OPERATIONS AND SUPPLY CHAIN MANAGEMENT
Vol. 14, No. 4, 2021, pp. 496 – 506
ISSN 1979-3561 | EISSN 2759-9363

A Study on Transfer Pricing Considering Fairness and Profitability

Qian Huang
Waseda Research Institute for Science and Engineering,
Waseda University, Japan
E-mail: huangqian@akane.waseda.jp (*Corresponding Author*)

Shunichi Ohmori
Department of Business Design and Management,
Waseda University, Japan
E-mail: ohmori0406@aoni.waseda.jp

ABSTRACT

Transfer pricing is the setting of the price for goods or services sold among related subsidiaries within an organization. This is an important financial and business issue that has been ignored in many studies concerning supply chain network designs. Some studies have considered transfer pricing into production and supply chain planning; however, total profit optimization is single-objective and does not consider the satisfaction of individual subsidiary from a fair perspective. Considering sustainable development as fairness is also extremely important for a long-term strategy for an organization; therefore, this study focuses on balancing the trade-off between fairness and total profit on the design problem of supply chain network using transfer pricing. Meanwhile, a multi-item, multi-subsidiary, and multi-stage problem is solved by the integrated method of mixed-integer linear programming and fuzzy programming proposed by this study. From the experimental results, we verify that the transfer pricing can maximize the total profit of the supply chain network. In addition, the proposed multi-objective optimization model that considers fairness can benefit subsidiaries with minimal satisfaction while acquiring adequate total profit.

Keywords: *supply chain network design, transfer pricing, fairness, mixed-integer linear programming, fuzzy programming*.

1. INTRODUCTION

Along with the globalization of production, an increasing number of new factories are set up away from the mother company. Adapting to local rules and aiming to control the local factory efficiently, factories and sales subsidiaries are incorporated into independent profit centers. Therefore, trade prices among subsidiaries must be decided in the transaction of accruing goods or services. “Transfer price” is the transaction price, whereas “Transfer pricing” means the setting of the prices for goods or services sold among related subsidiaries within an organization. In recent years, the trend of transaction activities not only ranges across a group company but also extends to different group companies in the supply chain. Depending on the determined values of transfer prices, the revenue and cost are quite different among subsidiaries. Moreover, due to the difference in tariff/tax rates, transfer pricing has a significant impact on customs duties and corporate taxes, resulting in varying after-tax profit obtained by each subsidiary. To prevent illegal dumping, subsidiaries can follow the possible range of transfer pricing set by the Organization for Economic Co-operation and Development (OECD) guideline of arm’s length principle. The basic methods are comparable uncontrolled price method, cost-plus method, and resale-price method. Other methods are generated from local laws corresponding to various situations. Although the transfer price cannot be greatly adjusted within the arm’s length principle, when the transaction volume is higher, the effect on the profit of subsidiaries is more pronounced (revenue or cost = transfer price × transaction volume). Particularly, the gaps of tax rates among subsidiaries over different jurisdictions (higher or lower tax rate) can cause transfer pricing to increase the total profits of a whole group company besides the individual profit of related subsidiaries. Therefore, for a tax planner of a global group company, how to decrease the total taxes necessitates contemplation. Meanwhile, for a top decision-maker in the company, setting a reasonable transfer price to fulfill the group company’s requirement and finding a way to relieve the conflict among subsidiaries and the group company are crucial.

Mukhtar and Azhar (2020) developed a value co-creation model for a competitive supply chain. They explained the necessity of well-integrated decision-making through the collaboration of supply chain subsidiaries. Meanwhile, Batwa and Norrman (2020) explored the possibility of applying blockchain technology in supply chain finance to monitor the financial flows and allocate financial resources in the supply chain. How to allocate financial resources appropriately is the key issue to solve, wherein we think that setting preferable transfer prices among subsidiaries is one of the appropriate methods. Some studies have focused on maximizing total profit by setting transfer prices; however, a problem occurs when subsidiaries and the group company are in conflict about the profit. The objective is maximizing the total profit of the group company; thus, some subsidiaries acquire worse benefits allocation to comply with the group company. Consequently, sacrificed subsidiaries receive a bad evaluation of corporate performance because of their little profit. This creates dissatisfaction from the sacrificed ones, and they feel "unfair" among the group company. Therefore, despite the efficient objective in the total profit of a group company, the sustainable objective of fairness among a group company must be considered. How to find a way to balance the total profit and fairness is necessary.

This study focuses on considering the fairness and profitability of a group company using transfer pricing. We propose a decision model to measure the satisfaction of each subsidiary and the entire group company and to decide the status of fairness using maximize the minimum approach, which is hitherto unexplored. Fuzzy programming is used to determine transfer prices and production–distribution volumes, and the mathematical model is proposed in a multi-item, multi-subsidiary, and multi-stage global supply chain.

2. LITERATURE REVIEW

2.1 The Single Objective of Cost Minimization and Profit Maximization

Production–allocation and production–distribution–allocation problems are the basic problems in production and supply chain planning. Many studies have considered minimizing total costs (Cunha and Mutarelli, 2007; Aydinel *et al.*, 2008; Tsiakis and Papageorgiou, 2008), which are composed of manufacturing, distribution, inventory costs, and so on. Production and distribution activities are exhaustively discussed to find an efficient way to reduce total costs. Some studies shifted the viewpoint from minimizing total costs to maximizing total profits (Olhager *et al.*, 2001; Park, 2005; Feng *et al.*, 2008). Profit-center that controls the financial factors of the business is currently preferable to the cost-center. Cost minimization has been improved for many years; the potential profit is not only limited to cost improvement but also to revenue improvement and the balance between cost/revenue improvement. Some studies discussed production decision problems with consideration of sales planning. For example, Olhager *et al.* (2001) provided two perspectives on long-term capacity management for production and sales strategies and argued the significance of simultaneously focusing on production and sales planning problems. Meanwhile, Feng *et al.* (2008) extended the research theory based on Olhager *et al.* (2001) by using constructed mathematical models to describe the production network. They provided both an integrated model and a decoupling model for the production and sales planning problem. The advantage of an integrated model has been demonstrated through numerical experiments.

