



International Journal of Information and Decision Sciences

ISSN online: 1756-7025 - ISSN print: 1756-7017

<https://www.inderscience.com/ijids>

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DOI: [10.1504/IJIDS.2025.10069090](https://doi.org/10.1504/IJIDS.2025.10069090)

Article History:

Received:	11 January 2021
Last revised:	03 January 2022
Accepted:	15 April 2022
Published online:	04 February 2025

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Abstract: Environmental customer collaboration has recently attracted a big attention from researchers and industrial professionals. Many studies show that companies may reach high performance level by considering customer collaboration and environmental regulations. However, literature in the green supply chain management (GSCM) suggests having more structured collaboration and information exchange processes between supply chain partners based on new technologies. For this reason, this work proposes a hybrid solution based on multi-agent systems (MAS) and mixed integer linear programming (MILP) to automate and facilitate the environmental customer collaboration process. The study demonstrates how MAS can be used in the GSCM context to improve communication and reduce complexity. An industrial study case in the automotive spare parts sector is used to demonstrate the applicability of the established MAS model.

Keywords: green supply chain management; multi-agent systems; supply chain management; customer collaboration; environmental regulation.

Reference to this paper should be made as follows: El Idrissi, M.D., Charkaoui, A. and Echchatbi, A. (2025) 'Hybrid multi-agent framework for green supply chain management', *Int. J. Information and Decision Sciences*, Vol. 17, No. 1, pp.32–50.

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1 Introduction

With increasing environmental awareness from customers, stakeholders, government legislations and environmental organisations, 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 (Zhu et al., 2012). Green supply chain considers factors like resources efficiency and environmental impact in the supply chain, aiming to reduce impact on environment, maximise the resources utilisation and economic benefits across the entire product lifecycle (Laari et al., 2016; Zhao, 2019). Furthermore, many studies highlight that practicing green supply chain leads to benefits like reduced waste, reduced air emissions and increased energy efficacy (Bajaj et al., 2016). The environmental customer collaboration has been defined as a very important green supply chain practice that can improve the organisations performance (Zhu et al., 2007). Indeed, the environmental performance can be improved if organisations collaborate more with the upstream suppliers and downstream customers (Vachon and Klassen, 2008). On the other hand, environmental regulation is also one of the main drivers, which positively affect the GSCM adoption. Organisations should consider many factors such as product pricing, import duty and environmental taxes in their green supply chain strategies (Khan et al., 2016). Despite 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 (Kusi-Sarpong et al., 2016). Therefore, this study attempts to fill in this gap in the literature by proposing a MAS framework combined with mixed integer linear programming to facilitate the communication and information exchange in the GSCM context.

This paper is organised as follows. Section 2 describes 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 conclusions 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” (Srivastava, 2007). GSCM provides many environmental practices along the product life cycle (Zhu et al., 2008). 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 depends on for their survival (Woo et al., 2016). Furthermore, the customer collaboration influence organisations to adopt some strategies such as GSCM (Zhu et al., 2012). Indeed, many researchers identified collaboration with customers for eco-design, cleaner production, and using less energy during product transportation as an important variable (Angappa et al., 2015). Therefore, organisations need to make interactions with customers to improve the environmental supply chain performance (Green et al., 2012).

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 (Zhu et al., 2005). Coskun et al. (2016) combined different tax systems and analysed their impact on the GSCM. Yu et al. (2016) 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. (2016) highlighted that the product recovery and the government subsidy have a positive impact on reverse supply chain performance.

Currently, there is a growing interest in using new technologies such as MAS in the supply chain modelling. In the literature conducted by Jain et al. (2009), it was indicated that the use of advanced communication technology could be useful for supply chain collaboration and integration. Wei et al. (2012) concluded that information technology-based exchange relationship and information integration can improve the performance in supply chain. In the GSCM, the MAS modelling have gained more attentions among researchers. Ghadimi et al. (2018) provide structured information exchange process to make better sustainable decisions by maintaining a long-term relationship between a manufacturer and its suppliers. Uygun and Dede (2016) highlighted the benefits distribution of GSCM partners according to their sensitivity to green products and income sharing contract. Mishra et al. (2012) propose a MAS structure to solve the complexity of including waste management and recycling in the GSCM. Giret et al. (2017) propose a reverse manufacturing process following a service oriented manufacturing paradigm through a virtual market supported by intelligent agent 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 highlight that the issues and requirements in the other dyadic relationship such as manufacturer-retailer in the green supply chain should be further investigated (Ghadimi et al., 2018).

