

# SCAMM-CPA: A supply chain agent-based modelling methodology that supports a collaborative planning process

Jorge E. Hernández\*, M.M.E. Alemany, Francisco C. Lario & Raúl Poler

## abstract

Multi-agent system technologies are currently becoming a strong modelling tool for supporting the complexities present in planning supply chains. As supply chains are composed by nodes needing common agreement to fulfil their own requirements, the multi-agent system thus represents a suitable tool for modelling negotiation, mainly within a collaborative context. Nevertheless, a review of the relevant literature revealed a certain deficiency in existing agent-based modelling methodologies supporting collaborative supply chain planning. This paper has thus proposed a novel agent-based modelling methodology to cover such deficiency to make a real contribution towards supply chain agent-based modelling within a collaborative planning environment. This methodology was supported by the relevant aspects found in the literature review regarding collaborative planning within a multi-agent context (agent definition, scope, decisional level, distribution and supply chain network entities, modelling technique, interaction, coordination mechanism, advantages and disadvantages) and explicit methodologies supporting the agent-based modelling of any type of problem under consideration. By considering the corresponding literature review, the proposed new methodology synthesised existing knowledge in the field and both fulfilled and enriched each of its phases with our own modellers' knowledge. This study adopted a static view of a real automotive supply chain network so as to present a first real multi-agent-based supply chain model approach as an application of this novel modelling methodology.

**Key words:** multi-agent system (MAS), collaborative planning (CP), collaborative operational planning (COP), modelling methodology, supply chain management (SCM), distribution and supply chains and networks (DSC-N), literature review.

## resumen

SCAMM-CPA: Una metodología de modelado del proceso de planificación colaborativa en cadenas de suministros basada en sistemas MultiAgente

En la actualidad la tecnología de los sistemas MultiAgente es una poderosa herramienta de modelado para apoyar los procesos de planificación en entornos complejos. De esta manera, dado que una cadena de suministro se compone de nodos, los que a su vez se encuentran buscando acuerdos entre ellos para poder cumplir con sus propios requerimientos, se ha visto que los sistemas MultiAgente sirven adecuadamente para apoyar el modelado de procesos, en este caso, de negociación bajo un contexto colaborativo. Si bien la tecnología de Agentes se encuentra en voga, a partir de un estudio bibliográfico llevado a cabo en el documento, se ha detectado que la existencia de metodologías que se orienten al desarrollo de modelos basados en sistemas MultiAgente, para apoyar los procesos de planificación colaborativa, resulta escaso. Así, el presente trabajo plantea una metodología novedosa para apoyar el modelado del proceso de planificación colaborativa en cadenas de suministro.

Finalmente, se presenta una perspectiva estática de un proceso relacionado con una cadena de suministro del sector del automóvil con el propósito de entregar al lector una aproximación a la aplicabilidad de la metodología y también, de presentar la aplicación de los sistemas MultiAgente en cadenas de suministro reales.

**Palabras clave:** Sistemas MultiAgente (MAS), Planificación Colaborativa (CP), Planificación Operativa Colaborativa (COP), Metodología de Modelado, Gestión de la Cadena de Suministro (SCM), Redes de Suministro y Distribución (DSC-N), Revisión de Literatura Científica.

## résumé

SCAMM-CPA: Une méthodologie de modélisation du processus de planification en collaboration en chaînes de fournitures basée sur des systèmes Multi Agent

Actuellement la technologie de systèmes Multi Agent est un instrument puissant de modélisation pour l'appui de processus de planification en milieux complexes. Étant donné qu'une chaîne de fourniture se compose de réseaux intermédiaires, négociant, à leur tour, des accords entre chaque réseau dans le respect de leurs propres exigences, on observe que les systèmes Multi Agent sont d'une grande utilité pour appuyer la modélisation de leurs processus de négociation, dans le cas présent, dans un contexte de collaboration. Bien que la technologie d'Agents soit d'actualité, une étude bibliographique menée dans ce document a permis de détecter l'existence peu élevée de méthodologies orientées au développement de modèles basés sur des systèmes Multi Agent, pour appuyer les processus de planification en collaboration. Ce travail propose une méthodologie nouvelle pour appuyer la modélisation du processus de planification en collaboration dans les chaînes de fournitures.

Finalment, on effectue la présentation d'une perspective statique d'un processus en relation avec une chaîne de fourniture du secteur automobile afin de donner au lecteur une approximation de l'applicabilité de la méthodologie et de lui présenter l'application des systèmes MultiAgent en chaînes de fourniture réelles.

**Mots-clés:** Systèmes Multi Agent (MAS), Planification en Collaboration (CP), Planification Opérationnelle en Collaboration (COP), Méthodologie de Modélisation, Gestion de la Chaîne de Fourniture (SCM), Réseaux de Fourniture et Distribution (DSC-N), Révision de Bibliographie Scientifique.

## resumo

SCAMM-CPA: Uma metodologia de modelado do processo de planificação colaborativa em cadeias de abastecimento baseada em sistemas MultiAgente

Na atualidade a tecnologia dos sistemas MultiAgente é uma poderosa ferramenta de modelado para apoiar os processos de planificação em ambientes complexos. Desta maneira, dado que uma cadeia de abastecimento compõe-se de nodos, os que a sua vez encontram-se buscando acordos entre eles para poder cumprir com seus próprios requerimentos, tem-se visto que os sistemas MultiAgente servem adequadamente para apoiar o modelado de seus processos, neste caso, de negociação sob um contexto colaborativo. Ainda que a tecnologia de Agentes se encontra em voga, a partir de um estudo bibliográfico realizado no documentos, verificou-se que a existência de metodologias que se orientem ao desenvolvimento de modelos baseados em sistemas MultiAgentes, para apoiar os processos de planificação colaborativa, é escassa. Assim, o presente trabalho estabelece uma metodologia nova para apoiar o modelado do processo de planificação colaborativa em cadeias de abastecimento.

Finalmente, apresenta-se uma perspectiva estática de um processo relacionado com uma cadeia de abastecimento do setor automotor com o propósito de entregar ao leitor uma aproximação à aplicabilidade da metodologia e também, de apresentar a aplicação dos sistemas MultiAgente em cadeias de abastecimento reais.

**Palavras chave:** Sistemas MultiAgente (MAS), Planificação Colaborativa (CP), Planificação Operativa Colaborativa (COP), Metodologia de Modelado, Gestão da Cadeia de Abastecimento (SCM), Redes de Abastecimento e Distribuição (DSC-N), Revisão de Literatura Científica.

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## Introduction

Nowadays companies are focusing their businesses on those activities they know better (known as core competences), and subcontracting the rest of the activities to other specialized companies. Moreover, Bercerra (2008) establishes that a growing importance, in the last four decades, is being given to the study of joint production systems, especially to the analysis concerning to the entrepreneurial companies and their configurations. In addition, the supply chain management research is oriented primarily on the efficient configuration of processes and also to the allocation of resources (Carter et al., 2007). Consequently, the main product or service characteristics (design, price, quality, etc.) depend on various companies involved in their creation, which allows the Distribution and Supply Chains and Networks (DSC-N) to appear and grow. Moreover, the development and consolidation of this enterprise activity format can be reinforced also by the market internationalization and globalization, the Customer Business Orientation (B2C), the Service Orientation (B2B), and the emerging knowledge societies (Manthou et al., 2003). In addition, the nets openness and the communication and information technology improvements have reduced the transaction costs in a considerable manner, and also allowed the evolution of the classical linear supply chains towards integrated companies in semi-independent organization nets forms (Hagel & Singer, 1999). Thus, to be successful in a turbulent environment, organizations must elevate agility across entire supply chains (Li et al., 2008). Under this context, it can be seen how the modern manufacturing systems are moving out from the vertical integrated enterprises towards semi-independent organization nets, suppliers and distributors, which offer value to the customers. In addition, Alemany et al. (2008) set out the complexity that the conventional product pack process related to different supply chains implies, this due to the fact that the inherent product pack order request characteristics. In this sense the future of the business opportunities will be related to the competences regarded to companies that belongs to a supply net (Rice & Hoppe, 2001). In this new scenery, the DSC-N should manage them in an adequate and integrated way, leading to the concept of Supply Chain Management (SCM). SCM is defined by the Global Supply Chain Forum (GSCF) as the integration of key business processes from end user through original suppliers that provide products, services, and information that add value to customers and other stakeholders (Lambert & Cooper, 2000). At the tactical-operational planning level, the task of Master Planning (MP) plays a crucial role (coordination problem). The coordination process of autonomous, yet in-

ter-connected tactical-operational planning activities is referred to as Collaborative Planning (CP) in what follows (adapted from Dudek & Stadtler, 2005). Therefore, the CP in a DSC-N constitutes a decision-making process that involves the interaction components, exhibiting a wide range of dynamic behaviour (Jung & Jeong, 2005). Moreover, from a decentralized collaboration point of view, every node will consider their collaborative and non-collaborative partners (customers and suppliers) in order to carry on their planning processes (Poler et al., 2008). Thus, it is possible to say that it is necessary (in a supply chain network) to resolve conflicts between several decentralised functional units, because each unit tries to locally optimise its own objectives, rather than the overall supply chain objectives. Because of this, in the last few years, the visions that cover a CP process such as a distributed decision-making process are getting more important than the centralized perspective.

