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Designing of a Global Logistics System for the ICGCPS under Considering Overseas Markets

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Abstract. This paper proposes a way of designing of a global logistics system for "the international cooperative global complementary production system" (ICGCPS) constructed in ASEAN region. ICGCPS is a global production system with several production bases located in a number of countries. In order to assemble the final products and sell them in the domestic market, each production base produces only special kinds of components and parts with the total demand required all the participating countries, and supplies them to the other production bases each other. In the ICGCPS, there are a number of important decision-making problems such as identifying which countries are suitable to produce specified components and parts, and deciding how to transport components and parts between the production bases. In the initial period of this system, each production base focused on its domestic market so that the final products it produced were sold only in the country where the base was located. Recently, some production bases have expanded sales to overseas markets. Taking this fact into account, we propose a production and transportation planning model in this paper that takes into account the export quantity of the final products, formulating it into a mathematical programming problem. Using this, we propose a way for managing the supply chain processes of the ICGCPS in order to improve performance measurements such as the total lead-time, the inventory quantity at the depot and the average rate of loading. A numerical example is presented to clarify the procedure proposed in this paper.

Keywords: Global Complementary Production System, Transportation Route, Transportation Scheduling

1. INTRODUCTION

The International Cooperative Global Complementary Production System (ICGCPS) is a global production system with several production bases located in a number of countries. Each production base produces only special kinds of components and parts with the total demand required for all the participating countries, and supplies them to the other production bases each other. Hence, ICGCPS is a kind of supply chain network whose flows of materials are bi-directional. Regarding the ICGCPS, Katayama *et al*. (2000) proposed some mathematical models for designing an international supply network system in the form of a mathematical programming problem. Hiraki (1996) and Hiraki *et al.* (1999) proposed ordering models based on the concept of a pull type ordering system. They created mathematical models in order to analyze the variations of ordering, withdrawal and inventory quantities at each process and stock point. Su *et al.* (2000) analyzed a way of trans-porting components and parts between the participating countries under considering transshipment and mixed loading in the case of the transportation model that did not involve a depot. Hiraki *et al.* (2002, 2004) and Hiraki (2005) developed the basic

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concept of formulating a transportation model involving a depot. Based on these research studies, this paper proposes a model for designing a production and transporttation planning system in the ICGCPS which takes into account the export quantity of the final products to overseas markets by the following way. (1) We propose a way of determining the adequate transportation routes and quantity by evaluating two kinds of objective functions: (a) the total transportation lead-time, and (b) the maximum flow of the components and parts. (2) Calculating the transportation interval and average transportation quantity, we determine the initial inventory quantity required. (3) A numerical example is presented to illustrate the procedure mentioned above.

2. CAR INDUSTRIES IN THE ASEAN 4

After ASEAN six countries established the Brand-to-Brand Complementation (BBC) scheme in 1988, they agreed to establish the ASEAN Free Trade Area (AFTA) and signed an agreement on the Common Effective Preferential Tariff (CEPT) scheme for AFTA in 1992. In 1996, the countries of ASEAN signed the ASEAN Industrial Cooperation (AICO) scheme to accelerate the AFTA agreement. The Japanese car industries started to utilize economies of scale through mass production in different countries and by exchanging components and parts under the BBC and AICO schemes. We call the global production system that produces the final products through the exchange of components and parts the International Cooperative Global Complementary Production System (ICGCPS). Production and sales volume of cars in ASEAN 4 (Indonesia, Malaysia, Philippines and Thailand) increased smoothly until the start of the Asian currency crisis in July, 1997. In 1998, production and sales units in the ASEAN 4 decreased to only 30% of the 1997 figure. In order to overcome this economic depression, the car industries made an effort to export their products. The production level for cars recovered to the pre-crisis level in 2002 and the sales level recovered in 2004. Figure 1 and Figure 2 show the time series of production and sales quantities for cars in the ASEAN 4. Thailand plays an important role for the car industries in the ASEAN region and has often been referred to as the

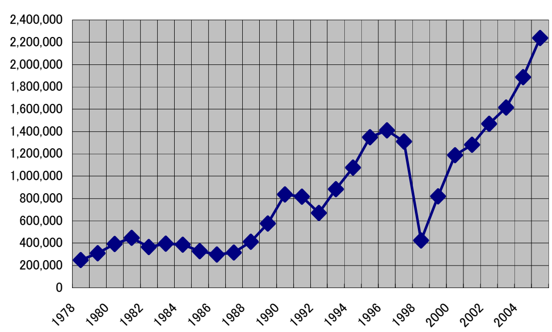

Figure 1. Production quantity of cars in the ASEAN 4.