Table 1 Literature review of MAS usage in GSCM

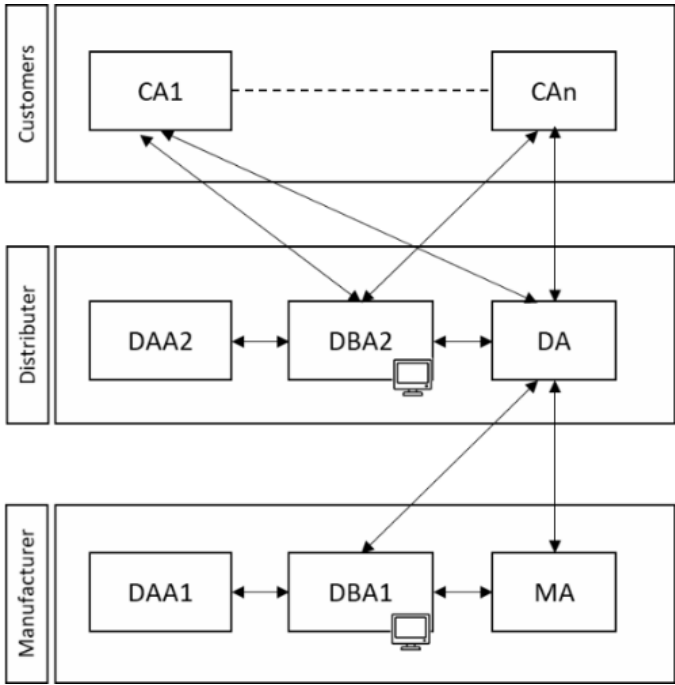
<i>Authors</i>	<i>Year</i>	<i>GSCM process</i>	<i>Paper type</i>	<i>Description</i>	<i>MAS methodology and communication channel</i>	<i>Findings</i>
Mishra et al.	2012	Reverse logistics	Study case	Reduce waste and recycling management complexity in the GSCM	MALLET	Practical framework from waste collection to recycled components distribution
Hsieh	2015	All processes	Study case	Framework for sustainable supply chain configuration	FIPA	Scheduling problem in sustainable supply chain can be addressed by MAS.
Giret et al.	2017	Green manufacturing	Study case	Sustainable manufacturing system platform supported by intelligent software agents	ANEMONA	MAS help to include sustainability in manufacturing systems
Ghadimi et al.	2018	Green procurement	Study case	Improve sustainable procurement decisions through structured information exchange process.	FIPA	MAS is able to reduce communication and information exchange problems
Ben Mekki et al.	2019	All processes	Research paper with conceptual model	Intelligent dynamic system based on agents interaction to study sustainability in the context of SMEs	FIPA	MAS helps to highlight the sustainability assessment process in SME context

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 considering the environmental regulation as well. Furthermore, the proposed framework encompasses a sub model using the mixed integer linear programming (MILP) completes the agent technology, because the properties of agent-based approaches and optimisation techniques 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, distributor and customer. These three supply chain partners should collaborate to make a sustainable decision about product delivery. The manufacturing company is the seller in this process and its customer is the distributor, which is the seller for many customers. In this study, we consider a supply chain which consists of a manufacturer, a distributor and many customers. The defined agents for this MAS structure are as follows: delivery allocation agent DAA1 (manufacturer), delivery allocation agent DAA2 (distributor), distribution agent DA, manufacturer agent MA, database agent DBA1 (manufacturer), database agent DBA2 (distributor) and customer agent CA. Figure 1 illustrates the defined agents.

Figure 1 Proposed MAS structure



For illustration purposes, the relationship between the distributor and customers is studied. Table 2 illustrates the defined agent and their responsibilities.

