization, softization and trend towards service economy of work, increase of the unemployment problem or an environmental problem, is changing rapidly now. Moreover, a customer demand increases increasingly and diversification of goods and shortening of the life cycle are progressing. Under a mass production system, it is difficult to respond quickly to what a customer demands and to sell to it. For that reason, there is a problem which holds a lot of unsold inventories. That is, in consideration of profits, a viewpoint of the company which moreover considered society and earth environment is desired from now on. The concept from a supply chain to sustainable development needs to be developed. This thesis examines the optimization of management efficiency and environmental impact assessment in the manufacturing industry. The purposes are application of the mathematical model for a manufacturing efficiency improvement and a proposal of a framework, and construction of an environmental load estimated system. Based on the theory of supply chain management and life cycle assessment, it clarifies about the procedure from problem finding to the proposal of an improvement strategy.

Acknowledgements

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Chapter 1

Introduction

In recent years, in connection with expansion of various activities, a resources problem, an environmental problem, etc. are aggravation on a global scale. Present mass production and mass consumption increased the load to environment, and has influenced the environmental problem greatly. Since environmental problem is importance today, the product evaluation by LCA (Life Cycle Assessment) [1–3] attracts attention more and more. In the life cycle (from manufacture to disposal) of a product, LCA totals the resources and energy which receive from environment, and the amount of energy discharged by environment [4, 5]. And the influence is analyzed and evaluated quantitatively. Moreover, SCM (Supply Chain Management) [6] which is one of the management methods of corporate activity also attracts attention recently. SCM is the method of managing synthetically a customer's order, and from supply of materials to stock management and delivery of a product using a computer. Each supply chain is not optimal, but the whole is optimal. By reducing extra stock etc. using SCM for a company, it is thought that it not only lowers cost, but it leads to reduction of an environmental load.

In this thesis, the environment assessment method in the manufacturing industry is developed. And construction of an environmental load estimation system is aimed at. Composition and the contents of each chapter are shown as below.

Chapter 1 describes the background of this thesis, and the outline of the purpose and the thesis.

Chapter 2 explains LCA which is the method of evaluating the environmental load in the lifetime of a product [7–9]. And the LCA framework in ISO14000 is explained [10]. Moreover, various companies are developing the LCA system uniquely today. Therefore, the LCA system in each company is also explained. Next, PSO (Particle Swarm Optimization) which is an recent optimization technique is explained. PSO is the optimization algorithm developed through observation of a social system, and attracts attention as an effective new optimization technique to the problem which calculates the optimal value of continuation space [11]. And revised PSO (MOPSO) for multiple purpose optimization is explained [12].

Chapter 3 proposes the method of setting up the optimum purchasing lot size for SCM. Here, the supply chain which consists of a retailer, a wholesaler, a delivery center, and a factory is considered, and the new optimal model in the physical distribution is proposed. In a proposal model, it can be predicted profits increase by sharing information in all rather than having information on each stage of a supply chain. And an optimum order quantity is set up using an optimization technique so that profits may become the maximum.

Chapter 4 proposes the production planning model corresponding to mass customization in the manufacturing industry. A solution is obtained without assuming the distribution form of demand quantity to the product production planning problem of the supplier corresponding to the order-received environment (namely, sharp change of an order received) caused by mass customization. About the inventory transition on planning of production, it is clearly shown that raising the low place of inventory as much as possible in a period leads to an improvement of an unfulfilled order rate. Next, taking cost into consideration, inventory transition which makes the minimum inventory maximum is formulated based on a Min-Max strategy. And the production planning system corresponding to mass customization when the distribution form of demand quantity is unknown is proposed.

Chapter 5 aims at reduction of cost and an environmental load by applying SCM and LCA simultaneously. First, the model which is compatible in the cost reduction and environmental load reduction in the whole life cycle is formulated. In order that calculation of environmental load data is being large scale and complicated, it constructs an environmental load estimation system. By using this system, the environmental load from the materials procurement of a product to disposal is calculated. And the optimum order quantity which considered the balance of cost and an environmental load is calculated using a multiple purpose optimization technique.

Chapter 6 proposes the LCA system which can understand the life cycle and environmental impact of a product quantitatively. Shortening of the computation time of environment assessment is expected by using a proposal system. And reduction of the environmental impact substance discharged from a company can be aimed at.

Chapter 7 summarizes this thesis. This chapter describes all results obtained, and gives the further research problems.

Chapter 2

Preliminaries

2.1 Life Cycle Assessment

2.1.1 Definitions of LCA

The procedures for initiating, conducting and reporting LCA studies in a proper manner have been defined by several international organisations during recent years. Many workshops have been carried out on LCA since 1990. In particular in 1993, in response to an increasing need for guidance in LCA, the European and North American organisations of the Society for Environmental Toxicology and Chemistry (SETAC) organised a "Code of Practice" Workshop in Portugal [13, 14]. The outcomes of the workshop were summarised in a booklet called "Guidelines for Life Cycle Assessment:A Code of Practice".

More recently, the guidelines and principles relating to LCA studies were defined by ISO/TC 207/SC 5 working group using specific international standards, namely ISO 14040. Methodological details are reported in the supplementary ISO standard 14041 which has already been accepted and the Draft International Standards (DIS) 14042 (Impact Assessment) and 14043 (Interpretation) [15–17].

The ISO-standard 14040 defines an LCA as following: "LCA is a technique for assessing the environmental aspects and potential impacts associated with a product, by:

- compiling an inventory of relevant inputs and outputs of a product system;
- evaluating the potential environmental impacts associated with those inputs and

outputs;

- interpreting the results of the inventory analysis and impact assessment phases in relation to the objectives of the study".

The assessment includes the entire life cycle of the product, process, or activity, encompassing extracting and processing raw materials, manufacturing, transportation, distribution, use, re-use, maintenance, recycling and final disposal [18, 19].

Further on, the LCA addresses environmental impacts of the system under study in the general areas of ecological consequences, human health and resource use. It typically does not address economic considerations or social effects. Additionally, like all other models, LCA is a simplification of the physical system and cannot claim to provide an absolute and complete representation of every environmental interaction [20–22].

"The prime objectives of carrying out a LCA are:

- to provide a picture as complete as possible of the interactions of an activity with the environment
- to contribute to the understanding of the overall and interdependent nature of the environmental consequences of human activities; and
- to provide decision-makers with information which defines the environmental effects of these activities and identifies opportunities for environmental improvements".

2.1.2 LCA framework and the ISO 14000 Pattern

The ISO standardized the technical framework for the LCA methodology in the 1990s. On this bases, according to ISO 14040 (1997), LCA consists of the following steps (Figure 2.1) [23, 24].

- Goal and scope definition
- Inventory analysis

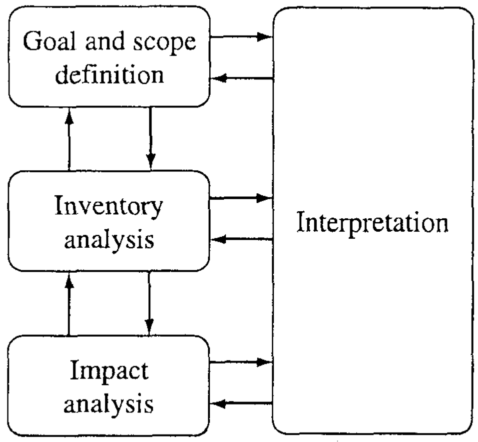


Figure 2.1: LCA framework

- Impact assessment
- Interpretation

LCA is not necessarily carried out in a single sequence. It is an iterative process in which subsequent rounds can achieve increasing levels of detail (from screening LCA to full LCA) or lead to changes in the first phase promoted by the results of the last phase.

The steps of LCA are distributed along ISO patterns. For example, ISO 14040 (1997) provides the general framework for LCA. ISO 14041 (1998) provides guidance for determining the goal and scope of an LCA study and for conducting a life-cycle inventory (LCI). ISO 14042 (2000) deals with the life-cycle impact assessment (LCIA) step and ISO 14043 (2002)provides statements for the interpretation of results produced by an LCA. Moreover, technical guidelines illustrate how to apply the standards [25–27].

2.1.2.1 Goal and scope definition

The goal and scope definition is designed to obtain the required specifications for the LCA study. During this step, the strategic aspects concerning questions to be answered and identifying the intended audience are defined. To carry out the goal and scope of the LCA study, the practitioner must follow some procedures:

1. Define the purpose of the LCA study, ending with the definition of the functional unit, which is the quantitative reference for the study.

2. Define the scope of the study, which embraces two main tasks:

   - Establish the spatial limits between the product system under study and its neighborhood that will be generally called "environment".

   - Detail the system through drawing up its unit processes flowchart, taking into account a first estimation of inputs from and outputs to the environment (the elementary flows or burdens to the environment).

3. Define the data required, which includes a specification of the data necessary for the inventory analysis and for the subsequent impact assessment phase.

2.1.2.2 Inventory analysis

The inventory analysis collects all the data of the unit processes within an product system and relates them to the functional unit of the study. In this case, the following steps must be considered:

1. Data collection, which includes the specification of all input and output flows of the processes within the product system (product flows, i.e., flows to other unit processes, and elementary flows from and to the environment)

2. Normalization to the functional unit, which means that all data collected are quantitatively related to one quantitative output of the product system under study;usually, 1kg of material is chosen, but often other unites such as a car or 1 km of mobility are preferable

3. Allocation, which means the distribution of emissions and resource extractions within a given process throughout its difference products, e.g., petroleum refining providing naphtha, gasolines, heavy oils, etc.

4. Data evaluation, which involves a quality assessment of the data (e.g., by eventually performing a sensitivity analysis)

Inventory analysis uses quantitative data to establish the levels and types of energy and materials input to an industrial system and the product output and environmental releases that result, as shown schematically in Figure 2.2 [28,29]. The approach is based on the idea of a family of materials budgets, in which the analyst measures the inputs and outputs of energy and resources as well as the resources embedded in the resulting products and by-products,both those resource flows with value and those that are potential liabilities. The assessment is ideally done over the entire life cycle-materials extraction, manufacture, distribution, use and disposal.

The result of the inventory analysis, consisting of the elementary flows related to the functional unit, is often called the life-cycle inventory table.

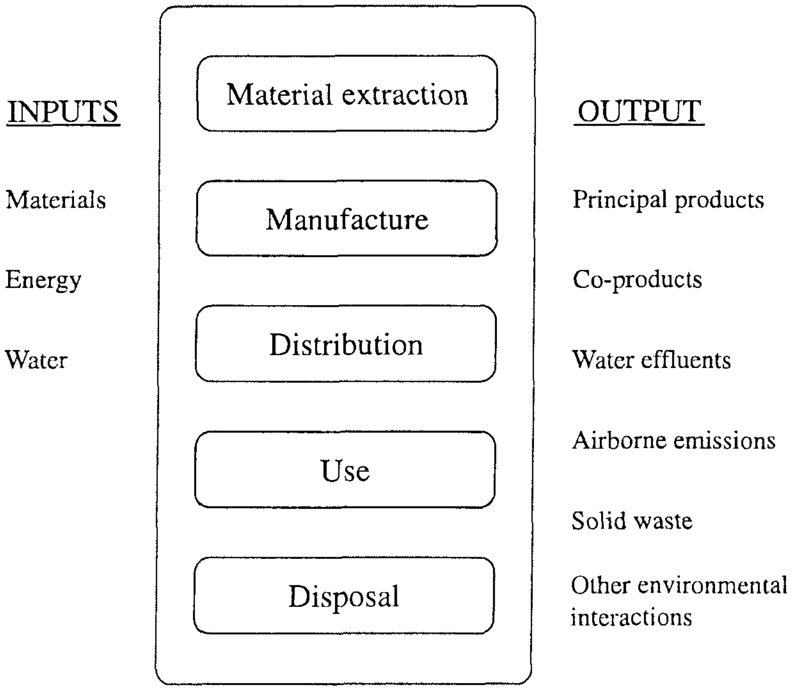


Figure 2.2: The elements of a life cycle inventory analysis

2.1.2.3 Impact assessment

The impact assessment phase aims at making the results from the inventory analysis (IA) more understandable and more manageable in relation to human health, the availability of resources, and the natural environment [30]. To accomplish this, the inventory table will be converted into a smaller number of indicators. The mandatory steps to be taken in this regard are:

1. Select and define impact categories, which are classes of a selected number of environmental impacts such as global warming, acidification, etc.

2. Classify by assigning the results from the IA to the relevant impact categories.

3. Characterize by aggregating the inventory results in terms of adequate factors (so-called characterization factors) of different types of substances within the impact categories; therefore a common unit is defined for each category. The results of the characterization step are known as the environmental profile of the product system.

2.1.2.4 Interpretation

The interpretation phase aims to evaluate the results from the inventory analysis or impact assessment and compare them with the goal of the study defined in the first phase. The following steps can be distinguished within this phase:

1. Identification of the most important results of the IA and impact assessment

2. Evaluation of the study's outcomes, consisting of a number of the following routines:completeness check, sensitivity analysis, uncertainty analysis and consistency check

3. Conclusions, recommendations and reports, including a definition of the final outcome, a comparison with the original goal of the study, drawing up recommendations, procedures for a critical review, and the final reporting of the results

The results of the interpretation may lead to a new iteration round of the study, including a possible adjustment of the original goal.

2.1.3 Company's LCA System

2.1.3.1 Honda Lifecycle Assessment System

Honda Motor Co., Ltd.'s newly implemented Honda LCA System [31–33] is designed to provide a quantitative assessment of the environmental impact created by all areas of company activities. The system will aid Honda in its pursuit of the world's highest level of environmental management, by providing quantitative information on environmental impact over the entire product lifecycle, from manufacture to disposal. This will aid in establishing specific goals for environmental impact reduction, resulting in less environmental burden due to Honda's products and corporate activities and a better environment for all (Figure 2.3).

