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Multi Agent Approach for Environmental Customer Collaboration: Study Case in Automotive Spare Parts Sector

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ABSTRACT

Recently, Environmental Customer collaboration has gained a considerable attention among researchers and Industrial enterprises. Many studies highlight that organizations can achieve a good performance level while considering customer collaboration and environmental regulation. However, the literature in the Green Supply Chain Management (GSCM) suggests having a more structured collaboration and information exchange process based between Supply Chain partners on new technologies. Towards this end, a hybrid approach based on Multi Agent Systems and Multi Objective Linear Programming is proposed as mean of automating and facilitating the environmental customer collaboration process. This research shows that MAS can be utilized to reduce the complexity and facilitate communication in the GSCM context. The applicability of the developed MAS approach is demonstrated using an industrial case study in the automotive spare parts sector.

1. INTRODUCTION

With increasing environmental awareness from customers, stakeholders, government legislations and environmental organizations, companies are asked to implement more sustainable strategies to reduce the environmental impact of the industrial activities. Therefore, all these internal and external calls led the companies to adopt the concept “Green” into their Supply Chain. [1]. Green Supply Chain considers factors like resources efficiency and environmental impact in the Supply Chain, aiming to reduce impact on environment, maximize the resources utilization and economic benefits across the entire product lifecycle [2, 3]. Furthermore, many studies highlight that practicing Green Supply Chain leads to benefits like reduced waste, reduced air emissions and increased energy efficacy [4]. The environmental customer collaboration has been defined as a very important Green Supply Chain practice that can improve the organizations performance [5]. Indeed, the environmental performance can be improved if organizations collaborate more with the upstream suppliers and downstream customers [6]. On the other hand, environmental regulation is also one of the main drivers, which positively affect the GSCM adoption. Organizations should consider many factors such as product pricing, import duty and environmental taxes in their Green Supply Chain strategies [7]. Despites the importance of environmental customer collaboration as an internal driver and environmental regulation as an external driver for GSCM implementation, few studies combined these two parameters based on new information technology approach such as MAS, which makes the Supply Chain systems more flexible and agile [8]. Therefore, this study attempts to fill in this gap in the literature by proposing a MAS framework combined with Multi Objective Linear programming to facilitate the communication and information exchange in the GSCM context.

This paper is organized as follows. Section 2 describe the existing literature review and related work of the research topic. Section 3 presents the structure MAS framework, the delivery allocation sub model and negotiation protocol for the different agents. Experiments are conducted in Section 4 to prove the capability and applicability of the proposed MAS framework using a real case scenario from automotive spare parts sector. Finally, a conclusion and perspectives for future works are presented in Section 5.

2. LITERATURE REVIEW AND RELATED WORKS

GSCM can be defined as “integrating environmental thinking into Supply Chain Management including product design, material sourcing and selection, manufacturing process, delivery of the final product to the customers as well as end of life management of the product after its useful life [9]. GSCM provides many environmental practices along the product life cycle [10]. The environmental customer collaboration is a key GSCM practice, which can improve the Supply Chain performance, as customers are one of the most important stakeholders that firms depend on for their survival [11]. Furthermore, the customer collaboration influence organizations to adopt some strategies such as GSCM [1]. Indeed, many researchers identified collaboration with customers for eco-design, cleaner production, and using less energy during product transportation as an important variable [12]. Therefore, Organizations need to make interactions with customers to improve the environmental Supply Chain performance [13].

The environmental regulation and institutional pressure is another important factor, which encourages the GSCM adoption by the companies. For example, Chinese Government implemented some environmental regulations on manufacturers to promote GSCM and therefore to increase export and attract foreign investment [14]. Coskun et al. [15] combined different tax systems and analyzed their impact on the GSCM. Yu et al. [16], constructed three green manufacturing decision making models which are penalty and reward model, the non-government intervention model and the tax subsidy model, and discovered that the penalty and reward model is the best model to encourage Supply Chain partners to adopt GSCM practices. Ameknassi et al. [17] highlighted that the product recovery and the government subsidy have a positive impact on reverse Supply Chain performance.

