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An Intelligent Multi-agent Based Model for Collaborative Logistics Systems

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Abstract

In recent years, there has been a steady growth in the use of information systems in the logistics domain towards facilitating an agile distribution process. This study investigates the problem of collaboration planning in logistics and proposes an agent-based approach for better management of collaborative logistics. Based on the approach, a decision support system is designed that utilizes RFID technology for ensuring inventory accuracy.

The proposed approach involves three steps. In the first step, a conceptual agent based model is designed. In the second step, the game theory method is utilized to intensively study and analyze suppliers' collaboration and carriers' collaboration that represent major objectives proposed in the preceding model. Finally, correctness of the games is verified by formulating them mathematically. Developed optimization equations are fundamental to the operation research field. They employ the simplex and goal algorithms of linear programming.

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Keywords: Agent based model; decision support system; game theory; less than truck load; linear programming; supply chain management

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1. Introduction

Citizens' demands are increasing and accordingly, there is a considerable load on developing efficient distributive logistics. This accentuates the need to develop an optimized approach for handling and managing freights' distribution to eliminate any existing problems. Supply chain management is usually performed in collaboration between various logistical entities. The collaboration especially in the transportation field is happening by exchanging commodities

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and sharing vehicles' weights (Bailey *et al.*, 2011).

The collaboration requires rapid and effective technique. Agent technique is recommended because it provides velocity and accuracy in performing the work. Accordingly, implementing an agent based model will speed up the supply chain process, make it just-in-time, just-in-request, more accurate, and efficient.

Major addressed problem is the unorganized distribution of freight, which creates lots of negative consequences such as the LTL problem. This problem results in crowding of the city roads and air pollution, which in turn affects citizens' health negatively. Hernández *et al.* (2011) claim that LTL idle weights in transporting vehicles. Another considerable problem is the unorganized communication between various logistical entities, which causes deficiency in satisfying customers' requests. Thus, it is significant to investigate the reasons behind these and other problems and solve them, which is the goal of this study.

2. Conceptual Agent-based Model

The designed model as illustrated in Figure 1, includes six autonomous agents interacting properly with each other as well as with the surrounding environment. To achieve the overall goal of the model, each agent has a major role to play. Following is an explanation of each agent in the proposed intelligent decision support system:

- The RFIDG Agent: The agent major role is to receive data from the RFID reader and places them into the merchandise database after filtering to ensure their accuracy. Moreover, the agent removes duplicate scanned records and displays alert messages in case of sensing exotic behaviors. Such as scanning a product that has been placed in the wrong area. Since scanning products involve human intervention, then there are chances for errors. Thus, the agent's major role becomes significant. Besides its major role, the RFIDG agent holds all products unfiltered information. Then, whenever any supplier inquires about any particular information of a specific product that is not entered into the filtered accurate database, the supplier will contact the RFIDG agent to get that particular detail.
- The Retailer Agent: When a human retailer logs into the system to request a shipment; the retailer agent notifies both the supplier agent and the carrier agent. It notifies the supplier agent to allow it to search in its database about the requested freight. While, notifying the carrier agent to enable it to check in its records for arranged shipments with LTL that will pass nearby the retailer's saved location in the system, it also recommends lower cost delivery of shipments to that retailer in a specific date, which will eliminate the LTL problem.
- The Supplier Agent: Once the retailer agent informs the supplier agent about a new retailer's request; the supplier agent starts searching inside its database about the requested product and then, replies back to the retailer about the status of the request as either available or not. It also recommends another availability date of the needed product or another available amount if different from retailer's request. In case the retailer requests unavailable commodity or more than the available amount in supplier's depot, the supplier agent will search other suppliers in the system who have enough amount of the requested commodity with reasonable price and high quality, and will recommend to the original supplier to collaborate with them. Suppliers' collaboration allows satisfying customers' needs. Note that for each specific supplier, the agent keeps record of the most collaborated suppliers. Thus, it recommends them first at later times for that specific supplier, which makes the supplier agent an intelligent agent. In addition, the supplier agent rate suppliers' performance, which is based on many criteria such as availabilities of their products, qualities, prices, and coping situation with other suppliers. In the recommendation list of suppliers to collaborate with, suppliers with higher rates get listed after the most collaborated suppliers.
- The Carrier Agent: In case the shipment request is confirmed by the retailer then, the supplier agent informs the carrier agent that there is a shipment delivery request. Therefore, the carrier agent will search inside its database for an available vehicle in the required date and with adequate weight to assign it to the delivery order. Afterwards, the carriers' database will be updated automatically and a confirmation number is generated and sent through the agent to both the supplier and the retailer. Moreover, once a retailer logs-in to the system, the carrier agent gets notified by the retailer agent that she needs a freight delivery. Hence, the carrier agent looks for arranged delivery vehicles with LTL that will pass nearby that retailer's location to offer lower cost shipments to that retailer enabling him to allocate the available empty weight in the shipping vehicle. The carrier agent rates carriers' performance, which is based on their efficiency in delivering freights to right retailers and within expected times. For instance, the carrier agent weights a carrier high if he always delivers on time and lowers his rate if he has late deliveries for few times.