The implementation of multi-agents systems depends on the communication used between agents through an agent communication language (ACL) with predefined syntax, semantics and pragmatics. The foundation for intelligent physical agents (FIPA) communication and interactions can be used as an ACL messages form. In this step of our MAS design, the agents communication and interaction is done using FIPA interactions protocols. Table 3 shows these interactions.

Table 2 Agents responsibilities

<i>Agent</i>	<i>Responsibility</i>	
CA	1	Confirm an order to DBA2
	2	Receive an order saving confirmation from DBA
	3	Get delivery allocation result from DA
	4	Negotiate and send delivery confirmation to DA
DAA2	1	Ask DBA to provide delivery data
	2	Receive delivery data from DBA
	3	Calculates the optimal delivery quantity
	4	Ask DBA to save delivery quantity in the database.
DBA2	1	Get order confirmation from CA
	2	Save CA orders in the database
	3	Inform CA about orders saving.
	4	Receive delivery data request from DAA2
	5	Send delivery allocation data to DAA2
	6	Save the delivery quantity in the database
DA	1	Ask DAA2 to provide delivery allocation result
	2	Get delivery allocation result from DAA2
	3	Negotiate the delivery allocation result with CA
	4	Get delivery confirmation from CA

Table 3 Agents interactions

<i>Agent</i>	<i>Interaction</i>	<i>Role</i>	<i>Protocol</i>	<i>With</i>
CA	Confirm an order to DBA2	1	FIPA request	DBA
CA	Negotiate and send delivery confirmation to DA	4	FIPA CFP	DAA
DAA2	Ask DBA to provide delivery data	1	FIPA request	DBA
DAA2	Ask DBA to save delivery quantity in the database	4	FIPA request	DBA
DBA	Inform CA about orders saving.	3	FIPA inform	CA
DBA	Send delivery allocation data to DAA2	5	FIPA inform	DAA2
DA	Ask DAA2 to provide delivery allocation result	1	FIPA request	DAA2
DA	Negotiate the delivery allocation result with CA	3	FIPA inform	CA

4 Computational elements for the proposed MAS

4.1 Delivery sub model

The delivery sub model is a mathematical model based on mixed integer linear programming (MILP), which will be used as the internal behaviour of the agent DAA2 and include financial and environmental objectives. The financial cost is related to all necessary expenses for storage and transportation to deliver the products. The environmental cost is given based on environmental taxes and CO₂ emissions related to

the products delivery. For this reason, a MILP is used to construct the model as the number of approaches combining financial and environmental factors to address Supply Chain design problems is still low (Wang et al., 2011).

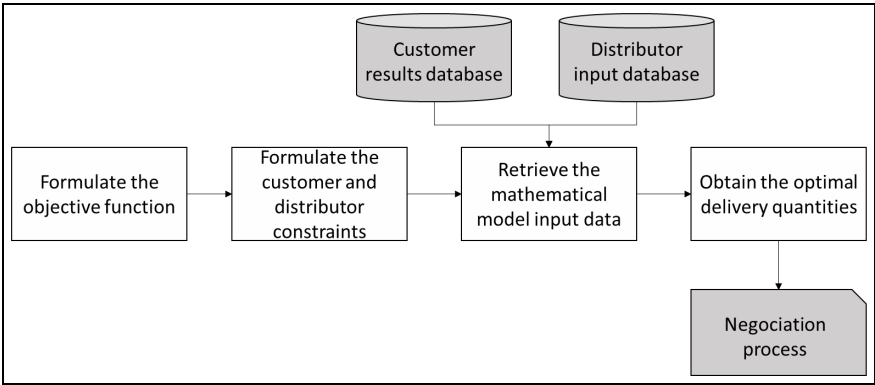
In fact, total cost measure to account for all financial expenses related to the delivery of products and environmental cost is evaluated based on the environmental taxation as well as the total emission of CO₂ for a given transportation mode. In this study, we consider that these cost indicators have the same proportion of the total cost in the implementation process and these two objectives are conflictual. Table 4 illustrates these costs elements.