"Detroit of Asia" in recent years. Figure 3 and Figure 4 show the time series of production and export quantities of cars in Thailand. Figure 4 clearly shows that the export quantity increases rapidly in the eight years after the Asian currency crisis. Taking these facts into account, we propose a new production and transportation planning model in next section.

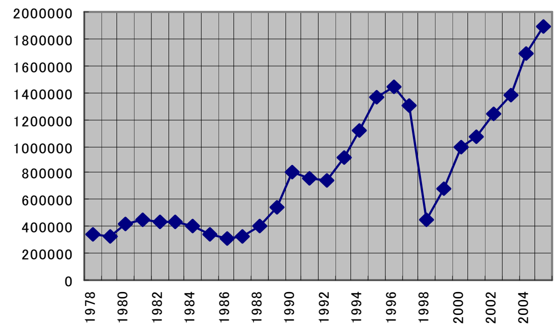

Figure 2. Sales quantity of cars in the ASEAN 4.

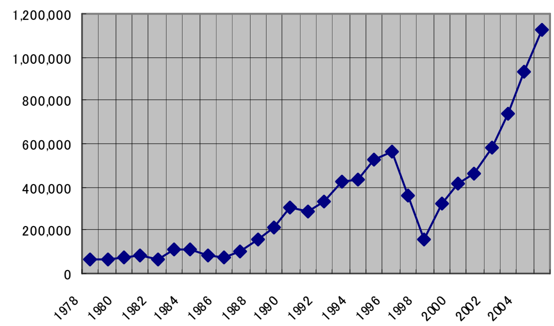

Figure 3. Production quantity of cars in Thailand.

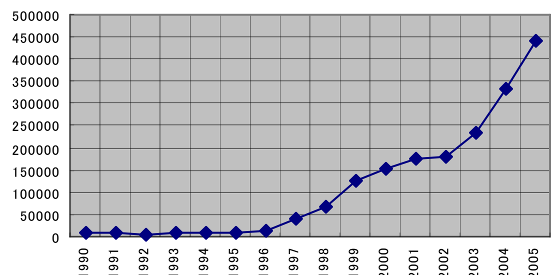

Figure 4. Export quantity of cars in Thailand.

3. TRANSPORTATION MODEL CONSIDERING OVERSEAS MARKETS

3.1 Assumptions and Notation

Let us consider the ICGCPS satisfying the following conditions:

(1) It consists of $m+1$ countries. m of them are called pro-

duction bases and produce components and parts. A further one is the logistical base called a depot.

(2) Each production base produces particular components and parts to the level of total demand required in all the participating countries, and supplies them to the other production bases.

(3) To produce final products, every components and parts produced by the production bases is utilized.

(4) Components and parts are transshipped at the depot only.

(5) Some production bases export the final products to overseas markets.

Let us define notation as follows:

M: the set of production bases.

$M = \{1, 2, \cdots, m\}$.

$M0 = M \in \{0\}$, where, 0 is a depot.

N: the set of overseas distributors.

$N = \{m+1, m+2, \cdots, m+n\}$.

c_i : the number of components and parts produced at the production base i $(i \in M)$.

C_i : the set of components and parts produced at the production base i $(i \in M)$.

$C_i = \{1, 2, \cdots, c_i\}$ $(i \in M)$.

p_i : the number of final products produced at the production base i $(i \in M)$.

P_i : the set of final products produced at the production base i $(i \in M)$.

$P_i = \{1, 2, \cdots, p_i\}$ $(i \in M)$.

$d1_{hi}$: the quantity of type-h final product produced at the production base i that is supplied to the domestic market during the predetermined time span $(h \in P_i; i \in M)$.

$d2_{hij}$: the quantity of type-h final product produced at the production base i that is exported to the overseas distributor j during the predetermined time span $(h \in P_i; i \in M; j \in N)$.

$b_{hij}{}^k$: the quantity of type-k components and parts produced at the production base j that is required to produce a final product h that is produced at the production base i $(i, j \in M; i \neq j; h \in P_i; k \in C_j)$.

d_{ij}^k : the quantity of type-k components and parts produced at the production base i that is required for transportation from the production base i to production base j during the predetermined time span $(i, j \in M; i \neq j; k \in C_i)$. It is calculated by Equation (1).

$$d_{ij}^k = \sum_{h \in P_i} b_{hij}{}^k * d1_{hj} + \sum_{h \in P_i} b_{hij}{}^k * \sum_{l \in N} d2_{hjl} \quad (i, j \in M; i \neq j; k \in C_i) \tag{1}$$

L_{ij} : the transportation lead-time from i to j $(i, j \in M0; i \neq j)$.