- The Network Agent: This agent is responsible about measuring congestion on delivery routes and informing the city administrator agent about existing severe congestion. In addition, it assigns the supplier's location as an origin point and the retailer's location as a destination point to calculate the shortest delivery path between them and sends it to the carrier to enable him to deliver freights on time. Afterwards, the agent scans the shortest delivery route looking for neighboring retailers to the original one who initiated the freight's delivery order and sends the list to the carrier agent. This enables the carrier agent to send lower cost delivery offers to the retailers on the neighboring list if the freight's order is causing LTL problem. The agent saves shortest paths with their neighboring retailers list to be able to recall them faster on future shipments.
- The City Administrator Agent: Once the carrier agent informs the city administrator agent about arranged freight delivery order, the agent announces the delivery rules of the city where the shipment is arranged, to both the carrier and the supplier. Announcing cities' delivery rules enable suppliers and carriers to obey with the rules. In case of rules violation, the city administrator agent recommends other alternative solutions to them. One solution can be dividing the shipment on two smaller vehicles instead of the large prohibited vehicle's size. Another solution can be changing delivery time to be within allowed times. The city administrator agent should provide the carrier with the second shortest delivery route in case of receiving severe congestion alerts from the network agent. In case, the carrier cannot go through the second shortest delivery route, then the agent should be able to take other decisions. Another solution can be dispatching shipment to another retailer than the planned one in case of delivering to more than one retailer. Successful decisions will be stored in agent's history to be used in future similar situations. Thus, the agent is considered intelligent because it uses its knowledge and historical information to recommend best decisions.

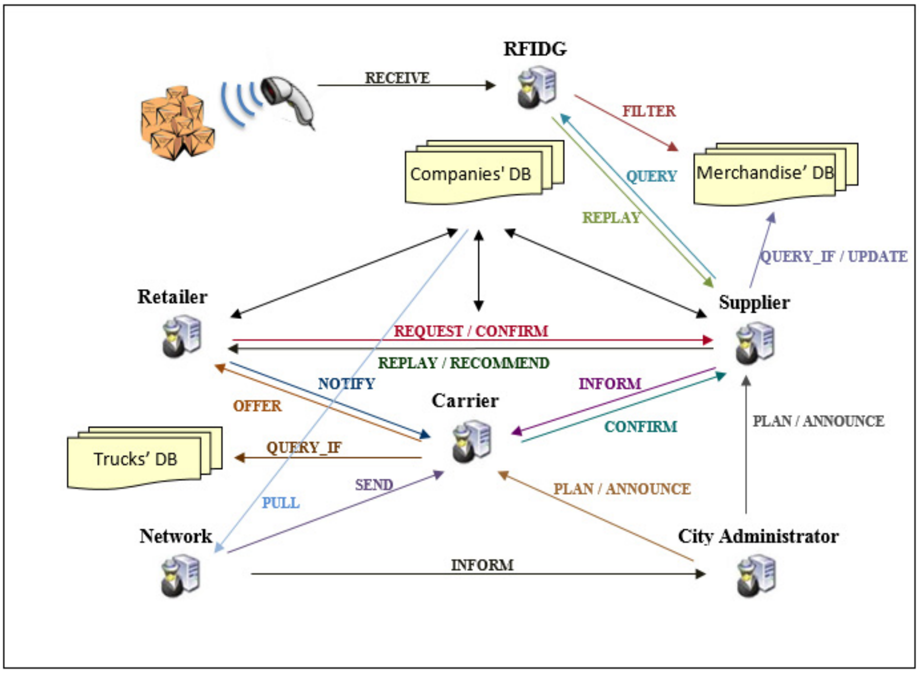

Fig.1. Designed conceptual multi-agent based model

3. Game Theory for Suppliers in Coalition

This game represents suppliers' collaboration toward maximizing profits, and at the same time satisfying retailers' needs. The game is a sequential-move game in which players take turns. Therefore, buyers play first to place purchasing orders and afterwards, sellers take turn to evaluate buyers' decisions and respond to them accordingly. Although, the game is a multistage (dynamic) game; it also has simultaneous-moves of players at the time that each set of players take turn. This occurs when all of the buyers request purchases from sellers at the same time without knowing that other buyers are also requesting the same seller for the same product. The game attains the "Nash

Equilibrium” solution concept since it intends to profit all players entering the game and since suppliers cannot achieve better profits by switching strategies.

Players
S_x: The set of all suppliers entering the game as sellers, for x ∈ $\{1,2,3, \dots, n\}$.
B_y: The set of all suppliers entering the game as buyers, for $y \in \{1,2,3, \dots, m\}$.

Notions
SC_x: Seller's cost price, SS_x: Seller's selling price, SP_x: Seller's total profits.
BC_y: Buyer's cost price, BS_y: Buyer's selling price, BP_y: Buyer's profits.

Strategies

Some of the rules were common between all players as following:

- All suppliers concern with making higher profits, which represent the payoff in this game
- Suppliers enter the game as either seller or buyer but, once a supplier enters; he is not allowed to change status

Beside the common strategies between both of the sellers and buyers, each one of them has his own defined rules. For example sellers follow below strategies:

1. Aim to sell higher quantity of their products
2. Prefer to sell with the assigned selling price not lower
3. If a seller found out that two buyers or more causing him the same profits then, he will sell to the buyer with the lowest id assuming that s\he entered the game earlier and thus, got the higher priority.