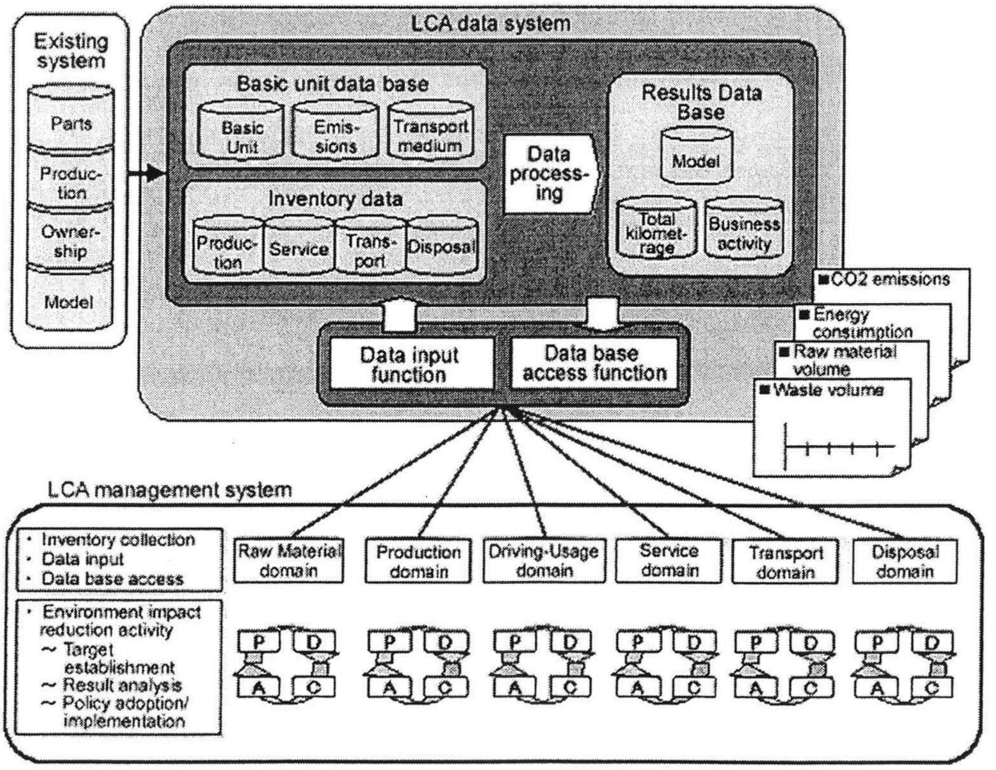


Figure 2.3: Honda LCA System

The Honda LCA System is composed of two subsystems:the Honda LCA Data

System and the Honda LCA Management System. A single, unified system is applied to all of Honda's two-wheeled, four-wheeled, and power products. Since the system is used by departments actually involved in environmental impact data collection, they are able to act directly to reduce environmental impact, and derive quantitative results in a timely fashion.

In the past, Honda's environmental impact reduction activities have been carried out separately with respect to each area of concern: Green Factories for production; Green Dealerships for sales activities; Green Offices for the headquarters and regional buildings; Green Purchasing for purchasing activities; and Green Logistics for distribution. The LCA Project was launched in order to unify these independent activities to obtain a clear grasp of the overall environmental impact of each individual product, and to use this information as a basis for reducing that impact.

Honda views LCA as a vital tool for environmental impact assessment. In addition to applying the lessons learned through these assessment activities in its corporate and product development activities, the company also publishes the "Honda Environmental Annual Report."

Features of the Honda LCA System

- Honda LCA Data System

  Inventory data on all environmental impact factors (primary/secondary resource and energy consumption, quantities of materials disposed of, quantities recycled, etc.) are stored in a host computer under centralized management for retrieval as needed. An Web application is used so that the data can be shared throughout the company. In the future, the system will be accessible by Honda's business partners and offices all over the world.

- Honda LCA Management System

  In this system, target values for the activities of each department involved in environmental impact reduction are determined at an in-house environmental conference, and a PDCA (Plan, Do, Check, Action) plan is implemented. The system promotes the use of common target values throughout Honda's diverse operations.

Examples of LCA System activities

- Determining gross output of corporate activities (the total environmental impact produced by all of Honda's corporate activities).
  - Benefits
    - Able to ascertain changes in environmental impact from year to year
    - Able to forecast the effects of environmental impact reduction programs for each individual department
- Determining running gross output (the annual environmental impact of Honda products owned and used in Japan).
  - Benefits
    - Able to ascertain the annual environmental impact of vehicles sold
    - Able to forecast the contribution to future reduction in environmental impact of new products under development

2.1.3.2 Environmental Management Information System of NEC

NEC has adopted an environmental management information system (EMIS) [34–36], which gathers environmental performance data from the whole group through our internal intranet and allows for central management. The system has helped to improve the efficiency of environmental data collection and site management, the managerial efficiency in the Environmental Management Department and the efficiency in management operations. Currently, the EMIS has been applied to NEC and its manufacturing subsidiaries. In FY 2004, the system will be implemented in overseas affiliates and domestic sales, service and software subsidiaries (Figure 2.4).

Characteristics

- Allows efficient maintenance of environmental management systems
- Allows for a broad reduction in redundant data-handling and labor by consolidating information
- Allows benchmarks for comparison of energy, waste and management of chemical substances at each site
- Allows advanced management of environmental activities and smooth information disclosure to stakeholders

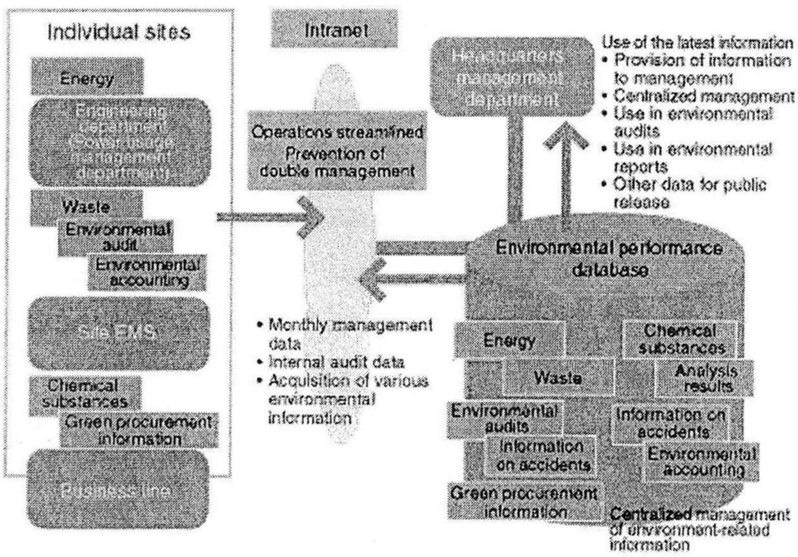


Figure 2.4: EMIS

2.1.3.3 System Integration Life Cycle Assessment (SI-LCA) of Hitachi

When utilizing as a system combining hardware or some software, construction of the solution which lessens influence on earth environment more is tackled. In Hitachi, the environmental impact in the whole life cycle until it is discarded from the time of developing a product was computed by having changed it into CO_2, and the method evaluated quantitatively was developed with the Hitachi group [37–40]. It is a tool for being made to perform proposal of the system which can tell on the visitor who is performing active conduct of business which considered environment. The amount of discharge of CO2 in the whole life cycle to disposal is integrated through development and use from the plan stage of a system (Figure 2.5).

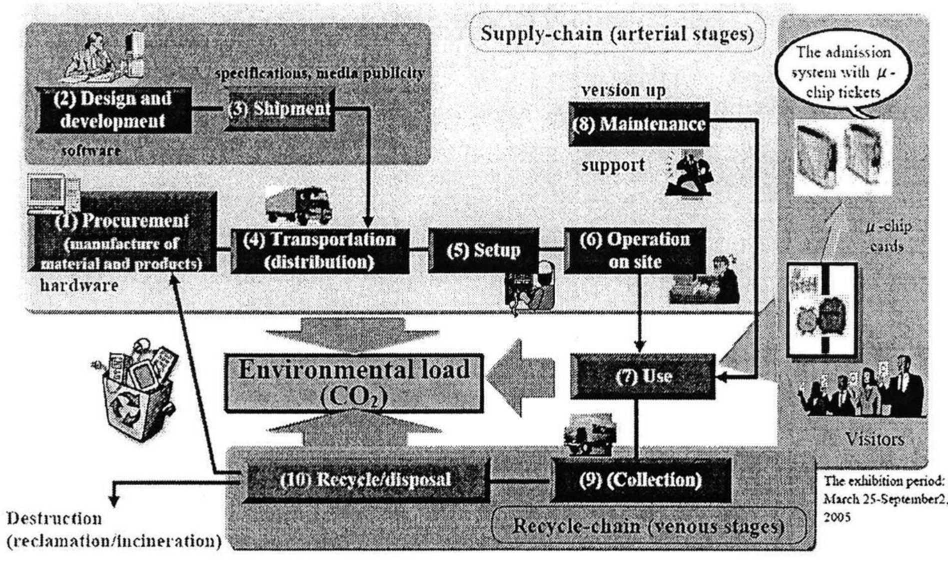


Figure 2.5: SI-LCA

2.2 Particle Swarm Optimization

2.2.1 Foundation of Particle Swarm Optimization

PSO is the optimization technique based on the action of groups, such as bird, fish, and man's social activity. They are carried out based on continuing evolution, sharing the information in a group. PSO is the technique of calculating the optimal solution in consideration of the past search history from the best information (pbest) which a solid (Particle) has, and the optimal value (gbest) of the group (Swarm) formed from the solid. In PSO, each particle has the information about a position and speed. And it searches in a group, having an interaction. The optimal solution is calculated by updating the position and speed of an each particle [41, 42].

<u>Renewal of Position and Speed</u>

By using the position $\mathbf{x}_l^t$ and speed $\mathbf{v}_l^t$ of an individual l of the tth time search, the

$t+1$th time position $\mathbf{x}_l^{t+1}$ and speed $\mathbf{v}_l^{t+1}$ are updated by the following formula.

$$\mathbf{x}_l^{t+1} = \mathbf{x}_l^t + \mathbf{v}_l^{t+1}, \tag{2.1}$$

$$\mathbf{v}_l^{t+1} = w\mathbf{v}_l^t + \alpha_1 \cdot rand_1 \cdot (\mathbf{p}_l^t - \mathbf{x}_l^t) + \alpha_2 \cdot rand_2 \cdot (\mathbf{p}_g^t - \mathbf{x}_l^t). \tag{2.2}$$

$rand_1$ and $rand_2$ are [0, 1] random numbers. α_1 and α_2 are parameters, and it is often that they are decided to be as follows.

$$\alpha_1 + \alpha_2 = 4 \tag{2.3}$$

In addition, w is a parameter to be called momentum. $\mathbf{p}_l^t$ shows the best solution (pbest) when individual l searches to the tth time. On the other hand, $\mathbf{p}_g^t$ shows the whole group's best solution (gbest) in the tth search. As shown in Figure 2.6, each searching point generates the position information of one's best solution (pbest) and the position information of group's best solution (gbest) [43].

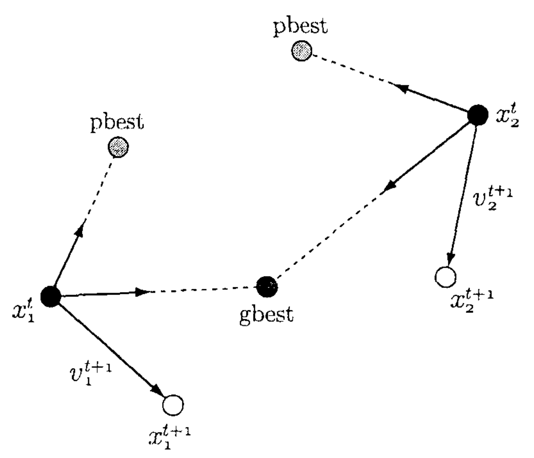


Figure 2.6: Move of Search Point

Algorithm of PSO

The basic algorithm of PSO is as follows (Figure 2.7).

[step1]

The number of individuals and the number of the maximum search are decided.

[step2]

The initial position $\mathbf{x}_l^t$ and the initial speed $\mathbf{v}_l^t$ are decided at random to each individual. And it is set to $t = 1$.

[step3]

Function value is calculated for each individual.

[step4]

$\mathbf{p}_l^t$ and $\mathbf{p}_g^t$ are calculated.

[step5]

The speed and the position of each individual are updated according to Equations (2.1) and (2.2).

[step6]

If the number t of search is below the number of the maximum search, it returns to **[step3]** as $t = t + 1$. Otherwise, search is ended.

