ISSN 1870-4069

A Multi-Agent System for the Inventory and Routing Assignment

Conrado Augusto Serna Urán[1], Cristian Giovanny Gómez Marín[2],
Julián Andrés Zapata Cortes[3], Martín Darío Arango Serna[2]

[1] Universidad de San Buenaventura,
Colombia

[2] Universidad Nacional de Colombia,
Colombia

[3] Institución Universitaria CEIPA,
Colombia

conrado.serna@usbmed.edu.co

Abstract. In the supply chain management research field, the analysis strategies and the joint management of inventory and transport of goods have increased attention because of current changes and tendencies in the goods interchange process. However, the computational complexity and the problems that may arise in the integration processes of the different actors become the majority of proposals difficult to implement. In this paper, we develop a multi-agent system (MAS) for solving the inventory and routing assignment problem. The proposed multi-agent system facilitates the integration of the distribution processes and the inventory management in a supply network with one depot and n customers. The model is based in the autonomy of the actors to manage their capacity, demand, and integration of the transport process. To solve the resulting vehicle routing problem, we use a 2-opt local search heuristic.

Keywords: inventory routing problem, multi-agent system, supply chain management, supply chain collaboration.

1 Introduction

The integration of the distribution and inventory process is one of the main strategies to produce cost efficiency and satisfactory service levels among the actors of the supply chain. The objective of this integration is to reduce the global cost of the distribution process, which include the holding and the transport costs (Zapata, 2016).

The implementation of this type strategy is difficult due to two different problems: the mathematical complexity of the problem and the fact that the involved actors try to conserve specific and individual objectives.

As a solution to these difficulties, some authors have found in the multi-agent systems a promising alternative because of its versatility and ease implementation. The multi-agent systems use the distributed computing paradigm (Arango-Serna, Serna-Urán, & Zapata-Cortes., 2018), furthermore, the use of multi-agent systems facilitate the representation of the supply chain actors in artificial agents with their capacities and specific goals interacting in a coordinated and collaborative function system. The multi-agent systems consist in multiple agents interacting to solve a common problem, compete for the use of shared resources or simply they coordinate each other to avoid conflicts (Arango-Serna & Serna-Urán, 2016; Serna-Urán, 2016).

This article presents a Multi Agent simulation-based model for the freight distribution process. The model seeks to reduce the total distribution costs involving the decision of the transportation and inventory plans. In the first part of the article, a short literature background about the integration of transportation and inventory decision, and Multi agent Systems is presented. Then, the propose multi agent model is explained and later applied in a median size problem. Finally, the analysis and some conclusions are stated.

2 Background

Guerrero et al. (2013) argue that inventory management and distribution decisions are related to each other, since inventory depends on the frequency and time to supply companies, as well as orders and product costs (Arango-Serna et al., 2015). The decision of simultaneously assign the inventory and transportation is carried out following two types of mechanisms: Decomposition and aggregation: The decomposition mechanism separates the problem into two phases, in which the first determines the inventory and the second the transportation routes (Kang and Kim, 2010).

The aggregation mechanism finds the solution to the problem simultaneously, producing the inventory and transport decisions directly. To solve this problem, the most studied model is the Inventory Routing Problem (IRP) (Arango-Serna et al., 2016), which is based on the Vendor Managed Inventory and seeks to combine the transport and inventory allocation problem to reduce the global distribution costs (Arango-Serna et al., 2016).

In recent years, the supply chain management have received much interest to be modeled as a multi-agent system (Aminzadegan, Tamannaei, & Rasti-Barzoki, 2019; Avci & Selim, 2016; Ghadimi, Ghassemi, & Heavey, 2017; Goncalo & Morais, 2016; Kumari, Singh, Mishra, & Garza-reyes, 2015; Pal & Karakostas, 2014; Sitek, Wikarek, & Grzybowska, 2014), in which each agent seeks to maximize his profits instead of the general benefit of the supply chain. Each agent acts autonomously, interacts with other agents, reacts to changes in the environment and makes proactive decisions (Böhnlein, Schweiger, & Tuma, 2011; Wang, Wong, & Wang, 2013).

Table 1. Agents description. own source.

