Conceptual Framework for Agent-Based Modeling of Customer-Oriented Supply Networks

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Abstract. Supply Networks (SN) are complex systems involving the interaction of different actors, very often, with different objectives and goals. Among the different existing modeling approaches, agent-based systems can properly represent the autonomous behavior of SN links and, simultaneously, observe the general response of the system as a result of individual actions. Most of research using agent-based modeling in SN focuses on production issues. To the best of our knowledge, other relevant issues affecting SN competitiveness have not been fully studied such as the impact of customer's individual behavior or SN adaptability to changes in customer choices due to his/her decision-making context. In such a context, simulating SN oriented to the customer with context adaptability skills will allow researchers and practitioners to better look at ways to improve the relations between the SN and its customers, as well as to enhance SN's competitiveness. This paper presents our work in process about the design of an agent-based model of customer-oriented supply networks. Our focus is on the inclusion of the customer's purchase decision-making process and the SN adaptability. A preliminary model is developed based on a real-life case study from the floriculture sector in Colombia.

Keywords: Supply network · Multi-agent · Modeling · Simulation · Customer-oriented · Framework

1 Introduction

According to current definitions in the literature, a supply network "consists on all stages involved, directly or indirectly, in fulfilling a customer request. The SN not only includes manufacturers and suppliers, but also transporters, warehouses, retailers, and customers themselves" [1, p. 19]. The management of supply networks can be defined as all things required to influence the behavior of the SN and get the expected results [2].

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Effective management of these structures requires simultaneous improvement in both level of service to customers and efficiencies in internal operations of the organizations within the SN. Each supply network has its own unique set of market demands and operational challenges; each actor (company) of the SN must make decisions individually and collectively regarding production, inventory, facility location, transportation, and even information management [2]. The complexity of these decisions has increased in today's globalized markets; supply networks compete in multiple aggressive and changing environments. Continuous adaptation of their operating principles to search, face and act are paramount in response to new business challenges and opportunities in order to survive and remain competitive in the global market [3]. As a consequence, traditional SN's have evolved to become virtual, collaborative, complex and adaptive systems [4–6].

The academic literature has witnessed the proposition of multiple approaches for operational, tactical and strategic analyses of SN, including optimization (mathematical and/or heuristic), system dynamics, simulation and multi-agent modeling (e.g., [7–10]). Among those different modeling approaches, the multi-agent paradigm serves to model actors (agents) in the supply network as independent entities with a defined perception of their local environments, as well as to handle the impact of interconnectivity at a global level [3]. In other words, multi-agent systems (MAS) allow representing the system's behavior as result of the interactions between its members and the environment. The scientific literature has for a long time centered the study of SN structures on production, in which agents interact in response to messages sent and received in order to fulfill a demand requirement. However, this focus must be widened in order to actually respond to current needs and requirements of customers. It is hence necessary to analyze SN as costumer-oriented systems by taking into account the customers' decisional processes and their context. All this is done in order to improve the level of customers' satisfaction.

This paper aims at integrating the customers and their decisional processes into the analysis of SN. The goal is to exploit the benefits of multi-agent systems (MAS) as a tool of context-awareness analysis of supply networks in order to improve the SN competitiveness. At this point, the current paper presents our work in process on the design of an agent-based model of a customer-oriented SN. To illustrate the framework, a preliminary model is developed based on a real-life case study from the floriculture sector in Colombia.

This paper is organized as follows. Section 2 presents an overview of relevant related research. Section 3 describes the main features of a customer-oriented supply network. Section 4 is devoted to the description of the proposed multi-agent modeling framework in which the real-life case study is taken as an example of its implementation. The paper ends in Sect. 5 by presenting some concluding remarks and drawing directions for further research.

2 Overview of Related Literature

This section is devoted to present an overview of related academic works about modeling and simulation of supply networks using Multi-Agent Systems (MAS). For the purpose of this paper, we followed the principles of systematic literature review (SLR), in contrast to

narrative reviews, by being more explicit in the selection of the studies and employing rigorous and reproducible evaluation methods [11, 12]. Indeed, from a methodological point of view, a literature review is a systematic, explicit, and reproducible approach for identifying, evaluating, and interpreting the existing body of documents [13, 14]. To this end, we defined relevant keywords ("Supply Networks" and "Multi-agents") and searched in academic databases (Proquest, Scopus, ISI Web of Knowledge/Science, IEEE) for research papers published in English since 2003. A total of 53 academic papers are finally shortlisted and analyzed (see [15]). A summary of findings of this review is presented next. Interested reader in the complete classification of reviewed papers is invited to check the internal project report at http://ashiy.javeriana.edu.co/~agora/.