On the other hand, buyers follow below sequential strategies:

1. Buy products with higher quality
2. Buy from sellers who offer selling prices that are less than both of the buyer's cost price and selling price i.e. $SS_x < BC_y$ & $SS_x < BS_y$. Set this situation as “Higher Profits”
3. Buy from sellers who offer selling prices that are equal the buyer's cost price but, less than buyer's selling price i.e. $SS_x = BC_y$ & $SS_x < BS_y$. Set this situation as “Same Profits”
4. Buy from sellers who offer selling prices that are greater than the buyer's cost price but, less than buyer's selling price i.e. $SS_x > BC_y$ & $SS_x < BS_y$. Set this situation as “Lower Profits”
5. Buy from sellers who offer selling prices that are equal the buyer's selling price for the aim of satisfying consumer's order (not for increasing supplier's profit) i.e. $SS_x = BS_y$. Set this situation as “Break Even”. Break even points occur when the profits equal zero.
6. Do not buy from sellers who offer selling prices that are greater than the buyer's selling price i.e. $SS_x > BS_y$. Set this situation as “Loss”.

3.1. Game Theoretic Scenario

Assume that five sellers and three buyers entered the game as illustrated in Table 1.

Table 1. Suppliers entered the game (input table)

Seller ID	Product	Availability Date	Quantity	Quality	Cost Price	Selling Price
S_1	Rice	02-April-2014	900 Kg	High	$20/ Kg	$24/ Kg
S_2	Rice	16-January-2014	3000 Kg	Middle	$15/ Kg	$20/ Kg
S_3	Rice	01-May-2014	2000 Kg	Low	$09/ Kg	$17/ Kg
S_4	Rice	04-May-2014	500 Kg	High	$19/ Kg	$20/ Kg
S_5	Rice	28-February-2014	1000 Kg	High	$19/ Kg	$22/ Kg
Buyer ID	**Product**	**Required Date**	**Quantity**	**Cost Price**	**Selling Price**	**Requirement**
B_1	Rice	01-August-2014	1800 Kg	$18/ Kg	$20/ Kg	(Selling Price -1)
B_2	Rice	30-May-2014	2000 Kg	$20/ Kg	$24/ Kg	Same Selling Price
B_3	Rice	06-June-2014	3500 Kg	$20/ Kg	$25/ Kg	Same Selling Price

Looking to the first buyer, he needs 1800 Kg of rice. Thus, looking for sellers with "High" quality first. There is S_1 , S_4 , and S_5. The buyer decided to purchase all the 500 Kg of rice from S_4. This decision is made because S_4 has the lowest selling price among other sellers that selling high quality products. The buyer still needs more 1300 Kg of rice. Considering that the other two sellers with high quality products will cause a loss to the buyer since their selling prices ($24 and $22) are higher than the buyer's selling price ($20). Then, the buyer decided to buy the rest needed kilograms of rice from S_2. Rest of the buyers will evaluate sellers same as the first buyer did. Therefore, the program will generate the first output Table 2.

Table 2. Maximizing profits from buyers' perspective (output table1)

BuyerID	SellerID	Sellers Ordering	Bought Quantity	Quality	Profits	Status
B_1	S_1		0 Kg	High	$0	Loss
B_1	S_2	2	1300 Kg	Middle	$1300	Lower Profits
B_1	S_3		0 Kg	Low	$0	Higher Profits
B_1	S_4	1	500 Kg	High	$500	Lower Profits
B_1	S_5		0 Kg	High	$0	Loss
B_2	S_1	3	500 Kg	High	$0	Break Even
B_2	S_2		0 Kg	Middle	$0	Same Profits
B_2	S_3		0 Kg	Low	$0	Higher Profits
B_2	S_4	1	500 Kg	High	$2000	Same Profits
B_2	S_5	2	1000 Kg	High	$2000	Lower Profits
B_3	S_1	3	900 Kg	High	$900	Lower Profits
B_3	S_2	4	1100 Kg	Middle	$5500	Same Profits
B_3	S_3		0 Kg	Low	$0	Higher Profits
B_3	S_4	1	500 Kg	High	$2500	Same Profits
B_3	S_5	2	1000 Kg	High	$3000	Lower Profits

Note that, the "Sellers Ordering" filed in above table indicates the best order of sellers from the buyers' point of view in regard to making higher profits while buying best quality in market.

Following is the first version of buyers' decisions about recommended sellers to collaborate with.

$B_1 \rightarrow S_4 , S_2$
$B_2 \rightarrow S_4 , S_5 , S_1$
$B_3 \rightarrow S_4 , S_5 , S_1 , S_2$

After buyers have sent purchasing requests to sellers; each seller will evaluate all buyers, paying more attention to the ones that already sent him purchasing request. Sellers will assign sequential numbers to buyers starting by one and moving up. Note that one means the buyer with the best assessment in regards to purchasing the highest amount and/or making the highest profits. The buyers ordering is demonstrated in the "Buyers Ordering" field of Table 3. The first seller received two purchasing orders from B_2 and B_3. Therefore, the seller calculated the profits achieved from collaborating with each one of the buyers. It is found that B_3 will maximize the seller's profits since B_3 ordered all of the available kilograms of rice with S_1. Hence, the seller decided to collaborate fully and sell to B_3.