2.2 Transfer Pricing in Supply Chain Management

Transfer prices seem to be the boundary between the profits of upstream and downstream subsidiaries. Transfer pricing allows a group company to generate a profit (or cost) for each subsidiary separately, making managers aware of the value that goods or services have for other subsidiaries of the group company. The appropriate setting of transfer prices can help coordinate upstream and downstream subsidiaries, which will influence not only the reported profit of each subsidiary but also the allocation of the manufacturer's resources (Heath, 2009). Hammami and Frein (2014) presented different transfer pricing methods, such as the cost-plus, resale-price, and profit-split methods. According to the OECD guidelines, selecting an internal pricing method always aims to identify the most appropriate method for a particular case. No one method is suitable in every possible situation. Moreover, Hammami and Frein (2014) adopted a profit-split method, because transactions within an offshore manufacturer are highly inter-related, and they had difficulty finding comparable products for various specifics in their case study. Further, the cost-plus method is a traditional method widely used by manufacturers, because the manufacturing information for a manufacturer can be easily obtained using this method compared with the resale-price method. Under the cost-plus method, the transfer price of the product is determined by markups which is a gross profit margin based on production activities. In other words, this method is appropriate if reliable information can be obtained about the markups. Miller and Matta (2008) adopted a cost-plus transfer price method in their profit maximization model that simultaneously considers production and distribution planning. They treated markups, ranging between 10% and 40%, as variables. The total profit of the company was found to be different when markups are different between subsidiaries. Therefore, setting a proper transfer price is crucial for a manufacturer to maximize total profit. In addition, Heath (2009) stated that transfer pricing is not just related to the profit allocation among subsidiaries; it is also an effective tool for resource allocation. Hsu and Hu (2020) presented that transfer prices are related to global tax planning; a part of profit can transfer from high tax rate country to low tax rate country using transfer pricing. Integrating global tax planning with supply chain decisions can help maximize the after-tax profit. Kim *et al.* (2018) explained that taxes are big expenses for a global company; decision-makers should also consider tax planning in supply chain planning and design. They analyzed tax planning with different supply chain policies, particularly how to balance the advantage of production cost and tax rate. Other studies have proposed supply chain strategy under various conditions; the policy of transfer prices, detail of tax planning, and types of market channel are exhaustively analyzed in these studies (Wang *et al.*, 2016; Kopel and Löffler, 2020; Niu *et al.*, 2019).

The aforementioned studies have focused on improving efficiency, such as total cost and total profit, with single-objective functions. However, the satisfaction of individual subsidiary from a fair perspective is not considered. The profitability of each subsidiary, especially the sacrificed ones, must also be considered. To solve this problem, firms should consider fairness among a group company simultaneously as sustainable objective, except the efficient objective of maximizing the total profit. This study focuses on optimizing the total profit and the fairness among the group company considering individual satisfaction using a fuzzy programming.

3. PROPOSED MODEL

This section describes the proposed model. In particular, Section 3.1 presents a supply chain network design model that maximizes total profit under fixed transfer price. Section 3.2 describes a total profit maximization model with variable transfer price. Finally, Section 3.3 describes a multi-objective optimization model considering fairness using a fuzzy programming.

3.1 Total Profit Maximization Supply Chain Network Design Model

Let $N = N_S \cup N_I \cup N_C = \{1, \cdots, n\}$ denote a set of nodes. Let $N_S \subseteq N$ be a set of external supplier nodes, $N_C \subseteq N$ be the set of external customer nodes, and $N_I \subseteq N$ be a set of internal nodes. We define an internal node as a set of nodes that can adjust the transfer price. It includes the case where they are a set of firms in the same group or different firms with strong partnerships.

Let $A = \{(i,j) | i \in N, j \in N\}$ be a set of arcs. Let a_{ij} denote a binary constant that takes 1 if $(i,j) \in A$, and 0 otherwise. Let $S = \{s = 1, \cdots, m\}$ denote a set of items, where the item is a generic term for anything processed and transported in the supply chain, such as materials, parts, and products. Let ϕ_{st} denote the number of parts t required to produce item s, and is used to represent the bill of material (BOM) structure. Let d_{is} be the amount of demand for item s at each customer node $i \in N_C$.

Furthermore, let p_{ijs} be the transfer price of item s from node i to node j. We assume p_{ijs} is constant in this section, whereas it is a decision variable in the following and subsequent sections. We also assume that the trade is made on a cost insurance and freight (CIF) basis and that the shipping source bears the cost of transportation. We further assume that node i receiving the item pays an import tax on the purchase price of the item. A corporate tax is imposed on profits for node $i \in N_I$.

Indices and Sets

- $N = \{1, \cdots, n\}$: A set of nodes
- N_C: A set of external customer nodes
- N_I: A set of internal nodes
- N_S: A set of external supplier nodes
- $S = \{s = 1, \cdots, m\}$: A set of items
- $A = \{(i,j) | i \in N, j \in N\}$: A set of arcs

Parameters

- f_{is}: Setup cost of production line of item s in production node i
- v_{is}: Unit variable cost of item s in production node i
- c_{ijs}: Unit transportation cost of item s from node i to node j
- t^I_{ijs}: Tariff rate of item s between node i to node j
- ϕ_{st}: Number of parts t required by item s in the production process
- d_{is}: Demand of item s in sales node i
- q_{is}: Production capacity of item s in production node i
- t^C_i: Corporate tax in node i
- p_{ijs}: Transfer prices of item s from node i to node j