Table 4 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 modelling approach, a multi-objective optimisation is implemented to construct this model as there is a few numbers of approaches combining financial and environmental issues in multi-objective frameworks to address the supply chain design problem (Wang et al., 2011). The workflow of this model starts with the objective function and constraints formulation, then it retrieves the input data from the database. 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 CO₂ 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 Proposed model



The description of the proposed model is explained in three subsections namely problem definition, model elements, model formulation.

4.1.1 Problem definition

In this model, many products are considered and there are several transportation modes (i.e., road, rail, etc). Our model is designed according the below assumptions:

- customer demand is known and deterministic
- customer demand is satisfied by any distributor warehouse
- many transportation modes are possible
- products have no quality issues
- distance used between the different nodes is known
- the unit transportation costs is known.

4.1.2 Model elements

4.1.2.1 Sets

- i manufacturers
 j distributors
 k customers
 l transportation modes
 m products.

4.1.2.2 Parameters

- de_{ijl} Distance between manufacturer i and distributor j using transportation mode l .
 de_{jkl} Distance between distributor j and customer k using transportation mode l .
 TC_{ijml} Transportation cost of product m from manufacturer i to distributor j using transportation mode l .
 TC_{jkm} 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} Storage cost of product m in distributor j warehouse.
 D_{km} Customer demand of product m .
 CA_{im} Warehouse capacity of manufacturer i of product m .
 CA_{jm} Warehouse capacity of distributor j of product m .
 C_{ijml} Capacity of transportation mode l for product m from manufacturer i to distributor j .
 C_{jkm} Capacity of transportation mode l for product m from distributor j to customer k .

X_{ijl}	Environmental tax from manufacturer i to distributor j using transportation mode l .
X_{jkl}	Environmental tax from distributor j to customer k using transportation mode l .
Y_l	CO ₂ emissions for transportation mode l .

4.1.2.3 Variables

Q_{ijml}	Quantity to be delivered from manufacturer i to distributor j of product m using transportation mode l .
Q_{jklm}	Quantity to be delivered from distributor j to customer k of product m using transportation mode l .

4.1.2.4 Parameters

The model is divided into two parts objective function and constraints. The model has two main objectives, the first one is to minimise total delivery cost which is the summation of transportation cost and storage cost, and the second is to minimise the environmental cost which is measured based on the environmental taxation and the CO₂ emissions related to the delivery process. It is assumed that the total emission of CO₂ is due to transportation. The mathematical formulation of the objective function is described in equation (1).

$$\begin{aligned}
& \text{Min} \sum_i \sum_j \sum_l \sum_m (de_{ijlm} \cdot T_{ijlm} \cdot SC_{im}) \cdot Q_{ijml} \\
& + \text{Min} \sum_j \sum_k \sum_l \sum_m (de_{jklm} \cdot TC_{jklm} + P_{jm} + SC_{jm}) \cdot Q_{ijlm} \\
& + \text{Min} \sum_i \sum_j \sum_l \sum_m (X_{ijl} \cdot de_{ijlm} \cdot Y_l) \cdot Q_{ijlm} \\
& + \text{Min} \sum_j \sum_k \sum_l \sum_m (X_{jkl} \cdot de_{jklm} \cdot Y_l) \cdot Q_{jklm}
\end{aligned} \tag{1}$$

S.C.

- The total demand from the customer k should equal or less then delivered quantity from distributor 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 distributor 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 :

$$\sum Q_{jkm} \leq C_{jkm} \quad (5)$$

- Total of quantity delivered by manufacturer i to distributor j should be equal or less than the warehouse capacity for product m :