Due to the complexity of Supply Chain network, it becomes difficult for managers and decision makers to anticipate the effects of their management policies on the Supply Chain performance. Hence, the development of new modelling approaches can be very helpful and provide great benefits for organizations [18]. Modelling approaches like analytic models and classical operational research methods can't solve completely the inherent complexity of the Supply Chain network, such as the high number of enterprises and all the interactions that take place between them, or the uncertainty present in most of their processes [19].

In the literature conducted by Jain, Wadhwa, and Deshmukh [20], it was indicated that the use of advanced communication technology could be useful for Supply Chain collaboration and integration. Wei et al. [21] concluded that information technology based exchange relationship and information integration can improve the performance in Supply Chain.

In the past years, there has been a big interest in using simulation approach to address Supply Chain networks topics. In particular, the usage of MAS in the Supply Chain modelling [22], because of the existing similarities between the actors in the Supply Chain network and the agents in the Multi Agents Systems. In fact, MAS can take into account the different interactions between Supply chain partners who act independently based on their own policies which gives Supply Chain decision makers and managers a better understanding of the whole system [19]. Therefore, MAS becomes one of the powerful modelling tool for Supply Chain networks [23].

A multi agent system is composed of many agents taking specific roles and interacting with each other in order to solve some problems beyond their individual capacities [24].

The agents interaction has different levels and it can go from information exchange to cooperation, coordination and negotiation to manage the different activities [25]. The "agent-based modeling is the most appropriate tool for systems with high degree of location and distribution and dominated by discrete decision such as Supply Chain [26]. In fact, Multi-agent systems aim to deal Supply Chain complexity such as bullwhip effects, poor communication results, and poor coordination between members of the supply chain [27].

The approaches based on the agent modelling have been often seen as a promising way to address complex problems and heterogeneous issues in the Supply Chain such as resources allocation problems. However, MAS systems have a distributed structure, which may have some limitations in terms of the solution quality. In other words, the agents will not have a complete overview of the state of the system and also will not realize easily the impact of their individual activities [28]. Therefore, the characteristics of the agent based models can be complemented by the other optimization models such Multi Objective Linear Programming (MOLP) [29].

Optimization methods such MOLP are used in the Green Supply Optimization problems. In fact, Hugo and Pistikopoulos [30] used MOLP, which integrated Life Cycle assessment into the design and planning decisions. Many environmental factors were considered together with financial criteria to formulate the planning task. Abdallah et al. [31] presented a different MOLP in which the green procurement concept was studied. The aim was to select a supplier with minimum impact on overall carbon footprint of the supply chain in order to minimize the carbon emission costs together with traditional supply chain costs. Tognetti et al. [32], developed a multi-objective optimizations model for strategic production networks planning which integrates both emissions and Supply Chain cost taking into account the production volume allocation and the energy mix. In this research, the proposed model is formulated as MOLP.

In the GSCM, the MAS modelling has gained more attentions among researchers. Ghadimi et al. [33] provides structured information exchange process to make better sustainable decisions by maintaining a long-term relationship between a manufacturer and its suppliers. Uygun and Dede [34] highlighted the benefits distribution of GSCM partners according to their sensitivity to green products and income sharing contract. Mishra et al. [35] propose a MAS structure to solve the complexity of including waste management and recycling in the GSCM. Giret et al. [36] propose a reverse manufacturing process following a service oriented manufacturing paradigm through a virtual market supported by intelligent agents software.

To our knowledge, none of the above works considered both the customer collaboration and environmental regulation in their models. Besides, there is no research study that investigates the applicability of MAS systems in enhancing communication and information exchange specifically for the environmental customer collaboration. For this reason, many researchers highlights that the issues and requirements in the other dyadic relationship such as manufacturer-retailer in the Green Supply Chain should be further investigated [33].

The main contribution of this paper is to develop a MAS framework to improve the information exchange and collaboration process with customers to improve the financial and environmental performance taking into account the environmental regulation as well. Furthermore, the proposed framework encompasses a sub model using the Multi Objective Linear Programming MOLP to complete the agent technology, because the properties of agent based approaches and optimization techniques can complement each other.