Decision Variables

- x_{ijs}: Transportation volume of item s from node i to node j
- y_{is}: 1 if production line of item s is set up in production node i
- z_i: Profit of node i after tax
- z_0: Total profit after tax
- R_i: Sales of node i
- F_i: Fixed cost of production of node i
- V_i: Variable cost of production of node i
- C_i: Transportation cost of node i
- B_i: Procurement cost of node i

$$\text{max.} \quad z_0 \tag{1a}$$
$$\text{s.t.} \quad z_0 = \textstyle\sum_{i \in N_I} z_i \tag{1b}$$
$$z_i = (1 - t^c_i) \times (R_i - F_i - V_i - C_i - B_i) \quad \forall i \in N_I \tag{1c}$$
$$R_i = \textstyle\sum_{j \in N} \sum_{s \in S} p_{ijs} x_{ijs} \quad \forall i \in N_I \tag{1d}$$
$$F_i = \textstyle\sum_{s \in S} f_{is} y_{is} \quad \forall i \in N_I \tag{1e}$$
$$V_i = \textstyle\sum_{j \in N} \sum_{s \in S} v_{is} x_{ijs} \quad \forall i \in N_I \tag{1f}$$
$$C_i = \textstyle\sum_{j \in N} \sum_{s \in S} c_{ijs} x_{ijs} \quad \forall i \in N_I \tag{1g}$$
$$B_i = \textstyle\sum_{l \in N} \sum_{s \in S} (1 + t^I_{lis}) p_{lis} x_{lis} \quad \forall i \in N_I \tag{1h}$$
$$\textstyle\sum_{i \in N} a_{ij} x_{ijs} - \phi_{st} \sum_{l \in N} a_{li} x_{lit} = 0, \forall i \in N_I, \forall s \in S, \forall t \in S \tag{1i}$$
$$\textstyle\sum_{i \in N} a_{ij} x_{ijs} \geq d_{js}, \quad \forall j \in N_C, \forall s \in S \tag{1j}$$
$$\textstyle\sum_{j \in N} x_{ijs} \leq q_{is} y_{is}, \quad \forall i \in N \tag{1k}$$
$$x_{ijs} \geq 0, \quad \forall (i,j) \in A, \forall s \in S \tag{1l}$$
$$y_{is} \in \{0,1\}, \quad \forall i \in N, \forall s \in S \tag{1m}$$

The objective function (1a) indicates that the overall after-tax profit is maximized. Meanwhile, constraint equation (1b) shows that the sum of the after-tax profit of each internal node is the overall after-tax profit, whereas constraint equation (1c) shows the calculation of the after-tax profit of each internal node. Constraint equations (1d), (1e), (1f), (1g), and (1h) show the sales, fixed cost of production, variable cost of production, transportation cost, procurement cost, and profit after tax for each internal node, respectively. Further, constraint equation (1i) shows the conservation equation for the flow of the item, whereas constraint equation (1j) indicates that the demand is satisfied. Constraint equation (1k) indicates that the capacity limit for each node is satisfied, and constraint equation (1l) shows that

x_{ijs} takes a non-negative value. Finally, constraint equation (1m) shows the binary condition of y_{is}. Problem (1) is a mixed-integer linear programming (MILP) problem; therefore, it can be solved efficiently using an off-the-shelf solver.

3.2 Design Model of the Supply Chain Network's Total Profit Maximization with Transfer Price Decisions

The model in the previous section assumed transfer prices to be constant. This section describes the total profit maximization model with the transfer price as the decision variable. If the transfer price is used as the decision variable, a non-linear term, $p_{ijs}x_{ijs}$, will be included in the definition of sales R_i in equation (1d) and the purchase cost in equation (1h). Thus, we linearize it using the following procedure.

First, we discretize the set of transfer price. Let $P_{ijs} = \{p_{ijsk} = p_{ijs1}, \cdots, p_{ijsK_{ijs}}\}$ denote a set of candidate transfer prices for item s from node i to node j, and $\mathrm{K_{ijs}} = \{k = 1, \cdots, K_{ijs}\}$ denote the subscript set of price options. Further, let π_{ijsk} be a binary variable that takes 1 when taking a price option k for item s from base i to base j, and 0 otherwise. Note that our assumption is that the purchase price from external suppliers and the selling price to external customers cannot be changed; therefore, the number of price options is set to 1. Using these definitions, we can define the determination of the transfer price in equations (2) and (3).

$$p_{ijs} = \sum_{k\in \mathrm{K}_{ijs}} \pi_{ijsk} p_{ijsk}, \quad \forall i, j, s \tag{2}$$

$$\sum_{k\in K_{ijs}} \pi_{ijsk} = 1, \quad \forall i, j, s \tag{3}$$

Also, the term $p_{ijs}x_{ijs}$ can be redefined as equation (4).

$$p_{ijs}x_{ijs} = \sum_{k\in \mathrm{K}_{ijs}} p_{ijsk}\pi_{ijsk}x_{ijs}, \forall i, j, s \tag{4}$$

We define a constant that indicates the upper bound $X_{ijs} = \min(d_{js}, q_{is})$ of x_{ijs}. We also define a variable r_{ijsk} to substitute $p_{ijs}x_{ijs}$ using the following equations:

$$r_{ijsk} \le \pi_{ijsk} X_{ijs} \tag{5}$$

$$r_{ijsk} \le x_{ijs} \tag{6}$$

$$r_{ijsk} \ge x_{ijs} - X_{ijs}(1 - \pi_{ijsk}) \tag{7}$$

$$r_{ijsk} \ge 0 \tag{8}$$

Using the above expressions, we can formulate the total profit maximization supply chain network design model with transfer price decisions as equation (9).