The first important output from this review is that supply networks have mainly been product-oriented and process-oriented, mostly representing make-to-order configurations, while only one paper focusing on make-to-stock and another on built-to-stock. Focus of reviewed works has usually been on production planning and control. In addition, these topics have been modeled with a biased attention into software development and information technology implementation. As a consequence, evidence from the review shows that collaborative issues have been settled from a software-system development perspective.

Another interesting outcome from our literature review is that, although the MAS paradigm has been employed to model SN as complex systems, few real life applications have been employed to validate the approaches in industrial settings. Hence, there is still a gap between academic models and real-life environments.

Due to the continuous increase of global competitors, traditional product-centered and process-centered orientations of SN have not been successful. Hence, it is necessary to focus on customers considering the demand side of the SN [16]. As a matter of fact, only costumer-centered SN's will be successful thanks to the coordination between products, services, and plans all together oriented to the fulfillment of costumers' satisfaction [17]. At this point, it is important to note that existing agent-based SN models do not explicitly include the customer or his/her decision-making process; the MAS modeling paradigm has only been used for isolated simulations of customer's decision processes (e.g., [18–20]).

In addition, as stated in the literature [17, 21], it is of great importance to study the organizational adaptation to costumer changes due to cultural, social, individual and psychological factors that affect costumer's purchase behavior, as well as product utilization and disposition behaviors. Therefore, the SN scope must expand and focus primarily on the customers who finally determine the systems survival. This requires looking forward for the integration of costumers into the SN [21]. The current paper aims at fulfilling this gap in the academic literature. A case study from the Colombian floricultural sector is analyzed, but the modeling framework intends to be as general as possible to be applied to other industrial sectors.

3 The Customer-Oriented Supply Network

Before presenting the proposed conceptual MAS framework for customer-oriented SN, it is first required to identify the different processes within the supply network required to fulfill customer demands. To this end, the Supply Chain Operations Reference model

(SCOR®) will be employed [22]. In the SCOR® model, each company of the SN may perform five macro processes: Plan, Source, Make, Deliver and Return. Through the detailed performance of the activities within these processes, all companies interact through the SN, developing business relationships that finally accomplish both individual enterprise objectives and, most important, global profit. This is done by means of collaboration as a way to align individual companies towards this general objective. The processes supporting the scope of our model are presented in Table 1. In addition, the right side of Fig. 1 describes the relations and the processes occurring at each link between SN actors. Within the loop, arrows are centered in each SN company (some processes occur inside). However, these relations do not currently regard the customer; the customer appears as a passive SN actor. This behavior is far distant from real life. Customer's nature is active, and purchase decisions give sense and guarantee SN survival.

Table 1. Make-to-order processes codification according to SCOR® reference model [27].

Process-level 1	Process-level 2	
Plan	sP1. Plan supply chain	sP3. Plan make
	sP2. Plan source	sP4. Plan deliver
Source	sS2.1. Schedule product deliveries	sS2.4. Transfer product
	sS2.2. Receive product	sS2.5. Authorize supplier payment
	sS2.3. Verify product	
Distribution	sD2.1. Process inquiry and quote	sD2.8. Pick product
	sD2.2. Receive, configures, enter and validate order	sD2.9. Pack product
	sD2.3. Reserve inventory and determine delivery date	sD2.10. Load product and generate shipping documents
	sD2.4. Consolidate order	sD2.11. Ship product
	sD2.5. Build loads	sD2.12. Receive and verify product by customer
	sD2.6. Route shipments	sD2.13. Install product
	sD2.7. Receive product from source or make	sD2.14. Invoice
Make	sM2.1. Schedule production activities	sM2.4. Package
	sM2.2. Issue sourced/in-process product	sM2.5. Store finished product
	sM2.3. Produce and test	sM2.6. Release finished product for delivery