3. THE PROPOSED MAS APPROACH

In this study, we consider a three echelon Supply Chain which can be seen as a network of three layers such as manufacturer, distributer and customer. These three downstream members of the Supply Chain should collaborate to make a sustainable delivery decision. The manufacturing company is the seller in this process and its customer is the distributer, which is the seller for many customers. In this study, we consider one manufacturer, one distributer and many customers. In the suggested MAS structure, seven types of agents are identified: Customer Agents CA, Delivery Allocation Agent DAA2 (Distributor), Database Agent DBA1

(Distributor), Distribution Agent DA, Delivery Allocation DAA1 (Manufacturer), Database Agent DBA2 (Manufacturer) and Manufacturer Agent MA. Figure 1 illustrates the defined agents.

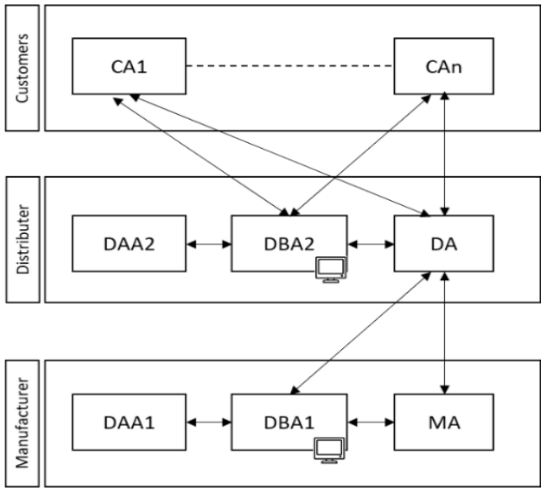

Figure 1. MAS structure

For illustration purposes, we will focus on the dyadic relationship between the distributer and customers. Each agent has some specific functions and responsibilities in this process. Table 1 illustrates the defined agent with their respective responsibilities:

Table 1. Agents responsibilities

Agent	Interaction	Protocol	With
CA	Send orders confirmation to DBA	FIPA request	DBA
CA	Send delivery confirmation to DA	FIPA request	DAA
DAA2	Request delivery allocation data from DBA	FIPA request	DBA
DAA2	Request the delivery quantities to be saved to in the database by DBA	FIPA request	DBA
DBA	Inform the CA that the orders are saved.	FIPA inform	CA
DBA	Send delivery allocation data to DAA	FIPA inform	DAA2
DA	Request delivery allocation result from DAA2	FIPA request	DAA2
DA	Inform and negotiate the delivery allocation result with CA	FIPA inform	CA

The success of a multi-agent architecture depends on effective communication between agents using a certain Agent Communication Language (ACL) to interpret and manipulate unexpected changes and actions to take. An agent communication language is a language whose syntax, semantics and pragmatics are precisely defined. Agent Communication Language (ACL) messages can be based on the FIPA Agent communication specifications. In addition, MAS interactions can be achieved using the FIPA Semantic Language (SL) content language, which is a string-coded content language. In this step of MAS design, the agents interaction analysis is done using the FIPA interactions protocols based on the defined responsibilities of each agent. Table 2 shows these interactions.

Table 2. Agents interactions

Agent	Responsibility
CA	1. Send orders confirmation to DBA2
	2. Receive a confirmation from the DBA2 that the orders are received
	3. Receive delivery allocation result from DA
	4. Send delivery confirmation to DA
DAA2	1. Request delivery allocation data from DBA
	2. Receive delivery allocation data from DBA
	3. Calculates the optimal delivery quantities using the mathematical delivery allocation model
	4. Request the delivery quantities to be saved to in the database by DBA.
	5. Receive the CA confirmation to proceed with the delivery
DBA2	1. Receive orders confirmations from CA
	2. Save orders confirmation from CA in the database
	3.Inform the CA that the orders are saved.
	4. Receive delivery allocation data request from DAA
	5. Send delivery allocation data to DAA
	6. Receive the delivery quantities and save them in the database
DA	1. Request delivery allocation result from DAA2
	1. Receive delivery allocation result from DAA2
	2. Inform and negotiate the delivery allocation result with CA
	3. Receive CA confirmation and proceed with delivery

4. COMPUTATIONAL ELEMENTS FOR THE PROPOSED MAS APPROACH

4.1 Delivery sub model

In this section, the delivery allocation model of the developed MAS approach is explained. This mathematical model is used as the internal behavior activity of the DAA2 incorporating both financial and environmental indicators and it is based on MOLP.