T: the predetermined time span.

w: the capacity of a transport vessel. We assume that all the transport vessels have the same capacity.

(i, j): the transportation of components and parts from i to j $(i, j \in M0; i \neq j)$.

$(i, 0, j, i)$: the transportation route from the production base i to production base j which is composed of a sequence of three transportations $(i, 0)$, $(0, j)$ and (j, i) $(i, j \in M; i \neq j)$.

We consider a transportation route to be one where the transport vessels come back to the production base where they started and we assume that the transport vessels are all assigned to particular transportation routes. We call the transportation method whose set of transportation routes is given by Equation (2) the "mixed-loading transshipment method."

$$R = \{(i, 0, j, i) \mid i, j \in M; i \neq j\} \tag{2}$$

Figure 5 shows a conceptual diagram of the supply chain network of ICGCPS considered in this paper. It is composed of four local production bases like the ASEAN 4 (Indonesia, Malaysia, Philippines, Thailand), one depot (Singapore) and two overseas distributors.

3.2 Variables

Let us define variables for the transportation route $(i, 0, j, i)$ as follows:

$x_{i0ji}(i, 0; i, k)$: the transportation quantity of $k \in C_i$ that is transported from the production base i to depot 0 by the transportation $(i, 0)$ $(i, j \in M; i \neq j)$.

$x_{i0ji}(0, j; h, k)$: the transportation quantity of $k \in C_h$ that is transported from the depot 0 to production base j by the transportation $(0, j)$ $(j \in M; i, h \in M\text{-}\{j\})$.

$x_{i0ji}(j, i; j, k)$: the transportation quantity of $k \in C_j$ that is transported from the production base j to production base i by the transportation (j, i) $(i, j \in M; i \neq j)$.

3.3 Constraints

a) Maximum flow of the components and parts.

Maximum flow of the components and parts for the transportation rout $(i, 0, j, i)$ is represented by Equation (3).

$$y_{i0ji} = \max\Big\{ \sum_{k \in Ci} x_{i0ji}(i, 0; i, k), \sum_{h \in M\text{-}\{i\}} \sum_{k \in C_h} x_{i0ji}(0, j; h, k), \sum_{k \in C_j} x_{i0ji}(j, i; j, k) \Big\} \quad (i, j \in M; i \neq j) \tag{3}$$

b) Transportation routes to be utilized.

Transportation route to be utilized is represented by Equation (4).

$$z_{i0ji} = \begin{cases} 1 \ (if \quad y_{i0ji} > 0) \\ \\ 0 \ (if \quad y_{i0ji} > 0) \end{cases} \quad (i, \in M; i \neq j) \tag{4}$$

We call the transportation route $(i, 0, j, i)$ that takes $z_{i0ji}=1$ the active transportation route. Let us denote Z as the set of active transportation routes.

