Supply Chain Planning with Cross-echelon Reverse Logistics Using Data Envelopment Analysis and Particle Swarm Optimization

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Abstract. This paper addresses the problems associated with the partner selection and distribution planning in the supply chain system with cross-echelon reverse logistics. We introduce an optimization mathematical model for multi-echelon, multi-product and multi-period system based on manufacturing loss, transportation loss, and resource limitation constraints. Furthermore, a solving methodology applying data envelopment analysis (DEA) and particle swarm optimization (PSO) based on mathematical model is developed. The DEA is used to evaluate the performance of existing partners and select some important partners. A PSO approach is proposed to select kernel partners and allocate the distribution quantity between the kernel partners. Finally, a cross-echelon reverse supply chain framework with 4 echelons, 2 products and 3 periods is used to demonstrate the suitability of this proposed methodology.

Keywords: supply chain planning, cross-echelon reverse logistics, partner selection, data envelopment analysis, particle swarm optimization

1. INTRODUCTION

Fleischmann et al. (1997) described reverse logistics as all activities or approaches, when products are returned from users to manufacturers and then sold again in the market. Trebilcock (2001) and Cohen (1988) pointed out that remanufacturing mode could save 40%~60% in production costs every year. Some experts applied reverse logistics to many fields, such as the steel industry (Spengler et al., 1997), carpet recycling (Ammons et al., 1997), electronic equipment (Jayaraman et al., 1999), sand recycling (Barros et al., 1998), and reusable packing materials (Kroon et al. 1995). In addition, Sheu et al. (2005) attempted to address integrated logistics through a linear multi-target planning model, and suggested a product return and subsidy policy for enterprises. Min et al. (2006)

analyzed the reverse logistics planning issue as to how the customers could return products purchased over the Internet to the suppliers, and applied heuristic algorithm to solve the nonlinear mixed integer programming for the purpose of cost minimization. Evans et al. (2007) established a forward and reverse supply chain network based on third-party logistics, and applied a mixed-integer nonlinear planning model to dynamically integrate the distribution network, while considering factors such as multiple products, multiple echelons and capacity constraints. Finally, they endeavored to solve optimized forward and reverse networks with heuristic algorithm.

Hence, this paper discusses the selection of cross-echelon supply chain partners and distribution planning, in order that defective products could be sent back from downstream supply chain partners to upstream partners for reprocessing purposes based on the degree of damage. Gen and Cheng (1997) pointed out that, cross-echelon logistics could be deemed as a knapsack problem (i.e. NP-Hard problem) containing capacity constraint, position, and quantity allocation. This problem will become more complex since capacity constraints, transportation losses, and manufacturing losses are considered in this research.

This paper presents a DEA is used to evaluate the business performance of supply chain partners and an optimal mathematical model for supply chain partners selection and distribution planning in cross-echelon reverse logistics services with considering manufacturing loss, transportation loss, and resource constraints. In addition, a PSO is employed to solve the optimal mathematical model for finding a cross-echelon reverse logistics plan.

2. PROPOSED METHODOLOGY

2.1 DEA Model

u_r, v_i	Weight of r-th output and i-th input
X_{ik}	Performance of k-th supply chain partner under i-th input criterion
Y_{rj}	Performance of j-th supply chain partner under r-th output criterion
n	Number of evaluated units
m	Number of input factors
s	Number of outputs
ε	A minimal positive value

The CCR-I (Charnes, 1978) model is used to obtain the business performance of supply chain partners in different echelons, with CCR-I model shown below:

$$Max \quad hk = \frac{\sum_{r=1}^{s} u_r Y_{rk}}{\sum_{i=1}^{m} v_i X_{ik}} \tag{1}$$