Neighborhood of PSO

From Equations (2.1) and (2.2), the $t+1$th position $\mathbf{x}_l^{t+1}$ of Individual l can change as follows

$$\mathbf{x}_l^{t+1} = \mathbf{x}_l^t + w\mathbf{v}_l^t + \phi(p - \mathbf{x}_l^t). \tag{2.4}$$

where ϕ and p in Equation (2.4) are as follows, respectively.

$$\phi = \alpha_1 \cdot rand_1 + \alpha_2 \cdot rand_2, \tag{2.5}$$

$$p = \frac{\alpha_1 \cdot rand_1 \cdot \mathbf{p}_l^t + \alpha_2 \cdot rand_2 \cdot \mathbf{p}_g^t}{\alpha_1 \cdot rand_1 + \alpha_2 \cdot rand_2}. \tag{2.6}$$

It means that this will generates a new point inside the neighborhood in which the position carried out parallel translation only of the $w\mathbf{v}_l^t$ from the present position $\mathbf{x}_l^t$. Equation (2.4) serves as a form which multiplied the search direction vector $p - \mathbf{x}_l^t$ by the step width ϕ. Moreover, ϕ adds two uniform random numbers from Equation (2.5). And the distribution of the minimum value 0, maximum $\alpha_1 \cdot rand_1 + \alpha_2 \cdot rand_2$,

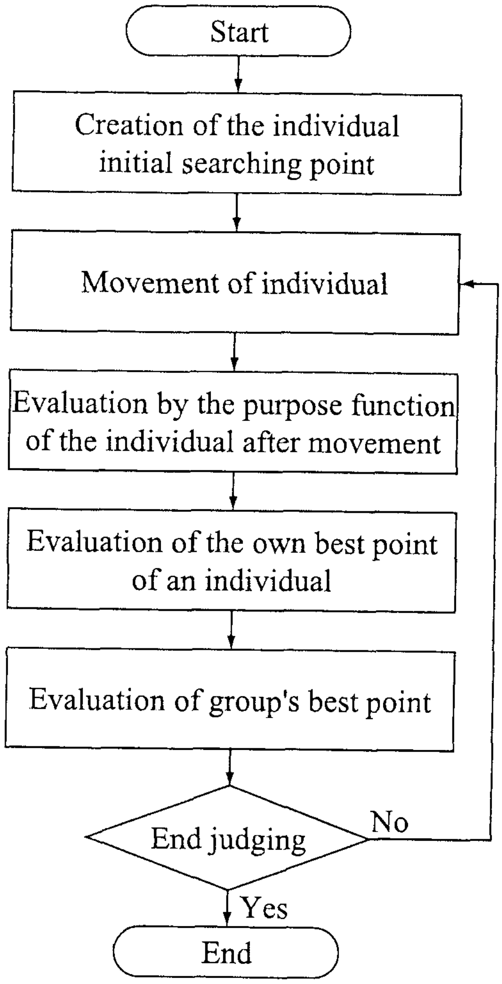


Figure 2.7: Algorithm of PSO

and average $(\alpha_1 \cdot rand_1 + \alpha_2 \cdot rand_2)/2$ is followed. Therefore, it is thought that PSO has an effect method with probable step width and similar structure.

Outline of Momentum

In PSO, momentum becomes small gradually according to the following formula as search progresses.

$$w = w_{\max} - \frac{t(w_{\max} - w_{\min})}{t_{\max}}, \tag{2.7}$$

where, $w_{\max}$ and $w_{\min}$ are the maximum and minimum of momentum, and $t_{\max}$ is the maximum number of search. Using the following value from the result of many numerical computations is recommended.

$$w_{\max} = 0.9, \tag{2.8}$$

$$w_{\min} = 0.4. \tag{2.9}$$

As for momentum, the amount of parallel translation from the present position $\mathbf{x}_l^t$ of Individual l becomes smaller as search progresses, as indicated in Equation (2.4).

<u>**The Best Value Save Type Mode**</u>

$\mathbf{p}_g^t$ in a Equation (2.2) expresses the individual (gbest) which gives the best value in the whole group's inside in the k-th search. However, this serves as an individual that gives the best value inside the point updated by the Equations (2.1) and (2.2). That is, pbest is saved until the objective function is updated. However, gbest is updated for every number of searches. Thereby, not only global search capability but local search capability is decreased. Consequently, settling might be delayed. Then, it crowds together toward the best solution obtained in old search, the whole moves, and a model whose local search capability improves is also proposed. This is called the best value save type model. It is the model which replaced $\mathbf{p}_g^t$ in a Equation (2.2) as follows.

$$\mathbf{v}_l^{t+1} = w\mathbf{v}_l^t + \alpha_1 \cdot rand_1 \cdot (\mathbf{p}_l^t - \mathbf{x}_l^t) + \alpha_2 \cdot rand_2 \cdot (\mathbf{p}_g - \mathbf{x}_l^t) \tag{2.10}$$

$\mathbf{p}_g$ expresses the individual which gives the best value obtained by old search. That is, $\mathbf{p}_g$ is not changed until the best value of $\mathbf{p}_l^t$ in old search is updated. As a result, local search capability improves.

2.2.2 Multi Objective Particle Swarm Optimization

PSO consists of very brief algorithm. However, it is the technique of the ability to solve a continued type nonlinear optimization problem efficiently. It is observed as the optimization technique for the single purpose function in recent years. The multiple-purpose optimization technique MOPSO which has improved the algorithm of PSO so that it could deal with a multiple-purpose optimization problem is proposed. MOPSO can ask for the multiple-purpose optimal solution set, i.e., the Pareto solution set, efficiently [44–46].

In MOPSO, the searching point $\mathbf{x}_l^t \in R^m$ which is distributed in the shape of a group and moves in the search space of m dimension generates the move vector $\mathbf{v}_l^t \in R^m$ using the position information $\mathbf{p}_g^t \in R^m$ on the Pareto solution shared with group's position information $\mathbf{p}_l^t \in R^m$ of the best solution which self has in groups, and it searches for a solution. And it is the technique of considering a set of $\mathbf{p}_g^t \in R^m$ which finally remained as the Pareto optimum meeting set. The search scheme of MOPSO is shown below [47, 48].

Algorithm of MOPSO

Figure 2.8 shows the Algorithm of MOPSO [49, 50].

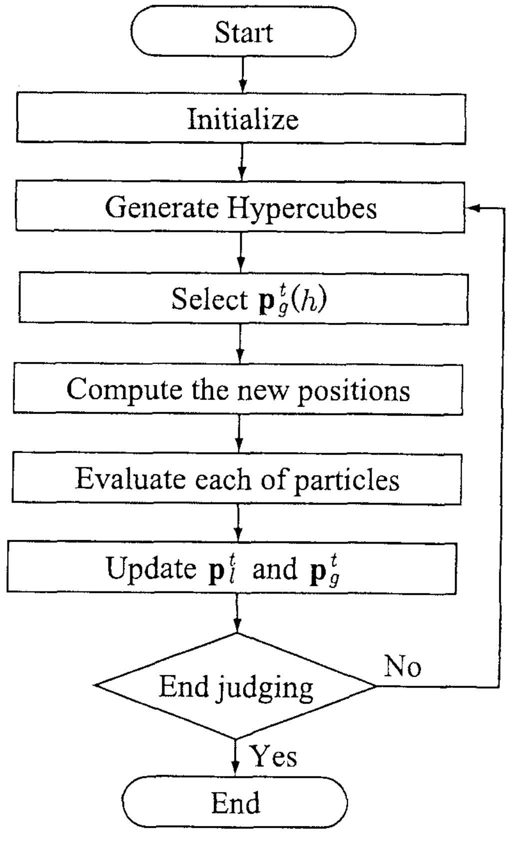


Figure 2.8: Algorithm of MOPSO

[step1]

First, the searching point number N_{I_e} , the number of times of repetition N_T, and saving point number maximum $N_{R_e}^{\max}$ are determined. And initial setting of $\mathbf{x}_l^t(i_e)$, $\mathbf{p}_l^t(i_e)$, $\mathbf{p}_g^t(r_e)$, $\mathbf{v}_l^t(i_e)$ is performed. However, i_e expresses a searching point number and r_e expresses a saving point number. $\mathbf{x}_l^t(i_e)$ $(1 \leq i_e \leq N_{I_e})$ determined at random within a limit value, and sets with $\mathbf{v}_l^t(i_e) = 0$ $(1 \leq i_e \leq N_{I_e})$, $\mathbf{p}_l^t(i_e) = \mathbf{x}_l^t(i_e)$ $(1 \leq i_e \leq N_{I_e})$, $\mathbf{p}_g^t(r_e) = \mathbf{x}_l^t(i_e)$ $(r_e = i_e, 1 \leq r_e \leq N_{I_e})$. $\mathbf{p}_g^t(r_e)$ $(N_{I_e} + 1 \leq r_e \leq N_{R_e}^{\max})$ does not have an initial value, and it is $N_{R_e} = N_{I_e}$ in initial setting when the saving point number is set to N_{R_e}.

[step2]

In the case of dealing with n purpose optimization problem $(n > 1)$, since a searching point $\mathbf{x}_l^t(i_e)$ has n purpose functions, the position in the n-dimensional purpose functional space is decided by those values. And each searching point can be evaluated. The position information $\mathbf{p}_l^t(i_e)$ on the best solution which these searching points itself has, and the position information $\mathbf{p}_g^t(r_e)$ on the Pareto solution shared in groups have n objective functions similarly, and exist in n-dimensional objective function space. A Hypercube (n-dimensional cube) is generated so that only arbitrary numbers may divide the n-dimensional purpose functional space where all $\mathbf{p}_g^t(r_e)$ exists.

[step3]

The procedure which chooses $\mathbf{p}_g^t(h)$ which is needed when generating a move vector $\mathbf{v}_l^t(i_e)$ at [step4] is as follows. In objective-function space, the number of $\mathbf{p}_g^t(r_e)$ which belongs to each Hypercube is set to α paying attention to all the Hypercube containing at least one $\mathbf{p}_g^t(r_e)$. $rand()$ is set to the uniform random numbers from 0 to 1. $rand()/\alpha$ specifies one Hypercube which becomes the maximum and sets to as Hypercube h. $\mathbf{p}_g^t(r_e)$ is chosen at random from Hypercube h, and selected $\mathbf{p}_g^t(r_e)$ is set to $\mathbf{p}_g^t(h)$. Thus, it draws near to the domain where the density of $\mathbf{p}_g^t(r_e)$ is low by choosing $\mathbf{p}_g^t(h)$. And it is effective in the ability to perform wide range search.

[step4]

In the $t+1$th search, the i_eth searching point $\mathbf{x}_l^{t+1}(i_e)$ moves to the new position shown by Equation (2.11) according to the move vector $\mathbf{v}_l^{t+1}(i_e)$ described by formula Equation (2.11) in search space.

$$\mathbf{v}_l^{t+1}(i_e) = w\mathbf{v}_l^t(i_e) + rand_1()(\mathbf{p}_l^t(i_e) - \mathbf{x}_l^t(i_e)) + rand_2()(\mathbf{p}_g^t(h) - \mathbf{x}_l^t(i_e)) \quad (2.11)$$

$$\mathbf{x}_l^{t+1}(i_e) = \mathbf{x}_l^t(i_e) + \mathbf{v}_l^{t+1}(i_e), \quad (2.12)$$

In Equation (2.11), w expresses an inertia weight and $rand_1()$, $rand_2()$ expresses the uniform random numbers from 0 to 1. The 1st term of the right-hand side is a vector showing the inertia to the direction to which it moved last time. The 2nd term of the right-hand side is a vector which draws a searching point near to the position of the best solution which self has. The 3rd term of the right-hand side is a vector which draws a searching point near to the position of $\mathbf{p}_g^t(h)$. In addition, various search becomes realizable by random numbers $rand_1()$, $rand_2()$.

[step5]

An objective-function value is calculated from the position of a searching point $\mathbf{x}_l^{t+1}(i_e)$.

[step6]

This step consists of the following [step6-1]-[step6-6].

[step6-1]

When $\mathbf{x}_l^{t+1}(i_e)$ is superior to $\mathbf{p}_l^t(i_e)$ to a certain objective-function value, it updates $\mathbf{p}_l^t(i_e)$ to $\mathbf{x}_l^{t+1}(i_e)$.

[step6-2]

Although $\mathbf{x}_l^{t+1}(i_e)$ is superior to $\mathbf{p}_l^t(i_e)$ to a certain purpose function value, when inferior to $\mathbf{p}_l^t(i_e)$ to other purpose function values, it decides at random whether to update $\mathbf{p}_l^t(i_e)$ to $\mathbf{x}_l^{t+1}(i_e)$.

[step6-3]

When $\mathbf{p}_g^t(r_e)$ inferior to $\mathbf{x}_l^{t+1}(i_e)$ exists to all the objective-function values, one is updated to $\mathbf{x}_l^{t+1}(i_e)$. Except it, it is deleted by next processing [step6-6].

[step6-4]

When $\mathbf{x}_l^{t+1}(i_e)$ is excellent in at least one purpose function value to all $\mathbf{p}_g^t(r_e)$ (that is, it is the Pareto solution), if it is $N_{R_e} < N_{R_e}^{\max}$, $\mathbf{x}_l^{t+1}(i_e)$ is saved as new $\mathbf{p}_g^t(r_e)$ $(r_e = N_{R_e} + 1)$. Moreover, since the one saving point number increases at this time, the saving point number is set to $N_{R_e} + 1$.

[step6-5]

If it is $N_{R_e} \geq N_{R_e}^{\max}$ on condition of [step6-4], the number of $\mathbf{p}_g^t(r_e)$ saves only $\mathbf{x}_l^{t+1}(i_e)$ belonging to the Hypercube which is below a certain value as new $\mathbf{p}_g^t(r_e)$ $(r_e = N_{R_e}+1)$. Moreover, at this time, since the one saving point number increases, the saving point number is set to $N_{R_e} + 1$.

[step6-6]

$\mathbf{p}_g^t(r_e)$ which becomes a non-Pareto solution at the time of preservation and updating is deleted. The saving point number at this time is newly set to N_{R_e}.

[step7]

The procedure from [Step2] to [Step6] is repeated until it reaches the specified number N_T of repeated calculation. Search will be ended if the number of calculation reaches N_T. And a final set of $\mathbf{p}_g^t(r_e)$ is considered as the Pareto optimum solution set.

Chapter 3

Target Inventory Strategy in Multistage Supply Chain

3.1 Introduction

In recent years, the automobile industry has been advancing the cost cut by a merger, the introduction of foreign capital, promotion of competition of a supplier, etc. It becomes very important in near future to remove waste of the production business and to realize needs of an individual customer and the conformity nature to a change of a market. In particular, we are satisfied a variety of customer specification in product and service, without dropping the productive efficiency in a great need of mass customization in SCM.

PSO is one of the methods solving a nonlinear optimization problem efficiently and developed by Kennedy through the simulation of the simplified social model. It is known as a result of much old numerical simulations that it is possible to calculate the semi optimal solution of multimodal function of a continuous variable with a high accuracy.

In this paper, we propose the setting method of the optimum order quantity by PSO for SCM [51]. Proposed method provides a new optimal model in logistics of SCM which consists a retailer, a wholesaler, a distributor and a factory. And we set up the optimum order quantity from which the profits of the whole SCM become the maximum by using PSO.