The rest of the sellers will evaluate buyers same as the first one did. Note that, the third seller has a low quality product and thus, no buyer asked him for a purchase. However, because this game satisfies the "Nash Equilibrium" solution concept; where no player supposed to lose, then by the end of the game the third seller founds that both of B_2 and B_3 still needs more kilograms of rice. While, all other sellers have sold out their quantities. Therefore, the seller offered his available kilograms of rice to both of the buyers. Hence, the program will generate the second output Table 3, which represents maximizing profits from sellers' perspective.

Table 3. Maximizing profits from sellers' perspective (output table2)

Seller ID	Buyer ID	Buyers Ordering	Sold Quantity	Profits	Buyer's Requirement
S_1	B_1		0 Kg	$0	(Selling Price -1)
S_1	B_2	2	500 Kg	$2000	Same Selling Price
S_1	B_3	1	900 Kg	$3600	Same Selling Price
S_2	B_1	2	1300 Kg	$5200	(Selling Price -1)
S_2	B_2		0 Kg	$0	Same Selling Price
S_2	B_3	1	1100 Kg	$5500	Same Selling Price
S_3	B_1		0 Kg	$0	(Selling Price -1)

S_3	B_2		0 Kg	$0	Same Selling Price
S_3	B_3		0 Kg	$0	Same Selling Price
S_4	B_1		500 Kg	$0	(Selling Price -1)
S_4	B_2	1	500 Kg	$500	Same Selling Price
S_4	B_3	1	500 Kg	$500	Same Selling Price
S_5	B_1		0 Kg	$0	(Selling Price -1)
S_5	B_2	1	1000 Kg	$3000	Same Selling Price
S_5	B_3	1	1000 Kg	$3000	Same Selling Price

Based on Table 3 and after sellers' evaluation to buyers; sellers made their decisions about recommended buyers to collaborate with as following:

$S_1 \rightarrow B_3$
$S_2 \rightarrow B_1, B_3$
$S_3 \rightarrow B_2, B_3$
$S_4 \rightarrow B_2$
$S_5 \rightarrow B_2$

After_that sellers confirmed their decisions, and assuming that buyers agreed on these collaboration decisions. Because it maximizes their profits, as well as, it satisfies their purchasing requests. We can now visualize the final version of buyers' decisions about recommended sellers to collaborate with:

$B_1 \rightarrow S_2$
$B_2 \rightarrow S_4, S_5, S_3$
$B_3 \rightarrow S_1, S_2, S_3$

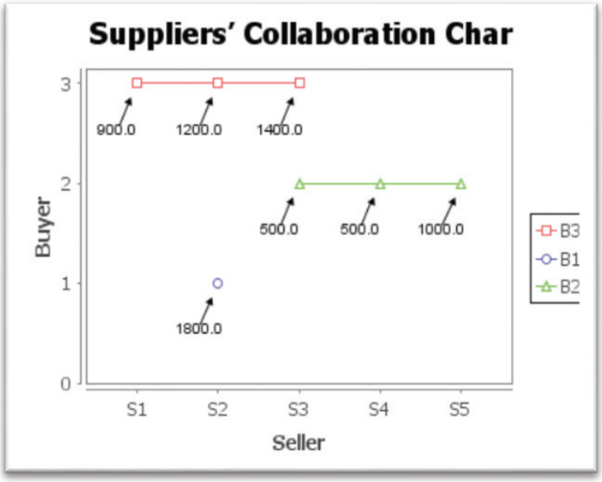

Fig. 2. Suppliers' collaboration chart

Figure 2. Demonstrates the most recommended supplies to collaborate with. Noticing that, all entered players have collaborated either fully or partially and that there is no loser in this scenario. Thus, it fulfills the "Nash Equilibrium" solution concept.

3.2. Mathematical Formulation

This section formulates the main objective of the modeled game theory for suppliers in coalition mathematically. Considering the main objective, which is to maximize suppliers achieved profits then, a linear programming model that is solved using the simplex algorithm is developed.

Decision variable

Q_x: Quantity supplied by the x^{th} supplier. $x \in \{1,2,3,\dots,n\}$. Q_x is represented in kg.

Parameters

R_x: Requested quantity from the x^{th} supplier.
A_x: Available quantity with the x^{th} supplier.
Ps_x: Selling price of the x^{th} supplier.
Pc_x: Cost price of the x^{th} supplier.
P_x: Total profits achieved by the x^{th} supplier(s).

Objective function

The objective function concerns with maximizing suppliers' profits through satisfying retailers' purchasing orders.

$$\text{Max } P_x = \sum_{x=1}^{n}(Ps_x - Pc_x) * Q_x \quad (1)$$

Subject to

$$Q_x \leq A_x \text{ for } x \in \{1,2,3 \dots, n\} \quad (2)$$

$$\sum_{x=1}^{n} Q_x \leq \sum_{x=1}^{n} R_x \quad (3)$$

$$Q_x \geq 0, \text{ for } x \in \{1,2,3,\dots,n\} \quad (4)$$

Constraint (2) ensures that the supplier has enough quantity of the requested freights to be supplied. While, constraint (3) ensures that the total supplied quantity satisfied the retailer's requested quantity of the freight. Finally, constraint (4) makes sure that there is a positive quantity of the freight to supply, for $x \in \{1,2,3,\dots,n\}$.