In this context, the relevant literature on linking and coordinating the planning process in a decentralized manner, distinguishes three main approaches: DSC-N coordination by contracts, multi-agent systems and mathematical programming models (Dudek & Stadtler, 2005). And there exist a few contributions that combine mathematical programming approaches with decentralized decision-making (Bhatnagar et al., 1993; Simpson & Erengüç, 2001; Barbarosoglu & Özgür (1999); Dudek & Stadtler, 2005). In recent years, the multi-agent approach for managing the supply chain at the tactical and operational levels has emerged. It views a supply chain as composed of a set of intelligent (software) agents, who are responsible for one or more activities and interacting with other related agents in planning and executing their responsibilities (Fung & Chen, 2005). Galland et al. (2003) consider the multiagent system (MAS) as the new modelling paradigm which combines the object-oriented modelling with the distributed artificial intelligence aspects. Hence, multiagent models offer a good approach to model long supply chains with several autonomous firms who may operate with various levels of flexibility (Jain & Benyoucef, 2008). In this sense, the multiagent system architecture considers the information exchange and the individual relationship among the individual agents, which will favour the cooperation between the agents and obtain better solutions than those obtained by the centralized systems. Therefore, the main reasons why the multiagent system is an adequate modelling technique for a CP decision-making process are as follows:

- The decision-making in a DSC-N is usually developed in a distributed way among different DSC-N entities with their own objectives and information:

- With regard to the objectives, this technique incorporates the social factor to represent the desires, interest and beliefs that may be declared in the system.
- The process of information exchange, whether sequential or concurrent, can be very time-consuming, due to the very large amount of diverse information required.
- Finally, this modelling technique presents many advantages when reflecting the dynamism related to each entity that is involved in the DSC-N processes.

Accordingly, this paper presents a novel methodology named “SCAMM-CPA” (which stands for Supply Chain Agent-based Modelling Methodology that supports a Collaborative Planning Approach). It supports the collaborative operation planning modelling of DSC-N under a distributed decision-making context step by step. This is supported by the multiagent systems and enriched through mathematical programming models. The objective of this methodology is to facilitate the understanding, analysis and modelling of the Collaborative Operational Planning (COP) process based on the multiagent systems and mathematical programming models by means of the structured description of those relevant aspects to be analysed. The phases and contents of the methodology will not only assist in building the model of the actual CP process (AS-IS model), but also allow to identify possible ways and choices in order to later make an ideal selection among them (TO-BE model).

This paper is organized as follows. First, in Section 2, a scientific literature review regarding the main aspects considered for the agent-based modelling in a COP context and the existing methodologies are addressed. In Section 3, a supply chain agent modelling methodology considering a COP approach is proposed based on nine main blocks or stages (problem identification, problem conceptualization, parameterization, main

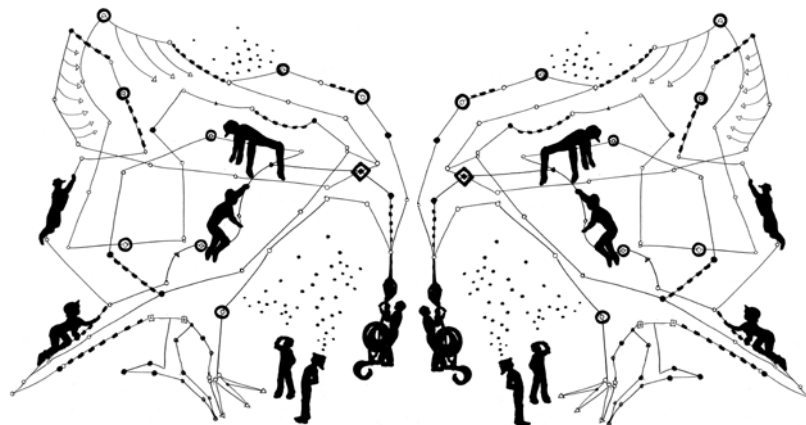
agents identification, analysis of interdependence relationship among agents: identify intermediate agent, behaviour among agents representation, conceptual agent-based modelling, development of the agent-based application, validation). Moreover, in order to enrich the novel contribution of the SCAMM-CPA proposal, Section 3 extends briefly its theoretical contribution to real automotive supply chain sector. Then, in Section 4, a comparative analysis between the proposed methodology and the literature review results is carried out. Finally, in Section 5, the main conclusions and further research are addressed.

## Literature Review

In this section, a literature review, which will be useful for supporting the proposed methodology that will be explained in detail in the next section (Section 3), is presented. The review method is as follows. First, a review of the scientific literature is made on existing methodologies that support either the development of COP process models or other processes that are related to the SCM in DSC-N environments using MAS. Second, with the objective of completing the above analysis, the literature review has been expanded to any modelling methodology based on MAS and developed for any problem characteristics. The phases of these methodologies have been useful to establish, mainly, the technical SCAMM-CPA methodology phases.

### *Main aspects considered for the agent-based model*

To define the content of each established SCAMM-CPA methodology phases, the relevant aspects that each author has considered in order to develop a MAS model in the particular context of CP and in the general context of SCM, are presented. Table I shows the nine main aspects detected and also the authors who are considering those. From this Table I, it can be ob-



served that most of these authors define the scope (column 2), the modelling technique (column 5) and the interaction between agents (column 6).

The aspects considered in Table 1 are described as follows:

- **Agent definition:** This aspect establishes if the author under study proposes an agent definition or not in the development of their work. Hence, 71% of the authors do not establish an agent definition, whereas 29% do it.
- **Scope:** According to the analysed information, it is possible to define the problem typology and the domain or scope considered. In this sense, the scopes that have been detected are: agent behaviour study (CS1), supply chain management (CS2), communication among agents (CS3), architecture of MAS (CS4), development of MAS application (CS5), implementation of MAS (CS6). In this case, 16% of the authors consider the CS1 aspect, 29% consider the CS2 aspect, 10% consider the CS3 aspect, 6% consider the CS4 aspect, 20% consider the CS5 aspect, and the remaining 18% consider the CS6 aspect.
- **Decisional level:** This category makes reference to the decisional level in which the studied problem can be framed. Three decisional levels are defined: strategic, tactical and operational levels. The level combinations detected in the scientific literature are: strategic (DL1), tactical (DL2), operational (DL3), strategic-tactical-operational (DL4), strategic-tactical (DL5), strategic-operational (DL6), tactical-operational (DL7), and without specification (NE-DL). In this case, DL1 is considered by 6% of the authors, DL2 appears in 20% of the cases, DL3 in 4%, 14% of the authors consider DL4, 4% of the authors establish the DL5, DL6 appears in just 2% of the authors, 20% consider DL7, and the remaining 29% of the authors do not establish an explicit decisional level configuration (NE-DL).
- **DSC-N Entities:** This dimension makes reference to the part of the DSC-N modelled through the MAS systems. The main configurations detected are: customer, distributor, manufacturer and supplier. The combinations that have been found are: customer (CSCE1), customer-distributor (CSCE2), customer-supplier (CSCE3), customer-manufacturer (CSCE4), customer-distributor-manufacturer (CSCE5), customer-manufacturer-supplier (CSCE6), and without specification (NE-CSCE). Therefore, 2% of the authors consider the configuration CSCE1, 8% are considering the CSCE2 configuration, 18% of the authors consider CSCE3, 16% consider CSCE4, 12% consider CSCE5, and the configura-

tion CSCE6 is considered by 20% of the authors. Finally, 22% of the authors do not specify it in an explicit way (NE-CSCE).