In fact, total cost measure to account for all financial expenses related to the delivery of products and environmental cost is evaluated based on the environmental taxation as well as the total emission of CO_2 for a given transportation mode. In this study, we consider that these cost indicators have the same proportion of the total cost in the implementation process. Table 3 illustrates these costs elements:

Table 3. Costs elements

Total cost	Delivery cost	Transportation Cost
		Storage cost
	Environmental cost	CO_2 related cost
		Environmental taxation

Since two Supply Chain performance indicators are used in the modeling approach, a multi objective optimization is implemented to construct this model as there is a few number of approaches combining financial and environmental issues in multi objective frameworks to address the supply chain design problem [37]. The workflow of this model starts with the objective function and constraints formulation, then it retrieves the input data from the data base. The outcome of this model will allow a company to determine the optimal delivery quantities to the customers, select the most appropriate transportation mode to move the products and measure CO_2 emissions related to the delivery process. Therefore, useful information will be provided to the decision maker, allowing for better analysis and creating more sustainable decisions. Figure 2 illustrates the workflow of the proposed model:

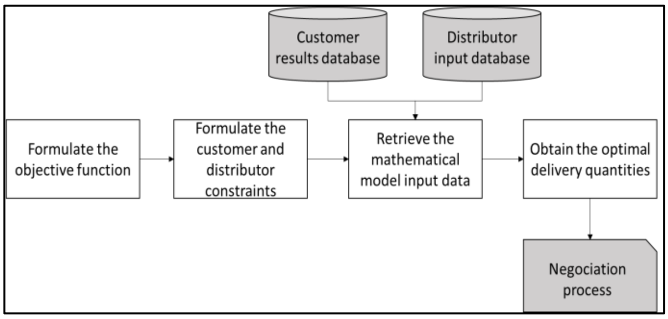

Figure 2. MAS structure

The description of the proposed model is explained in two sub-sections namely problem definition, and model formulation.

4.1.1 Problem definition

The proposed model is composed of two main echelons namely manufacturer warehouses and customer locations. Many products are considered and there are several transportation modes (i.e. road, rail, etc). below are the assumptions stated to establish this model:

- Demand of all customers is known and deterministic;
- Every customer demand is always satisfied by any manufacturer warehouse.
- Several transportation alternatives are available;
- Products are defect free;
- Distance between network nodes (used for CO_2 emissions evaluation) are assumed to be given by the straight path between facilities;
- The unit transportation costs is predefined

4.1.2 Model formulation

The formulation of the proposed model is divided into two parts, objective function and constraints. The model has two main objectives, the first one is to minimize total delivery cost which is the summation of transportation cost and storage cost, and the second is to minimize the environmental cost which is measured based on the environmental taxation and the CO_2 emissions related to the delivery process. it is assumed that the total emission of CO_2 is due to transportation. The mathematical formulation of the objective function is described in Eq. (1).

$$\begin{aligned} & Min \sum_i \sum_j \sum_l \sum_m (de\ ijlm\,.TC\ ijlm + SC\ im).Qijml \\ & + Min \sum_j \sum_k \sum_l \sum_m (de\ jklm\,.TC\ jklm \\ & + SC\ jm)\ Qjklm \\ & + Min \sum_i \sum_j \sum_l \sum_m (X\ ijl\,.\ de\ ijlm\,.Yl\,).Q\ ijlm \\ & + Min \sum_j \sum_k \sum_l \sum_m (X\ jkl\,.de\ jklm\,.Yl).Qjklm \end{aligned} \tag{1}$$

The total demand from the customer k should equal or less then delivered quantity from distributer j using transportation mode l for product m.