The proposed model of the SN including the customer can be seen in the right side of Fig. 1, in which the enhancing processes are highlighted with bolded lines. The processes included are the ones referred to the purchase decisions made by the customer (PDM) and the marketing processes: Consumer Analysis, Product Design, Distribution Channel Relations and Communication with the customer [19]. These are defined in the figure as MK 1, 2, 3, 4. When simulating these SN relations among

multiple actors, and the impact of context-awareness on the processes, customer-facing metrics proposed by SCOR® reference model [22], such as Perfect Order fulfillment, order fulfillment cycle time, upside SN flexibility and adaptability (towards suppliers), Downside SN adaptability (towards de final consumer) will reflect its improvement, and measure reliability, responsiveness and agility of the SN under different scenarios.

4 Framework Based on Agents for Customer-Oriented SN

Multi-agent modeling is a tool that allows the simultaneous representation of multiple actors and their relationship. In the proposed model, further simulation will allow the customer decision-making agent to decide and generate a purchase order based on the context adapted information the SN offered initially. This section describes in detail the proposed agent-based system for customer oriented supply networks. As a matter of illustration, several parts of the framework will refer to a case study from the floricultural sector in Colombia.

4.1 Context-Aware Customer-Oriented Supply Networks: Considering Both Customer and Context Profiles

MAS modeling allows the creation of an agent able to perceive the customer's context and to change related SN processes in regard to the input received. In order to model this context-awareness functionality, following the ideas highlighted in [23], the context must be determined. In general terms, it can be defined by the customer's profile and the context profile. The former is the characterization of preferences, tastes, habits, interests, restrictions and benefits of the customer, while the later is characterized by several variables including spatial-temporal variables, infrastructure, as well as social technology, normative and environmental variables. All these describe the context in which the customer is immersed. These context characteristics are refined regarding each scenario. Some authors (e.g., [24]) have considered the context to be defined by the information registered in purchase orders, reception goods notes and shipment notes, but not the customer's environment itself. It is thus necessary to "capture" the customer's mental model of context [25].

In order to illustrate the inclusion of customer and context profiles within the proposed MAS model, the case personalized flower bouquet is considered. Figure 2 shows these two example profiles.

On the first hand (left side of Figure), the customer profile is explained. Tastes are customer's characteristics regarding the product due to past purchase and usage experiences. These include bouquet types, flowers, colors and varieties bought and the moments in which they were enjoyed. Preferences are customer choices from a list, for example ornaments to include in the bouquets, delivery options and costs (or prices). Interests are costumers' current trends (e.g., purchase motivation). Habits can be seen as customers' behavior regarding purchase frequency. Basic information as location and purchase type, recipients and restrictions variables determines the customer's specific profile. On the other hand (right side of Figure), the context profile is formed by the variables that characterize the processes context in which customers interact with