$s.t$:

$$\frac{\sum_{r=1}^{s} u_r Y_{rj}}{\sum_{i=1}^{m} v_i X_{ij}} \le 1, \ j = 1,....,n \tag{2}$$

$$u_r, v_i \ge \varepsilon > 0, \quad r = 1,...,S, \quad i = 1,....,m \tag{3}$$

Symbols for maximum performance model and minimum cost and time model:

p	Period index
i	Echelon index of network
ri	Echelon index of cross-echelon reverse network
g	Product items
m, n	Partner index
$MinCP_{i.m}^{g}$	Minimum production capacity of partner m for product g at echelon I
$MaxCP_{i.m}^{g}$	Maximum production capacity of partner m for product g at echelon I
$SC_{i.m}$	Efficiency of partner m at echelon i
$PD_{i.m}$	Defect ratio of partner m at echelon i
$TFD_{((i.m),(i+1.n))}$	Transportation loss from partner m at echelon i to partner n at echelon $i+1$
$SPC_{i.m}$	Production cost of partner m at echelon i
$STC_{((i.m),(i+1.n))}$	Transportation cost from partner m at echelon i to partner n at echelon $i+1$
$X_{((i.m),(i+1.n))}^{p.g}$	Transportation quantity from partner m at echelon i to partner n at echelon $i+1$ for product g in period p
$PX_{i.m}^{p.g}$	Production quantity of partner m at echelon i for product g in period p
$RX_{((i.m),(i-ri.n))}^{p.g}$	Quantity of defective products returned from partner m at echelon i to partner n at echelon i-ri for product g in period p
$MD_{m}^{p.g}$	Customer demands of partner m for product g in period p
$UMD_{i}^{p.g}$	Supply quantity at echelon i for product g in period p
$SQ_{i.m}$	Product quality of partner m at echelon i
$ST_{((i.m),(i+1.n))}$	Transportation time from partner m at echelon i to partner n at echelon $i+1$
$ACT_{i.m}^{'}$	$\begin{cases} 1 & \text{if production takes place at partner } m \text{ at stage } i \\ 0 & \text{otherwise} \end{cases}$
MP	Minimum supply chain partners
[ ]	An integer function to gain the integer value of the real number by eliminating its decimal

2.2 Maximum Performance Model

Seeking for maximization of performance provided that the demand is met.

$$Max \quad \sum_{i=1}^{I} \sum_{m=1}^{M_{i+1}} SC_{i.m} \times ACT_{i.m}^{'} \tag{4}$$

s.t:

$$\sum_{m=1}^{M_i}\left[MaxCP_{i.m}^{p.g}\times(1-PD_{i.m})\right]\times ACT_{i.m}^{'}\geq UMD_i^{p.g}\quad for\quad all\quad p,g,i \tag{5}$$

$$\sum_{m=1}^{M_i} ACT_{i.m}^{'} = MP\qquad for\quad all\quad i \tag{6}$$

2.3 Minimum Cost and Time Model

Seeking for minimization of transportation cost, production cost, and transportation time, as well as maximization of production quality of cross-echelon supply chain partners in forward and reverse logistics.

$$\begin{aligned}
Min\quad & \sum_{p=1}^{P}\sum_{i=1}^{1}\sum_{m=1}^{M_i}\left[\left(SPC_{(i.m)}-SQ_{(i.m)}\right)\times\sum_{n=1}^{N_i}X_{((i.m),(i+1.n))}^{p.g}\right]\\
&+\sum_{p=1}^{P}\sum_{i=1}^{I}\sum_{m=1}^{M_i}\sum_{n=1}^{N_i}\left[\left(STC_{((i.m),(i+1.n))}+ST_{((i.m),(i+1.n))}\right)\times X_{((i.m),(i+1.n))}^{p.g}\right]\\
&+\sum_{p=2}^{P}\sum_{i=2}^{I}\sum_{ri=1}^{i-1}\sum_{m=1}^{M_i}\left[\left(SPC_{(i.m)}-SQ_{(i.m)}\right)\times\sum_{n=1}^{N_i}RX_{((i.n),(i-ri.m))}^{p.g}\right]\\
&+\sum_{p=2}^{P}\sum_{i=2}^{I}\sum_{ri=1}^{i-1}\sum_{m=1}^{M_i}\sum_{n=1}^{N_i}\left[\left(STC_{((i.n),(i-ri.m))}+ST_{((i.n),(i-ri.m))}\right)\times RX_{((i.n),(i-ri.m))}^{p.g}\right]
\end{aligned} \tag{7}$$