Agent name	Description
Customer Agent	It asks for service order defined by quantity, location and period of time of their demand. The agent customers base their decision process on the inventory cost analysis criterion. They expect to be served in a just in time process.
Service Control Agent:	Builds delivery services defining the quantity, period and location of the delivery. Search for reducing the transportation cost and augmenting the use of the vehicles without exceed their capacity form the cluster of requests.
Route Agent	Builds the routes of services using the 2-OPT local search heuristic.
Collaboration (integrator) Agent	This agent explores solutions for transportation cost reduction. The customers with a high ratio between holding and transportation costs are proposed to integrate other service routes. The transportation cost is computing from the cost of insert the customer to an evaluated route.

In this sense, the decision process of integrate the minimization of inventory and transportation costs can be modeled as a multi-agent system, in which customers, suppliers and transporters interact. Regardless every actor has their own interests, they must be balanced to optimize the total costs of the supply chain. This modelling is presented in the next section.

3 Multi-Agent System for the Inventory and Routing Decision

Taking advantage of the benefits of distributed computing, the decentralization of tasks and the coordination and integration between supply chain actors, a multi-agent system (MAS) to solve the combined problem of inventory and routing assignment was developed.

This multi-agent system is based on the representation of the customers and the transport-logistics operator as virtual agents that reproduce the input data from the physical system to the virtual system. The logistic operator develops the information exchange and the coordination processes among all agents in the multi-agent system. The multi-agent model is composed by the agents presented in table 1.

By using a *collaborative strategy*, the logistic operator (*Agent service control*) requests the customers (*Agents customer*) for the demand information at the *t* period, in order to generate the service orders. The customers may accept or reject the proposal of the *Agent service control*. If the proposal is accepted, the Agent service control request to the agent route to build a route for each service at the t period. Finally, Agent Collaboration searches for possible improvements by changing requests on the routes based on the location of the client and the period *t* of the demand.

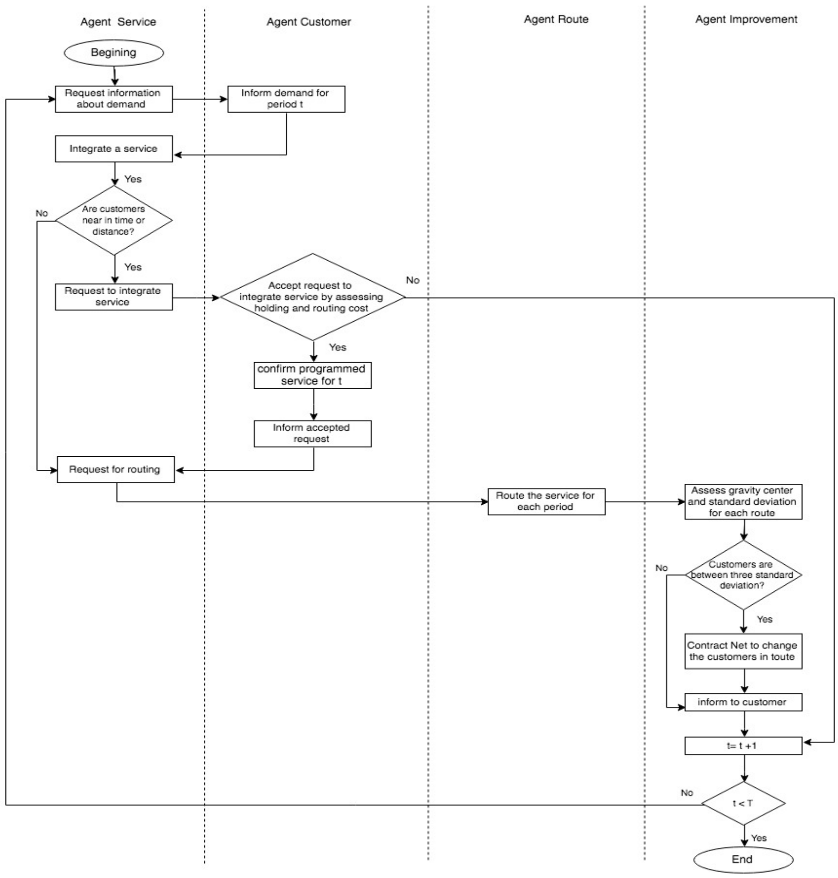


Fig. 1. Communication process at the multi-agent system. Own source.