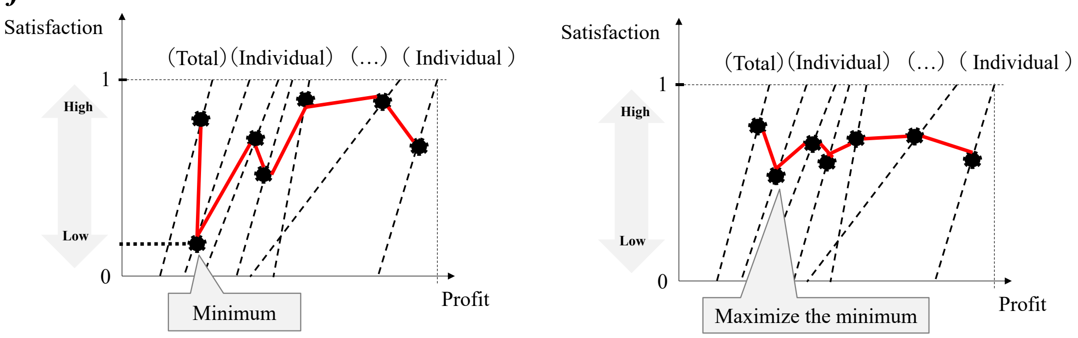
$$
\begin{array}{llll}
\max. & z_0 & & (9a)\\
\text{s.t.} & (1b)\text{-}(1\,m) & & (9b)\text{-}(9m)\\
 & \sum_{k\in K_{ijs}} \pi_{ijsk} = 1, & \forall (i,j) \in A, \forall s \in S & (9n)\\
 & r_{ijsk} \le \pi_{ijsk} X_{ijs}, & \forall (i,j) \in A, \forall s \in S, \forall k \in \mathrm{K_{ijs}} & (9o)\\
 & r_{ijsk} \le x_{ijs}, & \forall (i,j) \in A, \forall s \in S, \forall k \in \mathrm{K_{ijs}} & (9p)\\
 & r_{ijsk} \ge x_{ijs} - X_{ijs}(1 - \pi_{ijsk}), & \forall (i,j) \in A, \forall s \in S, \forall k \in \mathrm{K_{ijs}} & (9q)\\
 & r_{ijsk} \ge 0, & \forall (i,j) \in A, \forall s \in S, \forall k \in \mathrm{K_{ijs}} & (9r)\\
 & \pi_{ijsk} \in \{0,1\} & \forall (i,j) \in A, \forall s \in S, \forall k \in \mathrm{K_{ijs}} & (9s)
\end{array}
$$

The constraint equation (9n) indicates that one price option is selected. Meanwhile, constraint expressions (9o), (9p), and (9q) show the same linearization as in equations (5), (6), and (7). Moreover, constraint equation (9r) shows the non-negativity of r_{ijsk}, whereas constraint equation (9s) shows the binary nature of π_{ijsk}. Problem (9) is a MILP; hence, it can be solved efficiently using off-the-shelf solvers.

3.3 Design Model of the Supply Chain Network's Fair Profit Maximization with Transfer Price Decisions

Problems in section 3.1 and 3.2 are oriented toward maximizing total profits. However, a concern that some subsidiaries will significantly sacrifice their profit arises. This study proposes a multi-objective optimization model for maximizing the total profit and the fairness status among the group company.

In general, "fairness" means the quality of treating people equally or in a way that is right or reasonable (Cambridge Dictionary). In this study, we define "fairness" as the status of maximizing the minimum satisfaction among a group company, as shown in **Figure 1**.



(a) unfair (b) fair

Figure 1 Fairness status in this study

The multi-objective profit maximization model can be formulated as equation (10). Let $|N_I| = n'$, and let $N_I = \{i = 1, \cdots, n'\}$ for the subscript set starting from 1.

$$\text{max.} \quad z_0, z_1, \cdots, z_{n'} \qquad (10a)$$
$$\text{s.t.} \quad (9b)\text{-}(9s) \qquad (10b)\text{-}(10s)$$

The objective function (10a) shows the maximization of total profit and individual profit among the group company. Problem (10) is difficult to solve as it is a multi-objective optimization model. Therefore, we apply fuzzy programming to obtain the solution.

Fuzzy programming is a multi-objective optimization method proposed by Zimmermann (1978). It is a linear programming problem that includes fuzzy goal and fuzzy constraints. Problem (10) can be interpreted to have a fuzzy goal, which is to make the profit of each internal node approximately more than a certain value.

$$\begin{aligned} \text{max.} \quad & z_0 \gtrapprox Z_0 & (11a) \\ & z_1 \gtrapprox Z_1 & \\ & \vdots & \\ & z_{n'} \gtrapprox Z_{n'} & \\ \text{s.t.} \quad & (9b)\text{-}(9s) & (11b)\text{-}(11s) \end{aligned}$$

Here, $\lessapprox$ are the fuzzy constraints that denote "approximately less than." Such a fuzzy goal can be quantified by specifying the corresponding membership function. Zimmermann (1978) defined the membership function $\mu_{zi}(x)$, which indicates the degree of achievement of each objective function $z_i(x)$, as follows:

$$\mu_{z_i} = \begin{cases} 1 \ldots\ldots\ldots & z_i \geq z_i^{\min} \\ \dfrac{z_i - z_i^{\min}}{z_i^{\max} - z_i^{\min}} \ldots\ldots\ldots\ldots & z_i^{\min} \leq z_i \leq z_i^{\max} \\ 0 \ldots\ldots\ldots & z_i \leq z_i^{\min} \end{cases}$$

$z_i^{\max}$ and $z_i^{\min}$ are the upper and lower limits of the objective function value z_i, respectively. This is illustrated in **Figure 2**, where μ_{z_i} can be interpreted as the degree of truth of satisfaction with the earned profit of z_i. If μ_{z_i} falls below the lower limit of z_i^{min}, it can be interpreted as unsatisfied, whereas satisfied if it exceeds the upper limit of $z_i^{\max}$.

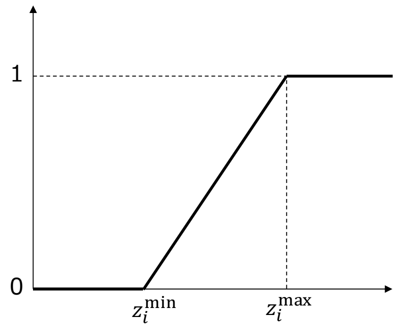


Figure 2 Membership function of zi

Zimmermann (1978) proposed that the upper and lower bounds of each objective function, $z_i^{\max}$ and $z_i^{\min}$, should be set from payoff matrices where each row vector denotes the solution of the problem of maximizing z_i while ignoring the other objective functions. Also, Bellman and Zadeh's decision (1970) is to maximize the minimum membership function.