3.2 Outline of Supply Chain Management

There is a flow of business, starting from supply of materials or parts, production, sale, and a physical distribution and finally delivering goods to consumers. It is the supply chain which regarded the flow of this business as a chain of one big supply [52–54].

SCM is managing the flow of information, the flow of goods, and the flow of money, in a supply chain. And it is making the whole supply chain correspond quickly environmental change of the market and optimize dynamically . That is, it does not necessary optimize every section or company, but the flow of the business in connection with information, goods, and money is seen from the viewpoint of the whole supply chain. And it is a design concept of the management system which maximizes the cash-flow efficiency of the whole supply chain by performing reform of information sharing and a business process. The conceptual diagram of SCM is shown in Figure 3.1.

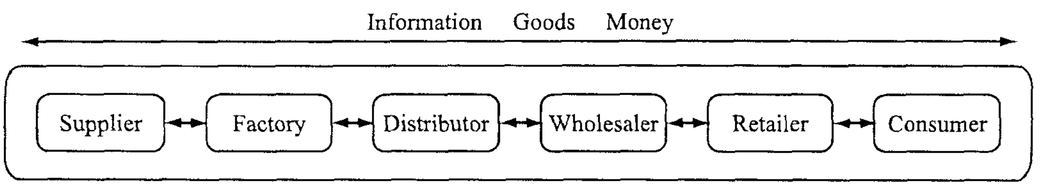


Figure 3.1: Conceptual diagram of SCM

The background of SCM

By change of consumers' lifestyle, or diversification of needs, the life cycle of goods has become short and the goods have not sold continuously in the long run. As a result, if goods are not offered in accordance with consumers' timing, sales do not go up. And the unnecessary stock left unsold will be held. Because the stock and the physical distribution cost which occupies big specific gravity in the cost of goods were reduced while the bad days had come and sales made little increase, a result which many companies take in was brought. Although SCM has been fashion in the past several years, what resembled this is carried out from the old days in a supermarket or convenience store (CVS). The headquarters organization of retail stores, such as a supermarket and CVS, took the lead, and has controlled the time and quantity of supply on the basis of the order information of a producer, a maker, a physical distribution, and a wholesale company.

Merit of SCM

- Merit of company
  - A market and a customer's needs can be satisfied promptly.
  - Rationalization of the amounts of supply, such as raw material.
  - Useless production is lost and manufacturing efficiency improves.
  - Rationalization of stock.
  - Rationalization of the amount of physical distributions.
  - Since production cost decreases as a result, a good price falls down and a profit improves.
- Merit of consumers
  - Goods needed can be purchased at a quantity needed and a price needed by a place needed and method, when wanting.

The point of systematization of SCM

- Sharing of information

  The key point of SCM is the accuracy and speed of demand forecasting. Money of stock or disposal changes with sizes of the error of prediction especially as what has short quality maintenance, such as food. It is a big point that the system which can share high-precision information quickly can be constructed.

- Cooperation between companies

  In the case of customer relationship management(CRM), it may be realizable if organization is prepared in a company. However, two or more companies need to cooperate each other in SCM.

Table 3.1: The example of practical use of the system in SCM

Business	Contents	Use system
Collection of consumer information	Information is collected from POS sales data and ordering data of a retail store, information is exchanged and shared by EDI, and it uses for the planning of demand, a stock forecast, etc.	POS EOS EDI E-commerce
Prediction of demand	External factors, such as consumers' purchase trend, the weather, etc., are considered, diversified analysis is conducted, and demand is predicted.	DP
Production and a physical distribution plan	In order that all the processes such as supply of materials, production, and a physical distribution are optimized, planning of production, delivery planning, etc. are planned.	SCP FP
Delivery time reply	The delivery time to an order is replyed. A reply is offered from productive capacity and a schedule to a sudden order or a lot of order.	Df

- The system which is flexible and is extensible

  In order to realize SCM, it is necessary to exchange data with mission critical systems, such as Point of sale(POS), Electronic Data Interchange(EDI), sales management, and production control. Moreover, since it is necessary to deal with a lot of data, the speed of processing is also big problem. From this reason, the system excellent in flexibility and extendibility is needed.

Table 3.1 is shown the example of practical use of the system in SCM.

3.3 Model Formulation

3.3.1 Basic Model of Single Stage in Supply Chain

It is thought that consumer causes demand for one retailer. Here, demand at stage k in period i is shown by normal distribution $D_i^k \in N(d, \sigma^2)$ with average d and variance σ^2. Demand forecast $\tilde{d}_i^k$ during lead time at stage k is formulated by

$$\tilde{d}_i^k = L^k \hat{d}_i^k \tag{3.1}$$

where L^k is a lead times for stage k and $\hat{d}_i^k$ is demand forecast at stage k in period i using moving average method with period Θ.

$$\hat{d}_i^k = \frac{\sum_{\theta=1}^{\Theta} D_{i-\theta}}{\Theta} \tag{3.2}$$

Standard deviation of demand forecast during a lead time at stage k is given by $\tilde{\sigma}_i^k = \sqrt{L^k}\sigma$. Under these environment, target inventory level at stage k in period i is expressed by

$$y_i^k = \tilde{d}_i^k + a^k \tilde{\sigma}_i^k \tag{3.3}$$

where, a^k is control parameter about customer satisfaction at stage k. And, order quantity O_i^k at stage k in period i is given by

$$O_i^k = D_i^k + y_{i+1}^k - y_i^k \tag{3.4}$$

3.3.2 Formulation of Multistage Supply Chain

We formulate foundamental model which is discussed in this paper. In problem definition and formulation, we consider these quantities such as D_i^k, y_i^k, O_i^k, S_i^k, where S_i^k denotes inventory at stage k in period i. Figure 3.2 shows four steps in a simple supply chain. Index k expresses retailer by 1, wholesaler by 2, factory by 3, and supplier by 4. We consider price of product, p_D^k, order and logistics cost, p_O^k, restocking fee, p_r^k, restocking fee in demand, p_b^k, holding cost, p_S^k, and stock out cost, p_u^k, per unit.

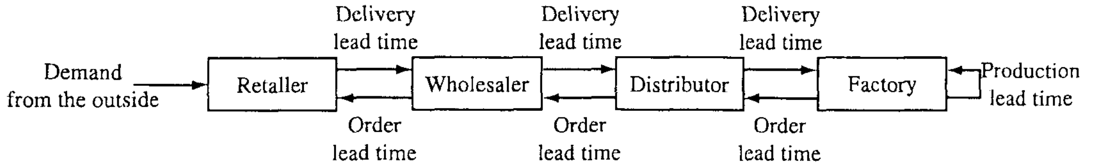


Figure 3.2: SCM of Four Stages

We formulate problem deciding the order variable $x_i^k(x^k_{ts-L^k_e+1}, x^k_{ts+1}, \ldots, x^k_{ts+tp})$. Maximizing profit of total supply chain ts as follows, where ts is a plan start time and tp is plan period.

$$\max \quad \sum_{k=1}^{m} \sum_{i=ts-L_e^k+1}^{ts+tp} (p_D^k D_t^k - c_i^k) \tag{3.5}$$

$$\text{s.t.} \quad c_i^k = p_s^k S_i^k + p_u^k u_i^k + p_O^k O_i^k + p_r^k r_i^k + p_b^k b_i^k, \tag{3.6}$$

$$z_{i+1}^k = S_i^k - y_i^k + O_{i-L_O^k+1}^k - r_i^k, \tag{3.7}$$

$$y_i^k = D_i^k - b_i^k, \tag{3.8}$$

$$S_i^k = \min(f_+(z_i^k), \hat{S}^k), \tag{3.9}$$

$$u_i^k = f_-(z_i^k), \tag{3.10}$$

$$O_i^k = f_+(x_i^k), \tag{3.11}$$

$$r_i^k = \min(S_i^k, f_-(x_i^k)), \tag{3.12}$$

$$D_i^k = O_i^{k-1}, \tag{3.13}$$

$$b_i^k = r_{i-L_r^{k-1}}^{k-1}, \tag{3.14}$$

$$L_e^k \geq L_O^k \geq 0, \tag{3.15}$$

$$\hat{S}^i \geq 0, \tag{3.16}$$

$$L_r^k \geq 0. \tag{3.17}$$

In multistage supply chain, $D_i^1 = O_i^0$ is given at random such as $D_i^1 \in N(d, \sigma^2)$. $D_i^k (k \geq 2)$ are given by Equation (3.13). c_i^k denotes total cost of multistage and from Equation (3.9) to Equation (3.14) are derived by model assumptions. r_i^k denotes restocking in order, b_i^k restocking in demand, u_i^k quantity out of stock and z_i^k inventory variable. $\hat{S}^k$ denotes limit inventory in stage k. And inventory quantity S_i^k should not be beyond limit inventory $\hat{S}^k$ in each stage. We also consider lead time of order, L_O^k, restocking, L_r^k, and plan, L_e^k. Figures 3.3 and 3.4 shows that L_O^k is a lead time until it orders from the next stage $k+1$ and returns to the present stage k, and L_r^k is a lead time which until it returns the goods to the next stage $k+1$ from the present stage k. L_e^k is lead time of period to build a plan.

Figures 3.5, 3.6, 3.7 and 3.8 show the inventory quantity S_i^k, quantity out of stock u_i^k, order quantity O_i^k, and restocking in order r_i^k.

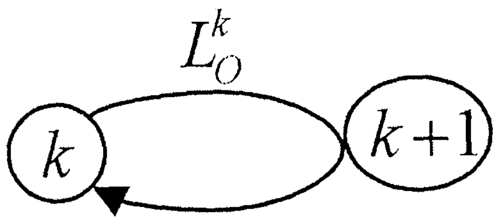


Figure 3.3: Lead Time of Order

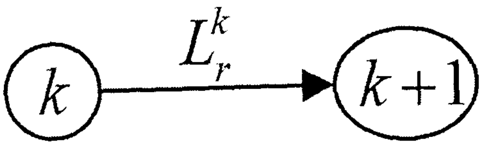


Figure 3.4: Lead Time of restocking

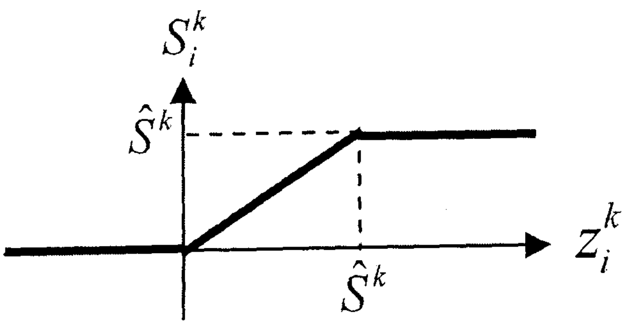


Figure 3.5: Inventory quantity

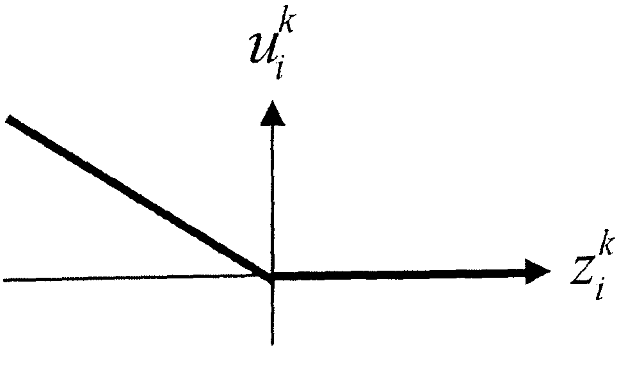


Figure 3.6: Quantity out of stock

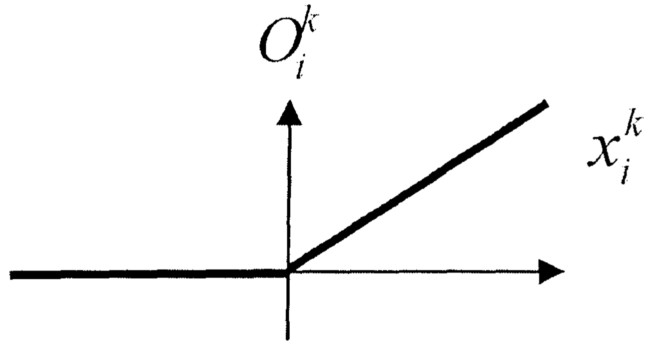


Figure 3.7: Order quantity

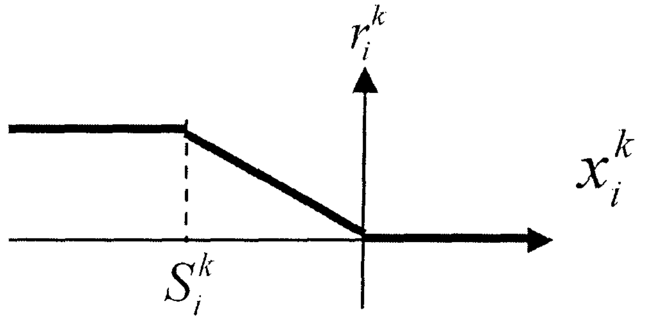


Figure 3.8: Restocking in order

3.4 Numerical Example

In this section, the proposed model is solved using PSO. Figure 3.9 shows the outline of dynamics. We set the plan start time $ts = 20$, plan period $tp = 10$ and lead time of period to build a plan $L_e^k = 5$. In other words period 16-30 are prediction periods.