The communication and coordination process carried out by the model can be depicted in Figure 1, and it is explained below:

The communication protocols between agents allow generating flexibility in the multi-agent system, through the structured management of the information that each agent receives and sends. In the multi-agent system designed, the interaction between the agents is ruled by the Request and Contract Net protocols, as can be seen in figure 2. The operations of the protocols are:

- ***Request Protocol (RP):*** The RP is a communication protocol that allows the agents to make information requests and actions to other agents with specific behaviors, capabilities and resources. This protocol allows the multi-agent system to initialize the service offers process by the logistics operator by requesting demand information. Each customer returns its demand information in period *t*. With this information, the service agent establishes the service for the period *t*.

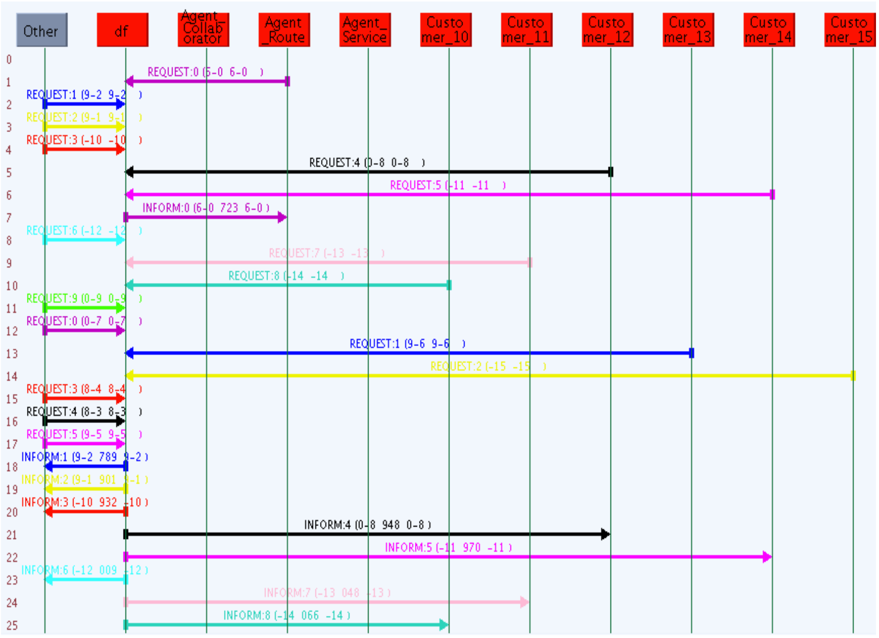


Fig. 2. Communication among agents during simulation. Own source.

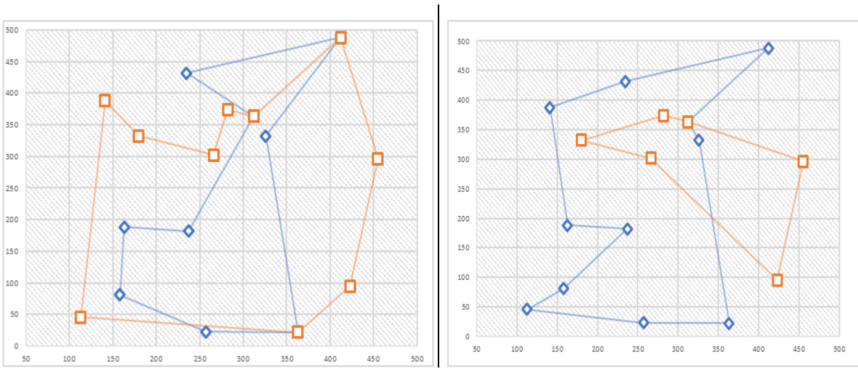
- The CNP is a negotiation protocol in which the agent that initiates the process (improvement agent) makes a request to the participating agents (agents Route) to send the cost proposals of including a customer in a service for the period $t + l$. The route agents evaluate the cost and benefit of including the customer in the existing route. With the answers of the route agents, the improvement agent selects and assigns the best proposal.