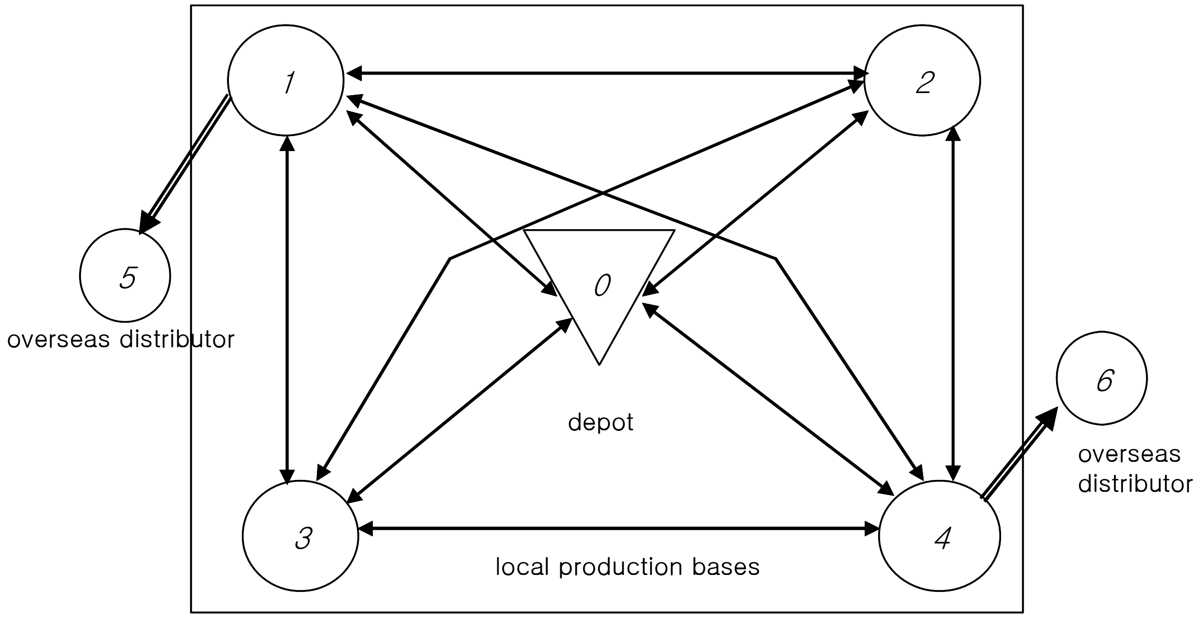

Figure 5. Conceptual diagram of the supply chain network of ICGCPS($m = 4$, $n = 2$).

c) Export quantity at each production base.

Export quantity at each production base during the predetermined time span has to satisfy Equation (5).

$$\sum_{j\in M-\{i\}} x_{i0ji}(i, 0; i, k) + \sum_{j\in M-\{i\}} x_{j0ij}(i,j; i,k) = \sum_{j\in M-\{i\}} d_{ij}^{k} \quad (i\in M;\ k\in C_i) \tag{5}$$

d) Import quantity at each production base.

Import quantity at each production base during the predetermined time span has to satisfy Equation (6).

$$\sum_{j\in M-\{i\}} x_{i0ji}(h, i; h, k) + \sum_{j\in M-\{i\}} x_{j0ij}(0, i; h, k) = d_{hik} \quad (i\in M;\ h\in M-\{i\};\ k\in C_h) \tag{6}$$

e) Equilibrium relationship at the depot.

Inflow quantity of the components and parts has to be equal to the outflow quantity at the depot. Hence we have to satisfy the equilibrium relationship at the depot shown in Equation (7).

$$\sum_{j\in M-\{i\}} x_{i0ji}(i, 0; i, k) = \sum_{j\in M-\{i\}} x_{i0ji}(0, j; i, k) + \sum_{j,h\in M-\{i\},\, j\neq h} x_{j0hj}(0, h; i, k) \quad (i\in M;\ k\in C_i) \tag{7}$$

f) Nonnegative condition.

All the variables have to have nonnegative values. Hence we have to satisfy the nonnegative condition (8).

$$\begin{aligned} &x_{i0ji}(i, 0; i, k) \geqq 0 \quad (i, j\in M;\ i\neq j;\ k\in C_i) \\ &x_{i0ji}(0,j; h, k) \geqq 0 \quad (j\in M;\ i, h\in M-\{j\};\ k\in C_h) \\ &x_{i0ji}(j, i; j, k) \geqq 0 \quad (i, j\in M;\ i\neq j;\ k\in C_j) \end{aligned} \tag{8}$$

3.4 Objective Functions

Let us introduce the objective functions. In this paper, we consider the total lead-time and the average rate of loading of the transport vessels as the critical performance measures for managing the supply chain process of the ICGCPS. It is desirable to minimize the total number of transport vessels required in order to increase the rate of loading of such vessels. As it is difficult to formulate the problem of minimizing the number of vessels required in the form of the mathematical programming problem, we will attempt to minimize the maximum flows of the components and parts instead of minimizing the number of vessels. From this point of view, we will attempt to introduce a two-stage search method. Initially, we select the transportation routes that minimize the sum of transportation lead-times (phase 1). Next, we will determine the transportation quantity that minimizes the maximum flows of components and parts in order to increase the rate of loading of transport vessels (phase 2).

Phase 1: Minimizing the sum of transportation lead-times.

We call the mathematical programming problem that minimizes the objective function (9) under the constraints (3)-(8) "phase 1" of the mixed-loading transshipment method.

$$f_1 = \sum_{i,j\in M,\, i\neq j} L_{i0ji} * z_{i0ji} \tag{9}$$

Where, $L_{i0ji} = L_{i0} + L_{0j} + L_{ji}$ $(i, j\in M;\ i\neq j)$.

Let us denote the optimum value of the objective function (9) as f_1*.