$$\sum Q_{ijm} \leq CA_{ijm} \quad (6)$$

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

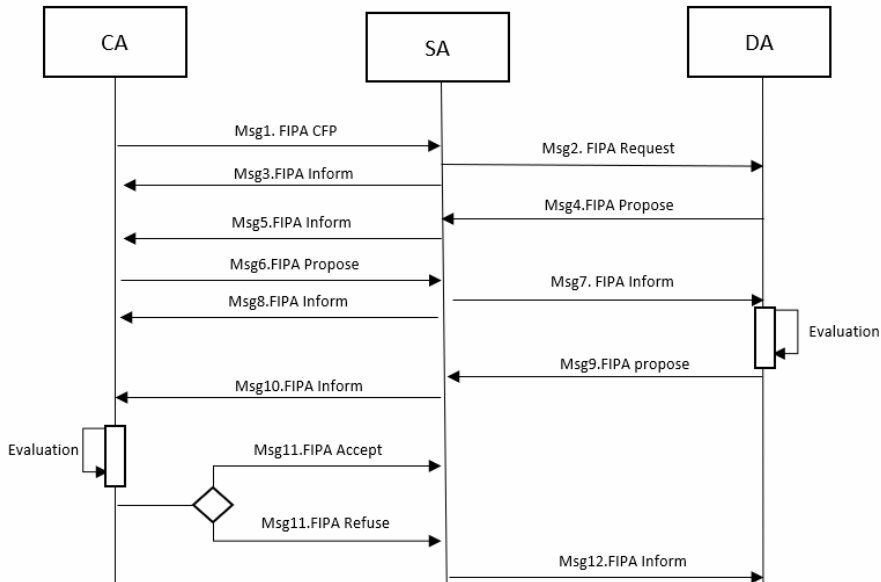
$$\sum Q_{jkm} \leq CA_{jkm} \quad (7)$$

In this current research, MATLAB has been utilised to optimise 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 between distributor and customer

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. A new supervisor agent SA is introduced to facilitate communication between the customer and distributor.

Figure 3 Negotiation process



The distributor agent has the objective of minimising 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 minimising 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).

Before describing the dynamic, we define here the different variables:

- K: k^{th} iteration of the negotiation process
- Begin_TCDA: total cost provided by the delivery sub model
- 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
- R: reduction function which difference between the last distributor offer and k^{th} customer offer.

These parameters 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 send 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 SA which sends a request to provide a proposal to DA (Msg2), Therefore DA generates its first offer (Msg4) with cost equal either to Begin_TCDA or Min_TCDA. In the meantime, SA informs CA that the CFP is sent to DA (Msg3).

- *Msg1: CA.CFP*
- *Msg2: SA.Request (SA_request)*
 - 1 SA.request = CA.CFP
 - 2 Send (SA_request, SA, DA)
- *Msg3: SA.Inform (SA_Inform_1)*
 - 1 SA.inform = 'CA.CFP is sent to DA'
 - 2 Send (SA_inform_1, SA, CA)
- *Msg4: DA.Propose (DA.first_offer)*
 - 1 If (Begin_TCDA $\leq$ Min_TCDA)
 - 2 Then DA_offer(0) = Begin_TCDA
 - 3 Else DA_offer(0) = Min_TCDA
 - 4 EndIf

5 Send (DA_offer(0), DA, SA)

- *Msg5: SA.Inform (SA_inform_2)*

1 SA.inform = DA offer(0)

2 Send (SA_inform_2, SA, CA)

Once SA receives Msg4 from DA, it sends it directly to CA (Msg5) which generates its first offer as well (Msg6) with a target cost equal to Max_TCCA.

- *Msg6: CA.Propose (CA.first_offer)*

1 CA.offer(0) = Max_TCCA

2 Send (CA_offer(0), CA, SA)

- *Msg7: SA.Inform (SA_Inform_3)*

1 SA.inform = CA offer(0)

2 Send (SA_inform_3, SA, DA)

- *Msg8: SA.Inform (SA_Inform_4)*

1 SA.inform = 'CA offer(0) is sent to DA'

2 Send (SA_inform_4, SA, CA)

SA receives the CA offer (Msg6) and sends it to DA for evaluation (Msg7). In the meantime, SA informs CA that the proposal is sent to DA (Msg8). DA starts to evaluate the received first offer from CA. the first step is to check if CA_offer(k) does not exceed the Begin_TCDA to make sure delivery sub model output is considered. 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 applies 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 SA (Msg9).

- *Msg9: 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, SA)

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, SA)

10 End If

- *Msg10: SA.Inform (SA_Inform_5)*

- 1 SA.inform = DA_offer(k)
- 2 Send (SA_inform_5, SA, CA)

SA forwards the DA offer to CA (Msg10). 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 (Msg11) to SA. Otherwise if the received offer DA_offer(k) is similar to previous one, then CA sends a refuse_proposal message (Msg11).