Table 3.2 shows the comparison when giving x_i^k by the normal distribution and PSO. In the case of a normal distribution, it is the case where distribution is changed by an average of 30. Each stage and total at that time, average, standard deviation, the best value, and the worst value are shown. And it shows the result of PSO. In an average and the best value, it turns out that the way as a result of PSO is good except stage1. However, the value of stage1 is worse and worse. Figures from 3.10 to 3.15 are the result of a normal distribution when a best solution comes out by total, and

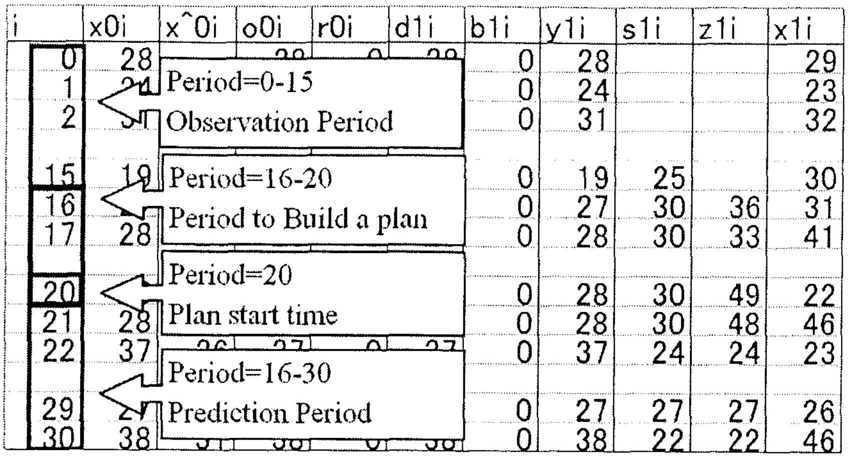


Figure 3.9: Outline of dynamics

as a result of PSO. As for these graphs, the solid lines shows stage 1, the dashed lines stage 2 and the dotted lines stage 3. Figures 3.10 and 3.11 are result of quantity out of stock. From these figures, in result of PSO, the times of stock out are small. And the quantity of stock out is small, too. Figures 3.12 and 3.13 are result of inventory quantity. In result of PSO, it turns out that there is little inventory quantity except stage 3. Figures 3.14 and 3.15 are result of order quantity. In result of PSO, it turns out that the quantity of order is not changed sharply.

Table 3.2: Comparison of results

	Stage1	Stage2	Stage3	Total
Average	287121	275585	262507	825213
Standard Deviation	9453	30619	59549	539460
Best	302283	320354	331152	871647
Worst	272315	231835	138916	734781
PSO	256148	337778	331343	925271

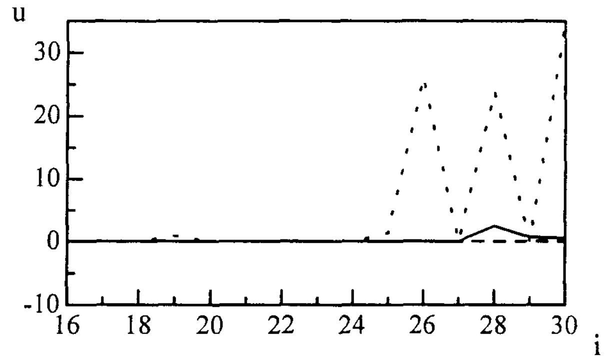


Figure 3.10: Result of quantity out of stock by $N(30,9)$

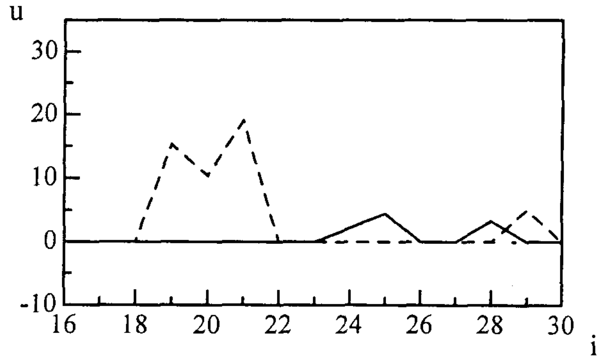


Figure 3.11: Result of quantity out of stock by PSO

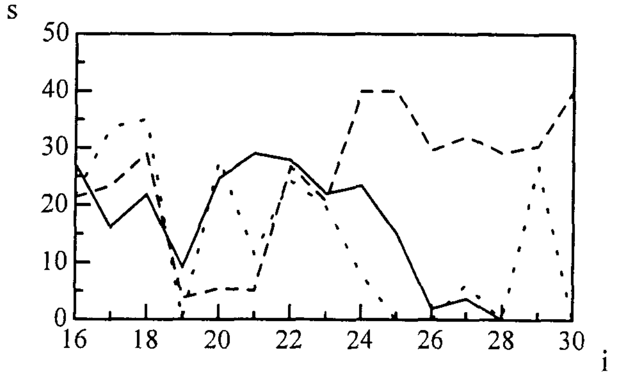


Figure 3.12: Result of inventory quantity by $N(30,9)$

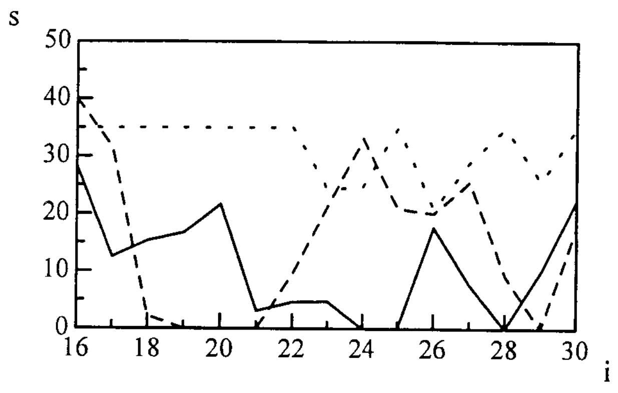


Figure 3.13: Result of inventory quantity by PSO

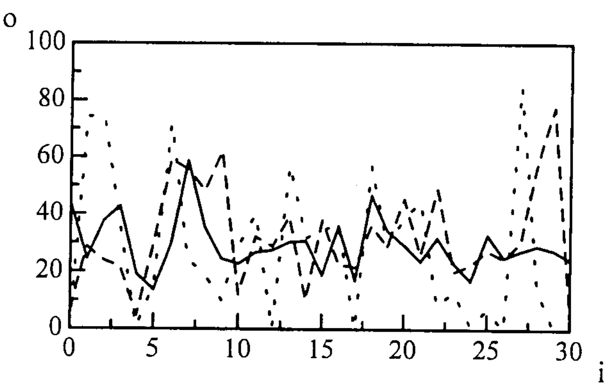


Figure 3.14: Result of order quantity by $N(30, 9)$

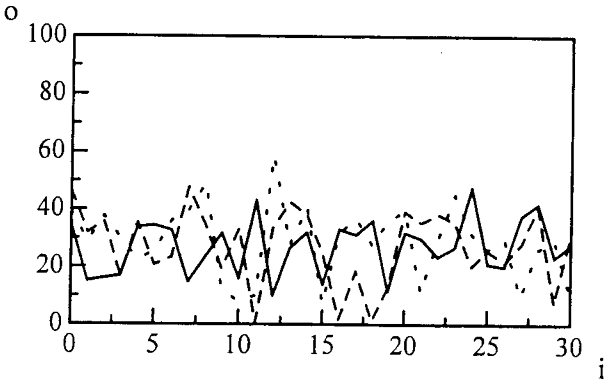


Figure 3.15: Result of order quantity by PSO

3.5 Conclusion

In this chapter, we have proposed the setting method of the optimum order quantity by PSO for SCM. Proposed method has provided a new optimal model in logistics of SCM which consisted of a retailer, a wholesaler, a distributor and a factory. And it is thought to be effective to set up the optimal order quantity from which the profits of the whole SCM become the maximum by use of PSO.

Chapter 4

Production Planning System with Multi-Stages for Controlling Bullwhip Effect

4.1 Introduction

In the manufacturing industry, the establishment of mass customization is a pressing need. This mass customization is a management system which produces efficient specified customer requested products with diversification in case that the products are outside the catalog [55, 56]. The design method of a new production planning system (Mass Customization Production Planning System: MCPS) has been proposed by the supplier between the maker in the manufacturing industry, and a processing assembly type supplier [57,58]. 1) The lead time customer request (delivery lead time) includes the case it is shorter than the lead time producer need to products (production lead time). 2) The difference between forecast products and order products are not distinguished. 3) It does not depend on the production style.

The production planning problem is formularized as a probabilistic planning problem by giving the insufficient attainment rate of planning target without setting the safety inventory or the base inventory [57]. The production planning is the problem of the supplier corresponding to the order environment caused by mass customization. Since the problem [57] extends problem [58] to the multi-commodity problem, the character and convergence etc. of a solution are discussed in detail under the particular subject of the multi-commodity problem.

These papers till now have assumed the demand distribution is known. However, actually, the distribution form of demand is unknown actually, and may be unable to specify. In this paper, we describe the solution method of the production planning problem [57, 58] without assuming the demand distribution type of demand. That is, the relation between the insufficient attainment rate and inventory transition [57, 58] is described. From these considerations, "making the bottom of inventory into a high rank as much as possible in a period about inventory transition on a plan" shows improvement of the insufficient attainment rate. Next, based on this idea, we derive a formulation of "the inventory transition which makes the minimum point inventory become maximum" by Min-Max strategy taking cost into consideration. This chapter calculates the approximate solution of the formulized production planning problem by using PSO.

PSO is thought that it can solve even if a production plan is extended to nonlinearly by using PSO [59].

4.2 Production Planning System Corresponding to Mass Customization Under Known Demand Distribution

First, the demand quantity from the maker to the supplier in mass customization environment is assumed to be a normal distribution. Second, the inventory transition in the last production base of the supplier corresponding to the variation of order from the maker is rationalized over period n. Finally, the problem which determines the production quantity is formularized.

Notations

i : Period number ($i \leq n$).

D_i : Maker's demand quantity in the period i. It follows the normal distribution with given mean value (notification) $\bar{d}_i$, the standard deviation ω_i. D_i and D_j are independent of each other.

X_i : Production quantity of period i.

S_i : Inventory quantity of period i. The initial inventory quantity is S_0.

p_i : Manufacturing cost per unit in period i.

h_i : Inventory cost per unit in period i.

T : Total production of period n. That is, $\sum_{i=1}^{n} X_i = T$.

R : The production constraint set (Linear constraint).

SO : Unfulfilled order rate until period n, i. e., It is, the probability that the inventory runs out at least once until period n.

β : The unfulfilled order rate of planning target. It means the unfulfilled order rate which is permitted under a standard production lead time. In fact, it should be avoided that the unfulfilled order of delivery is covered by performing urgent production and urgent transportation. But naturally it involves the increase of cost. Therefore, the unfulfilled order rate of plan target is the index under the standard production and delivery activities.

Formulation 1

$$\min \quad E\left(\sum_{i=1}^{n} p_i X_i + \sum_{i=1}^{n} h_i S_i\right), \tag{4.1}$$

$$\text{s.t.} \quad S_0 + \sum_{t=1}^{i} X_t - \sum_{t=1}^{i} \bar{d}_t \geq 0 \quad (\forall i \leq n), \tag{4.2}$$

$$S_i = S_0 + \sum_{t=1}^{i} X_t - \sum_{t=1}^{i} \bar{d}_t, \tag{4.3}$$

$$\sum_{i=1}^{n} X_i = T, \tag{4.4}$$

$$SO \leq \beta, \tag{4.5}$$

$$(X_1, X_2, \cdots, X_n) \in R, \tag{4.6}$$

$$X_i \geq 0 \quad (\forall i \leq n). \tag{4.7}$$

The problem with one item is formulated as setting to solve supplier's products individually. Here Equation (4.1) is the minimization of expectation of the total of manufacturing cost and the inventory cost. Equation (4.2) is non-negative constraint of the inventory in each period during the range of demand which is lower than the previous order information from the maker to the supplier. Equation (4.3) is the aggregate inventory in period i. D_t is the random variable, and so S_t is the random variable. Equation (4.4) is the total amount constraint of products. Equation (4.5) is the constraint of the unfulfilled order rate of planning target. Equation (4.6) is ordinary production constraint. Equation (4.7) is the nonnegative constraint of products amount in each period. A solution is obtained by solving successively the partial problem defined as a linear programming problem [57].

4.3 Production Planning System for Mass Customization Under Unknown Demand Distribution

4.3.1 The Essential Features of Solution

When the demand distribution form is known, the inventory amount S_i in period i is below the unfulfilled order rate β_i of each period [57]. For that purpose, as shown in Figure 6.7, the expectation of inventory amount S_i in period i above K_i should satisfy in quest of y and K_i given as Equations (4.8) and (4.9).

$$\beta_i = \int_{-\infty}^{y} \frac{1}{\sqrt{2\pi}\sigma_i} e^{-\frac{(S_i - m_i)^2}{2\sigma_i^2}} dS_i, \tag{4.8}$$

$$K_i = m_i - y. \tag{4.9}$$

However, Equations (4.8) and (4.9) cannot be constituted in the range of this study because the demand distribution is unknown.

Therefore at first the relation between the unfulfilled order rate and the inventory transition is derived. From these considerations, "an inventory transition on a plan, making the highest rank in a period the bottom of inventory is optimize." shows that it is predominance to the unfulfilled order.