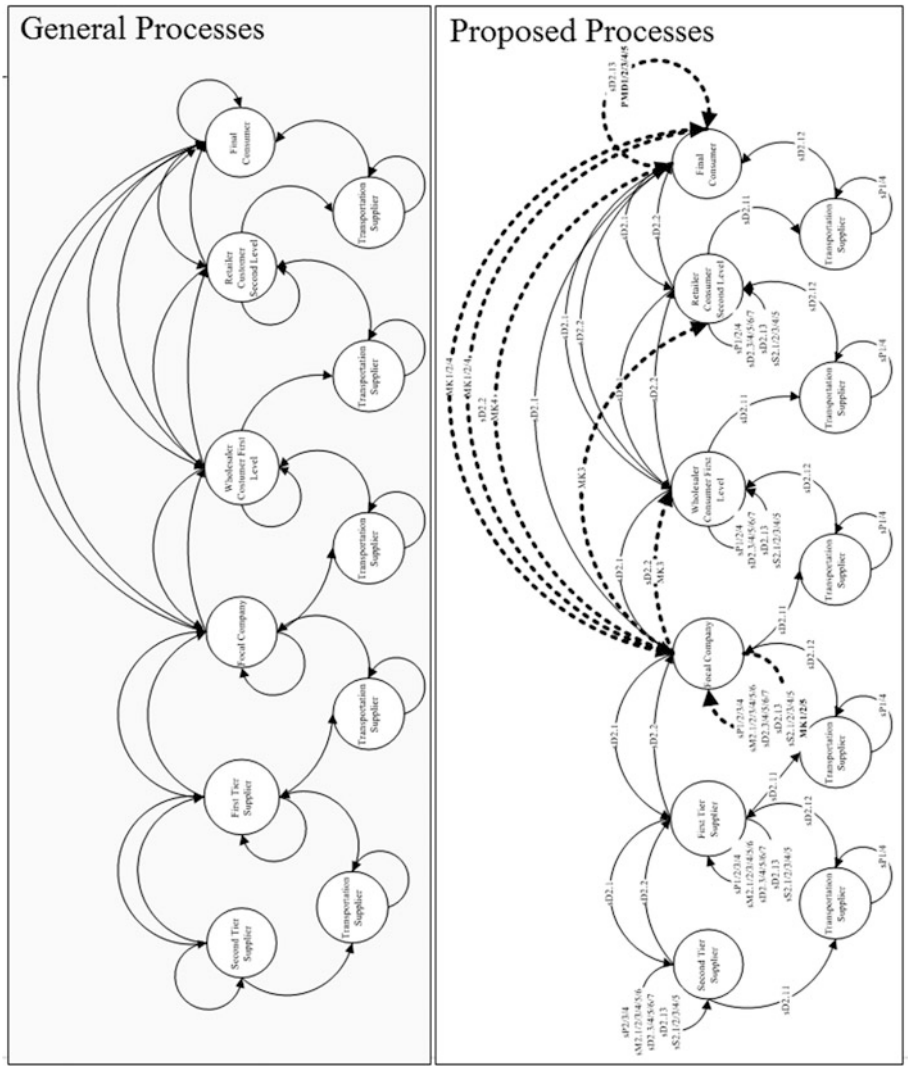

Fig. 1. General (left) and proposed (right) processes and relations diagrams.

the SN. The spatial and temporal characteristics regarding purchase occasions due to cultural situations, and the different taxes and customs regulations affect each customer. Also purchase channels, environmental issues (e.g., weather and humidity levels) affect the customers' possibilities towards his/her access to specific products.

The multi-agent model represents a set of customers defined by their individual profiles and contexts. Regarding this characterization, he/she will make a purchase decision. At the same time, the SN establishes a relation with the customer updating both profiles and context information in order to personalize the offers. In response, the system will adapt processes related to bouquet design and channel options impacting

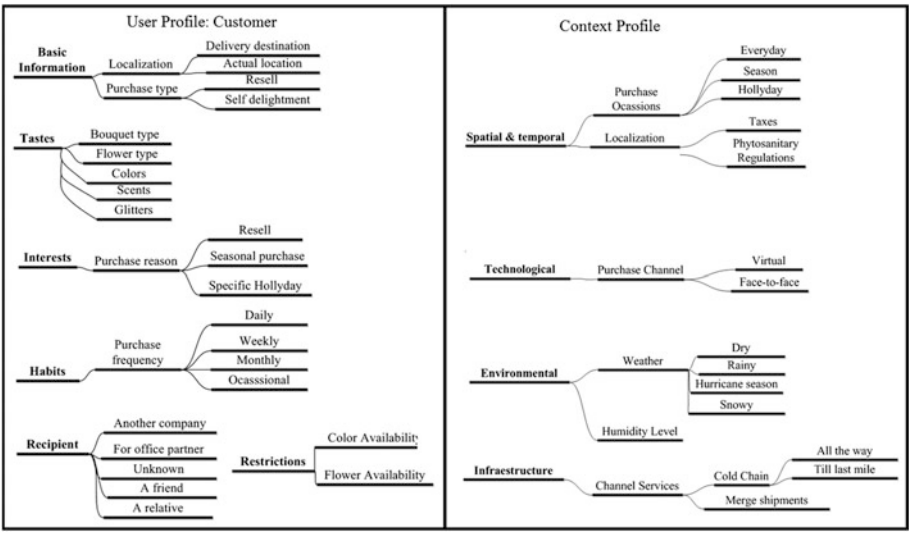

Fig. 2. User profile and context profiles applied to Flower Company Case.

upstream processes. As stated in [26], it is necessary to consider external conditions when simulating SN; they are the origin of complexities of these systems.