$s.t$:

$$\begin{aligned}
&\sum_{n=1}^{N_i}X_{((i.m),(i+1n))}^{P.g}=\sum_{n=1}^{N_i}[(PX_{i.m}^{p.g}\times(1-PD_{i.m}))\times(1-TFD_{((i.m),(i+1.n))})]\\
&+\sum_{n=1}^{N_i}RX_{((ri.m),(i.n))}^{p-1.g}
\end{aligned} \tag{8}$$

$for\quad all\quad p,g,m\quad and\quad i=1$; $ri=2,3,4,....,I$

$$\begin{aligned}
&\sum_{n=1}^{N_i}X_{((i.m),(i+1.n))}^{p.g}=\sum_{n=1}^{N_i}[(PX_{i.m}^{p.g}\times(1-PD_{i.m}))\times(1-TFD_{((i.m),(i+1.n))})]\\
&+\sum_{n=1}^{N_i}RX_{((i+1.n),((i+1)-ri.m))}^{p-1.g}-\sum_{n=1}^{N_i}RX_{((i+1.m),((i+1)-ri.n))}^{p.g}\quad for\quad all
\end{aligned} \tag{9}$$

$p,g,m\quad and\quad i=1,2,3,...,I-1$; $ri=1,2,3,....,I-1$, $ri<i$

$$\begin{aligned}
&\sum_{n=1}^{N_i}X_{((i-1.m),(i.n))}^{p.g}=\sum_{n=1}^{N_i}[PX_{i.m}^{p.g}\times(1-PD_{i.m})\times(1-TFD_{((i-1.m),(i.n))})]\\
&-\sum_{n=1}^{N_i}RX_{((i-1.m),(i.n))}^{p.g}\quad for\quad all\quad p,g,m\quad and\quad i=I
\end{aligned} \tag{10}$$

$$MinCP_{i.m}^{g}\leq\sum_{n=1}^{N_i}[(X_{((i.m),(i+1.n))}^{p.g}\times(1-TFD_{((i.m),(i+1.n))}))]\leq MaxCP_{i.m}^{g} \tag{11}$$

$for\quad all\quad p,g,m$

$$\sum_{n=1}^{N_i}X_{((i.m),(i+1.n))}^{p.g}\times(1-PD_{i.m})=MD_m^{p.g}\quad for\quad all\quad p,g,m \tag{12}$$

$$\sum_{n=1}^{N_i}RX_{i.m}^{p.g}=\left(\sum_{n=1}^{N_i}PX_{i.m}^{p.g}+\sum_{n=1}^{N_i}RX_{((i.m),(i+1.n))}^{p-1.g}\right)\times PD_{i.m} \tag{13}$$

$for\quad all\quad p,g,m\ and\quad ri=1,2,3,....,I-1$, $ri<i$

$$RX_{i.m}^{p.g}=\sum_{n=1}^{N_i}RX_{((i.m),((i-ri_i.n))}^{p.g}\quad for\quad all\quad p,g,m\ and \tag{14}$$

$ri=1,2,3,....,1-1$, $ri<i$

$$\begin{cases}X_{((i.m),(i+1.n))}^{p.g}\geq 0\\ X_{((i.m),(i+1.n))}^{p.g}\in Integer\end{cases}\quad for\ all\ p,g,i,m,n \tag{15}$$

$$\begin{cases}RX_{((i.m),(i-ri.n))}^{p.g}\geq 0\\ RX_{((i.m),(i-ri.n))}^{p.g}\in Integer\end{cases}\quad for\ all\ p,g,i,m,n\quad and \tag{16}$$

$ri=1,2,3,....,1-1$, $ri<i$

2.4 PSO Solving Model

Step 1: implement the distribution plan by the evaluation result in the first phase; first, set the relevant coefficients such as: particle number, velocity, weight and iteration number, and take every forward/reverse transportation line and every product as a particle, with the forward and reverse particle swarm codes. During forward transportation, the demand, transportation losses, production defects, and constraints (8)-(16) are used to randomly generate generation numbers, meanwhile, every particle has its initial velocity and position parameters, which are randomly generated between 0-1 for subsequent velocity and position updating. During reverse transportation, the distribution is performed according to the defect number generated by downstream supply chain partners.