4 Multi Agent System Application

The MAS was tested using a distribution example, which consider 15 customers, one supplier and a 3-period time horizon. The simulation was carried out using JADE®. For the first period, all customers can supply their demand from the inventory, in that sense no service has been integrated by the logistic operator.

For the second period, there are two different services: the first one is integrated according with the information that the customers have send to the operator, and the second one is integrated through the interaction between customers and operator to figure out local decision for each customer. With these interactions in the second period, the customers that are subscribed for this service are supplied. Then, it is required to compute the needs for the third period.

When the service integration has finished, the agent route start to build their route using the *2-opt* local search heuristic to compute the cost of the routes for each service in each period. The results of the behavior of this agent is showed in table 2.



(a) initial solution (b) Improved solution

Fig. 3. Improvement of solution in the MAS. Own source.

Table 2. Routes for each service-period. Own source.

Period	Routes	Cost (U$)
t=2	0, 1 , 4 , 14 , 12 , 13 , 7 , 9 , 8 , 0	13,77
t=3	0, 5 , 11 , 2 , 3 , 10 , 13 , 15 , 6 , 9 , 0	15,14

Table 3. Final routes after the collaboration among agents. Own source.

Period	Routes	Transport cost	Inventory cost
t=2	0, 7 , 13 , 12 , 10 , 14 , 1 , 4 , 3 , 8 , 9 , 0	15,08	14,09
t=3	0, 5 , 2 , 11 , 15 , 6 , 0	8,54	0

With these results, the agent collaboration begins to make their analysis and trigger the contract net protocol with the agent's routes to find a better inventory and transportation cost combination for the system.

First, it should compute the gravity center, the average distance, and the standard deviation for the bigger and more expensive route. The customers that their distance to the center of gravity are bigger than three standard deviation are selected to evaluate a change in the route.

The contract net protocol asks for the routes to compute the cost of each route with and without the selected customers and the collaborator agent compute the inventory cost of make the changes in route to take the decision of change the customer of route or not. The final integrated services for periods t=2 and t=3 and their routes are presented in table 3.

With the agent collaborator, the total cost decrease US $5,89, equivalent to 15,64% less than the initial solution. Figure 3 presents the initial and improved solutions of the routes obtained with the Multi-agent system.

5 Conclusions

In this article, the combined inventory and transportation decision process in the supply chain was modeled as a multi-agent system that facilitates the analysis of the relationships between customers and suppliers in a framework of autonomy and collaboration. The model proposes an easy-to-implement and functional architecture in companies in which the inventory administration is not completely centralized. For this, different agents were designed to support the distribution and storage processes, which integrate functions and interaction protocols to make decisions based on their own resources and interests. However, the agents also evaluate their decisions based on principles of collaboration and global efficiency.

The results found by the multi-agent system do not correspond to the optimal solution, which can be obtained using the Inventory Routing Problem (IRP). Unlike the IRP, the proposed multi-agent system is more flexible, which considers the individual capacities and goals of the different agents involved in the distribution process. The multi-agent system seeks to improve the solutions in a collaborative framework through heuristic procedures that include the negotiation processes (request and contract net protocols) and the analysis of the storage conditions and the route cost.

As future research work, it can be analyzed more complex instances of the distribution process and its results should be compared with the optimal solutions produced by optimization methods such as the IRP model, with the aim of deriving how close the results of the multi-agent model are with respect to these optimal distribution plans. In addition, as future lines of research, it is suggested the integration of new agents in the model, which allow the development of simulation process closer to real situations, including suppliers, local administrators and other transport systems such as passengers and private transportation.

References

1. Aminzadegan, S., Tamannaei, M., Rasti-Barzoki, M.: Multi-agent supply chain scheduling problem by considering resource allocation and transportation. Computers & Industrial Engineering, 137(08) (2019)
2. Arango-Serna, M.D., Andrés-Romano, C., Zapata-Cortés, J.A.: Collaborative goods distribution using the IRP model. DYNA, 83(196), pp. 204−2012 (2016)
3. Arango-Serna, M.D., Serna-Urán, C.: New contract net negotiation protocol based on fuzzy inference applied to the supply chain. Universidad, Ciencia y Tecnología, 20(81), pp. 176–187 (2016)
4. Arango-Serna, M.D., Serna-Urán, C.A., Zapata-Cortes., J.A.: Multi-agent system modeling for the coordination of processes of distribution of goods using a memetic algorithm. In: Alor-Hernández, G.-A.J., Maldonado-Macías, G.A., Sánchez-Ramírez, C. (Eds.), New perspectives on applied industrial tools and techniques. Management and Industrial Engineering, pp. 71–89, Springer (2018)