Figure 4.2(a) and Figure 4.2(b) shows two inventory transitions. Comparing with

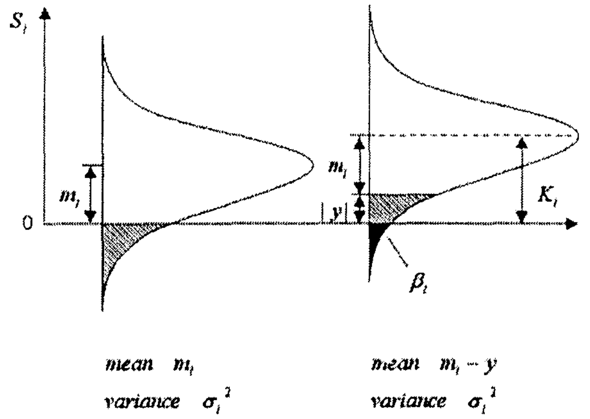
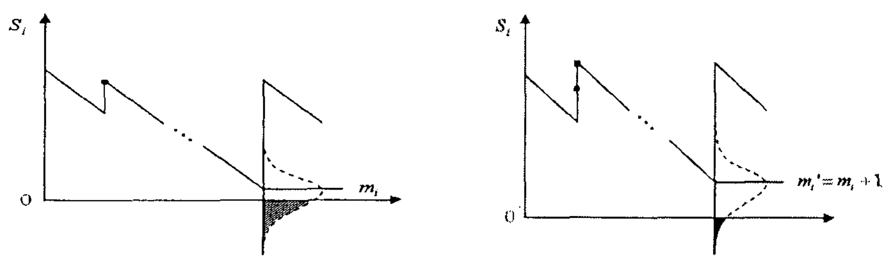


Figure 4.1: Basic idea of the solution when demand distribution is known



(a) Inventory before improvement (b) Inventory after improvement

Figure 4.2: Improvement of stock out

Figure 4.2(a), Figure 4.2(b), note that in period i the production amount X_i in Figure 4.2(b) is more than the in Figure 4.2(a) by 1. In the case that demand distribution is known, the unfulfilled order rate in Figure 4.2(b) improve than that of Figure 4.2(a).

Therefore in the case that the distribution of demand amount is unknown, the probability that inventory in Figure 4.2(b) becomes less than 0 becomes small, and it is predominance to unfulfilled order. That is, "making the inventory into a high rank as much as possible in a period about inventory transition of a plan" leads to the improvement of unfulfilled order.

Therefore as shown in Figure 4.3, this chapter's mission as for production planning problem is to find the inventory transition maximizing the minimum point by considering the cost.

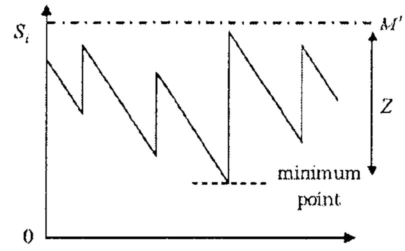


Figure 4.3: Basic idea of proposed solution when demand distribution is unknown

Formulation 2

A Min-Max strategy is introduced in order to realize that "inventory transition which makes the minimum inventory point maximum" based on formulation 1. That is, the inventory amount S_i in period i is calculated as shown in Equation (4.10) below.

$$\mathbf{min} \max_{i \leq n} |M^t - S_i|, \tag{4.10}$$

where M^t denotes the inventory amount of planning target. Then, Equations (4.11) and (4.12) are obtained by making Z into an artful continuous variable.

$$\mathbf{min} \quad Z, \tag{4.11}$$

$$\mathbf{s.t.} \quad |M^t - S_i| \leq Z \quad (\forall i \leq n). \tag{4.12}$$

The introduction of cost

In a usual production management business, the decision of the cost is unusual before the inventory level is decided. Therefore, it is difficult to set up a restrained cost in advance. Therefor, two objective functions are compounded. Equation (4.14) is a formula which adds the equivalent $f(Z)$ to Equation (4.13).

$$\sum_{i=1}^{n} p_i X_i + \sum_{i=1}^{n} h_i S_i, \tag{4.13}$$

$$\sum_{i=1}^{n} p_i X_i + \sum_{i=1}^{n} h_i S_i + \sum_{i=1}^{n} f_i(Z). \tag{4.14}$$

Formulation 3

The formulation of production planning problem in the case that demand distribution is unknown is as follows.

$$\min \quad \sum_{i=1}^{n} p_i X_i + \sum_{i=1}^{n} h_i S_i + \sum_{i=1}^{n} f_i(Z), \tag{4.15}$$

$$\text{s.t.} \quad S_0 + \sum_{t=1}^{i} X_t - \sum_{t=1}^{i} \bar{d}_t \geq 0 \quad (\forall i \leq n), \tag{4.16}$$

$$S_i = S_0 + \sum_{t=1}^{i} X_t - \sum_{t=1}^{i} \bar{d}_t, \tag{4.17}$$

$$\sum_{i=1}^{n} X_i = T, \tag{4.18}$$

$$|M^t - S_i| \leq Z \quad (\forall i \leq n), \tag{4.19}$$

$$(X_1, X_2, \cdots, X_n) \in R, \tag{4.20}$$

$$X_i \geq 0 \quad (\forall i \leq n), \tag{4.21}$$

where Equation (4.15) is the total cost after converting inventory level to existing cost. Equation (4.17) denotes the inventory amount S_i in period i, where S_i is a definite variable. S_i is eliminable from Equations (4.17) and (4.18), and so variables are X_i and Z.

Formulation 4

Formulation 3 is extended to the multi-commodity and multi-stage problem. Notations are defined as follows. And the multi-commodity problem is formulated.

Notations

i : Period number ($i \leq n$).

j : Item number ($j \leq m$).

k : Stage number.

$\bar{d}_{ij}$: Notified amount of item j in period i.

X_{ij} : Production amount of item j in the beginning of period i.

S_{ij} : Inventory amount of item j in the end of period i. Here the initial inventory amount is S_0.

p_{ij} : Manufacturing cost per unit of item j in period i.

h_{ij} : Inventory cost per unit of item j in period i.

T_j : Total of production amount of item j during periods n.

M_j^t : Inventory amount of planning target of item j.

λ_j : Parameter to replace inventory level with cost of item j.

Q_i : Constraint of manufacturing capacity in period i.

R_j : Production constraint set with respect of item j (Linear constraint).

$$\textbf{min} \quad \sum_{k=1}^{3}\sum_{j=1}^{m}\left(\sum_{i=1}^{n} p_{ij}^k X_{ij}^k + \sum_{i=1}^{n} h_{ij}^k S_{ij}^k + \sum_{i=1}^{n} f_i(Z_j^k)\right), \tag{4.22}$$

$$\textbf{s.t.} \quad S_{0j}^k + \sum_{t=1}^{i} X_{tj}^k - \sum_{t=1}^{i} \bar{d}_{tj}^k \geq 0 \quad (\forall i, j), \tag{4.23}$$

$$S_{ij}^k = S_{0j}^k + \sum_{t=1}^{i} X_{tj}^k - \sum_{t=1}^{i} \bar{d}_{tj}^k, \tag{4.24}$$

$$f(Z_j^k) = \lambda_h f_+\{(M_j^{tk} - Z_j^k) - S_{ij}^k\} + \lambda_n f_+\{Z_j^k - |M_j^{tk} - S_{ij}^k|\}$$
$$+ \lambda_r f_+\{S_{ij}^k - (M_j^{tk} + Z_j^k)\} \quad (\forall i, j), \tag{4.25}$$

$$\sum_{i=1}^{n} X_{ij}^k = T_j^k \quad (\forall j), \tag{4.26}$$

$$\sum_{j=1}^{m} X_{ij}^k \leq Q_i^k \quad (\forall i), \tag{4.27}$$

$$(X_{1j}^k, X_{2j}^k, \cdots, X_{nj}^k) \in R_j \quad (\forall j), \tag{4.28}$$

$$X_{ij}^k \geq 0 \quad (\forall i, j). \tag{4.29}$$

In the multi-commodity problem, manufacturing capacity restrictions of each period of Equation (4.27) are incorporated, where Z_j is artful continuous variable corresponding to item j. In a supply chain management, the middle stages inventory without short stock are requested to satisfy customer demand. For this purpose, we first determine stock level of each stage and then the degree of fulfillment on the inventory level. Of course we assume the degree of fulfillment on the inventory level in advance because the target inventory level depends on it. So this chapter discusses the optimization to the degree of fulfillment on the inventory level under the condition where the stock level is given.

4.4 Numerical Example

In a numerical simulation, two kinds of supplier products (parts) are considered. Tables 4.1 and 4.2 show the data of simulation.

Table 4.1: $\bar{d_{ij}}$ used in an example system of 2 items

i	1	2	3	4	5	6	7	8
d_{i1}^1	14	8	5	30	16	27	23	12
d_{i2}^1	20	20	20	15	15	15	15	15
d_{i1}^2	21	12	20	15	19	11	24	13
d_{i2}^2	14	21	23	28	19	6	16	8
d_{i1}^3	14	15	24	24	10	15	8	25
d_{i2}^3	12	23	21	6	22	17	10	24

Table 4.2: D_{ij} used in an example system of 2 items

i	1	2	3	4	5	6	7	8
D_{i1}^1	12	8	3	30	17	26	22	12
D_{i2}^1	18	20	17	15	9	19	15	13
D_{i1}^2	20	3	19	15	18	13	23	13
D_{i2}^2	13	22	22	26	17	7	17	10
D_{i1}^3	14	13	25	26	11	14	9	25
D_{i2}^3	12	23	19	7	24	17	10	23

Moreover, $p_{ij}^k = \{1, 1, \cdots, 1\}$, $h_{ij}^k = \{8, 7, \cdots, 1\}$, $\lambda_h = 500$, $\lambda_n = 100$, $\lambda_r = 200$, $S_{0j}^1 = 10$, $S_{0j}^2 = 12$, $S_{0j}^3 = 15$, $T_1^k = 135$, $T_2^k = 135$, $M_j^{t1} = 10$, $M_j^{t2} = 12$, $M_j^{t3} = 15$, $Z_j^1 = 5$, $Z_j^2 = 5$, $Z_j^3 = 5$, $\omega_i = 3$ for all j. About h_{ij}, stock is avoided as much as possible in the first half of a period by high weight. Figures 4.4 and 4.5 show the inventory quantity of item no. 1 and item no. 2 at stage 1-3. ● shows the result of inventory quantity of stage 1, ▲ the result of inventory quantity of stage 2 and ■ the result of inventory quantity of stage3.

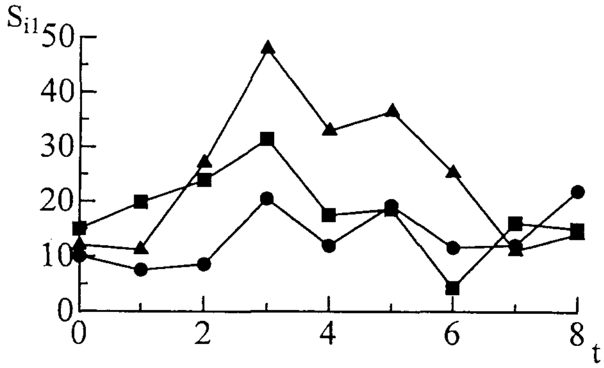


Figure 4.4: Inventory quantity of item no. 1

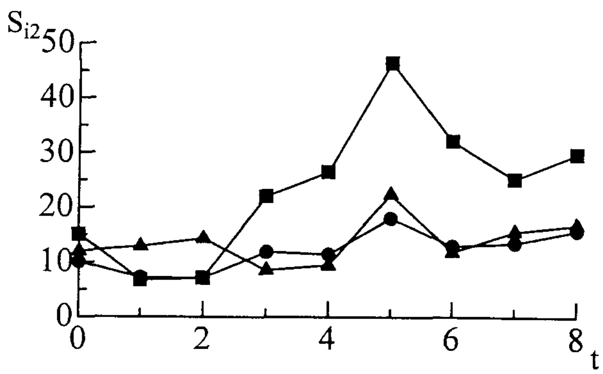


Figure 4.5: Inventory quantity of item no. 2

A change of inventory quantity about stage 1 at item no. 1 and stage 2 at item no. 2 is big. Figure 4.6 shows the result of bullwhip effect and cost when Z is changed as $Z = 3, 5, 7$. ○ shows the cost, △ the bullwhip effect of item no. 1 and □ the bullwhip effect of item no. 2. The bullwhip effect is estimated by

$$\text{B.E.} = \sum_{k=1}^{3} \frac{Var[X_{ij}^k]}{Var[D_{ij}^k]}. \tag{4.30}$$

From Figure 4.6, the cost becomes small as the value of Z grows. Here, the cost and the bullwhip effect are minimized at the time when $Z = 7$. It is important to request the optimal solution when Z because of minimizing the cost and the bullwhip effect.

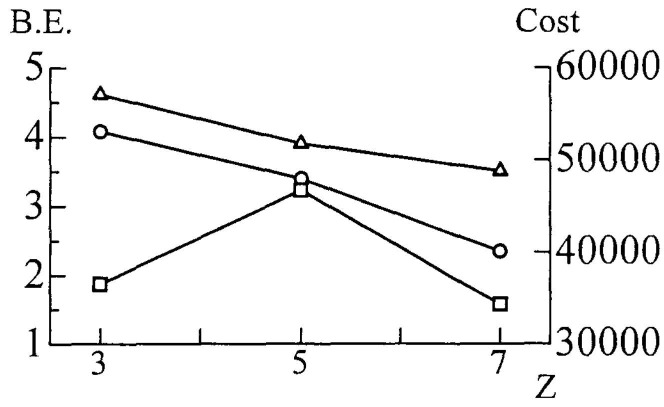


Figure 4.6: Result of bullwhip effect and cost

4.5 Conclusion

In this chapter, the improvement of the unfulfilled order rate has been shown by the policy "To optimize the rank of the bottom of the stock (the low point of the inventory) as high as possible in a period as for the inventory transition on plan". And, under the condition that there is no inventory shortage in a plan, "the inventory transition of maximization of minimum inventory point" is formulated by the Min-Max strategy while the cost is considered according to the current idea. Here, this model has been solved using PSO. Since it is possible that the present production plan problem is extended to be nonlinear, using PSO is considered promising.