Step 2: substitute forward and reverse particles, obtained from initial solutions, into the object function (7) to compute the target value of every particle.

Step 3: compare the target value of every particle in step 2 to obtain *Gbest*.

Step 4: modify *Pbest* and *Gbest*; if *Pbest* is superior to *Gbest*, *Gbest* is replaced by *Pbest*.

Step 5: update every particle's velocity and position using Inertia Weight Method (Eberhart et al., 1998)

$$v_i^{K+1}=wv_i^k+c_1\times\mathrm{rand}()\times(s_i^{k^*}-s_i^k)+c2\times rand()\times(s_i^{k^\#}-s_i^k) \tag{17}$$

$$s_i^{k+1}=s_i^k+v_i^{k+1} \tag{18}$$

Where, v_i^k is initial velocity of particle i, v_i^{k+1} is a new velocity of particle i, w is inertia weight, c_1 and c_2 are learning coefficients, $s_i^{k^*}$ is personal best position memory of particle i, $s_i^{k^\#}$ is group best position memory, s_i^{k+1} is a new position of particle i, and $rand()$ is a random number ranging between 0-1.

Step 6: check if constraints comply with the constraints and maximum velocity in Eqs. (8)-(16), otherwise perform Step 5.

Step 7: repeat steps 3-6, and compare *Gbest* separately by taking iteration number as the termination condition of computation, making the results show the distribution quantity and evaluation index of every forward and reverse line.

3. CASE STUDY AND RESULTS

This paper conducted a case study of a three-period reverse logistics model for two products under a {6-6-6-4} supply chain network framework, as shown in Figure 1. The defective products of every downstream supply chain partner may be sent back to the upstream for repair or replacement depending on the degree of damage. While the production plan is being prepared, it is required to consider capacity constraints, production costs, transportation costs, production quality, and transportation time of every supply chain partner. The relate data of supply chain partners, as shown in Tables 1 and 2.

Firstly, DEA is used to evaluate the business performance of every supply chain partner, on the precondition that input and output criteria are as defined. The inputs include number of staff and total assets, while outputs include operating income, with the details listed in Table 3. The supply chain in this case study includes 4 echelons, of which the preceding 3-echelon supply chain is comprised of 6 partners and the final echelon is comprised of 4 customers.