$$\sum Q\ jklm = d\ km \tag{2}$$

Total of quantity delivered by manufacturer I should equal or more than quantity delivered by distributer j to customer k using transportation mode l for product m.

$$\sum Q\ ijlm \geq \sum Q\ jklm \tag{3}$$

Total of quantity delivered by manufacturer I to distributor j should be equal or less than the transportation mode l capacity for product m.

$$\sum Q\ ijlm\ \leq C\ ijml \tag{4}$$

Total of quantity delivered by distributor j to customer k should be equal or less than the transportation mode l capacity for product m.

$$\sum Q\ jkml\ \leq C\ jkml \tag{5}$$

Total of quantity delivered by manufacturer *I* to distributor *j* should be equal or less than the warehouse capacity for product *m.*

$$\sum Q\ ijml\ \leq CA\ ijml \tag{6}$$

Total of quantity delivered by distributor *j* to customer *k* should be equal or less than the warehouse capacity for product m.

$$\sum Q\ jkml\ \leq CA\ jkml \tag{7}$$

In this current research, MATLAB has been utilized to optimize the developed delivery allocation bi-objectives mathematical model to identify the optimal delivery quantities which will be then used for the negotiation process.

4.2 Negotiation process

The negotiation is one to one bilateral negotiation. Both distributor and customer agents should negotiate the total cost provided by the delivery sub model and reach an agreement.

The distributor agent has the objective of minimizing the total cost including environmental and financial costs. It has also a maximum total costs Max TCDA that cannot be exceeded as well as a storage capacity CA that cannot be exceeded. Its dynamic knowledge consists of the negotiation of the total costs with the customer agent. This one has a fixed demand D that should be satisfied by the distributor agent. It has also the objective of minimizing the total cost TCCA. It has also to negotiate with the distributor agent the total costs.

Figure 3 describes the negotiation process between the distributor and the customer agents using exchanged messages (FIPA ACL Messages).

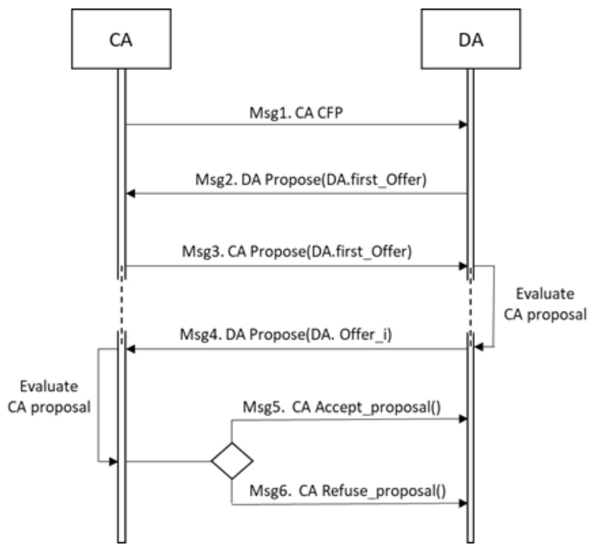

Figure 3. MAS structure

The parameters used in this negotiation process can be initiated differently according to the business case. In our model, we consider Begin_TCDA as the output costs of the sub delivery model including storage, transportation and environmental costs for a fixed delivered quantity.

In addition to the above-mentioned variables, we use the following function to sed a message from a source agent to destination agent: (Msg, Source, Destination).

The negotiation process is initiated by CA. it sends a call for proposal message (Msg1.CA.CFP) to DA. Therefore DA generates its first offer (Msg2) with cost equal either to Begin_TCDA or Min_TCDA

Msg1: CA. CFP

Msg2: DA.Propose (DA.first_offer)

1. If (Begin_TCDA <= Min_TCDA)
2. Then DA_offer(0) = Begin_TCDA
3. Else DA_offer(0) = Min_TCDA
4. EndIf
5. Send (DA_ offer(0) , DA , CA)

Once Msg2 is received, CA generates its first offer as well (Msg3) with a target cost equal to Max_TCCA.