- *Msg11: CA.Accept_proposal (CA.offer)*

- 1 If DA.Offer(k) $\leq$ (CA_Offer (k - 1))
- 2 Then send (Accept_proposal, CA, SA)
- 3 End if

- *Msg12: CA.Refuse_proposal (CA.offer)*

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

- *Msg13: SA.Inform (SA_Inform_6)*

- 1 SA.inform = 'Accept_proposal' or 'Refuse_proposal'
- 2 Send (SA_inform_6, SA, DA)

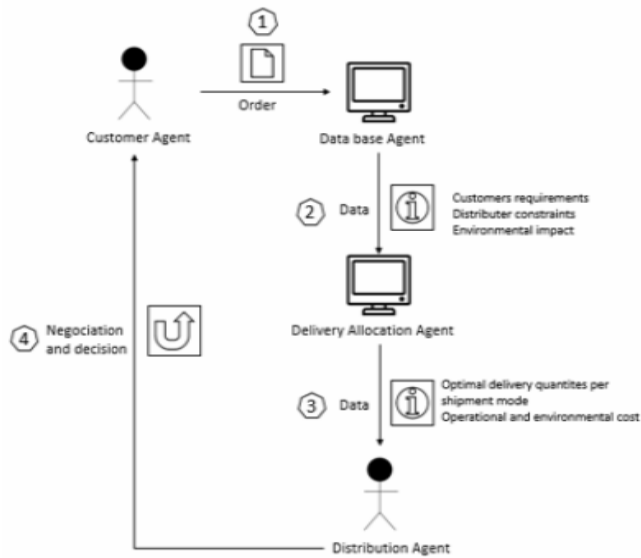
At the end, SA informs DA about CA final decision (Msg13).

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 considering a case study which consist of two distributors who have to supply 4 customers. Only one product is considered for this case study. The choice of these parameters (number of distributors, customers, and products) is related to the practical context of the study case, if there were more parameters to consider there will be no change from the structure perspective as the model is based on agent bilateral negotiation.

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.

The process starts with the customer order which will be saved in the database, 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 as the process will be similar for the rest of relationships. Figure 4 illustrates the MAS framework workflow.

Figure 4 Proposed MAS workflow

5.1 Delivery sub model results:

Table 5 illustrates the result of the delivery submodel 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 5 Delivery sub model results

Month	Customer 1 demand	Total cost	Q11
1	300	21,012	300
2	350	24,514	350
3	400	28,016	400
4	300	21,012	300
5	398	27,875	398
6	469	32,849	469
7	207	14,498	207
8	350	24,514	350
9	400	28,016	400
10	250	17,510	250
11	327	22,903	327
12	520	36,421	520

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.

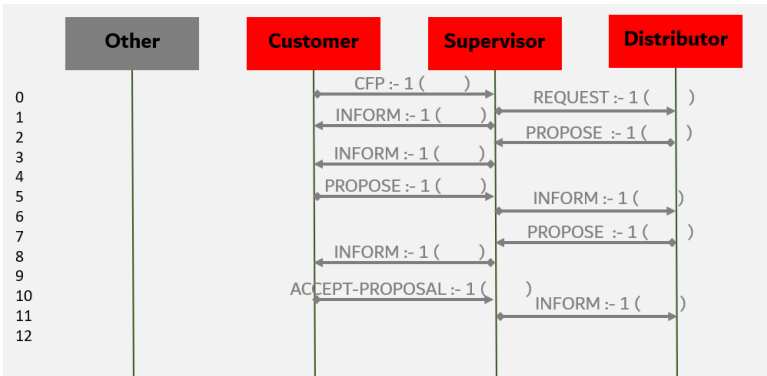
For this study case, it was confirmed that these two cost elements are changing twice a year. Table 6 illustrates the different values.

Table 6 Costs elements

Month	Min_TCDA	Max_TCCA
From 1 to 6	20,000	25,000
From 7 to 12	22,000	28,000

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.