4.2 Multi-agent System: Illustrating the Order Fulfillment Process

In order to effectively model customer-oriented supply networks, a multi-agent modeling methodology has to be employed. In our case, we have chosen the so-called Organizational Approach for Agent Oriented Programming (AOPOA) methodology [27] in order to analyze, design and implement the model. Understanding the problem domain can be achieved by stating the process activity flow in which SCOR processes are defined (Fig. 3). Due to the page limitation of the current paper, the remainder of this subsection illustrates the AOPOA modeling methodology for the Order Fulfillment process. The agent definition is the result of the description of user case diagrams, functional and non-functional requirements, activities, objectives, abilities, resources, relations and roles tables. Finally, Fig. 4 shows how, for each SN actor in the MAS model, agents with different capabilities can assume different functions, regarding their role. For example, the focal company can be represented in the MAS model by either agent Plan (FC-P), charged of rules and strategies between actors, or agent Make (FC-M), responsible of assembly processes, or agent Source (FC-S) responsible of sourcing, or agent Distribution (FC-D) managing of delivery processes, or agent Adaptation (FC-Ad) responsible of the customers' feedback and communications between actors upstream the SN.

Supplier collaboration in order fulfillment processes is critical for the SN survival; hence, agility can be achieved as well as enhanced competitiveness. Suppliers' and focal company response to requirements from customers are modeled by considering their context. For instance, the Order Fulfillment Process is improved with initial communications from the focal company to the customer, taking into account his/her

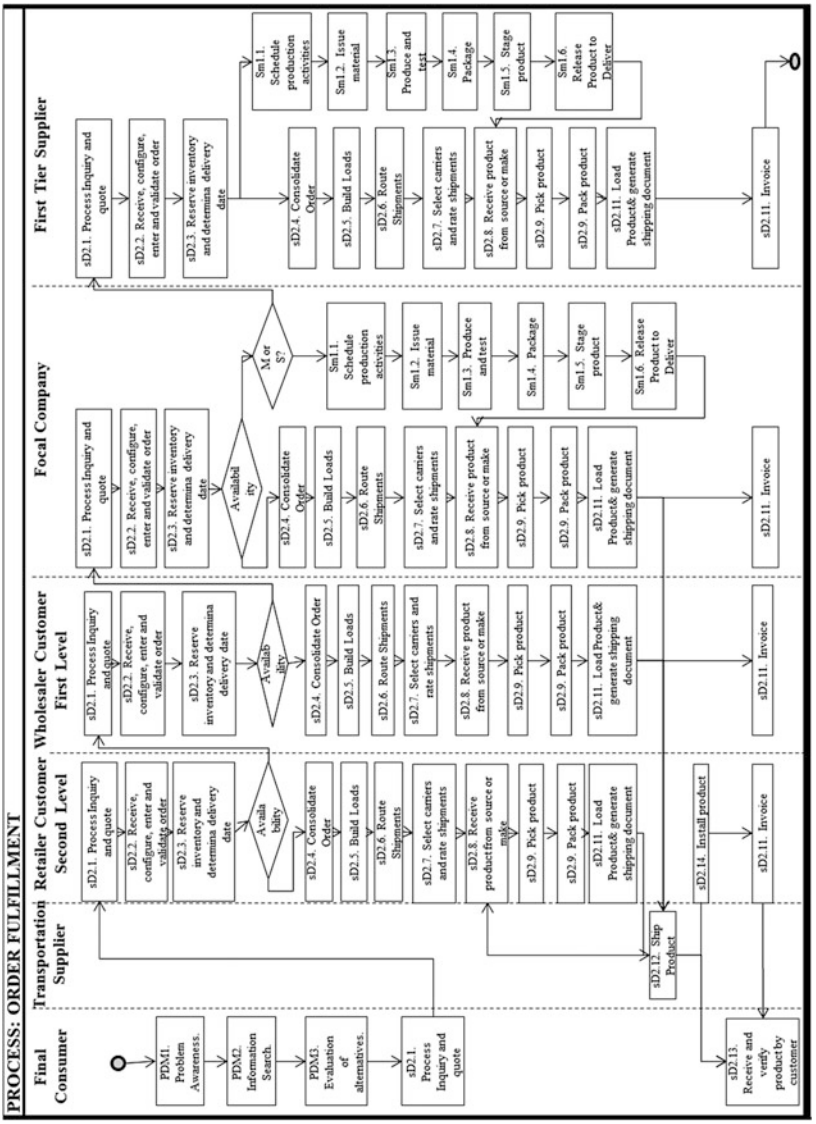

Fig. 3. Activities diagram of order fulfillment process flow.

context and the supplier's context. In our case, the agent adaptation sends, one or two days ahead to the historical request date, a personalized offer to the customer. This offer may respond to the environmental context profile in which the customer asks for flowers. The offering message considers customer's taste (e.g., bouquet and flower types, colors, and other preferences about ornaments).