$$\text{max.} \quad \min_{i \in N} \mu_{z_i} \qquad (12a)$$
$$\text{s.t.} \quad (9b)\text{-}(9s) \qquad (12b)\text{-}(12s)$$

can be transformed into the following linear programming:

$$\text{max.} \quad \lambda \qquad (13a)$$
$$\text{s.t.} \quad (9b)\text{-}(9s) \qquad (13b)\text{-}(13s)$$
$$\lambda\left(z_i^{\max} - z_i^{min}\right) + z_i^{\min} \leq z_i \qquad (13t)$$

4. CASE EXAMPLE

4.1 The Description of Supply Chain Network and Item

The heavy industry motivates our case study. The target company is a global company that has production and sales subsidiaries worldwide. The entire supply chain has two layers and four stages. The suppliers are in the top stream of the supply chain and supply raw materials or sub-parts to the parts factories. The parts factories are further divided into key parts factories and general parts factories. Key parts factories are established in developed countries such as the United States, Germany, and Japan that have technological capabilities, whereas general parts factories are established in developing countries such as Thailand and China. The assembly factories assemble parts from the parts factories using transfer prices and transform them to the final product. Up to this point, the production activity is completed, and the sales activity begins. Regional sales distributors procure final products from assembly factories using transfer prices and sell that to downstream customers. Finally, customers bought these final products from sales distributors at market prices (**Figure 3**).

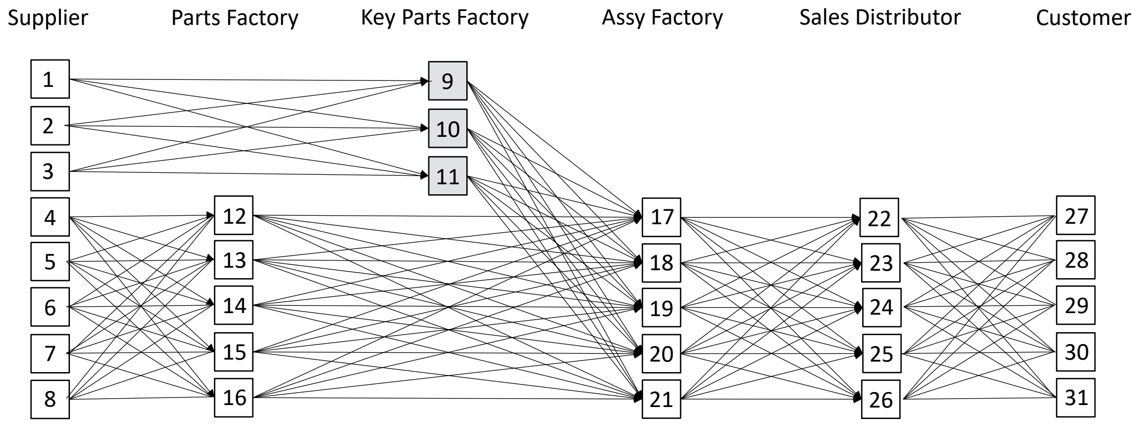


Figure 3 Global supply chain network

This study uses the concept of parts-group to simplify a BOM, because the final product consists of quite a large number of sub-parts and parts. **Figure 3** is an example: if the final product is denoted by 1, it consists of a key parts-group 2 and a general parts-group 3. The key parts-group 2 further consists of a sub-parts-group 4, and the general parts-group 3 consists of a sub-parts-group 5. The relationship between the BOM and the subsidiary is shown using the item-subsidiary number. For example, in **Figure 4**, supplier 1,2,3 denotes that suppliers 1, 2, and 3 can supply sub-parts-group 4.

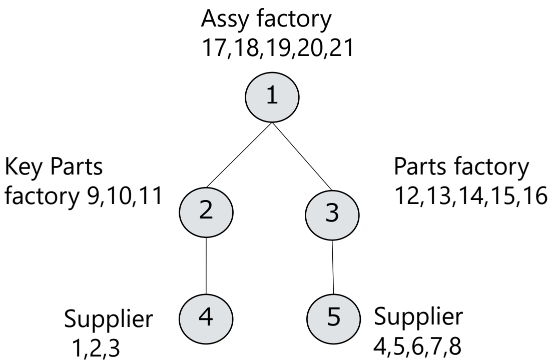


Figure 4 Bill of materials (BOM) and relationship with subsidiaries

4.2 *Input data*

The following are the data of the target nodes, arcs, and items:

- Number of nodes: 31
- Final product: 1
- Parts-group: 2
- Sub-parts-group: 2
- Set up cost of the production, unit variable cost of production: **Tables 1** and **2**
- Unit transportation cost between subsidiaries: **Table 3**
- Tariff rates between subsidiaries: **Table 4**
- Demand for end customers: **Table 5**
- Production capacity: **Table 6**
- Unit procurement price of parts: **Table 7**
- Unit sales price in end customer market: **Table 8**
- Corporate tax rate: **Table 9**

In addition, the candidate sets of transfer prices are prepared in three levels: low, middle, and high. Moreover, the profit margins are calculated by the corresponding unit production cost on 10%, 20%, 30%, respectively.

Table 1 Set up cost of production (millions of Yen)

Node i	Item k	Cost	Node i	Item k	Cost	Node i	Item k	Cost
9	2	47130.0	**14**	3	39348.0	**19**	1	40479.0
10	2	46660.0	**15**	3	39790.0	**20**	1	40733.0
11	2	43950.0	**16**	3	40046.0	**21**	1	40075.0
12	3	39178.0	**17**	1	40990.0			
13	3	40413.0	**18**	1	39101.0			

Table 2 Unit variable cost of production (Millions of yen)

Node i	Item k	Cost	Node i	Item k	Cost	Node i	Item k	Cost
9	2	5.0	**14**	3	3.0	**19**	1	3.0
10	2	5.0	**15**	3	3.0	**20**	1	3.0
11	2	5.0	**16**	3	4.0	**21**	1	4.0
12	3	4.0	**17**	1	4.0			
13	3	4.0	**18**	1	4.0			

Table 3 Unit transportation costs (Millions of yen)