Figure 5 Negotiation process in JADE platform (see online version for colours)

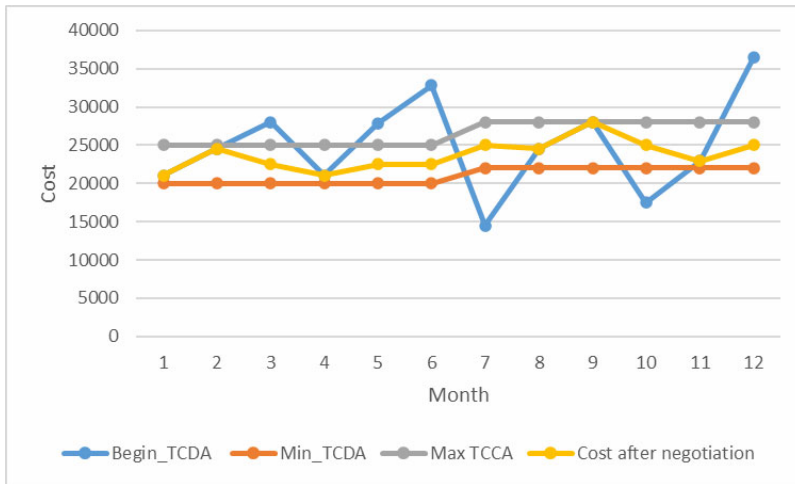


5.3 Interpretation

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.

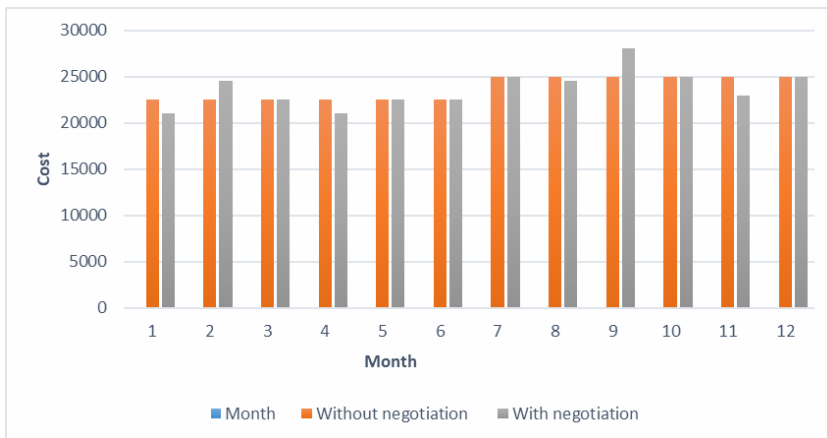
The delivery sub model output namely $Begin_TCDA$ was in the negotiation range between Min_TCDA and Max_TCCA and was considered as a final result for 6 months which guarantees that the environmental constraints are taken into consideration.

For months 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.

Figure 6 Negotiation process result (see online version for colours)

For months 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.

Figure 7 Comparison between scenarios with and without negotiation (see online version for colours)

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 285,000 whereas the total cost with negotiation is only 284,471. It means that the agents managed to come up with a total cost agreement less than the case where no environmental practices were considered.

6 Discussion

This work demonstrates how MAS can be used in the context of GSCM to facilitate the exchange and communication process between supply chain partners. The focus was on the relationship between customers and distributors. The MAS approach was complemented using MILP to consider more real-life constraints such as environmental taxes.

The result of the MILP model helps to provide a first input on the total delivery cost and optimal quantities to make a sustainable distribution decision. This input is the starting point of the negotiation process between distributors and customers based on MAS structure.

A comparison between a scenario with and without negotiation is presented to show the benefits of using MAS modelling and its impact on the total delivery cost. The model was tested, and the results were validated through a practical study case in the automotive spare parts sector using different parameters.

The main contributions of this work is first to confirm that MAS modelling is able to facilitate exchange and communication in the context of GSCM, in particular for the environmental customer collaboration field. Second, the combination of MAS and MILP can address more complex problems and makes the model more realistic. Furthermore, this study shows that considering environmental constraints in the distribution decision making process doesn't have negative impact on financial performance of the considered supply chain.

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.

7 Conclusions

In this paper, a hybrid approach based on multi-agents' systems and mixed integer 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 MILP 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 six 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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