Msg3 CA.Propose (CA.first_offer)

1. CA.offer(0) = Max_TCCA
2. Send (CA_offer(0) , CA , DA)

DA starts to evaluate the received first offer from CA. the first step is to check if CA_offer(k) doesn't exceed the Begin_TCDA to make sure delivery sub model output is taken into account. On the other hand, CA_offer(k) should be higher than Min_TCDA. If these conditions are met, then the new DA_offer(k) will be equal to the proposed CA_offer(k), otherwise DA appliers a new reduction function R which is a difference between its last made offer and the new CA_offer(k). If the new DA-offer (k) including the R value is still higher than the Min_TCDA, then the R value is deducted from the last made DA_offer(k-1), otherwise DA_offer(k) will be the same as the previous one DA_offer(k-1). The result is sent to CA for evaluation (Msg4).

Msg4: DA.Propose (DA.offer)

1. If ((CA.offer(k) <= Begin_TCDA) OR (Min_TCDA <= CA.offer(k)))
2. Then DA_offer(k)=CA_offer(k)
3. Send (DA_offer(k), DA, CA)
4. Else R = DA_Offer(k-1) – CA_offer(k)
5. If ((DA_Offer(k) - R) <= Min_TCDA
6. Then DA.Offer(k) = DA.Offer(k-1) – R
7. Else DA.Offer(k) = DA.Offer(k-1)
8. End If
9. Send (DA_offer(k), DA, CA)
10. End If

CA evaluates the DA_offer(k) by comparing it with the last made offer. If the DA_offer(k) is less than CA_offer(k-1), CA sends an accept_proposal message (Msg5) to DA. Otherwise if the received offer DA_offer(k) is similar to previous one, then CA sends a refuse_proposal message (Msg6).

Msg5: CA.Accept_proposal ()

1. If DA.Offer(k) ≤ (CA_Offer (k-1))
2. Then Send (Accept_proposal, DA, CA)
3. Endf

Msg6: CA.Refuse_proposal (CA.offer)

1. If (DA.Offer(k) = DA.Offer (k-1))
2. Then Send (Refuse_proposal, DA, CA)
3. EndIf

5. STUDY CASE

In this section, a practical scenario from industrial study case is adopted in the automotive spare parts sector. The main motivation of such adoption is to show the applicability of our MAS model using a real case scenario with relevant supply chain policies. The considered case study consists of 2 distributors who have to supply 4 customers. Only one product is considered for this case study. It was also confirmed that only sea freight is used as a transportation mode between the supply chain nodes. The customer places an order to the distributors on monthly basis, and then the distributors should make a proposal on delivery conditions and related costs that will be negotiated with the customer before the execution process.

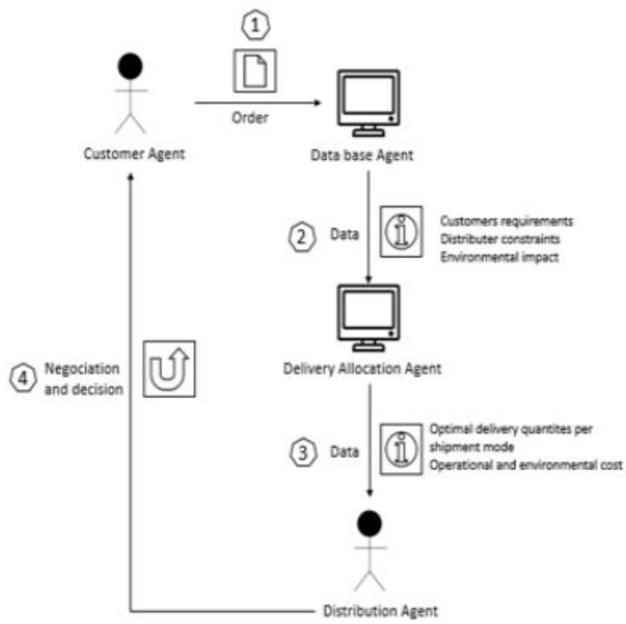

Figure 4. Workflow of proposed MAS framework

The process starts with the customer order which will be saved in the data base, then the delivery sub model described in previous section will provide the delivery proposal, then the negotiation process will start between the distributors and customers. For illustration purposes, we consider a negotiation process only between one distributor and one customer. Figure 4 illustrates the workflow of the proposed MAS framework.