Chapter 5

Production Control Technique for Environmental Consideration Management in Supply Chain

5.1 Introduction

SCM is the technique of carrying out management of the supply chain which treat from manufacture to the customer and includes a global operation. SCM aims at the profit improvement, a cost cut and shortening the production time for delivery in the whole supply chain. The management activities supported by modern mass production and mass consumption [55–57] are increasing the environment load [60] in many actual problems. In a near future management activities, it is necessary to take notice of the influence on environment etc., replying to various needs from a consumer. LCA is the technique of evaluating the environmental influence of the life cycle of a product. LCA [61, 62] is one of the evaluation methods for environmental preservation and evasion of resources drain. LCA gives not only the indicator of the recycling design for realizing sustainable development, but also the estimation of effective mechanism of manufacture. In LCA, it is important to reduce the environmental load when the products are manufactured at machine tool and the products are transported in logistics [63]. In order to solve a corresponding optimization problem, we use the PSO which is one of the meta-heuristics. PSO is often used as the simulation of the simplified social model. In this chapter, the life cycle assessment is incorporated to the supply chain. And, in a case of many kind of product, we determind the suitable order quantity considering the balance between cost and environmental load. For that purpose, we use the MOPSO, i. e., extended PSO for multiple purposes.

5.2 Environment-Conscious Supply Chain Management

The products influence the load to environment through the life cycle from the extraction stage of raw material to the disposal stage. The LCA can estimate the damage from the viewpoint of load factors by summing up environmental load at each stage. In this chapter, we focus on the environmental load of two stages, which are the logistics stage from supplier to manufacturer and the manufacturing stage using machine at supplier [64–66].

Figure 5.1 illustrates the target environmental load in this chapter. The unevenness in the order quantity of the type of a car concerned from a customer to a maker is set to σ_0, and the unevenness in order quantity of the product (part) concerned from a maker to a supplier is set to σ. Thus production planning and management system implementing mass customization is to control the production quantity in order not to be in short supply to firm order in supplier. If we can derive such compression mechanism for variation then it leads to the reduction of environmental load, because of unification of a delivery truck size in logistics, effective use of a machine tool in manufacture and so on [67, 68].

5.3 Model Formulation for Multi Objective

5.3.1 Basic Model of Single Stage in Supply Chain

It is thought that consumer causes demand for one retailer. Here, demand at stage k in period i is shown by normal distribution $D_i^k \in N(d, \sigma^2)$ with average d and variance σ^2. Demand forecast $\tilde{d}_i^k$ during lead time at stage k is formulated by

$$\tilde{d}_i^k = L^k \hat{d}_i^k \tag{5.1}$$

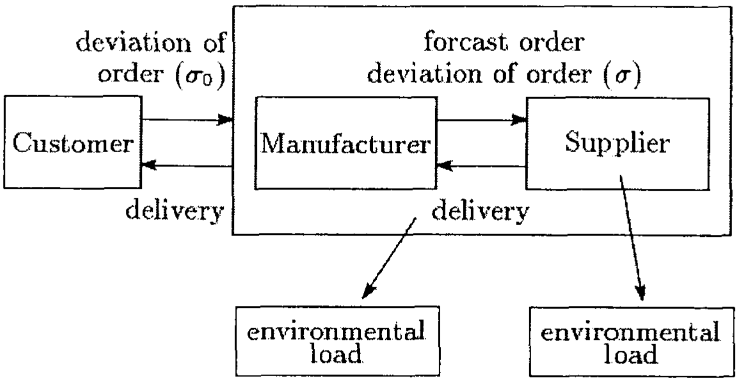


Figure 5.1: Target environmental load in environment-conscious supply chain management

where, L^k is lead times for stage k and $\hat{d}_i^k$ is demand forecast at stage k in period i using moving average method with period Θ.

$$\hat{d}_i^k = \frac{\sum_{\theta=1}^{\Theta} D_{i-\theta}}{\Theta} \tag{5.2}$$

Standard deviation of demand forecast during lead time at stage k is given by $\tilde{\sigma}_i^k = \sqrt{L^k}\sigma$. Under these situations, target inventory level at stage k in period i is expressed by

$$y_i^k = \tilde{d}_i^k + a^k\tilde{\sigma}_i^k \tag{5.3}$$

where, a^k is control parameter about customer satisfaction at stage k. And, order quantity O_i^k at stage k in period i is given by

$$O_i^k = D_i^k + y_{i+1}^k - y_i^k \tag{5.4}$$

5.3.2 Formulation of Multistage Supply Chain

We formulate foundamental model which is discussed in this chapter. In problem definition and formulation, we consider these quantities such as D_i^k, y_i^k, O_i^k, S_i^k, where S_i^k denotes inventory at stage k in period i. Index k expresses retailer by 1, wholesaler by 2, factory by 3, and supplier by 4. We consider price of product, p_D^k, order and logistics cost, p_O^k, restocking fee, p_r^k, restocking fee in demand, p_b^k, holding cost, p_S^k, and stock out cost, p_u^k, per unit. In the same way we consider environment load, cost for production, e_D^k, logistics, e_O^k, restocking in order, e_r^k, restocking in demand, e_b^k, and holding inventory, e_S^k, for per unit respectively.

We formulate problem deciding the order variable $x_i^k(x_{ts-L_e^k+1}^k, x_{ts+1}^k, \dots, x_{ts+tp}^k)$. Where is ts start time of a plan. tp planning period. x_i^k is determined as maximizing profit of total supply chain given as follows;

$$
\begin{aligned}
\textbf{min} \quad & \sum_{k=1}^{m} \sum_{i=ts-L_e^k+1}^{ts+tp} (c_i^k - p_D^k D_i^k) && (5.5)\\
\textbf{min} \quad & \sum_{k=1}^{m} \sum_{i=ts-L_e^k+1}^{ts+tp} g_i^k && (5.6)\\
\textbf{s.t.} \quad & c_i^k = p_s^k S_i^k + p_u^k u_i^k + p_O^k O_i^k + p_r^k r_i^k + p_b^k b_i^k, && (5.7)\\
& g_i^k = e_S^k S_i^k + e_O^k O_i^k + e_r^k r_i^k + e_b^k b_i^k + e_D^k D_i^k, && (5.8)\\
& z_{i+1}^k = S_i^k - y_i^k + O_{i-L_O^k+1}^k - r_i^k, && (5.9)\\
& y_i^k = D_i^k - b_i^k, && (5.10)\\
& S_i^k = \min(f_+(z_i^k), \hat{S}^k), && (5.11)\\
& u_i^k = f_-(z_i^k), && (5.12)\\
& O_i^k = f_+(x_i^k), && (5.13)\\
& r_i^k \min(S_i^k, f_-(x_i^k)), && (5.14)\\
& D_i^k = O_i^{k-1}, && (5.15)\\
& b_i^k = r_{i-L_r^{k-1}}^{k-1}, && (5.16)\\
& L_e^k \geq L_O^k \geq 0, && (5.17)\\
& \hat{S}^i \geq 0, && (5.18)\\
& L_r^k \geq 0. && (5.19)
\end{aligned}
$$

where c_i^k denotes total cost of multistage, g_i^k total environmental load of ,multistage. From Equation (5.11) to Equation (5.16) are derived by model assumptions. r_i^k denotes restocking in order, b_i^k restocking in demand, u_i^k quantity out of stock and z_i^k inventory variable. $\hat{S}^k$ denotes limit inventory in stage k. And inventory quantity S_i^k should not be beyond limit inventory $\hat{S}^k$ in each stage. We consider lead time of order, L_O^k, restocking, L_r^k, and plan, L_e^k. L_O^k is a lead time until it orders from the next stage $k+1$ and returns to the present stage k, and L_r^k is a lead time until it returns the goods to the next stage $k+1$ from the present stage k. L_e^k is lead time of period to build a plan.

5.4 Numerical Example

In this section, we use MOPSO to solve the proposed model. Figures 5.2 and 5.3 shows results of order quantity and demand quantity when we have given an order variable with MOPSO so that a cost and environmental load become minimize. Figure 5.4 is result about Cost and CO_2. We use a population of 45 particles, a repository size of 100 particles and from 100 to 10000 search times. Figure 5.4 shows that Cost and CO_2 converge in a constant value when search time is 10000. Table 5.1 shows that Cost and CO_2 in each stage when the search time is 10000. Cost and CO_2 can be reduced by carrying out the share of the information not only on each stage but on all stages.

Table 5.1: Total Cost and CO_2 in Each Stage

	Cost	CO_2
Stage 1	235855	4842
Stage 2	279183	18055
Stage 3	234895	22313
All Stage	749700	21254

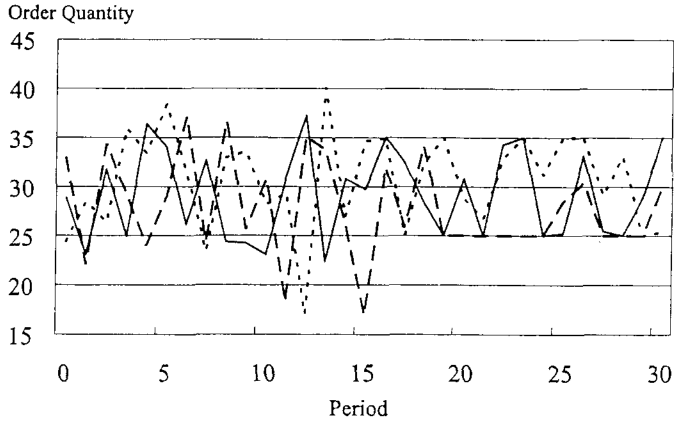


Figure 5.2: Result of Order Quantity

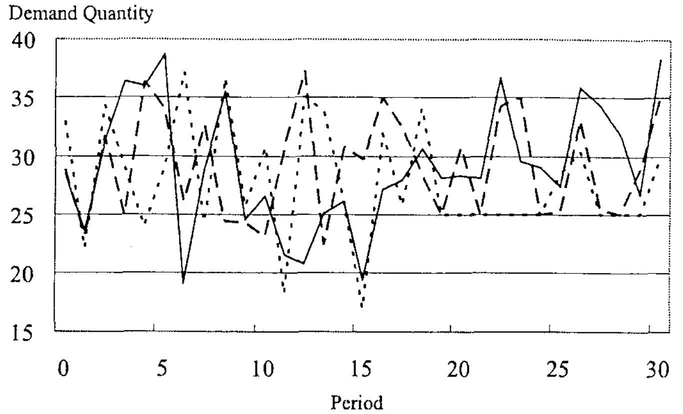


Figure 5.3: Result of Demand Quantity

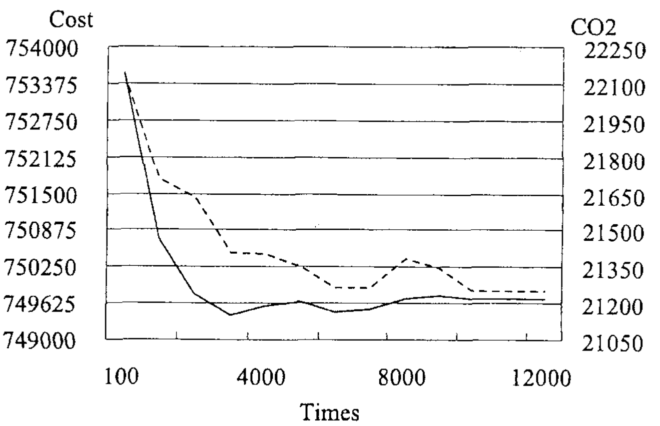


Figure 5.4: Result of Cost and CO_2

5.5 Conclusion

In this paper, we have proposed the optimum target order quantity considering environmental issuer for SCM by MOPSO. Proposed model has provided a new optimal strategy which focuses on environmental conscious in logistics and inventory of SCM from supplier to maker.

Chapter 6

Environmental Impact Estimation System

6.1 Introduction

In recent years, an environmental problem is serious and environment assessment is performed in various companies using LCA. When performing LCA evaluation, in order that computational complexity is huge, many LCA systems are developed. However, on occasions when medium and small-sized businesses and an individual perform the environment assessment, it is difficult to construct a LCA system. Moreover, for buying the LCA system marketed, it is very expensive. Therefor, we proposes and constructs the LCA system whose development / run environment is no charge. In a proposal system, the life cycle and environmental impact of a product can be grasped quantitatively. For that reason, an improvement of future environment and reduction of the environmental impact substance discharged from a company can be aimed at.

6.2 Feature of System

The feature of the constructed environmental impact estimation system is as follows.

The system in distributed environment

By using distributed type, a database can be operated from the computer of two or more different models distributed to a remote place, and information can be acquired in real time.

Standardization of environmental impact evaluation

The environmental impact which was being evaluated in each post or a company until now can be standardized. For that reason, it cannot be concerned with the size of a company but can evaluate.

Easy extension

Since it is constructing by JSP and MySQL which are no charge, anyone is easy to extend. Developing to the system which suited itself is possible.

The construction environment of a system is Table 6.1.

Table 6.1: Construction environment

OS	Windows XP
J2SE SDK	1.5.0
Tomcat	5.5.23
Apache	2.0.59
MySQL	5.0.27

6.3 Summary of System

Here, the summary of the constructed system is shown. Figure 6.1 shows the life cycle flow chart of the product in a certain company. A system is constructed based on this flow chart. A login check is first performed on a login page as shown in Figure 6.2. And if it succeeds in login, it will move to the main page of Figure 6.3. of the main page shows renewal of product information, and is Figure 6.4 for details. shows environmental impact coefficient renewal and is Figure 6.5 for details. can choose a product name, and as shown in Figure 6.6, it can display product information. can input the environmental impact for every process. And the result of having calculated the environmental impact for every process is Figure 6.7.