- **Modelling technique:** This dimension is related to the main MAS modelling techniques that have been used by the authors: conceptual models (MT1), simulation models (MT2), data structures (MT3), hierarchical trees (MT4), data diagrams (MT5), AUML (MT6), mathematical models (MT7), and without specification (NE-MT). Regarding to this, 49% of the authors consider the MT1 modelling technique, 4% consider MT2, 5% consider the MT3 technique, 2% consider MT4, 2% consider the MT5, 23% use a MT6 modelling technique, and 14% of the authors consider the MT7 modelling techniques. Finally, just 2% of the authors do not specify the modelling technique (NE-MT).
- **Interaction:** This aspect indicates if the authors explicitly consider the establishment of the interaction criteria in order to obtain the agreements among the DSC-N or system components. In this case, 98% of the authors consider the interaction among the entities, in contrast to 2% of the authors, who do not consider in an explicit way the interaction.
- **Coordination mechanism:** Every time when a supply chain node needs to receive or send information, it will have to do it by considering a series of norms and permissions that, previously, must have been established among the entities related to the nodes and, therefore, to the supply chain. These permissions are usually named rules or contracts in which falls the coordination mechanism. In this case, 35% of the authors establish a coordination mechanism; while 65% do not consider those mechanisms in an explicit way.
- **Advantages and disadvantages:** This dimension shows if the authors consider the advantages and disadvantages with regard to the agent-based model. In this case, 10% of the authors study these aspects, but 90% do not.

### ***Existing methodologies for the agent-based modelling***

From the scientific literature, the most relevant formal MAS modelling methodologies that are oriented toward supporting the modelling of any type of problem are presented in Table 2, where the corresponding authors, year, methodology name and the orientation problem are listed. As it can be seen from Table 2, no methodology has been found that gives support to the CP process in the DSC-N context.



**TABLE 1. Main agent-based model aspects considered by authors.**

Authors	Agent definition	Scope	Decisional level	DSC-N entities	Modeling technique	Interaction	Coordination mechanism	Advantages and disadvantages
Castelfranchi (1992)	X	X			X	X		X
Coen (1994)		X	X		X	X		
Smith <i>et al.</i> (1994)	X	X			X			
Hayes-Roth (1995)	X	X	X		X	X		
Russell and Norving (1995)	X	X		X		X		
Wooldridge and Jennings (1995)	X	X	X		X			
Franklin and Graesser (1996)	X	X		X	X			
Cooper <i>et al.</i> (1997)		X		X				
Milojicic <i>et al.</i> (1998)	X	X			X			
Jennings <i>et al.</i> (1998)		X			X	X		
Kjenstad D. (1998)		X	X		X	X	X	X
Parunak and VanderBok (1998)		X	X		X		X	X
Chen <i>et al.</i> (1999)		X		X	X	X		
Sadeh <i>et al.</i> (1999)	X	X	X	X	X	X		
Fox <i>et al.</i> (2000)		X		X	X	X	X	
Brandolese <i>et al.</i> (2000)	X	X	X		X	X		
Yan <i>et al.</i> (2000)		X		X	X	X		
Grolik <i>et al.</i> (2001)		X		X	X	X	X	
Julka <i>et al.</i> (2002)		X	X	X	X	X		
Odell <i>et al.</i> (2002)		X	X		X	X		
Sierra <i>et al.</i> (2002)	X	X			X	X		
Cavaleri <i>et al.</i> (2003)		X		X	X	X	X	X
Dastani <i>et al.</i> (2003)		X	X		X	X		
Galland <i>et al.</i> (2003)		X	X		X	X		
Kaihara <i>et al.</i> (2003)	X	X	X	X	X	X		
Karageorgos <i>et al.</i> (2003)		X			X	X		X
Azevedo <i>et al.</i> (2004)		X	X	X	X	X		X
Chan and Chan (2004)		X			X	X	X	
Hadeli <i>et al.</i> (2004)		X	X		X	X	X	
Lee and Hwang (2004)	X	X	X		X	X	X	
Schenneweiss y Zimmer (2004)		X	X	X	X	X	X	
Nishioka (2004)		X	X	X	X	X	X	
Allwood and Lee (2005)		X	X	X	X			
Caridi <i>et al.</i> (2005)		X	X	X	X	X	X	
Deshpande <i>et al.</i> (2005)		X	X		X		X	
Excelente-Toledo and Jennings (2005)		X			X		X	
Jung and Jeong (2005)		X	X	X	X	X		
Lejeune and Yakova (2005)		X	X	X	X	X	X	X
Lau <i>et al.</i> (2006)		X	X	X	X	X	X	
Reaidy <i>et al.</i> (2006)		X	X	X	X	X		
De la Fuente and Lozano (2007)		X	X	X	X	X	X	
Akanle and Zhang (2008)		X	X	X	X	X		
Jung <i>et al.</i> (2008)		X	X	X	X	X	X	
Lu and Wang (2008)		X	X	X	X	X	X	
García-Sánchez <i>et al.</i> (2009)	X	X	X	X	X	X		
Gomez-Gasquet <i>et al.</i> (2009)		X	X	X	X	X		
Henesey <i>et al.</i> (2009)		X	X	X	X	X	X	
Hernández <i>et al.</i> (2009)	X	X	X	X	X	X	X	
Oztemel and Tekez (2009)		X	X	X	X	X	X	

**TABLE 2. Agent-based modelling methodologies.**

Author	Methodology name	Methodology scope
Demazeau (1995)	VOWEL ENGINEERING	Development of components.
Ferber and Perrot (1995)	AALAADIN	To support the simple description of negotiation schemes and coordination by means of the systems multiagents.
Kendall <i>et. al</i> (1996)	KENDALL-MALKOUN-JIANG	Software engineering for the design of systems multiagents.
Kinny and Georgeff (1996)	BDI AGENTS	To use the object-oriented technologies for the development of models based on systems multiagents.
Iglesias <i>et al.</i> (1998)	Mas-CommonKads	To extend the methodology of engineering of the CommonKADS knowledge towards the use of object oriented techniques and use of protocols.
Miyashita (1998)	CAMPS	Establishment of an a suitable method to solve of satisfactory form the planning and programming of form distributed without losing of Vista the quality of the solutions.
Parunak and Vanderbok (1998)	DASCH	Specification of agents to model supply chains.
Nwana <i>et al.</i> (1999)	ZEUS	To establish a technological frame that has supported the creation of colaborativos systems of agents, so that the agents obtain their objectives of shared form.
Sadeh <i>et al.</i> (1999)	MASCOT	To provide a frame of work for the development and coordinated manipulation of planning solutions and coordination in multiple levels of abstraction of a provision chain.
Omicini (2000)	SODA	Use of agents in systems based on the connections of Internet.
Wooldridge <i>et al.</i> (2000)	GAIA	Application of the systems multiagents to situations MACRO (societies) and MICRO (individual).
Yan <i>et al.</i> (2000)	ROMAS	Specification of rolls for modeled of systems the multiagents considering the present tendency of the object oriented modeled one.
Bauer <i>et al.</i> (2001)	AIP	To extend the modeled one based on the diagrams UML to give support to the interaction that present/display the agents in agreements to the protocols that are considered.
Caire <i>et al.</i> (2001)	MESSAGE/UML	To support the engineering of systems of software based on agents.
Gupta <i>et al.</i> (2001)	SCADAS	The utility of the agents movable for the design and implementations of support to the management of the supply chain.
Wood and DeLoach (2001)	MASE	Considering the specification initial of a system, they are tried to provide a graphical support to the developers of systems multiagents.
Zice <i>et al.</i> (2001)	ZICE-SHENGPIG RUNTAO-MANSOOR	Development of technologies and applications based on systems multiagents to support the coordination processes.
Bresciani <i>et al.</i> (2002)	TROPOS	Constructions of modeled future based on systems multiagents considering the initial specifications of the system.
Gomez <i>et al.</i> (2002)	INGENEAS	To establish put-models based on systems multiagents to describe the problem.
Huget (2002)	UML Agent	To extend the use of UML object oriented towards its use in modeled of systems the multiagents.
Padgham and Winikoff (2002)	PROMETEUS	Development of intelligent agents.
Sierra <i>et al.</i> (2002)	SADDE	To establish a model based on systems multiagents considering like premisala Existence of modeling based on mathematical equations.
Bernon <i>et al.</i> (2003)	ADELFE	Design of adaptive multagentes systems.
Dikenelli and Erdur (2003)	SABPO	To identify the requirements associated to the interaction protocols during the design of the system based on mutliagentes.
Chella (2004)	PASII	To develop of agile way models based on systems multiagents.
Dangelmaier <i>et al.</i> (2005)	MASSCOP	To model to networks of agents and systems multiagents in surroundings of real time.
Symeonidiz <i>et al.</i> (2007)	SYMEONIDIS-ATHANASIADIS MI- TKAS	To demonstrate how the extracted knowledge can be formulated and how retraining can lead to the improvement of the agent intelligence.
Lian and Shatz (2008)	LIAN-SHATZ	By considering a new concept of "potential arcs," which is integrated into colored Petri net modeling to support the modeling of MASSs, the authors presents a modeling methodology based on the potential arc concept.
Tran and Low (2008)	MOBMAS	To support the design and analysis of the Multi-agent system by considering a ontolgy-based modelling approach.
García-Sánchez <i>et al.</i> (2009)	SEM-MAS	To present an ontology-based framework to seamlessly integrate the Intelligent Agents with the Semantic Web Services.