Phase 2: Minimizing the maximum flows of the components and parts

We minimize the sum of maximum flows of the components and parts on condition that the sum of transportation lead-time is f_1*. We call the mathematical programming problem that minimizes the objective function (10) under the constraints (3)-(8) and (11) "phase 2" of the mixed-loading transshipment method.

$$f_1 * = \sum_{i,j \in M,\ i \neq j} L_{i0ji} * z_{i0ji} \tag{10}$$

$$f_2 = \sum_{i,j \in M,\ i \neq j} y_{i0ji} \tag{11}$$

Phase 1 and phase 2 attempt to increase the rate of loading of transport vessels. We obtain the solutions of phase 1 and phase 2 by solving the 0-1 integer programming problem (Taha, 1987). However, this method does not assure us of maximizing the rate of loading of transport vessels. Therefore, this is a heuristic method.

3.5 Obtaining the Transport Vessels Required

Next, we calculate the transport vessels required. Let us define additional notation as follows;

n_{i0ji}: the number of times that a transport vessel can complete the active transportation route $(i, 0, j, i)$ during the predetermined time span. It can be calculated by Equation (12).

$$n_{i0ji} = [T/L_{i0ji}]^- \qquad ((i, 0, j, i) \in Z) \tag{12}$$

Where, $[X]^-$ is defined as the maximum integer less than X.

s_{i0ji}: the number of transport vessels required for the active transportation route $(i, 0, j, i)$ during the predetermined time span in order to satisfy the required demand quantity. It can be calculated by Equation (13).

$$s_{i0ji} = [y_{i0ji} / (w \times n_{i0ji})]^+ \qquad ((i, 0, j, i) \in Z) \tag{13}$$

Where, $[X]^+$ is defined as the minimum integer greater than X.

Then, the total number of transport vessels, TS, required to satisfy the demand quantity during the predetermined time span is given by Equation (14).

$$TS = \sum_{(i,0,j,i) \in Z} s_{i0ji} \tag{14}$$

4. PRODUCTION AND transportation PLANNING PROCEDURE

4.1 Obtaining the Transportation Interval and Average Transportation Quantity

We calculate the transportation interval and average transportation quantity under the following conditions;

(1) At each active transportation route, transport vessels start at regular intervals.
(2) At each active transportation route, transport vessels carry an equal volume of components and parts.

Let us introduce additional notation as follows;

r_{i0ji} : the transportation interval of the active transportation route $(i, 0, j, i) \in Z$. It can be calculated by Equation (15).

$$r_{i0ji} = [L_{i0ji} / s_{i0ji}]^+ \qquad ((i, 0, j, i) \in Z) \tag{15}$$

p_{i0ji} : the number of trips made by transport vessels on the active transportation route $(i, 0, j, i) \in Z$ during the pre-determined time span. It is calculated by Equation (16).

$$p_{i0ji} = [L_{i0ji} / r_{i0ji}]^- \qquad ((i, 0, j, i) \in Z) \tag{16}$$

$q_{i0ji}(i, 0; i, k)$: the average transportation quantity of $k \in C_i$ that is transported from the production base i to depot 0 by the transport vessels on the active transportation route $(i, 0, j, i) \in Z$.

$q_{i0ji}(0, j; h, k)$: the average transportation quantity of $k \in C_h$ that is transported from the depot 0 to production base j by the transport vessels on the active transportation route $(i, 0, j, i) \in Z$.

$q_{i0ji}(j, i; j, k)$: the average transportation quantity of $k \in C_j$ that is transported from the production base j to production base i by the transport vessels on the active transporta-tion route $(i, 0, j, i) \in Z$.

Then, these values are calculated by Eqs.(17)-(19).

$$q_{i0ji}(i, 0; i, k) = [x_{i0ji}(i, 0; i, k) / p_{i0ji}]^+ \qquad ((i, 0, j, i) \in Z;\ k \in C_i) \tag{17}$$

$$q_{i0ji}(0, j; h, k) = [x_{i0ji}(0, j; h, k) / p_{i0ji}]^+ \qquad ((i, 0, j, i) \in Z;\ j \in M;\ h \in M\text{-}\{j\};\ k \in C_h) \tag{18}$$

$$q_{i0ji}(j, i; j, k) = [x_{i0ji}(j, i; j, k) / p_{i0ji}]^+ \qquad ((i, 0, j, i) \in Z;\ k \in C_j) \tag{19}$$

4.2 Obtaining the Initial Inventory Quantity required

We calculate the initial inventory quantity required under the condition that a transport vessel starts from the original production base on its first journey in the predetermined time span on each active transportation route.