Numerical example

Assume that three suppliers in the market want to collaborate by sharing their available quantity of the products as illustrated in Table 4.

Table 4. Details of three suppliers in coalition

Suppliers (x)	Available Quantity (A_x)	Requested Quantity (R_x)	Cost Price (Pc_x)	Selling Price (Ps_x)
1	5000	1000	3	4
2	7000	8000	5	7
3	4800	5000	4	7

Case (1): Coalition between supplier 1 and 2

The problem is:
Maximize $P_{(1,2)} = \sum_{x=1}^{2}(Ps_x - Pc_x) * Q_x = 1 * Q_1 + 2 * Q_2$
Subject to:
$Q_1 \leq 5000$
$Q_2 \leq 7000$
$Q_1 + Q_2 \leq 9000$
$Q_1 \geq 0, \ Q_2 \geq 0$

Substituting values of given parameters and putting the problem in a free calculator for LP[1] , we get the following solution; the maximum $P_{(1,2)} = 1 * 2000 + 2 * 7000 = 16000\$$

The optimal value appeared at the point $\widehat{A}$ with the following co-ordinates (2000, 7000). The two resulted co-ordinates

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[1] http://www.zweigmedia.com/RealWorld/simplex.html

clarify the two needed quantities to supply.

Rest of the cases will be calculated similar to the first case. Table 5 summarizes all the collaborative cases and types.

Table 5. Numerical analysis for three suppliers in coalition

Supplier	Available Quantity	Requested Quantity	Supplied Quantity	Satisfy Customer?	Cost Price	Selling Price	Achieved Profits
1	5000	1000	1000	Y	3	4	1000
2	7000	8000	7000	N	5	7	14000
3	4800	5000	4800	N	4	7	14400
12	12000	9000	9000	Y			16000
13	9800	6000	6000	Y			15600
23	11800	13000	11800	N			28400
123	16800	14000	14000	Y			30600

We conclude from Table 5, that the grand full coalition between all the three suppliers in the market resulted in satisfying all the requested quantities of the freights. Moreover, each supplier was able to achieve higher profits than when working individually. Furthermore, the second and the third suppliers were not able to satisfy their customers' orders when working separately. On the other hand, when they collaborated with the other supplier in the market, they were able to satisfy their customers' requests.

We notice significant increase in the achieved profits as a result of sharing products' quantities in an efficient collaborative environment. Thereby, suppliers are highly recommended to work together and participate in coalition.

4. Game Theory for Carriers in Coalition

This game ensures successful collaboration among multiple carriers in the coalition. The game is a cooperative one time game because all players have the same interest, which is to deliver the requested quantities of the freights utilizing fully occupied shipping vehicles. Releasing fully occupied vehicles qualify the retailers to get minimized delivery costs, and at the same time, eliminate the LTL problem. The game includes mathematical analysis that assist in making optimized decisions in regard to utilizing capacities of the transporting vehicles leaving less empty weights in them. Thus, it is considered an optimal decision.

Players

B_j: The set of all carriers assigned in the game as benefactors, $j \in \{1,2,3, \ldots.., k\}$.
O_j: The set of all carriers assigned in the game as occupiers, $j \in \{1,2,3, \ldots.., k\}$.

Notions

Q_j: Quantity of the products asked to be delivered by the j^{th} carrier.
V_{ij}: The i^{th} collaborative shipping vehicle that belongs to the j^{th} carrier. Where i is a finite number indicating vehicles' id.
$D^{j}_{V_{ij}}$: Delivered quantity of the products by the j^{th} carrier utilizing the V_{ij} shipping vehicle.
Y_i: Maximum weight of the i^{th}collaborative shipping vehicle.
Z_j: Delivery cost charged by the j^{th} carrier.
LTL_i: Less than truck load in the i^{th} shipping vehicle.

Assumptions

1) Each carrier enter the game has exactly the same four weights of the collaborative shipping vehicles, which are specified as following: 11000, 9000, 7000, and 5000 kg.
2) Occupying full truckload qualifies 8% off the total delivery cost from each fully occupied vehicle.

Strategies

1) All carriers concern with occupying full truckloads to qualify their retailers to get minimized delivery cost, which represent the payoff in this game
2) Carriers can be either benefactors (their id starts with the letter "B") or occupiers (their id starts with the letter "O") but, not both. The game decides the role that each carrier play.
3) Two main steps are followed to reach the optimal solution:
    i. First, the set of the collaborative shipping vehicles to be released is identified.
    ii. Second, each carrier starts fulfilling his delivery demands from his released vehicles.
4) Assign carriers whom fully satisfied their delivery demands and still have available empty weights in their shipping vehicles as benefactors. On the other hand, assign carriers whom their planned released vehicles have not fully satisfy their delivery demands as occupiers.

4.1. Game Theoretic Scenario

Assume that three carriers entered the game as illustrated in Table 6.