5.1 Delivery sub model results

Table 4 illustrates the result of the delivery sub model for one distributor and one customer where Q11 refers to the quantity to be delivered from distributor 1 to customer 1 with the related total cost, which is named the Begin_TCDA cost for the negotiation process.

Table 4. Delivery sub model results

Month	Customer demand	Delivery cost	Envir. cost	Total cost	Q11
1	300	16599	4413	21012	300
2	350	19366	5148	24514	350
3	400	22133	5883	28016	400
4	300	16599	4413	21012	300
5	398	22021	5854	27875	398
6	469	25951	6898	32849	469
7	207	11453	3045	14498	207
8	350	19366	5148	24514	350
9	400	22133	5883	28016	400
10	250	13833	3677	17510	250
11	327	18093	4810	22903	327
12	520	28773	7648	36421	520

The total cost includes the delivery cost and environmental cost.

5.2 Negotiation process

As already mentioned in previous section, two costs elements are used for the negotiation process. First one is the min total cost Min_TCDA that can be paid by the distributor to its transportation company or logistics service provider, and then charged to the customer. Second one is the max total cost Max_TCCA that the customer can pay for the delivery.

For this study case, it was confirmed that these two cost elements are changing twice a year. Table 5 illustrates the different values:

Table 5. Delivery sub model results

Month	Min_TCDA	Max_TCCA
From 1 to 6	20000	25000
From 7 to 12	22000	28000

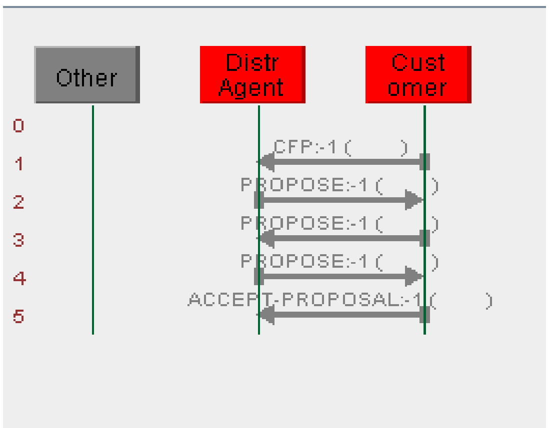

Figure 5. Negotiation process in JADE platform

The negotiation process is developed and simulated using JADE platform. Figure 5 illustrates the different ACL messages between the two agents. The implemented model differs from the iterated contract net protocol as a call for proposal is sent only at the beginning and there is no limitation of response time in each iteration.

5.3 Interpretation and discussion

The experiments done allowed us to check if the proposed model can lead the agents to reach an agreement about the total delivery costs. Figure 6 illustrates the different defined costs elements and also the outcome of the negotiation process

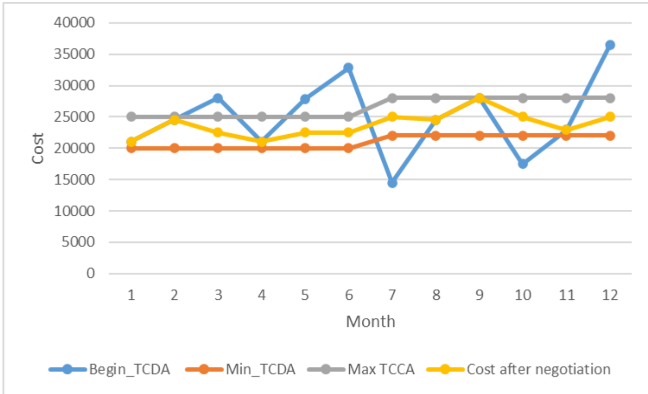

Figure 6. Negotiation process result

The delivery sub model output namely Begin_TCDA was in the negotiation range between Min_TCDA and Max_TCCA and was considered as a final result for 6 months which guarantees that the environmental constraints are taken into consideration.