Hence, the analyzed methodologies, regarding to its main consideration, have been classified by using two dimensions: modelling depth and sequence considered. For the first dimension (modelling depth), three categories can be distinguished: 1) those that address the problem from a conceptual point of view in order to obtain a conceptual model composed by a number of classes of agents and their relationships; 2) those that focus their scope in a technologic context, specifying the steps to follow in order to identify the system requirements and the technical aspects, in general; 3) those that are centred more on an experimental context in order to support the validation of the model. For the second dimension (sequence considered), two categories can be distinguished: 1) methodologies which are integrated by a set of sequential steps (sequential methodology); 2) methodologies defined by a number of steps without a specific order (non-sequential methodology).

The analyzed methodologies have been classified by using two dimensions: modelling depth and sequence considered. For the first dimension (modelling depth), three categories can be distinguished: 1) those that address the problem from a conceptual point of view in order to obtain a conceptual model composed by a number of classes of agents and their relationships; 2) those that focus their scope in a technologic context, specifying the steps to follow in order to identify the system requirements and the technical aspects, in general; 3) those that are centred more on an experimental context in order to support the validation of the model. For the second dimension (sequence considered), two categories can be distinguished: 1) methodologies which are integrated by a set of sequential steps (sequential methodology); 2) methodologies defined by a number of steps without a specific order (non-sequential methodology).

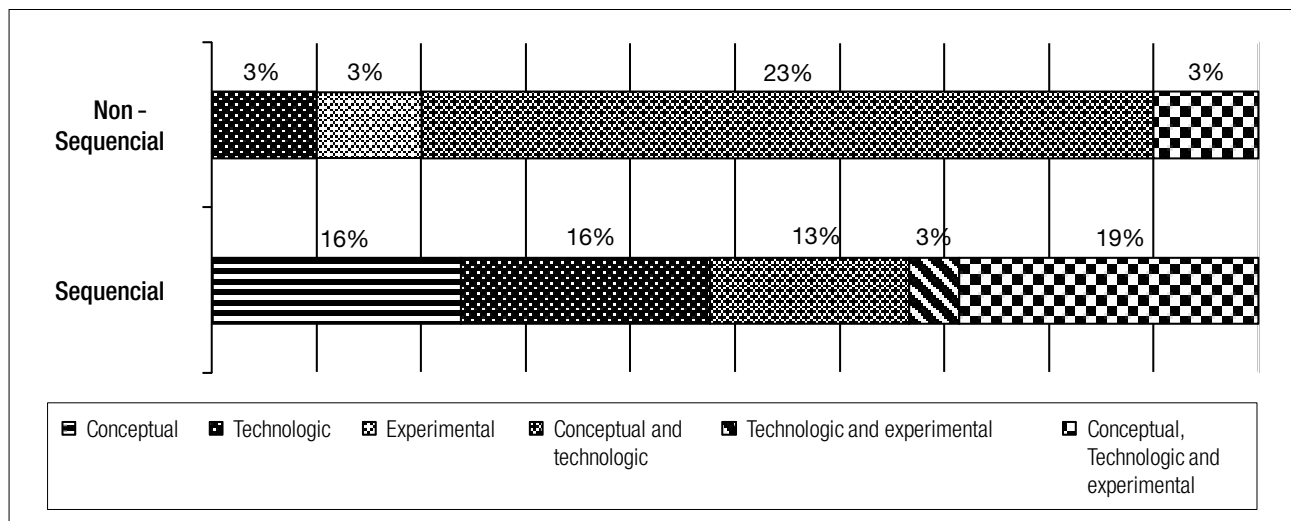
Figure 1 shows the results of the analysis, pointing out that most of the methodologies (68%) are sequential and the rest are non-sequential. Furthermore, the non-sequential methodologies are used to cover conceptual and technical aspect mostly (23%), while the sequential methodologies seem to be better to cover conceptual, technologic and experimental aspects (19%) as well as technological and conceptual aspects for itself (16% in both cases). Since the SCAMM-CPA methodology is oriented toward covering the conceptual, technical and experimental aspects, it is (according to the last analysis) appropriate to propose a sequential methodology.

Though this section does not expose the steps of the analysed methodologies, the SCAMM-CPA methodology has obviously taken them into account. However, in order to analyse the contributions of these authors to the SCAMM-CPA methodology and for not being repetitive, it is more suitable to first present the phases of the SCAMM-CPA methodology (Section 3) and later (Section 4) present its application to real supply chain of the automotive sector.

### The SCAMM-CPA Methodology

As Presley and Liles (2001) say, a methodology consists of two components: A modelling scheme defining the syntax and representational elements used to model an enterprise, and the method for developing the model. In addition, regarding to Hernández et al. (2008a), a methodology is oriented to support a better understanding of the actions to be carried out in process and also the obtain the results to be presented in a standardized way. Furthermore, a computer-based implementation is normally needed to help the manufacturing companies use the proposed methodology (Zhang & Sharifi, 2000). In addition, a methodolo-

**FIGURE 1. Percentage of appearance of the dimensions: model depth and sequential considered in the reviewed works.**



gy establishes a way for doing things with the main idea of standardizing the procedures related to a specific activity in order to obtain a better understanding about the actions to be carried out and the results to be presented. In this section, a methodology, oriented toward supporting the COP process in a DSC-N by considering the MAS technology and mathematical programming models, is proposed (SCAMM-CPA). This methodology consist of nine phases (Figure 3): Problem identification (A), problem conceptualization (B), parameterization (C), main agents identification (D), analysis of interdependence relationship among agents: identification of intermediate agents (E), behaviour among agents representation (F), conceptual agent-based model (G), development of the agent-based application (H), validation (I). The SCAMM-CPA methodology suggests a validation for each phase in addition to the traditional final validation, because it could reduce the high cost incurred when detecting and correcting errors from initial phases once the modelling has already finished.

### Phase 1. Problem identification

The first phase of the SCAMM-CPA methodology consists of analyzing the existing conceptual reference models that cover the COP process in the scope or sector under study. Since the COP process is a decision-making process, the problem will be studied from a functional and decisional point of view without forgetting that the decision-making process is made on a number of resources (physical view) that are organized in a certain way (organizational view) and also considering available information (informational view). In the following, each of the cited views is explained in more detail.

- **Functional view:** It describes the COP of the DSC-N as a set of functional domains that interact to establish the activities to develop, activation conditions and the execution sequence. In this sense, from a functional point of view, a business entity will be a collection of separated parts called enterprise domains (Abdmouleh *et al.*, 2004).
- **Organizational view:** It establishes how the DSC-N nodes are organized as well as the interaction type among them. According to Lejeune and Yakova (2005), these interaction types can be classified as communication, coordination, collaboration and competition. This view will contribute with relevant information about the objectives that each agent will have to consider, the congruence among them, the exchanged information and the trust among them.
- **Physical view:** Through this view the DSC-N configuration (nodes and arcs) is analyzed as well as the operational resources and items related to it. Abdmouleh *et al.* (2004) establish that the resource view is used to declare and define those objects that have the resource role in the execution of the activities and, moreover, Vernadat (1996) comments that the physical view will provide aspects like the enterprise flows, routs, geometry, etc.
- **Decisional view:** In this view the number of decisional levels (strategic, tactical and operational) as well as the decision-makers or decision centres in each level, will be established. Furthermore, it will be necessary for each decision centre to detail its decisional framework, that is, to specify the DSC-N nodes under its influence, its horizon and period planning and re-planning length, its objectives, its constrains, the exchanged information and type of interdependence among them. In order to analyze this view, it is interesting to consider the classification for the distributed decision-making process in a hierarchical context proposed by Schneeweiss (1999, 2003a y 2003b).
- **Informational view:** This view collects, manages and structures all the necessary information for the COP process including the value of the mentioned physical view relationships as well as the value of the decisions of each Decision Centre.