$P_{i0ji}^t(i, 0; i, k)$: the arrival quantity of $k \in C_i$ during the period t that is transported from the production base i to the depot by the transport vessels on the active transportation route $(i, 0, j, i) \in Z$.

$Q_{i0ji}^t(0, j; h, k)$: the shipping quantity of $k \in C_h$ $(h \in M)$ during the period t that is transported from the depot to production base j by the transport vessels on the active transporta-tion route $(i, 0, j, i) \in Z$.

$$P_{i0ji}{}^{t}(i,0;i,k) = \begin{cases} q_{i0ji}(i,0;i,k) \quad (t \in T_{i0ji}{}^{*}) \\ \qquad\qquad ((i,0,j,i) \in Z;\ k \in C_i) \\ 0 \quad (otherwise) \end{cases} \quad (20)$$

$$Q_{i0ji}{}^{t}(0,j;h,k) = \begin{cases} q_{i0ji}(0,j;h,k) \quad (t \in T_{ioji}{}^{*}) \\ 0 \quad (otherwise) \end{cases}$$

$$((i,0,j,i) \in Z;\ j \in M;\ h \in M - \{j\};\ k \in C_h) \quad (21)$$

Where, $T_{i0ji}{}^{*} = \{r_{i0ji},\ 2^{*}r_{i0ji}, \ldots, p_{i0ji}{}^{*}r_{i0ji}\}$

Then, the inventory quantity of $k \in C_i$ $(i \in M)$ at the depot at the end of the t th period, $B_0{}^{t}(i,k)$, is calculated by Equation (22).

$$B_0{}^{t}(i,k) = B_0{}^{t-1}(i,k) + \sum_{(i,0,j,i) \in Z} P_{i0ji}{}^{t}(i,0;i,k) - \sum_{(i,0,j,i) \in Z} Q_{i0ji}{}^{t}(0,j;h,k)$$
$$(t \in T_{i0ji}{}^{*};\ i \in M;\ k \in C_i) \quad (22)$$

It is necessary to prepare an initial inventory quantity that satisfies Equation (23) in order to transship the components and parts smoothly at the depot.

$$B_0{}^{0}(i,k) = \begin{cases} \| \min_{t \in T_{i0ji}{}^{*}} B_0{}^{t}(i,k) \| \quad (if\ \min_{t \in T_{i0ji}{}^{*}} B_0{}^{t}(i,k) < 0 \\ \qquad\qquad (i \in M;\ k \in C_i) \\ 0 \quad (otherwise) \end{cases} \quad (23)$$

Where, $\| \min_{t \in T_{i0ji}{}^{*}} X^{t} \|$ is defined as the absolute value of $\min X^{t}$ $(t \in T_{i0ji}{}^{*})$.

4.3 Production and Transportation Planning Procedure

Step 1: Calculate the production quantity of the components and parts (Eq. (1)).

Step 2: Determine the transportation routes and quantities by solving "Phase 1" (Eqs. (3)-(9)) and "Phase 2" (Eqs.(3)-(8), (10), (11)) of the mixed-loading transshipment method.

Step 3: Calculate the transport vessels required. (Eqs. (12)-(14))

Step 4: Determine the transportation interval and average transportation quantity. (Eqs. (15)-(19))

Step 5: Determine the initial inventory quantity at the depot. (Eqs.(20)-(22))

5. NUMERICAL EXAMPLE

Let us introduce a numerical example. We utilize the "Mathematical Program Software Xpress-MP" (Dash Associates, 2003) for the calculation.

5.1 Input Data

(1) Number of production bases: $m = 4$.
(2) Number of overseas distributors: $n = 2$.
(3) Number of components and parts: $c_1 = 2,\ c_2 = 2,\ c_3 = 2,\ c_4 = 3$
(4) Number of final products: $p_1 = 4,\ p_2 = 4,\ p_3 = 3,\ p_4 = 2$
(5) Quantity of final products supplied to domestic market: (vehicles);
$d1_{11} = 1000,\ d1_{21} = 500,\ d1_{31} = 300,\ d1_{41} = 720,\ d1_{12} = 500,\ d1_{22} = 300,\ d1_{32} = 220,\ d1_{42} = 60,\ d1_{13} = 500,\ d1_{23} = 620,\ d1_{33} = 250,\ d1_{14} = 1000,\ d1_{24} = 620.$
(6) Quantity of final products exported to overseas distributors (vehicles);
$d2_{111} = 1000,\ d2_{211} = 1000,\ d2_{311} = 500,\ d2_{411} = 0,\ d2_{112} = 1000,\ d2_{212} = 500,\ d2_{312} = 500,\ d2_{412} = 0,\ d2_{131} = 1500,\ d2_{231} = 500,\ d2_{331} = 0,\ d2_{132} = 500,\ d2_{232} = 0,\ d2_{332} = 500.$
(7) Bill of materials;