Table 6. Carriers entered the game (input table)

Carrier ID ($\boldsymbol{j}$)	Total Requested Quantities ($\boldsymbol{Q_j}$)
1	17000
2	26000
3	13000

First step: Identify the optimal set of the collaborative shipping vehicles to release

This step starts from the total requested quantities asked to be delivered by all carriers entered the game. Then, subtract it from the largest available vehicle weight ($Y_i - \sum_{j=1}^{k} Q_j$) till reaching zero. Note that, if the resultant quantity to be delivered equals or is divisible on the available vehicles' weights then, it will automatically occupy them. Based on the first assumption; there will be twelve shipping vehicles available for the coalition as illustrated in Table 7.

Table 7. Optimal set of released shipping vehicles (output table1)

Shipping Vehicles' Weights (Y_i)	Total Requested Quantities (Q_j)
$V_{11} = 11000$	56000
$V_{12} = 11000$	45000
$V_{13} = 11000$	34000
$V_{21} = 9000$	23000
$V_{22} = 9000$	14000
$V_{23} = 9000$	0
$V_{31} = 7000$	0
$V_{32} = 7000$	0
$V_{33} = 7000$	0
$V_{41} = 5000$	5000
$V_{42} = 5000$	0
$V_{43} = 5000$	0

Based on the results of Table 7, we conclude that six collaborative shipping vehicles should be released, which are $V_{11}, V_{12}, V_{13}, V_{21}, V_{22}, \& V_{41}$.

Second step: Satisfy carriers' delivery orders

This step fulfils each carrier delivery order utilizing his released shipping vehicles that were decided on the previous step. Subtract the total quantities of the products to be delivered by each carrier from the total available weight of all his released shipping vehicles. Based on the sign of the resulting number each carrier's role will be specified in the game. If the resulted number is positive then, the carrier will be assigned as a "Benefactor". While, if the resulted number is negative then, the carrier will be assigned as an "Occupier". Moreover, this step indicates the exact amount to give or to occupy.

Table 8. Assigned quantities to satisfy each carrier delivery order (output table2)

Carrier	Released Vehicles	$\sum_{i=1}^{4k} Y_{ij} - Q_j$	Assigned Role
1	V_{11} = 11000	25000 – 17000 = +8000	Benefactor
	$V_{21} = 9000$		
	$V_{41} = 5000$		
2	V_{12} = 11000	20000 – 26000 = -6000	Occupier
	$V_{22} = 9000$		
3	$V_{13} = 11000$	11000 – 13000 = -2000	Occupier

Based on the results of Table 8, we conclude that the first carrier is able to deliver all his requested quantities of the freight using his shipping vehicles. Furthermore, he has 8000 kg available empty weights in his shipping vehicles. Hence, he gives the empty weights to other carriers in the game. The second carrier is able to deliver only 20000 kg utilizing his planned shipping vehicles and he still needs to deliver 6000 kg. Thus, he will receive the needed weight from the benefactor's first carrier. The Third carrier is able to deliver only 11000 kg utilizing his planned shipping vehicle and he still needs to deliver 2000 kg. Thus, he will receive the needed weight from the benefactor's first carrier.

Table 9. Final quantities to deliver (output table3)

Carrier	Delivered quantity ($D^{j}_{V_{ij}}$)	Total ($\sum_{i=1}^{4k} D^{j}_{V_{ij}}$)
1	$D^{1}_{V_{11}}$= 11000	17000
	$D^{1}_{V_{21}}$= 6000	
2	$D^{2}_{V_{12}}$= 11000	26000
	$D^{2}_{V_{22}}$= 9000	
	$D^{2}_{V_{21}}$= 3000	
	$D^{2}_{V_{41}}$= 3000	
3	$D^{3}_{V_{13}}$= 11000	13000
	$D^{3}_{V_{41}}$= 2000	

The first carrier who is requested to deliver a total of 17000 kg of the freight, delivered it on two shipments utilizing his first and second collaborative transporting vehicles. The second carrier who is requested to deliver 26000 kg of the freight, delivered it on four shipments, utilizing his first and second transporting vehicles. Moreover, he collaborated with the first carrier to deliver his two remained shipments. While, the third and the last carrier who is requested to deliver 13000 kg of the freight, delivered it on two shipments, utilizing his first transporting vehicle and collaborating with the first carrier to deliver his remained quantity of the freight. Concluding that all of the released collaborative vehicles are fully occupied and thus, they are free of the LTL problem.

Assuming that all of the carriers in coalition agreed on these collaboration decisions. Because it satisfies their delivery orders, as well as, it qualifies them to minimize the delivery cost to their retailers. We can now visualize the carriers' collaboration chart as illustrated in Figure 3.

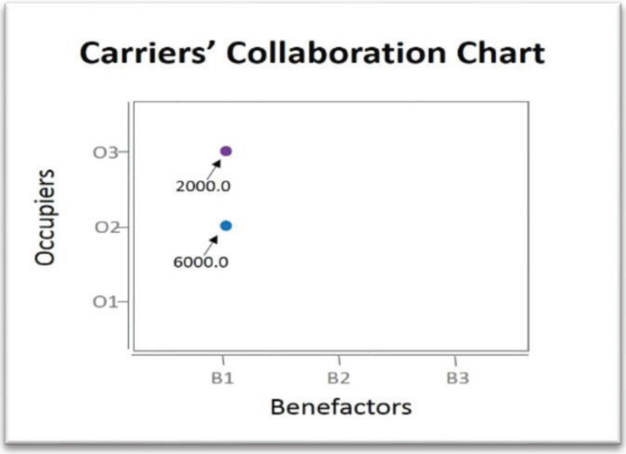

Fig. 3. Carriers' collaboration chart

Noticing that, all entered players have collaborated either fully or partially and that there is no loser in this scenario. Thus, it satisfies the "Nash Equilibrium" solution concept.