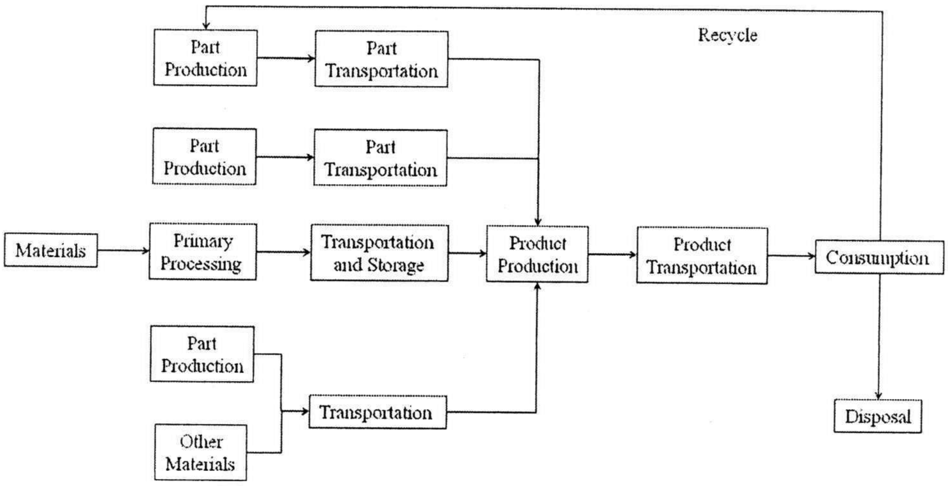


Figure 6.1: Flow Chart

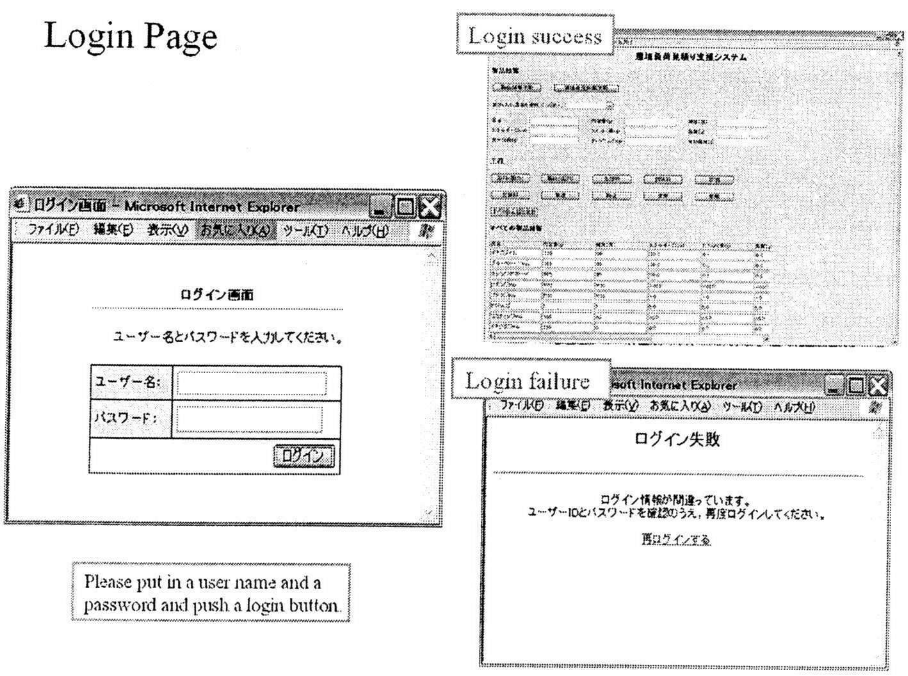


Figure 6.2: Login Page

Main Page

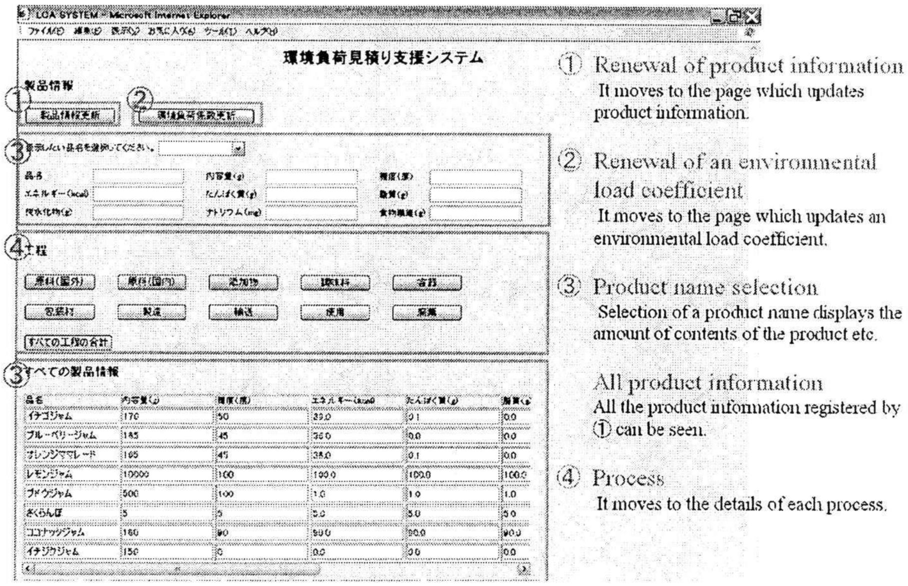


Figure 6.3: Main Page

① Renewal Page of Product Information

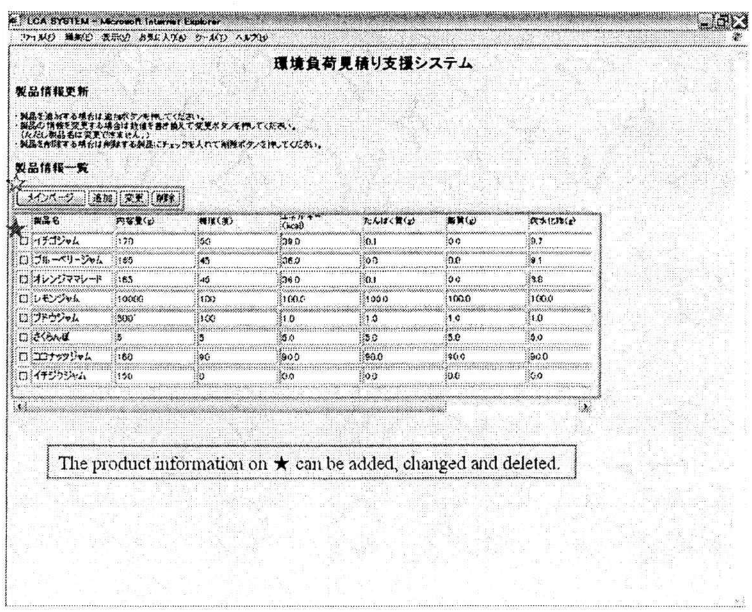


Figure 6.4: Renewal Page of Product Information

② Renewal Page of Environmental Load Coefficient

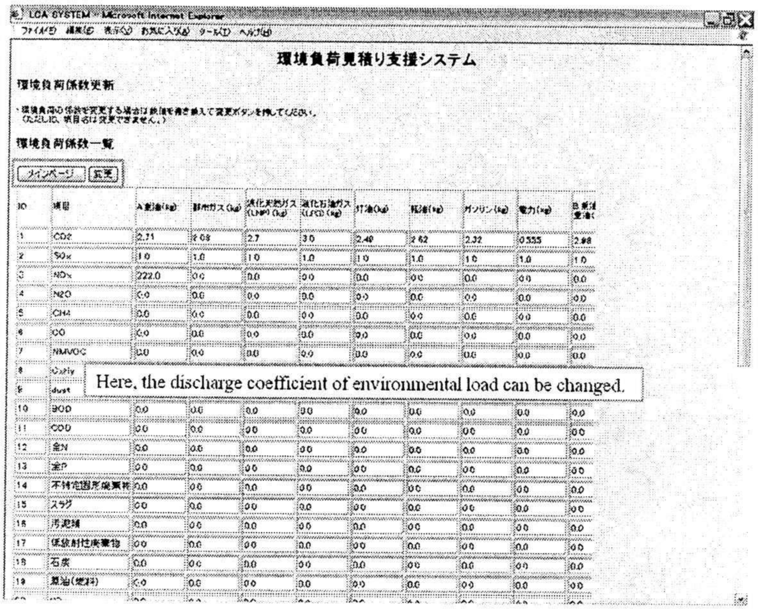


Figure 6.5: Renewal Page of Environmental Load Coefficient

③ Product Selection, All Product Information

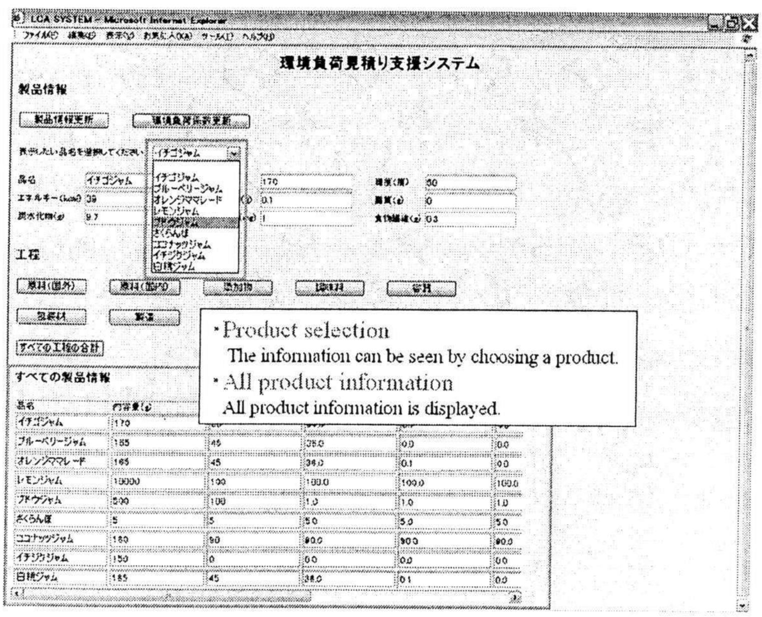


Figure 6.6: Product Selection, All product Information

④ Process -Sum Total of All Processes-

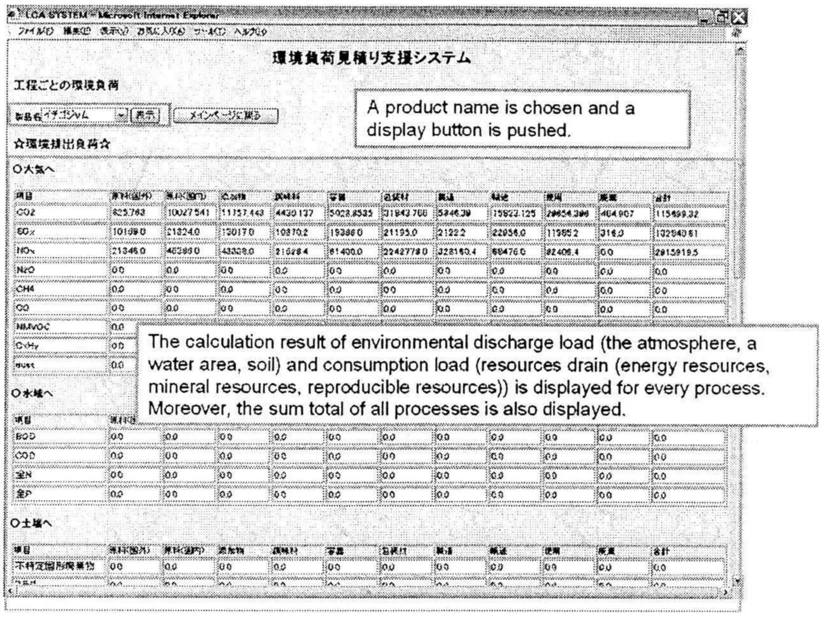


Figure 6.7: Process

6.4 Conclusion

Proposal and construction of a system which can understand the life cycle and environmental impact of a product quantitatively were performed. Shortening of computation time is expected by the proposal system using a LCA database. Moreover, the food company is actually evaluating the constructed system today. In the future, the constructed server can use it for other purposes, such as collection of questionnaire data. Moreover, it is extensible to a strategic environmental management system by including optimization in a system and developing it.

Chapter 7

Conclusion

This thesis has developed the environmental evaluation method in the manufacturing industry. And the optimum order quantity and proper inventory aiming at cost reduction have been set up, and the model which reconciles reduction of cost and an environmental load has been proposed.

Chapter 3 has proposed the method of setting up the optimum order quantity for SCM in case of one product. Here the supply chain which consists of a retailer, a wholesaler, a delivery center, and a factory has been considered. And the new optimal model in the physical distribution has been proposed. Then, using PSO, the optimum order quantity has been set up so that profits become the maximum. As a result, sharing information in all rather than having information on each stage of a supply chain has made profits increase. However, if actual, it is difficult to share information between each process or each company. Therefore, a future problem is the construction of the system which can share information.

Chapter 4 has proposed the production planning model corresponding to mass customization in the manufacturing industry under two kind of products. By raising the low place of an inventory as much as possible in a period, leading to an improvement of an unfulfilled order rate has been shown. Moreover, based on this point of view, inventory transition which makes the minimum point in stock maximum has been formulated based on the Min-Max strategy. As a result, the solution has been able to be obtained to the order production planning problem with respect to the supplier under a sharp change of received, without assuming the distribution of demand quantity.

Chapter 5 has proposed the model which reconciles reduction of cost and an environmental load. In order to calculate an environmental load, the environmental load estimation system has been constructed. And the optimum order quantity which considered the balance of cost and an environmental load has been calculated using MOPSO. Since the proposed model supports only one product, the proposal of the model corresponding to two or more products is aimed at from now on.

Chapter 6 has proposed the LCA system which can understand the life cycle and environmental impact of a product quantitatively. Shortening of the computation time of environment assessment can be performed by using a proposal system. And reduction of the environmental impact substance discharged from a company can be aimed at.

Future research should use not only process analysis but the input-output analysis, and evaluating an environmental load . Process analysis is used when LCA estimates today. Process analysis models the target product life cycle as an aggregate of a unit process. And the environmental load value of each unit process is investigated, and these environmental load values are totally. Input-output analysis is the calculation method adapting the analytical skills of the economic ripple effect, and calculates using an input-output table. Input-output analysis is used for LCA evaluated only using process analysis until now. As a result, it can calculate not only an environmental load at each process, but it can be taken into consideration whether it is mutually affected among segments of industry. And cost calculation is added to an environmental load estimation system. It aims at enabling it to calculate an optimum order quantity synthetically.

Finally we hope my research result becomes helpful to solve the environmental problem and do further purpose.

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