Personalized offers will attend to production and sourcing availabilities and product design preferences. Furthermore, regarding the context information, future orders can be initiated directly from the customer. This information is used by the Production Agent in order to modify the product (for the case under study, future bouquets) by changing the percentages of colors, for example. Figure 5 presents an example of SN simulated performance of the whole supply network based on context-awareness.

Processes such as product design (in the illustrative case, bouquet and packing, channel options and prices) will be adapted regarding the costumers' decisions. As result of context awareness, personalized product offers, based on product availabilities considering customers preferences, habits, interests and additional variables from his/her context that affect the product design and packing, are presented to the

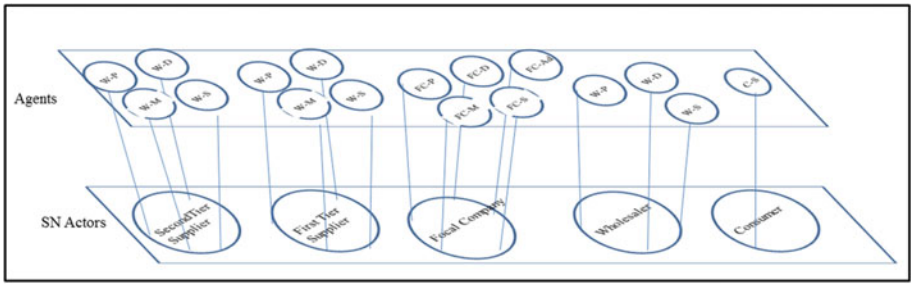

Fig. 4. Agent definition diagram.

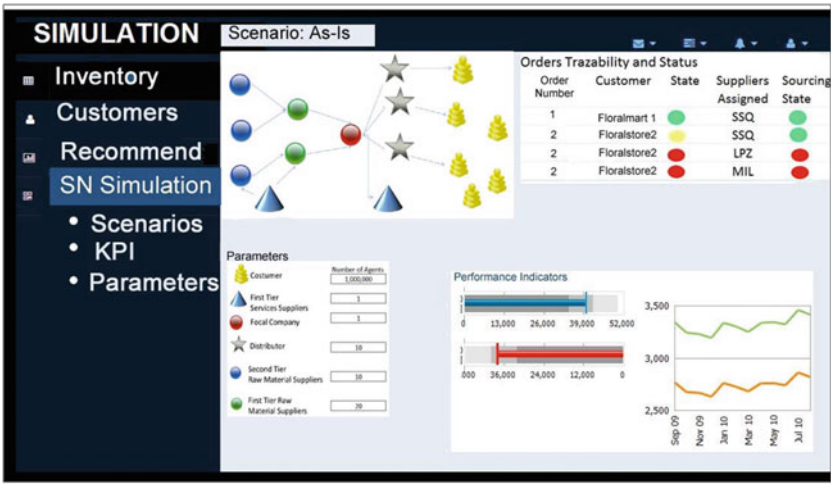

Fig. 5. Decision support tool: example of simulated key performance indicators.