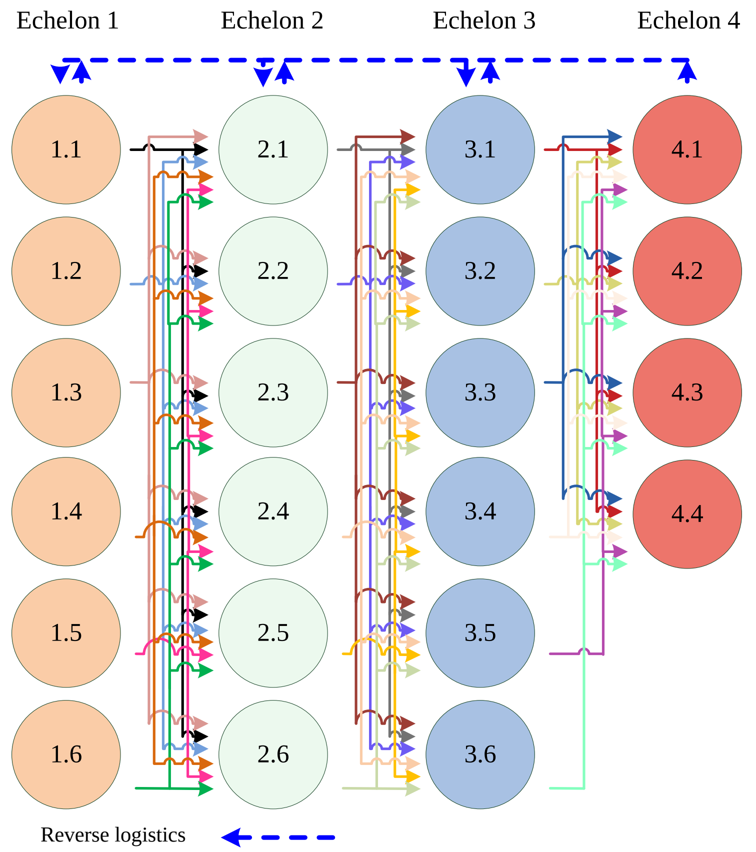

Figure 1: {6-6-6-4} cross-echelon reverse supply chain.

Table 1: Data of cross-echelon reverse supply chain network.

	Echelon 1						Echelon 2						Echelon 3					
	1.1	1.2	1.3	1.4	1.5	1.6	2.1	2.2	2.3	2.4	2.5	2.6	3.1	3.2	3.3	3.4	3.5	3.6
DR	0.03	0.01	0.02	0.02	0.03	0.02	0.02	0.01	0.03	0.02	0.01	0.05	0.05	0.02	0.01	0.02	0.03	0.02
PC	5	7	3	2	4	2	5	6	4	4	5	3	6	3	4	6	7	5
Q	7	5	8	4	9	7	7	9	8	6	8	7	7	6	5	8	8	9
MaxCP	30	20	50	40	35	50	20	10	15	30	35	30	30	35	20	30	30	20
MinCP	300	1100	800	500	1600	1300	400	520	600	1600	700	1600	610	750	850	110	750	1500

	Echelon 4							
Demand	Product 1				Product 2			
	4.1	4.2	4.3	4.4	4.1	4.2	4.3	4.4
Period 1	450	500	400	550	600	510	300	600
Period 2	350	400	550	600	600	490	550	370
Period 3	450	450	650	350	350	460	550	650

DR: Defect rate
PC: Production cost
Q: Quality level
MinCP: minimum production capacity
MaxCP: maximum production capacity

Table 2: Data of transportation line (partial list).

TL	1.1-2.1	1.1-2.2	1.1-2.3	1.1-2.4	1.1-2.5	1.1-2.6	1.2-2.1	1.2-2.2	1.2-2.3	1.2-2.4	1.2-2.5	1.2-2.6
TR	0.01	0.03	0.03	0.01	0.03	0.02	0.02	0.01	0.03	0.04	0.05	0.02
TC	3	5	8	6	6	4	3	2	7	7	6	5
TT	6	4	3	5	4	5	6	7	3	4	6	5
TL	1.5-2.1	1.5-2.2	1.5-2.3	1.5-2.4	1.5-2.5	1.5-2.6	1.6-2.1	1.6-2.2	1.6-2.3	1.6-2.4	1.6-2.5	1.6-2.6
TR	0.03	0.04	0.01	0.02	0.02	0.03	0.01	0.02	0.02	0.04	0.01	0.04
TC	5	4	6	3	3	3	6	7	7	3	8	8
TT	6	4	2	5	5	3	2	3	4	5	3	3
TL	2.3-3.1	2.3-3.2	2.3-3.3	2.3-3.4	2.3-3.5	2.3-3.6	2.4-3.1	2.4-3.2	2.4-3.3	2.4-3.4	2.4-3.5	2.4-3.6
TR	0.01	0.02	0.04	0.02	0.02	0.03	0.01	0.02	0.03	0.01	0.02	0.02
TC	1	3	3	2	5	6	3	7	6	2	1	4
TT	7	8	6	6	5	6	4	6	7	8	2	3
TL	3.1-4.1	3.1-4.2	3.1-4.3	3.1-4.4	3.2-4.1	3.2-4.2	3.2-4.3	3.2-4.4	3.3-4.1	3.3-4.2	3.3-4.3	3.3-4.4
TR	0.02	0.01	0.04	0.01	0.02	0.02	0.01	0.04	0.01	0.02	0.02	0.03
TC	2	8	5	6	2	3	6	6	1	4	6	6
TT	1	4	5	6	7	8	8	6	8	8	6	6

TL: Transportation line ; TR: Transportation defect rate; TC: Transportation cost; TT: Transportation time

Table 3: Business data.