The result of the COP process study from the above points of view must be the determination of those key aspects to be analysed for the specific problem under study, which constitutes the main inputs for the rest of the following phases.

### Phase 2. Problem conceptualization

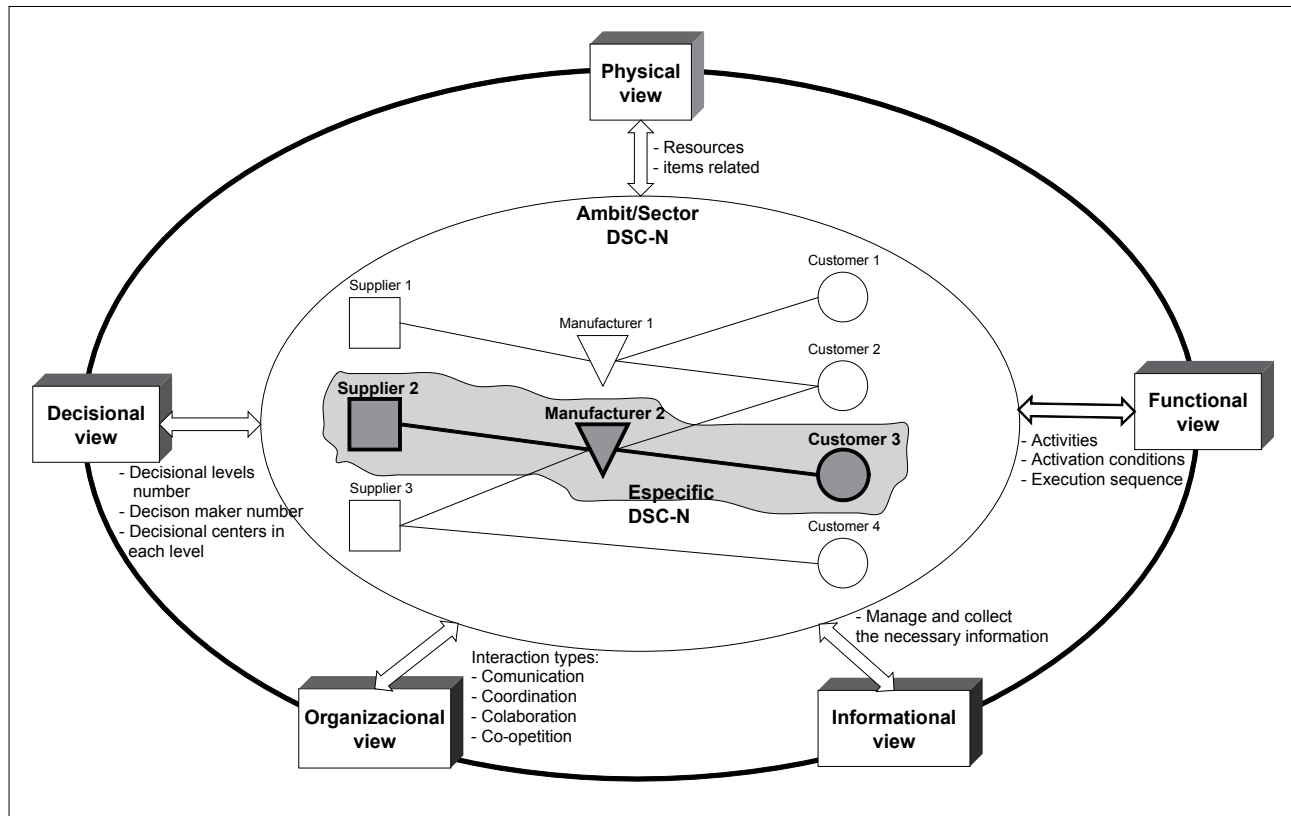
The objective of this second phase is to identify those parts of the specific DSC-N under the influence of the COP process that will act, and that belong to the scope or sector studied in the last phase. With regard to this, through each of the presented views, each part of the DSC-N under study will be described and analysed to particularize for it each of the key aspects defined in phase 1. In this way, the particular conceptual model of the system under study will be defined (Figure 2).

### Phase 3. Parameterization

Based on the particular conceptual model obtained from the above phase, it is necessary to define the decisional framework features for each decision-maker



FIGURE 2. Supply chain conceptualization.



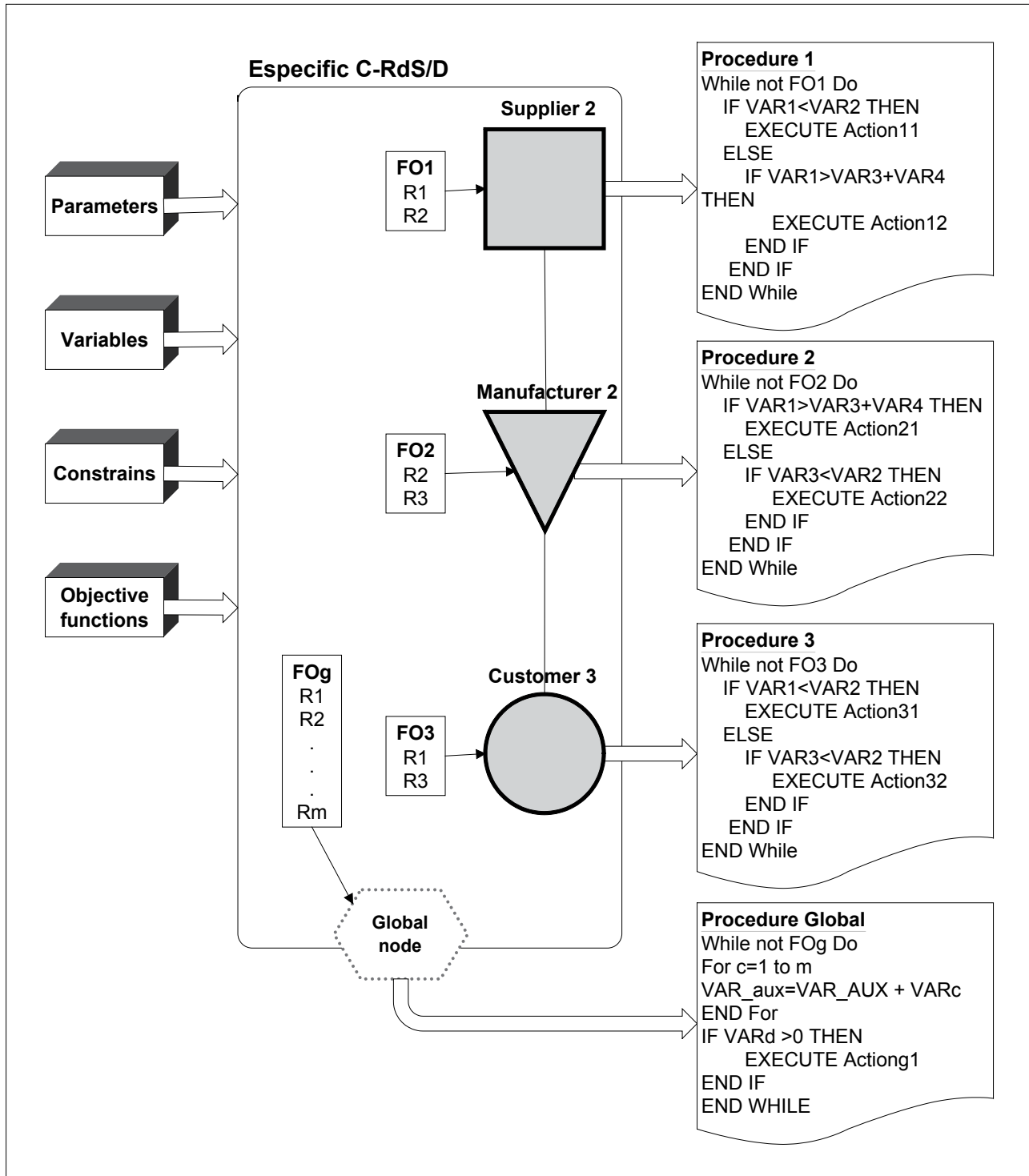
of the specific DSC-N and for the complete network, through the relationships between the different views that describe the problem under study. With regard to this, it will be necessary to specify:

- Which are the decisions to make (decisional variables extracted from the decisional view) and on what are going to act (indexes relative to the physical configuration and the items being processed, information extracted from the physical view).
- The pursued objectives (objective function from the decisional and organizational view)
- The constraints to be respected. The constraints are derived from:
  - The own physical system (derived from the product or resource view).
  - Political policies (decisional view).
  - Interdependence relationships with other decision centres (decisional and organizational views).
- The required information by each decision-maker as well as related to the content as to the necessary detail level in order to carry out the decision-making process:

- Parameters or data.
- Values of decisional variables of another interacting decision centres

As was mentioned before, the SCAMM-CPA methodology aims to combine the MAS with the potential of the mathematical programming models. Therefore, at this point the mathematical programming model related to each decision-maker and to the complete DSC-N will be formulated based on the decision framework features. Next, each of the later mathematical programming models will be moved to an algorithm or procedure through a specific programming language as well as a structured language of the if-then-else type. In Figure 3, an example of one DSC-N conformed by three nodes (supplier, manufacturer and customer) can be seen that assumes a decision-maker related to each of the nodes (but although could not be like that). It is necessary to highlight that the final result about the translation from the mathematical programming model to the structured language is not unique, but it will also depend on the modeller. Nonetheless, in the case where the resulting mathematical programming model (related to some decision-maker) would be simple to solve, there is the possibility to use the agents in order to manage the solution of this model through their connection to some additional solver software such as SOLVER, CPLEX, MPL, etc.

FIGURE 3. Algorithm related to each decision centre.

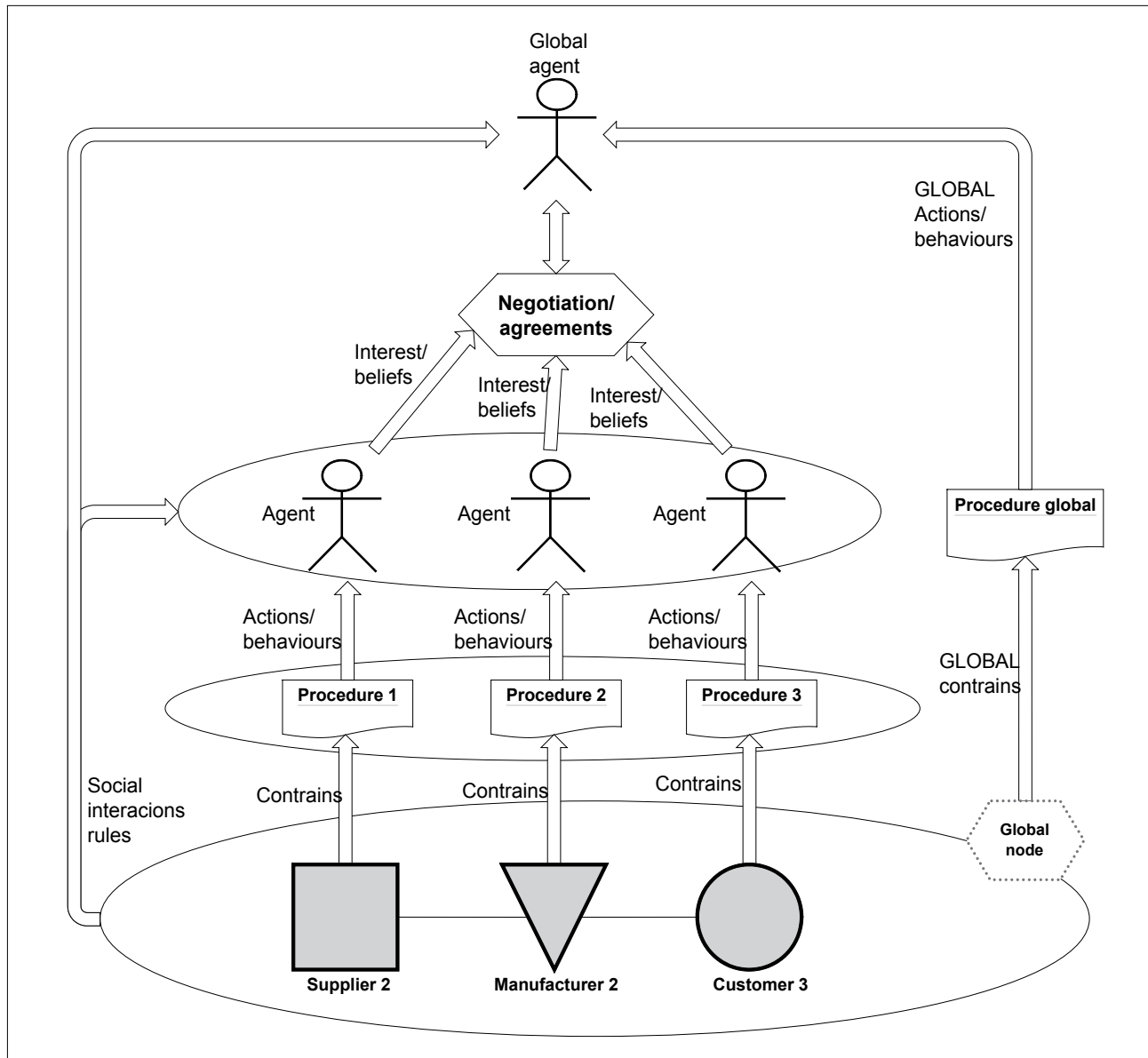


However, the resolution itself of the global mathematical model is not the objective of this phase. Nonetheless, in the last phase, validation (I), it is considered as an alternative to the establishment of some procedures in order to validate the final agent model by contrasting their results with the mathematical model results only in the case that the solution of the mathematical model will not be a hard task.

**Main agent identification**

From the particular conceptual model obtained in the second phase, and according to the algorithms or procedures obtained in the third phase, it is possible to define the number and type of necessary agents to cover the COP process and the relationship among them and with the algorithms established (Figure 4).

**FIGURE 4. Relationship between agents and algorithms.**



Traditionally, this phase will be developed through the trial and error technique. Nevertheless, for the COP process, as a minimum, it must be defined as many agents as decision centres exist at each level (tactical and/or operational) of the DSC-N (therefore as mathematical models formulated to each decision-maker). This information must be collected from the decisional view of the particular conceptual model. In addition, a global agent must be defined who will be in charge of proving and checking that the objectives (defined for the environment) are being fulfilled or not. Although the final agent number is a decision that belongs to the modeller, it must be taken into account the lower agent number limit that has already been mentioned, as well as the aspects regarding the resolution time of the system (better with less number

of agents) and to their maintainability (better with greater agent number).

**Phase 5. Analysis of interdependence relationships among agents: Identification of intermediate agents**

Through the functional, organizational and decisional views from the particular conceptual model of the CP process, it is possible to establish how the different decision-makers interact. Furthermore, in the last phase, the main agents related to each decision-maker were defined. At this point, it is possible to determine the interdependence relationship among the agents defined in phase four. Therefore, when the relationship among two or more agents can be described through a negotiation process, it is believed convenient the in-

corporation of the well-known intermediary agents. This type of agent has no decision responsibilities, but also only will be worried to verify the fulfilment of specific conditions related to the interdependence of the main agents involved. Once the definitive agents necessary for the system are defined, it is time for the construction of the electronic institutions for the agents. According to Sierra et al. (2002), the electronic institutions represent the behavioural rules that the agent society must consider and, in addition, are in charge of watching the possible rule violations. They also define the behavioural constraints in the sense of how much freedom each agent will have in order to develop in the interactive environment. In this sense, for the establishment of the electronic institutions (from a conceptual view), the following aspects must be considered:

- **Agents and roles:** The agents are those entities that participate actively in the electronic institution. This participation is carried out through interaction that facilitates the communication. Therefore, the roles represent behavioural patterns with regard to the act produced by dialogue established among the agents. In this sense, each agent must perform at least one role.
- **Dialogue framework:** This framework is oriented toward the context establishment under which, in an electronic institution, the interaction among agents is happening. In this sense, the establishment of the accepted communication acts among the agents will be supported by the establishment of ontology's and common languages allowing the communication and information exchange.
- **Scenery:** The different dialogues that the agents can consider are grouped in what is known as protocols. Therefore, scenery will cover an agent group that interacts through a well defined protocol.
- **Performative structure:** Taking into account that the sceneries may be connected among each other, the performative structure will be related to sceneries net. This net collects the relationships between the sceneries and simultaneous activities that are developed on it. Moreover, it dictates the norms that govern the mobility of the agents among the sceneries. In addition, an agent can participate in different sceneries with different roles.
- **Normative rules:** The actions that the agents do in a scenery may influence in a positive or negative way with respect to subsequent activities. There, the norms will represent the duties that each agent will have to fulfil or the duties that one agent imposes to another.