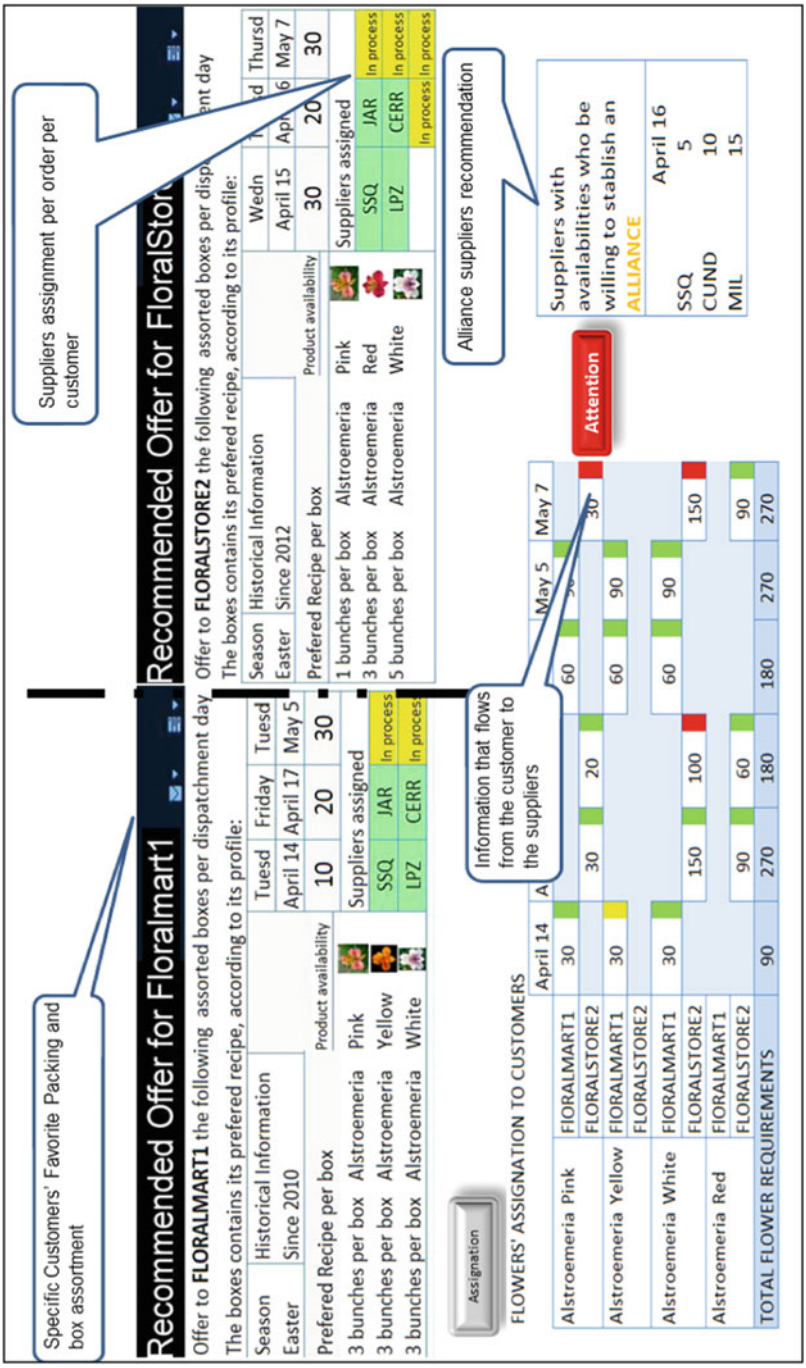

Fig. 6. Decision support tool: example of customized offering to customers.

customers considering the incoming product, the requests already assigned to customer with assorted availabilities. Additionally, external conditions can be considered to adjust incoming product forecasting for example, weather conditions under different periods (daily, weekly, monthly, year). Figure 6 illustrates how personalized offers to customers can be taken into account by our decision support tool, considering suggested suppliers to be recommended as allied SN actors.

5 Conclusions and Further Research

In order to respond to current market conditions in which the customer's decision-making process does impact the performance of supply networks, this paper proposed a conceptual modeling of SN based on the multi-agent paradigm. The goal was to have more insights about the explicit consideration of the customer decision-making process and context in the modeling framework, in order to gain competitiveness. A computational decision support tool is under development allowing the test of different scenarios and the evaluation of SN key performance indicators. The aim is to have this tool able to consider customer decisional process and hence provide information to SN managers for adapting processes in response to customers' context.

As this is a first step in the modeling and simulation of a customer-oriented supply network under context awareness, further research is still needed. In particular, we are still on the data collection stage of the research and hence more numerical validation of the multi-agent system and the simulation tool are to be done. Additionally, our future research will also focus on the application of collaborative relations among different actors of the supply network and include the adaptive processes so as to evaluate the impact on key performance indicators. Finally, current insights for the design of the decision support tool are based from a particular case study from the floricultural industry in Colombia. More tests and feedback is needed in order to have a generic multi-agent model and computation tool, exploitable in different industrial settings.

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