5. Arango-Serna, M.D., Zapata-Cortes, J.A., Gutierrez, D.: Modeling the Inventory Routing Problem (IRP) with multiple depots with genetic algorithms. IEEE Latin American Transactions, 13(12), pp. 3959 – 3965 (2015)
6. Archetti, C., Bertazzi, L., Laporte, G., Speranza, M.G.: A branch and cut algorithm for a vendor managed inventory routing problem. Transportation Science, 1(3), pp. 382–391 (2007)
7. Avci, M.G., Selim, H.: A multi-agent system model for supply chains with lateral preventive transshipments: Application in a multi-national automotive supply chain. Computers in Industry, 82, pp. 28–39 (2016)
8. Belykh, D.L., Botvin, G.A.: Multi-agent framework for supply chain dynamics modelling with information sharing and demand forecast. Communications in Computer and Information Science, 858, Springer International Publishing (2018)
9. Böhnlein, D., Schweiger, K., Tuma, A.: Multi-agent-based transport planning in the newspaper industry. International Journal of Production Economics, 131(1), pp. 146–157 (2011)
10. Daganzo, C.: Logistics systems analysis. Berlin Heidelberg, Springer (2005)
11. Ghadimi, P., Ghassemi, F., Heavey, C.: A multi-agent systems approach for sustainable supplier selection and order allocation in a partnership supply chain. European Journal of Operational Research, pp. 1–16 (2017)
12. Goncalo, T.E.E., Morais, D.C.: Agent-based negotiation protocol for selecting transportation providers in a retail company. In Proceedings IEEE International Conference on Systems, Man, and Cybernetics, SMC, pp. 263–267 (2016)
13. Guerrero, W.J., Prodhon, C., Velasco, N., Amaya, C.A.: Hybrid heuristic for the inventory location-routing problem with deterministic demand. Int. J. Production Economics, 146, pp. 359–370 (2013)
14. Kang, J.H., Kim, Y.D.: Coordination of inventory y transportation managements in a two-level supply chain. Int. J. Production Economics, 123, pp. 137–145 (2010)
15. Kumari, S., Singh, A., Mishra, N., Garza-Reyes, J.A.: A multi-agent architecture for outsourcing SMEs manufacturing supply chain. Robotics and Computer Integrated Manufacturing, 36, pp. 36–44 (2015)
16. Lopes, F., Coelho, H.: Bilateral negotiation in a multi-agent supply chain system. Lecture Notes in Business Information Processing, 61, pp. 195–206 (2010)
17. Pal, K., Karakostas, B.A.: Multi agent-based service framework for supply chain management. Procedia Computer Science, 32, pp. 53–60 (2014)
18. Serna-Urán, C.A.: Modelo multi-agente para problemas de recogida y entrega de mercancías con ventanas de tiempo usando un algoritmo memético con relajaciones difusas. Universidad Nacional de Colombia (2016)
19. Sitek, P., Nielsen, I.E., Wikarek, J.: A hybrid multi-agent approach to the solving supply chain problems. Procedia Computer Science, 35(C), pp. 1557–1566 (2014)
20. Sitek, P., Wikarek, J., Grzybowska, K.: A multi-agent approach to the multi-Echelon capacitated vehicle routing problem. In International Conference on Practical Applications of Agents and Multi-Agents Systems, pp. 121–132, Switzerland Springer, Cham (2014)

21. Wang, G., Wong, T.N., Wang, X.: An ontology based approach to organize multi-agent assisted supply chain negotiations. Computers and Industrial Engineering, 65(1), pp. 2–15 (2013)
22. Zapata-Cortes, J.A.: Optimización de la distribución de mercancías utilizando un modelo genético multiobjetivo de inventario colaborativo de m proveedores con n clientes. Universidad Nacional de Colombia (2016)