### **Phase 6. Behaviour among the agents representation**

The objective of this phase is to facilitate the agent-based model described in the following phase (Phase 7). In order to achieve this, it must be graphically represented the interdependence relationships among the agents defined from the electronic institution and from functional and organizational views on the particular conceptual model. Thus, by considering the fact that the information flows need coordination and also the individual links need to synchronize their scheduling activities to minimize wasted time (Hull, 2002), the behaviour of the agents will establish the main characteristics to be considered in order to support the properly communication mechanism. Protocols will work in order to allow the communication and message exchange among agents which will support the negotiation processes. There are different modelling techniques in order to carry out this phase, with the interactive UML diagram being the most widely used (Booch et al., 1999).

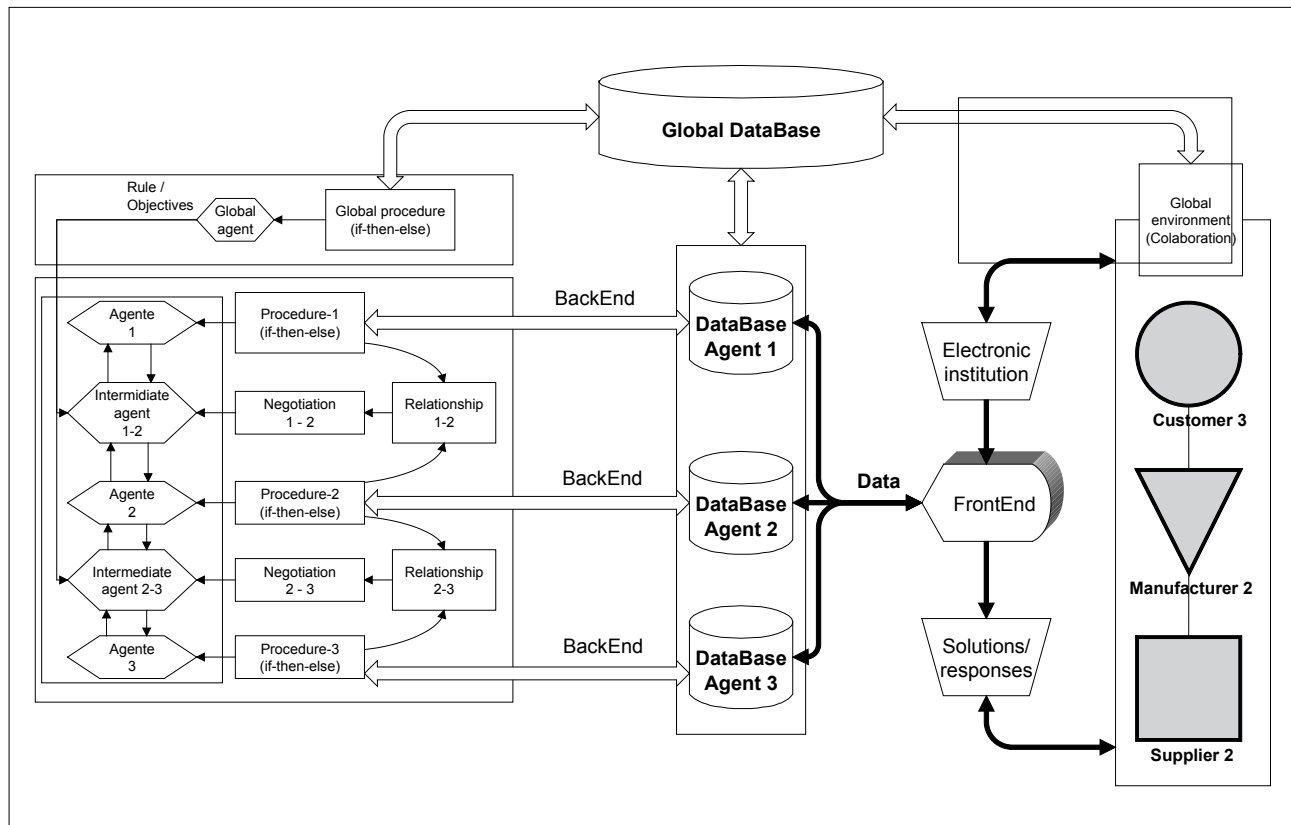
As an example of this, the authors refer the readers to the work of Hernández et al. (2008c), where a collaborative inventory management process is presented. This model considers the agent orientation modelling approach in order to define the customer, manufacturer and supplier. Important to highlight of this model is that the messages among the agents flow, at the beginning, from the customer to the manufacturer. The manufacturer should establish if he/she is capable of accomplishing the request of the costumer according to his actual situation, or if he/she should negotiate modifications in the delivery time and quantities. Next, with regard to the collaboration that exists between these DSC-N nodes, the planning will consider the answer a customer could send to the manufacturer, therefore the messages flow in an effective form. And it is allowed to generate plans and give most effective answers to the requirements asked in order to facilitate the agreement processing order to support the corresponding negotiation processes.

### **Phase 7. Conceptual agent-based model**

In this phase, the fusion among schemes is already presented, and the incorporation of technical aspects about the agent programming and the utilization of databases has to be done (Figure 5).

Therefore, considering the required information by each DSC-N decision-maker derived from the decisional framework, it would be necessary to determine the information to be transferred to each of the agents related in order to allow them to develop their tasks. This information could be introduced to the database Tables in a manual or in an automatic manner through

**FIGURE 5. Agent-based conceptual model.**



an interface or front-end which will feed the corresponding Table fields considering also the previously defined electronic institutions. Moreover, each database will feed each agent procedure with the required data through the back-end, which recognizes the agent language, and then it will receive the information from those agents that will support. In addition, in every case it will be necessary to have a global database that will be linked with the global agent who is responsible for the fulfilment of the objectives and interaction rules from the agent environment.

**Phase 8. Development of the agent-based application**

In this phase, the selection of the suitable programming language will allow the later programming of each agent considering the algorithm or procedures established in the third phase and the electronic institution from the fifth phase. In order to achieve this, the interactive UML diagram—defined in the sixth phase—and the conceptual agent-based model from the seven phases will be very useful. There exist specific software products designed to facilitate the agent programming such as ISLANDER (Esteva et al., 2002) and AMELI (Esteva et al., 2004) that have been developed by the artificial intelligence institute from the Autonomous University of Barcelona, Spain. Regardless of the soft-