Node i / Node j	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
1	1.0	2.0	1.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	2.0	1.0	2.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3	2.0	2.0	1.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4	-	-	-	0.4	1.6	2.1	1.3	1.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5	-	-	-	1.6	0.4	1.4	1.1	1.9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6	-	-	-	1.9	1.4	0.2	0.9	0.9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7	-	-	-	1.1	1.1	0.9	0.0	0.7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8	-	-	-	1.1	1.9	0.9	0.9	0.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9	-	-	-	-	-	-	-	-	0.3	1.5	2.0	1.2	1.2	-	-	-	-	-	-	-	-	-	-
10	-	-	-	-	-	-	-	-	1.5	0.3	1.5	1.0	1.8	-	-	-	-	-	-	-	-	-	-
11	-	-	-	-	-	-	-	-	1.2	1.8	1.0	0.8	0.3	-	-	-	-	-	-	-	-	-	-
12	-	-	-	-	-	-	-	-	0.3	1.5	2.0	1.2	1.2	-	-	-	-	-	-	-	-	-	-
13	-	-	-	-	-	-	-	-	1.5	0.3	1.5	1.0	1.8	-	-	-	-	-	-	-	-	-	-
14	-	-	-	-	-	-	-	-	2.0	1.5	0.1	1.0	1.0	-	-	-	-	-	-	-	-	-	-
15	-	-	-	-	-	-	-	-	1.2	1.0	1.0	0.1	0.8	-	-	-	-	-	-	-	-	-	-
16	-	-	-	-	-	-	-	-	1.2	1.8	1.0	0.8	0.3	-	-	-	-	-	-	-	-	-	-
17	-	-	-	-	-	-	-	-	-	-	-	-	-	0.2	1.4	1.9	1.1	1.1	-	-	-	-	-
18	-	-	-	-	-	-	-	-	-	-	-	-	-	1.4	0.2	1.4	0.9	1.7	-	-	-	-	-
19	-	-	-	-	-	-	-	-	-	-	-	-	-	1.9	1.4	0.0	0.9	1.1	-	-	-	-	-
20	-	-	-	-	-	-	-	-	-	-	-	-	-	1.1	1.1	0.9	0.2	0.9	-	-	-	-	-
21	-	-	-	-	-	-	-	-	-	-	-	-	-	1.3	1.9	0.9	0.7	0.4	-	-	-	-	-
22	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.3	1.5	2.0	1.2	1.2
23	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.5	0.3	1.5	1.0	1.8
24	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.0	1.5	0.1	1.0	1.0
25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.2	1.0	1.0	0.1	0.8
26	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.2	1.8	1.0	0.8	0.3

Table 4 Tariff rates

Node i / Node j	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
1	0.0	0.0	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	0.0	0.0	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3	0.0	0.0	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4	-	-	-	0.0	0.0	0.2	0.37	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5	-	-	-	0.0	0.0	0.2	0.17	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6	-	-	-	0.0	0.0	0.0	0.17	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7	-	-	-	0.0	0.0	0.2	0.0	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8	-	-	-	0.0	0.0	0.2	0.17	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9	-	-	-	-	-	-	-	-	0	0	0.2	0.37	0	-	-	-	-	-	-	-	-	-	-
10	-	-	-	-	-	-	-	-	0	0	0.2	0.17	0	-	-	-	-	-	-	-	-	-	-
11	-	-	-	-	-	-	-	-	0	0	0.2	0.17	0	-	-	-	-	-	-	-	-	-	-
12	-	-	-	-	-	-	-	-	0	0	0.2	0.37	0	-	-	-	-	-	-	-	-	-	-
13	-	-	-	-	-	-	-	-	0	0	0.2	0.17	0	-	-	-	-	-	-	-	-	-	-
14	-	-	-	-	-	-	-	-	0	0	0	0.17	0	-	-	-	-	-	-	-	-	-	-
15	-	-	-	-	-	-	-	-	0	0	0.2	0	0	-	-	-	-	-	-	-	-	-	-
16	-	-	-	-	-	-	-	-	0	0	0.2	0.17	0	-	-	-	-	-	-	-	-	-	-
17	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0	0.0	0.2	0.37	0.0	-	-	-	-	-
18	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0	0.0	0.2	0.17	0.0	-	-	-	-	-
19	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0	0.0	0.0	0.17	0.0	-	-	-	-	-
20	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0	0.0	0.2	0.0	0.0	-	-	-	-	-
21	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0	0.0	0.2	0.17	0.0	-	-	-	-	-
22	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0	0.0	0.2	0.37	0.0
23	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0	0.0	0.2	0.17	0.0
24	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0	0.0	0.0	0.17	0.0
25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0	0.0	0.2	0.0	0.0
26	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0	0.0	0.2	0.17	0.0

Table 5 The demand of market (piece)

Node i	Demand
27	10000
28	7143
29	17143
30	10000
31	4286

Table 6 Production capacity (piece)

Node i	Item 1	Item 2	Item 3	Node i	Item 1	Item 2	Item 3
9	-	21748	-	16	-	-	3686
10	-	21748	-	17	9200	-	-
11	-	20248	-	18	6343	-	-
12	-	-	9400	19	18843	-	-
13	-	-	6543	20	11700	-	-
14	-	-	19043	21	3486	-	-
15	-	-	11900				

Table 7 Unit procurement price (Millions of yen)

Node i /Node j	9	10	11	12	13	14	15	16
1	12.0	13.0	14.0	-	-	-	-	-
2	13.0	13.0	16.0	-	-	-	-	-
3	14.0	16.0	14.0	-	-	-	-	-
4	-	-	-	5.0	6.5	7.0	7.2	7.2
5	-	-	-	6.5	6.0	7.5	7.0	7.8
6	-	-	-	7.0	7.5	3.0	4.0	4.0
7	-	-	-	7.2	7.0	4.0	3.0	3.8
8	-	-	-	7.2	7.8	4.0	3.8	6.0

Table 8 Unit sales price (Millions of yen)

Node i/Node j	27	28	29	30	31
22	136.73	138.46	139.18	138.02	138.02
23	138.77	137.04	138.77	138.05	139.20
24	129.75	129.03	127.02	128.31	128.31
25	127.22	126.93	126.93	125.64	126.64
26	137.82	138.68	137.53	137.24	136.52