Table 1. Bill of materials.

i	j	1		2		3		4		
	h \ k	1	2	1	2	1	2	1	2	3
1	1			1	0	1	0	0	0	0
	2			0	1	1	0	0	0	0
	3			0	1	0	1	0	0	0
	4			0	1	0	1	1	1	1
2	1	1	0			1	0	0	0	0
	2	0	1			1	0	0	0	0
	3	0	0			0	1	1	1	1
	4	0	0			0	1	0	0	0
3	1	1	0	1	0			0	0	0
	2	1	0	0	1			1	1	1
	3	0	1	1	0			0	0	0
4	1	1	0	1	0	1	1			
	2	0	1	0	1	1	0			

(8) Transportation lead-time (days):

$L_{10} = L_{01} = 6,\ L_{20} = L_{02} = 8,\ L_{30} = L_{03} = 2,\ L_{40} = L_{04} = 2,\ L_{12} = L_{21} = 13,\ L_{13} = L_{31} = 2,\ L_{14} = L_{41} = 7,\ L_{23} = L_{32} = 10,\ L_{24} = L_{42} = 7,\ L_{34} = L_{43} = 2.$

(9) Predetermined time span (days): $T = 90$.
(10) Capacity of transport vessel (containers): $w = 350$.

5.2 Output results

Step 1: Calculate the production quantity of components and parts.

Initially, we calculate the required quantity of the components and parts to be produced at each production base during the predetermined time span. The results are as follows (containers);

Table 2. Production quantity of components and parts.

i	k \ j	1	2	3	4
1	1		500	3620	1000
	2		300	750	620
2	1	3000		3250	1000
	2	4020		1120	620
3	1	5000	800		1620
	2	2020	280		1000
4	1	720	220	1120	
	2	720	220	1120	
	3	720	220	1120	

Step 2: Determine the transportation routes and quantities.

(1) *Phase 1*

Solving phase 1, we have following results.

a) Active transportation routes:

$z_{1031} = z_{3013} = z_{2042} = z_{4024} = 1.$

b) The value of the objective function: $f_1^* = 54.$

(2) *Phase 2*

Solving phase 2, we have following results.

a) Active transportation routes:

$z_{1031} = z_{3013} = z_{2042} = z_{4024} = 1.$

b) Transportation quantity:

Transportation quantity for the active transportation routes becomes as follows(containers);

c) Maximum flows on the active transportation routes:

$y_{1031} = 7730, y_{3013} = 9180, y_{2042} = 11390, y_{4024} = 5520.$

d) Value of the objective function: $f_2^* = 33820.$

Step 3: Obtaining the transport vessels required.

The transportation lead-time for the active transportation routes, $z_{i0ji} = 1$, becomes as follows:

$L_{1031} = L_{3013} = 10$ and $L_{2042} = L_{4024} = 17.$

This is the minimum value of total lead-time required to transport the necessary quantity of components and parts. Utilizing the active transportation routes, we are able to reduce the total inventory quantity. The transport vessels required for the active transportation routes become as follows;

$s_{1031} = 3, s_{3013} = 3, s_{2042} = 7, s_{4024} = 4.$

Table 3. Transportation quantity of components and parts.

		(1, 0, 3, 1)			(3, 0, 1, 3)			(2, 0, 4, 2)			(4, 0, 2, 4)		
i	k	(1, 0)	(0,3)	(3,1)	(3,0)	(0, 1)	(1, 3)	(2, 0)	(0, 4)	(4, 2)	(4, 0)	(0, 2)	(2, 4)
1	1	1500					3620		1000			500	
	2	920					750		620			300	
2	1		3250			3000		6250					1000
	2		1120			4020		5140					620
3	1			5000	2420				1620			800	
	2			2000	1208				1000			280	
4	1		1120			720				220	1840		
	2		1120			720				220	1840		
	3		1120			720				220	1840		

Table 4. Average transportation quantity of components and parts.