4.2. Mathematical Formulation

This section formulates the main objectives of the modeled game theory for carriers in coalition mathematically. Considering the main objectives, which are to minimize the delivery cost to retailers and to maximize the shipping vehicles' utilization rate. Another implicit objective of the game is to minimize late deliveries because carriers' collaboration lead eventually to expedite the freights' dispatching and distribution process. All presented objectives developed using a multi-objective linear programming model that is solved using the goal algorithm. Presented model is similar in its development to a previous goal programming model suggested by Erdem and Göçen (2012) to solve the supplier evaluation and order allocation problem. The goal programming method ensures overreaching the targeted goals' levels.

Decision variable

$D_{V_{ij}}^{j}$: Delivered quantity of the products by the j^{th} carrier utilizing the V_{ij} shipping vehicle.

Parameters

α_{ij}: Fixed delivery costs. $i \in \{1,2,3,\dots,4k\}$ and $j \in \{1,2,3,\dots,k\}$
β_{ij}: Variable delivery costs.$i \in \{1,2,3,\dots,4k\}$ and $j \in \{1,2,3,\dots,k\}$
μ_i: Maximum weight of released vehicles. $i \in \{1,2,3,\dots,4k\}$
L_i: Late delivery rate. $i \in \{1,2,3,\dots,4k\}$

Goals

i. Minimize delivery cost

$$\frac{D_{V_{ij}}^{j}}{\sum_{i=1}^{4k} D_{V_{ij}}^{j}} * \sum_{i=1}^{4k}\left(\alpha_{ij}+\beta_{ij}\right) \leq Delivery\ cost\ goal, \text{for } j=1,2,3,\dots,k. \quad (1)$$

ii. Maximize vehicles utilization rate

$$\frac{\sum_{i=1}^{4k}\sum_{j=1}^{k} D_{V_{ij}}^{j}}{\sum_{i=1}^{4k}\mu_i} \geq \mathit{Vehicles}\text{ utility goal, for } j = 1,2,3,\dots,k \text{ and } i = 1,2,3,\dots,4k. \tag{2}$$

Minimize late deliveries

$$\frac{D_{V_{ij}}^{j}}{\sum_{i=1}^{4k} D_{V_{ij}}^{j}} * \sum_{i=1}^{4k} L_i \leq \mathit{Delivery\ time\ goal},\text{for } j = 1,2,3,\dots,k. \tag{3}$$

Regular constraints

$$\sum_{i=1}^{4k} D_{V_{ij}}^{j} \geq\ Q_j \text{for } j\ \in \{1,2,3,\dots,k\} \tag{4}$$

$$\frac{\sum_{i=1}^{4k}\sum_{j=1}^{k} D_{V_{ij}}^{j}}{\sum_{i=1}^{4k}\mu_i} = 1,\text{for } i\ \in \{1,2,3,\dots,4k\} \text{ and } j\ \in \{1,2,3,\dots,k\} \tag{5}$$

$$D_{V_{ij}}^{j} \geq 0,\ \text{ for } i\ \in \{1,2,3,\dots,4k\} \text{ and } j\ \in \{1,2,3,\dots,k\} \tag{6}$$

Constraint (4) ensures satisfying the requested quantity of the freight by making sure that the delivered quantity through all shipments is greater than or equal the requested quantity. While, constraint (5) ensures that the total shipped quantities by all transporting vehicles are occupying full truckloads. Constraint (6) makes sure that the shipped quantity cannot be negative.

Since the multi-objective linear programming model has three goals then, we denote each goal as G_γ, for $\gamma \in \{1,2,3\}$. Overreaching a goal is represented by a positive goal deviation variable G_γ^+.While, miss-reaching a goal is represented by a negative goal deviation variable G_γ^-.

Goal deviation constraints

Delivery cost goal:

$$\frac{D_{V_{ij}}^{j}}{\sum_{i=1}^{4k} D_{V_{ij}}^{j}} * \sum_{i=1}^{4k}\left(\alpha_{ij} + \beta_{ij}\right) - (\,G_1^+ -\ G_1^-) = \mathit{Delivery\ cost\ goal},\text{for } j = 1,2,3,\dots,k. \tag{7}$$

Vehicles utility goal:

$$\frac{\sum_{i=1}^{4k}\sum_{j=1}^{k} D_{V_{ij}}^{j}}{\sum_{i=1}^{4k}\mu_i}\ - (\,G_2^+ -\ G_2^-) = \mathit{Vehicles\ utility\ goal}, j = 1,2,3,\dots,k \text{ and } i = 1,2,3,\dots,4k. \tag{8}$$

Delivery time goal:

$$\frac{D_{V_{ij}}^{j}}{\sum_{i=1}^{4k} D_{V_{ij}}^{j}} * \sum_{i=1}^{4k} L_i - (\,G_3^+ -\ G_3^-) = \mathit{Delivery\ time\ goal},\text{for } j = 1,2,3,\dots,k. \tag{9}$$

Objective function

The omnibus objective function combines all identified goals. It is developed in respect to the cost associated with the deviation from the targeted goals' levels. Hence, a total deviation cost variables C_γ^+ and C_γ^- for $\gamma \in \{1,2,3\}$ are identified. The objective function intends to minimize these encountered costs.

$$\text{Minimize } \sum_{\gamma=1}^{3} C_\gamma^+\ G_\gamma^+ +\ \ C_\gamma^-\ G_\gamma^- \tag{10}$$

Numerical example

Assume that there are three carriers in collation and recall the notations used in Table 10.