Table 9 Corporate tax rates

Node i	rate	Node i	rate	Node i	rate
1	0.21	12	0.21	22	0.21
2	0.28	13	0.28	23	0.28
3	0.23	14	0.20	24	0.20
4	0.21	15	0.25	25	0.25
5	0.28	16	0.23	26	0.23
6	0.20	17	0.21	27	0.21
7	0.25	18	0.28	28	0.28
8	0.23	19	0.20	29	0.20
9	0.21	20	0.25	30	0.25
10	0.28	21	0.23	31	0.23
11	0.23				

5. NUMERICAL EXPERIMENTS

5.1 The Impact of Fixed Transfer Prices on Each Subsidiary

To check the impact of each subsidiary under fixed transfer prices, we used the proposed supply chain network design model with fixed transfer prices. The results are shown in **Table 10** (fixed transfer price). When the transfer price is fixed (middle level), the total profit of the network is 8,186,190 millions of yen, and the profit of each subsidiary is 0 to 5,300,850 millions of yen. Results reveal that the profit of subsidiaries 20, 23, 24, and 25 is 0, which are the lowest ones. In contrast, the profit of subsidiary 22 is 5,300,850 millions of yen, which is the highest one.

Subsidiary 20 is an assembly factory, and thus, its tariff rate is the highest in assembly factories; therefore, the procurement cost from the parts factory is high. Although the production capacity is substantial in other assembly factories, using subsidiary 20 may not be necessary.

Meanwhile, subsidiaries 23, 24, 25, and 22 are the same type as regional sales distributors; however, the gap of profit is sharply large. The reason is that the average selling prices of subsidiary 22 are higher than other sales distributors, and the procurement prices related to transfer prices can be significantly lower. Therefore, if the sales capacity is substantial in each sales distributor, especially in subsidiary 22, the final product will be more preferable to sell via subsidiary 22 than via subsidiaries 23, 24, and 25. Consequently, the profit of subsidiary 22 is considerable; conversely, the profit of subsidiaries 23, 24, and 25 may be terrible.

5.2 Effectiveness of Transfer Pricing

Transfer pricing as a decision variable is considered with the supply chain design model in this experiment to verify when the transfer prices are fluctuating and whether the total profit is increasing. Results in **Table 10** (variable transfer price) show that with the decision of transfer prices, the total profit of the supply chain network increased to 327,160 millions of yen compared to when the transfer price is fixed (middle level). This increase can be explained by the following: (1) the total profit is different due to the different transfer prices, and (2) the total profit can be increased if the transfer price is considered as a decision variable simultaneously with the supply chain network design. In other words, the effectiveness of the profit maximization model with transfer pricing is demonstrated.

For each subsidiary, the increased profit of the whole network is contributed by 13/14 subsidiaries. In other words, approximately 93% of the subsidiaries contributed to the increase in profits of 327,160 millions of yen. Therefore, the ideal transactions occur among the subsidiaries of upstream and downstream supply chain in a win-win situation.

Table 10 Individual and total profit with transfer pricing (Millions of yen)

Node i	TP fixed	TP variable	Fuzzy
9	260194	294555	104905
10	55192	64662	244209
11	259302	290484	232398
12	76005	84988	78591
13	51739	61161	30573
14	100539	115774	112308
15	50441	58706	68392
16	28235	35047	22559
17	560980	622599	323980
18	375698	415814	62536
19	811153	887117	766383
20	0	0	454327
21	255750	281488	240307
22	5300850	5300850	1088940
23	0	0	994984
24	0	0	972358
25	0	0	893126
26	106	106	1059110
Total	8186190	8513350	7749980

5.3 Effectiveness of the Multi-Objective Optimization Model Considering Fairness

An experiment is conducted using fuzzy programming to verify whether fair network design can be performed, including the satisfaction of each subsidiary, rather than the single-objective of total profit. Results in **Table 11** reveal that only 14/18 subsidiaries are originally profitable in the MILP model; however, all the 18 subsidiaries are profitable in the fuzzy model. In the MILP model, the gap between the maximum profit subsidiary and the minimum is 5,300,850 millions of yen, and the difference between the maximum satisfaction level and the minimum is 1. However, in the fuzzy model, the gap becomes smaller to $1088940 - 22559 = 1066382$, and the difference of satisfaction level is 0.863–0.205 = 0.658, which can be seen from the membership function in **Table 11**. These results verify the effectiveness of the multi-objective optimization model considering fairness using fuzzy programming.

Each subsidiary acquires its minimum satisfaction with maximum profit under fairness. There is no extreme sacrifice in profit, but the total profit will be sacrificed a little. In the MILP model, the membership function of the whole supply chain is 1, and the total profit is 8,513,300 millions of yen. Meanwhile, in the fuzzy model, the values are 7,749,980 and 0.55, respectively.

Table 11 Degree of membership function by fuzzy programming

Node i	TP fixed	TP variable	Fuzzy
9	0.86	1.00	0.21
10	0.01	0.05	0.81
11	0.86	0.98	0.76
12	0.75	0.95	0.81
13	0.78	1.00	0.28
14	0.55	0.75	0.70
15	0.44	0.61	0.80
16	0.83	1.00	0.70
17	0.90	1.00	0.54
18	0.91	1.00	0.21
19	0.77	0.88	0.71
20	0.05	0.05	0.86
21	0.91	0.99	0.86
22	1.00	1.00	0.21
23	0.00	0.00	0.21
24	0.00	0.00	0.21
25	0.00	0.00	0.21
26	0.00	0.00	0.21
Total	0.81	1.00	0.55

6. CONCLUSION

This study focused on balancing the trade-off between fairness and total profit of a global group company by transfer pricing using fuzzy programming, which has not been considered in previous studies. We proposed a multi-item, multi-subsidiary, and multi-stage model, and we solved the problem using MILP and fuzzy programming. From the experimental results, we were able to verify the considerable impact of the transfer price on the profit-shifting among subsidiaries of the supply chain. We also determined that the total profit can be maximized by transfer pricing. In addition, the proposed multi-objective optimization model that considers fairness can increase the profit of the subsidiary with minimum satisfaction, resulting in a status of fairness among a group company and pursuing the total profit.