		(1, 0, 3, 1)			(3, 0, 1, 3)			(2, 0, 4, 2)			(4, 0, 2, 4)		
i	k	(1, 0)	(0, 3)	(3, 1)	(3, 0)	(0, 1)	(1, 3)	(2, 0)	(0, 4)	(4, 2)	(4, 0)	(0, 2)	(2, 4)
1	1	69					165		34			28	
	2	42					35		21			17	
2	1		148			137		209					56
	2		51			183		172					35
3	1			228	110				54			45	
	2			91	59				34			16	
4	1		51			33				8	103		
	2		51			33				8	103		
	3		51			33				8	103		

Hence, the total number of transport vessels required becomes $TS = 17$. By utilizing these transport vessels, we are able to transport the required quantity of components and parts and to increase the average rate of loading.

Step 4: Transportation interval and average transportation quantity.

(1) The transportation interval for the active transportation routes becomes as follows:
$r_{1031} = 4$, $r_{3013} = 4$, $s_{2042} = 3$, $s_{4024} = 5$.

(2) The average transportation quantity for the active transportation routes becomes as follows:

Step 5: Initial inventory quantity required at the depot.

Initial inventory quantity required at the depot becomes as follows:
$B_0^0(1, 1) = 47$, $B_0^0(1, 2) = 30$, $B_0^0(2, 1) = 266$,
$B_0^0(1, 2) = 208$, $B_0^0(3, 1) = 75$, $B_0^0(3, 2) = 41$,
$B_0^0(4, 1) = 116$, $B_0^0(4, 2) = 116$, $B_0^0(4, 3) = 116$.

6. CONCLUSION

In this paper, we have considered a way of designing of the production and transportation planning system in the International Cooperative Global Complementary Production System involving a depot and taking into account the export quantity of the final products to overseas markets. Initially, we created a transportation model with a depot, "mixed-loading transshipment method", in the form of a mathematical programming problem and proposed a way for determining the set of active transportation routes and transportation quantity by evaluating two kinds of objective functions: (1) the total transportation lead-time and (2) the maximum flow of the components and parts. Next, we calculated the transport vessels required and clarified the production and transportation planning procedure by considering the transportation interval, average transportation quantity and the initial inventory quantity required. Finally, we presented a numerical example in order to explain the procedure mentioned in this paper. After determining the production and transportation planning, it is necessary to design an adequate ordering system for the ICGCPS. This needs to take into account the variation of demand quantity of the final goods and the fluctuation of transportation lead-time. It is also important to clarify the way to design an adequate buffer capacity economically. We would consider these problems as the subjects for a further study.

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REFERENCES

Dash Associates (2003), *XPRESS-MP User Guide-Release 13-*, Mathematical Program Software Manual.

Hiraki, S. (1996), Comparative analysis of ordering models for an international co-operative global complementary production system, *International Journal of Production Economics*, **44**, 105-117.

Hiraki, S., Ichimura, T., Katayama, H., and Ishii K. (1999), Designing of a pull type ordering system in the ICGCPS under considering transshipment and mixed-loading, *Proc. of the 2nd Asia-Pacific Conf. on Industrial Engineering and Management Systems*, *Kanazawa*, *Japan*, 369-372.

Hiraki, S., Ichimura, T., Katayama, H., and Ishii K. (2002), A Study on container ship routing problem for the international cooperative global complementary production systems, *Proc. of the 4th Asia-Pacific Conference on Industrial Engineering and Management Systems*, *Taipei*, *Taiwan*, 69-72.

Hiraki, S., Ichimura, T., Katayama, H., and Ishii K. (2004), A study on managing supply chain processes of the international cooperative global complementary production systems, *Proc. of the 5th Asia-Pacific Conference on Industrial Engineering and Management Systems*, *Gold Coast*, *Australia*, 34.3.1-34.3.12 (CD-ROM).

Hiraki, S. (2005), *International cooperative global complementary production systems for the automobile manufactures*, *In T. Tokimasa*, *S. Hiraki and N. Kaio (eds)*, *Applied Economic Informatics and Systems Sciences (Kyushu University Press)*, **7**, 141-153.

Katayama, H., Hiramatsu, H., and Hiraki, S. (2000), Dynamic characteristics of an ASEAN-China global logistics system: a case investigation of car industry, *In J. Singh*, *C. Lew and R. Gay (eds)*, *Computer Integrated Manufacturing*, **1**, Photoplates Pte. Ltd., Singapore, 147-159.

Su, Y. and Hiraki, S. (2000), A study on transportation methods of automobile components in the ICGCPS, *In J. Singh*, *C. Lew and R. Gay (eds)*, *Computer Integrated Manufacturing,* **1**, Photoplates Pte. Ltd., Singapore, 123-134.

Taha, H. A. (1987), Operations Research An Introduction (Fourth Edition). New York: MacMillan Pub. Co., 303.