$4k$: The total number of the collaborative shipping vehicles.

$\sum_{i=1}^{4k} Y_i$: Maximum available weight of all shipping vehicles.

Q_j: Total requested quantities of the products to be delivered by the carriers.
Z_j: Total delivery cost. For simplicity purposes we assume that the shipping cost equals two dollar per each delivered kilogram. $Z_j = (Q_j * 2)$, for $j \in \{1,2,3,\dots,k\}$
Used V_{ij}: The optimal set of the collaborative vehicles to fully satisfy carriers' delivery orders.
V_{ij} No.: The number of the used vehicles to perform the delivery.
LTL_i: The final resulted empty weight in the released shipping vehicles. It is calculated by subtracting the delivered quantity from the maximum weight of the released vehicles: $\sum_{i=1}^{4k} \mathrm{LTL_i} = (\sum_{i=1}^{4k} \mu_i - Q_j)$, for $j \in \{1,2,3,\dots,k\}$
Z_j^*: The updated total delivery cost after applying the percent of discount on it. It is calculated as:
$Z_j^* = (Z_j - \%DiscountZ_j)$[2] , for $j \in \{1,2,3,\dots,k\}$
%Dict., calculates the percent of discount that is qualified only when occupying full truckloads. It equals 0.08 for each fully occupied vehicle.

Table 10. Numerical analysis for three carriers in coalition

Carrier	$4k$	$\sum_{i=1}^{4k} Y_i$	Q_j	Z_j	Used V_{ij}	V_{ij} No.	LTL_i	Z_j^*	% Dict.
1	4	32000	17000	34000	11000, 7000	2	1000	31280	8%
2	4	32000	26000	52000	11000, 9000, 7000	3	1000	43680	16%
3	4	32000	13000	26000	5000, 9000	2	1000	23920	8%
12	8	64000	43000	86000	11000, 11000, 9000, 7000, 5000	5	0	51600	40%
13	8	64000	30000	60000	11000, 7000, 7000, 5000	4	0	40800	32%
23	8	64000	39000	78000	11000, 9000, 7000, 7000, 5000	5	0	46800	40%
123	12	96000	56000	112000	11000, 11000, 9000, 9000, 9000, 7000	6	0	58240	48%

Analyzing generated results in Table 10; the higher encountered discount rate appeared in the grand full coalition between all the three carriers as 0.48. That is because the grand coalition resulted in satisfying all the requested delivery orders utilizing only six collaborative shipping vehicles and leaving no empty weights in them. On the other hand, when carriers worked separately; they released seven shipping vehicles leaving a total of 3000 kg LTL.

Thereby, we notice that the carriers encountered the LTL problem when working individually while, the LTL problem was eliminated when they worked with each other's in an efficient collaborative environment. Furthermore, the carriers in the collation achieved higher discounts rates than the carriers in the non-collaborative scenarios. Thus, carriers are highly recommend to work together and participate in coalition.

5. Conclusion

The study presented a complete decision support system that goes along with the future foreseeable performances of modern logistics systems. It proposes employing advanced and intelligent technologies such as the agents and the RFID, and integrate them all into one powerful application to facilitate a successful collaboration between the various logistical entities. Thereby, it satisfies customers' expectations of delivering high quality standards.

This study highly recommends collaboration and provides efficient strategies to achieve successful collaboration between various logistics entities. Stakeholders might be satisfied running their businesses separately with no connection with other stakeholders in the market. However, there are considerable financial benefits that stakeholders might not pay attention to if they did not participate in collaborative scenarios. "*Transferring opportunistic dogma to be synergetic ethos of collaboration, succeeded majority of logistics organization*" (Giannakis & Louis, 2011).

Moreover, Lynch (2001) claims that the key to understanding collaborative logistics depends on recognizing how costs are distributed in logistics networks. Many scientists are promoting collaborative logistics. Tsai (2006) admits that efficient collaboration builds trust and strengthens communication. Building trusts is a demand in collaborative logistics because there is a need to share information and data between various logistical entities. Accordingly, building trusted relationships becomes significant. In addition, sharing information between supply chain entities

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[2] http://math.about.com/od/percent/a/alg1perc.htm

enable them to take better decisions and thus, optimize the dynamic logistics work (Mei, 2004). Businesses gain success through collaboration. Tarabori (2011) claims that collaborative relationships lead to significant financial gains.

Implementing the proposed application meets several essential advantages such as, automatism and real-time response, support decision making, achieve cost reduction, increase suppliers' profits, facilitate healthier environment, ensure high quality standards, attain time management, and provide collaborative framework. Major contributions of the study stems from considering rapid future advances, which make not only the technologies and strategies significant but also exploiting them to provide quality and velocity in delivering to customers.

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