Echelon 1				Echelon 2				Echelon 3			
Partners	Number of Staff	Total Assets	Operations Income	Partners	Number of Staff	Total Assets	Operations Income	Partners	Number of Staff	Total Assets	Operations Income
1.1	401	4,240	311,600	2.1	248	2,365	262,000	3.1	174	1,240	145,000
1.2	425	3,514	268,900	2.2	290	2,600	264,000	3.2	150	1233	132,000
1.3	366	3,060	283,000	2.3	233	1,800	188,000	3.3	158	1,133	125,000
1.4	391	3,400	284,600	2.4	310	2,970	235,000	3.4	194	1,523	142,800
1.5	294	2,850	218,400	2.5	311	2,750	275,000	3.5	146	1,356	151,000
1.6	313	2,980	216,330	2.6	197	2,160	214,000	3.6	102	965	116,100

Moreover, the correlation among number of staff, total assets, and operating income is checked through correlative analysis, with the correlation degree of inputs and outputs for supply chain partners listed in Table 4. It can be seen that there is no negative correlation among the criteria in every echelon. The business performance of every supply chain partner evaluated by the CCR-I model of the DEA-Solver, is as listed in Table 5. Based on the market demands, the number of partners of each echelon can be found out via the performance model. For instance, if 450, 500, 400, 550 products are required in the fourth echelon (customer) in the first period, 3, 4, and 5 supply chain partners are required in the first, second and third echelon separately.

Based on performance and market demand, the PSO method is used to solve the cost and time model to evaluate and select appropriate partners at every echelon and to form a distribution plan. The results are shown in Tables 6-8.

Table 4: Correlation coefficients.

Echelon 1				Echelon 2				Echelon 3			
	Number of Staff	Total Assets	Operations Income		Number of Staff	Total Assets	Operations Income		Number of Staff	Total Assets	Operations Income
Number of Staff	1	0.744	0.832	Number of Staff	1	0.846	0.646	Number of Staff	1	0..824	0.651
Total Assets		1	0.807	Total Assets		1	0.713	Total Assets		1	0.819
Operations Income			1	Operations Income			1	Operations Income			1

Table 5: Analytical results of CCR-I model.

Echelon 1			Echelon 2			Echelon 3		
Supplier Partner	Score	Rank	Supplier Partner	Score	Rank	Supplier Partner	Score	Rank
1.1	1	1	2.1	1	1	3.1	0.971	2
1.2	0.827	6	2.2	0.916	4	3.2	0.889	5
1.3	1	1	2.3	0.942	3	3.3	0.917	4
1.4	0.941	4	2.4	0.716	6	3.4	0.779	6
1.5	0.958	3	2.5	0.902	5	3.5	0.925	3
1.6	0.891	5	2.6	1	1	3.6	1	1

Table 6: First-period distribution plan.

		Period 1													
To		Echelon 1			Echelon 2				Echelon 3			Echelon 4			
Form		1.1	1.3	1.5	2.1	2.2	2.3	2.6	3.1	3.5	3.6	4.1	4.2	4.3	4.4
Echelon 1	1.1				$0^a/26^b$	87/10	0/0	10/0							
	1.3				111/87	8/76	0/0	432/592							
	1.5				0/16	428/81	171/510	997/982							
Echelon 2	2.1								85/61	0/0	23/64				
	2.2								33/36	178/2	288/123				
	2.3								11/191	99/80	55/219				
	2.6								90/197	177/670	1064/588				
Echelon 3	3.1											97/137	5/0	25/0	76/313
	3.5											89/207	144/225	10/0	189/283
	3.6											287/287	376/311	385/315	309/31

a: distribution quantity of product 1; *b*: distribution quantity of product 2

Table 7: Second-period distribution plan.