Based on experimental results, we proposed the following suggestions:

Implication (1). When designing a supply chain network, determining the optimal production volume and distribution volume with transfer pricing, which is an important financial factor, is efficient. By comparing the pros and cons, firms can avoid less efficient subsidiaries at the planning stage. However, suppose the decision-makers want to capture the potential market by supporting the less efficient ones. In that case, the transaction price between high or low tax rate area is considered to increase or decrease, which can allocate a part of profit from efficient subsidiaries to inefficient ones.

Implication (2). Transfer pricing in a single-objective optimization model has a significant impact on the total profit. The total profit is maximized and appears great from outside of a group company. However, it cannot be ignored that some subsidiaries are violently sacrificing profits to comply the total. In addition to the objective of total profit, fairness, which is different from efficient objective, should also be considered. If these sustainable indicators are not considered, a global company may face difficulty for its long-term development.

Implication (3). The total profit and individual profit must be balanced among subsidiaries; moreover, fairness consideration with profitability is essential. However, significantly sacrificing the overall benefits because of fairness is not recommended. Sustainable objective as fairness should be valued to support the efficient objective of total profit, so that companies can have a better economic cycle to support fairness. Suppose total profit declines significantly with fairness considering. In that case, the decision-makers should check whether the production resource of the subsidiary or the business environment is deteriorating. Moreover, the supply chain network with candidate production and sales subsidiaries should be reconsidered.

In future studies, an analysis of the weight between fairness and profitability should be considered. Moreover, a proposal for profit distribution between different groups with intangible assets seems interesting. Finally, global background such as rules of origin, exchange rates, and repatriation tax can be added to expand the model.

ACKNOWLEDGEMENT

This work was supported by JSPS KAKENHI Grant Number JP20K14987.

REFERENCES

Aydinel, M., Sowlati, T., Cerda, X., Cope, E., and Gerschman, M. (2008). Optimization of production allocation and transportation of customer orders for a leading forest products company. *Mathematical and Computer Modelling*, 48, 1158 – 1169.

Bellman, R. E., and Zadeh, L. A. (1970). Decision-making in a fuzzy environment. *Management science,* 17(4), B-141.

Batwa, A., and Norrman, A. (2020). A framework for exploring blockchain technology in supply chain management. *Operations and Supply Chain Management: An International Journal*, *13*(3), 294 – 306.

Cambridge Dictionary. The definition of fairness. *Cambridge Advanced Learner's Dictionary & Thesaurus.* https://dictionary.cambridge.org/dictionary/english/fairness.

Cunha, C. B., and Mutarelli, F. (2007). A spreadsheet-based optimization model for the integrated problem of producing and distributing a major weekly newsmagazine. *European Journal of Operational Research*, 176, 925 – 940. [3] X. Xu, From cloud computing to cloud manufacturing. *Robotics and computer-integrated manufacturing*, 28 (2012) 75 – 86.

Feng, Y., D'Amours, S., and Beauregard, R. (2008). The value of sales and operations planning in oriented strand board industry with make-to-order manufacturing system: Cross functional integration under deterministic demand and spot market recourse. *International Journal of Production Economics*, 115, 189 – 209.

Hammami, R., and Frein, Y. (2014). Redesign of global supply chains with integration of transfer pricing: Mathematical modeling and managerial insights. *International Journal of Production Economics*, 158, 267 – 277.

Heath, H., and Huddart, S. Slotta. (2009). Transfer Pricing. *International Strategy: WBA*, 434.

Hsu, V., and Hu, Q. (2020). Global sourcing decisions for a multinational firm with foreign tax credit planning. *IISE Transactions*, 52(6), 688 – 702.

Kim, B., Park, K. S., Jung, S. Y., and Park, S. H. (2018). Offshoring and outsourcing in a global supply chain: Impact of the arm's length regulation on transfer pricing. *European Journal of Operational Research*, 266(1), 88 – 98.

Kopel, M., and Löffler, C. (2020). Tax Differences and Global Supply Chain Architecture. *Available at SSRN 3607721*.

Miller, T., and Matta, R. (2008). A global supply chain profit maximization and transfer pricing model. *Journal of Business Logistics*, 29, 175 – 199.

Mukhtar, U., and Azhar, T. (2020). Inter-functional coordination to co-create value within integrated value chains for competitive supply chain. *Operations and Supply Chain Management: An International Journal*, *13*(1), 11 – 22.

Niu, B., Liu, Y., Liu, F., and Lee, C. K. (2019). Transfer pricing and channel structure of a multinational firm under overseas retail disruption risk. *International Journal of Production Research 57*(9), 2901 – 2925.

Olhager, J., Rudberg, M., and Wikner, J. (2001). Long-term capacity management: Linking the perspectives from manufacturing strategy and sales and operations planning. *International Journal of Production Economics*, 69, 215 – 225.

Park, Y. B. (2005). An integrated approach for production and distribution planning in supply chain management. *International Journal of Production Research*, 43, 1205 − 1224.

Tsiakis, P., and Papageorgiou, L. G. (2008). Optimal production allocation and distribution supply chain networks. *International Journal of Production Economics*, 111, 468 – 483.

Wang, Z., Gao, W., and Mukhopadhyay, S. K. (2016). Impact of taxation on international transfer pricing and offshoring decisions. *Annals of Operations Research*, 240(2), 683 – 707.

Zimmermann, H. J. (1978). Fuzzy programming and linear programming with several objective functions. *Fuzzy Sets and Systems*, 1(1), 45-55.

Qian Huang is a researcher at Waseda Research Institute for Science and Engineering, Waseda University in Japan. Her research interests include design and planning of global supply chain, optimization of production and logistics systems.

Shunichi Ohmori (PhD) is an associate professor in the department of Industrial & System Engineering, Waseda University in Japan, and a researcher at Institute of Global Production & Logistics at Waseda University, and a researcher at Data Science Institute at Waseda University. He received the master and Ph.D degree in engineering at Waseda University. His research interest lies in operations research and supply chain management.