For month 3 and 5, the Begin_TCDA was very close to the Max_TCCA, and therefore to be considered in the negotiation range. For this case a further negotiation about the qty to be delivered (Q11) can help to reduce the Begin_TCDA and take it as a final result.

For month 6 and 12, the Begin_TCDA is very high in comparison to the negotiation range. The cost for these months are referring to the biggest volume Q11 requested by the customer. A quantity efficiency negotiation protocol can be also implemented to reduce the Begin_TCDA.

For month 7 and 10, the Begin_TCDA is less than the negotiation range because of the low volume of these respective months. A quantity increase is necessary to increase the Begin_TCDA and also to compensate the quantity decrease for other months.

The objective of the proposed model is to help agents to reach agreements and take a collaborative sustainable decision for their supply chain. This objective has been largely reached. But, a comparison between the total cost without and with negotiation is necessary in order to see the impact of these sustainable decisions on the total cost. For our study case, it was confirmed the agreed cost is always the average between the Min_TCDA and Max_TCCA. Figure 7 shows the comparison between scenario 1 without negotiation and scenario 2 with negotiation.

We see that there is no big difference between the two costs before and after negotiation, which means that applying environmental practices did not have a negative impact on the financial performance of the considered Supply Chain. Furthermore, the total cost without negotiation for the whole year is 285000 whereas the total cost with negotiation is only 284471. It means that the agents managed to come up with a total cost agreement less than the case where no environmental practices were considered.

Figure 7. Comparison between scenarios with and without negotiation

The implementation of an additional negotiation protocol for the quantity efficiency will help further to decrease the total cost and therefore make the proposed model more beneficial for the Supply Chain partners.

6. CONCLUSION

In this paper, a hybrid approach based on multi agents systems and multi objective linear programming and was presented. The objective of this approach is to make information exchange and collaboration between the Supply Chain partners more easier for the GSCM implementation. The proposed framework encompasses of the MAS structure, the agents definition and interaction, mathematical delivery allocation model based on MOLP and the negotiation process between the different agents.

The applicability of the proposed framework was demonstrated through an industrial case study in the automotive spare parts sector. First, it was concluded that the different agents of this framework managed to reach an agreement about the total delivery cost. Second, the output of the delivery sub model was considered as a final result for the negotiation process 6 times. Finally, the proposed framework helps to decrease slightly the total cost in comparison with the initial scenario without negotiation. We also concluded that an additional quantity efficiency negotiation protocol is necessary to enhance the applicability of our delivery model output which will be developed in future works.

Enhancing the proposed negotiation process by adding other constraints related to the lead time can be proposed as a perspective for future works.

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NOMENCLATURE

i	Manufacturers
j	Distributors
k	Customers
l	Transportation modes
m	Products
De ijl	Distance between distributor j and customer K using transportation mode l
De jkl	Transportation cost of product m from manufacturer i to distributor j using transportation mode l
TC ijml	Transportation cost of product m from distributor j to customer k using transportation mode l

TC jkml	Transportation cost of product m from distributor j to customer k using transportation mode l
SC im	Storage cost of product m in manufacturer i warehouse
SC jm	Customer demand of product m
	Warehouse capacity of manufacturer i of product m
D km	Warehouse capacity of distributor j of product m
D km	Capacity of Transportation mode l for product m from manufacturer I to distributor j
CA jm	Capacity of Transportation mode l for product m from distributor j to customer k
C ijml	Environmental tax from manufacturer i to distributor j using transportation mode l
C jkml	CO2 emissions for transportation mode l
X ijl	Quantity to be delivered from manufacturer i to distributor j of product m using transportation mode l
X jkl	Quantity to be delivered from distributor j to customer k of product m using transportation mode l
Y l	Total cost provided by the delivery sub model.
Q ijml	Minimum costs that the distributor can pay for the delivery.
Q jkml	Amount charged by DA to CA
Begin_TCDA	Total costs that the customer can pay for this delivery.
Min_TCDA	Minimum costs that the distributor can pay for the delivery.
DA_Offer	Amount charged by DA to CA
Max_TCCA	Total costs that the customer can pay for this delivery.
CA_Offer	Amount paid by CA to DA