		Period 2													
To		Echelon 1			Echelon 2				Echelon 3			Echelon 4			
Form		1.1	1.3	1.5	2.1	2.2	2.3	2.6	3.1	3.5	3.6	4.1	4.2	4.3	4.4
Echelon 1	1.1				14/1	26/77	0/19	0/0							
	1.3				3/140	28/195	45/0	549/410							
	1.5				79/7	42/58	302/200	1175/1278							
Echelon 2	2.1	2/1	1/1	0/1					0/115	32/0	60/29				
	2.2	1/0	2/2	3/0	Reverse				3/0	0/0	90/139				
	2.3	1/12	4/2	1/2					131/0	100/169	101/41				
	2.6	40/61	21/16	10/0					526/210	469/400	599/950				
Echelon 3	3.1	0/1	2/4	4/7	0/0	0/0	3/5	2/7				91/194	0/22	335/84	180/0
	3.5	6/5	1/7	0/0	0/4	4/6	2/1	1/0				219/191	2/319	222/19	128/192
	3.6	10/2	4/3	0/5	10/1	0/5	2/3	2/1				58/246	418/354	14/475	318/195
Echelon 4	4.1	2/1	4/5	0/1	0/2	1/1	0/1	3/2	1/2	2/4	1/0				
	4.2	2/1	1/2	1/1	1/1	0/0	0/2	2/0	1/2	1/1	1/0				
	4.3	1/0	1/0	0/1	1/0	0/0	0/0	0/1	0/0	1/1	0/0				
	4.4	2/2	4/4	1/0	0/2	3/1	0/2	2/1	1/1	3/4	1/1				

Table 8: Third-period distribution plan.

		Period 3													
To		Echelon 1			Echelon 2				Echelon 3			Echelon 4			
Form		1.1	1.3	1.5	2.1	2.2	2.3	2.6	3.1	3.5	3.6	4.1	4.2	4.3	4.4
Echelon 1	1.1				3/5	0/63	18/0	118/10							
	1.3				72/16	156/104	61/148	229/455							
	1.5				0/40	237/16	41/285	1319/1240							
Echelon 2	2.1	1/0	1/3	0/0					63/55	0/0	10/4				
	2.2	0/3	1/1	0/0					259/4	18/15	100/158				
	2.3	2/5	8/0	1/2	Reverse				47/215	1/34	66/163				
	2.6	34/8	42/62	8/13					111/236	429/586	999/754				
Echelon 3	3.1	9/3	4/0	3/5	1/1	2/1	7/1	6/5				245/108	140/143	0/153	58/69
	3.5	4/5	0/0	5/4	3/2	4/1	2/4	0/1				0/214	0/0	235/156	191/233
	3.6	1/0	2/6	6/7	2/5	1/6	4/2	1/0				228/46	330/337	441/264	117/377
Echelon 4	4.1	0/1	2/3	3/3	2/1	0/2	1/2	0/1	1/0	1/2	1/4				
	4.2	1/2	0/0	3/2	0/1	1/0	1/2	0/0	0/2	0/0	2/1				
	4.3	0/1	0/0	3/1	1/0	0/1	0/1	0/0	0/1	0/1	1/0				
	4.4	2/3	3/0	2/1	0/0	2/0	2/2	2/2	1/2	3/1	2/1				

4. CONCLUSIONS

This paper established a methodology to discuss the selection of cross-echelon reverse supply chain partners and distribution planning. Firstly, DEA is used to evaluate the business performance of every supply chain partner to efficiently reduce the supply chain framework and improve the execution efficiency of the system. Then, an optimal mathematical model for selection of partners in the supply chain with considering resource constraints and transportation and production losses. Finally, a PSO is used to solve the optimal mathematical to implement the distribution plan. In addition, the results of a case show that the proposed methodology can find the appropriate production and transportation plan for the proposed reverse logistics problem.

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