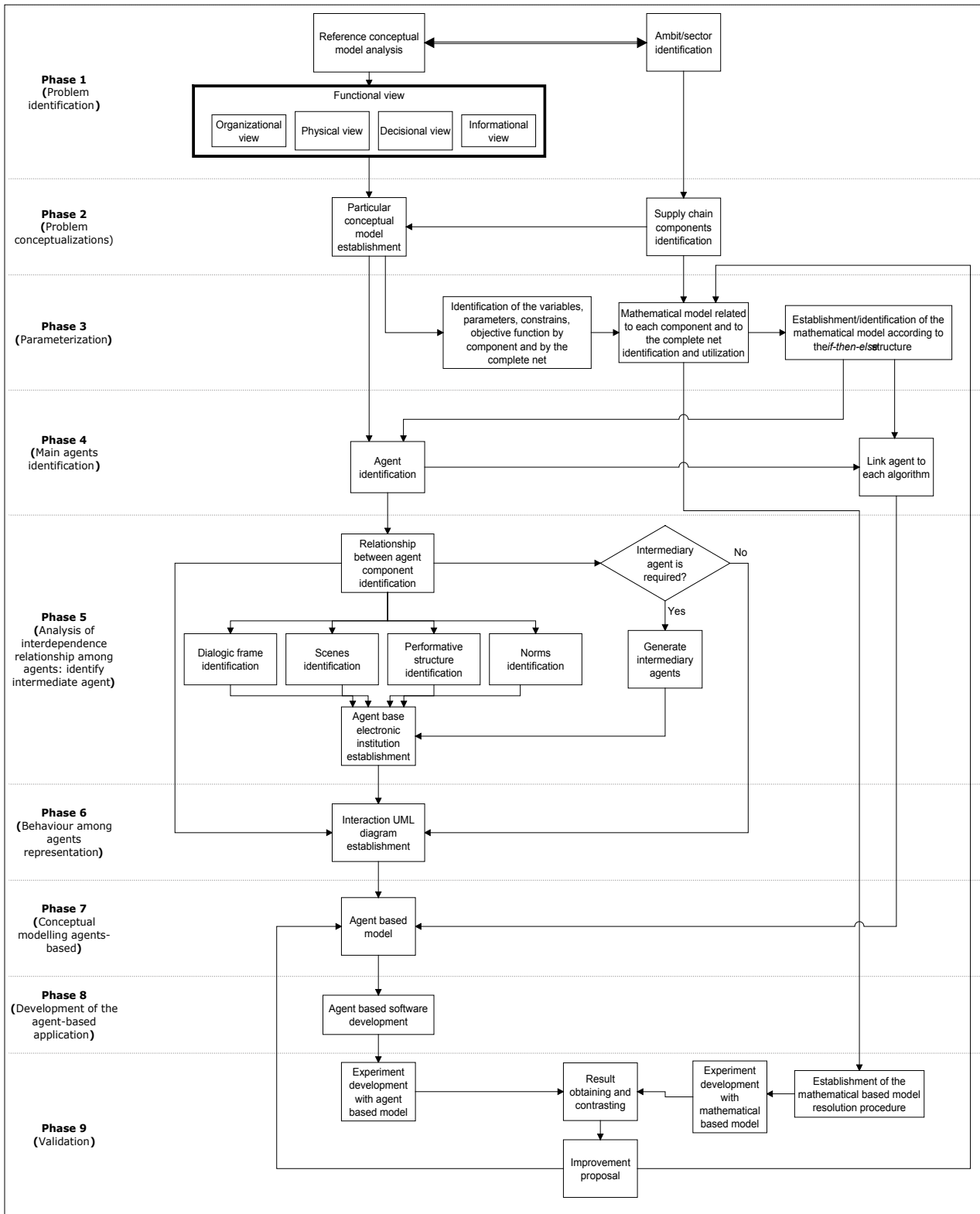
ware used, the result of this phase is an agent-based application. Moreover, in order to get an approach to a real case application of the SCAMM-CPA proposal, Section 4 is oriented to extend this phase to a real automotive supply chain agent-based model.

**Phase 9. Validation**

Considering that, as was established at the beginning of the methodology, during each phase a validation process has been carried out. This final validation phase is oriented toward the corroboration of the main results of the model. This means that this validation will show if the MAS is reacting or not in the correct way according to the different scenarios defined in the experiments. The results of these experiments must be compared with the real system behaviour, or historical data, or some existing model (such as a mathematical programming one), or simulation or artificial intelligence based model. In addition, once the multiagent model developed is validated and according to the results of the experiments, it could be possible to propose improvement changes in order to model other main aspects that had not been considered in the initial objectives and definitions. To support this, Figure 6 presents an overview of the SCAMM-CPA modelling methodology that the modellers are encouraged to follow.



FIGURE 6. Overview of the agent system based modelling methodology to support the COP process of the DSC-N (SCAMM-CPA).



### Automotive supply chain network based on MultiAgent system. A briefly case study

The analyzed supply chain is focused on a company which supplies seats for automobiles. Therefore, the

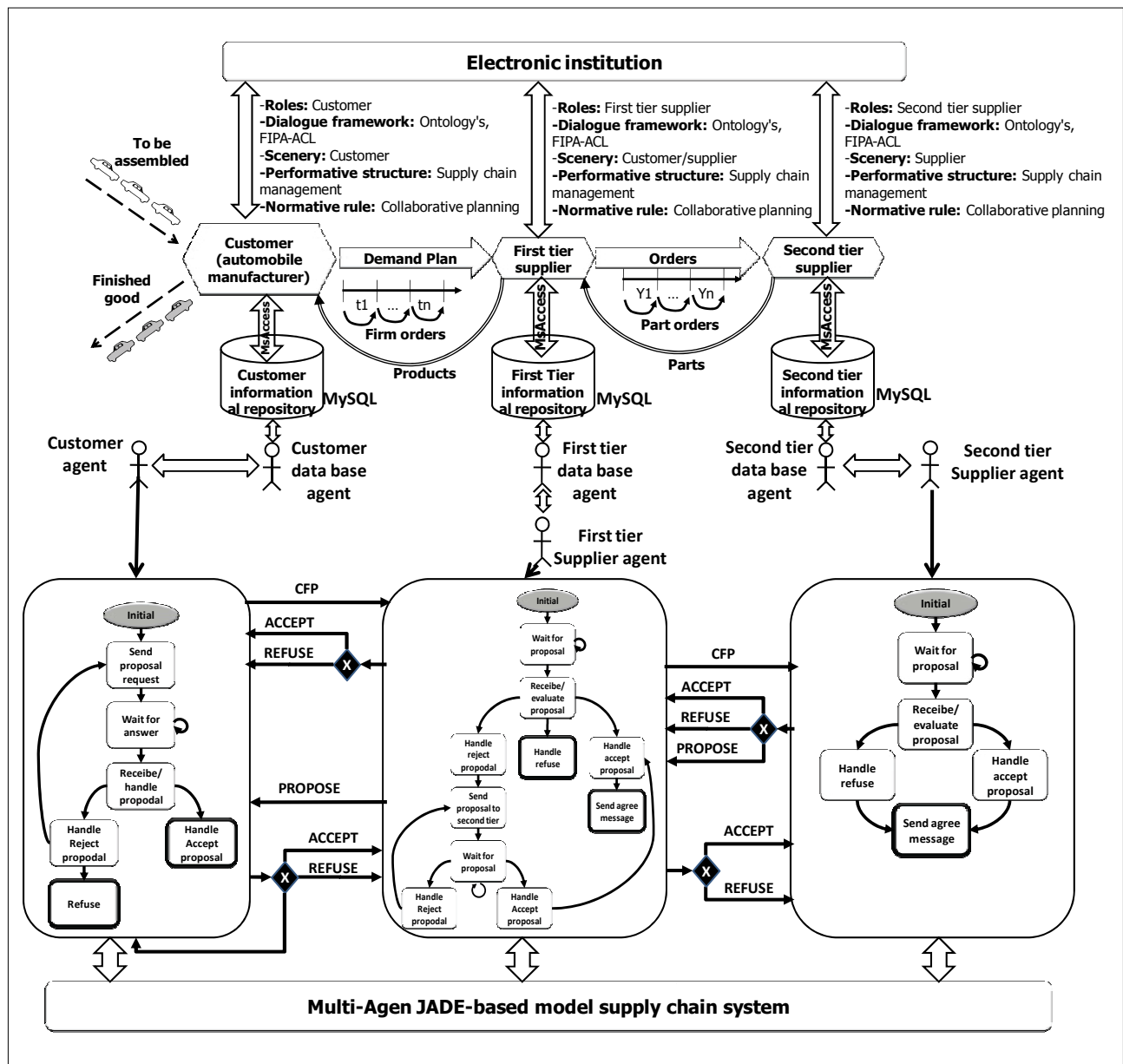
sharing information process implies to achieve a fitter and better decision making process. This is related to the fact that each decision making process, in the supply chain modelling context, will consider a negotiation process to generate better information and de-

isions as well. Thus, the proposed model considers as main components of the supply chain, the automobile manufacturer, first tier suppliers and the second tier suppliers. They share information among them in order to support the collaboration at a decisional making level. The model identifies the main aspects to support the collaboration in the planning aspects represented (see Figure 7). Hence, in accordance with the organizational chart of the company and with the need to establish a global view based on their information and decision-making process, the mains departments involved in the model are production, logistics and the department of informatics.

The processes associated with the transformation of the information are those related with the automo-

bile seat assembly and the material supply process. The production planning process is built around the bi-monthly reception of files sent by the automobile manufacturer, which every week is confirmed as firm order by considering some deviation in the demand. As for the material supply, this not only requires weekly and daily demand information, but also the information sent to the Logistics Department that enables it to manage and plan the future supply processes. Another important activity is the MRP (Material Requirement Planning) calculation. This system consider as main inputs the customer demand, inventory quantity on hand, material which is already coming in the transport from the second tier supplier, the available capacity. Thereafter, the calculus is done by using the enterprise resource planning system which is au-

**FIGURE 7. Automotive supply chain Agent-based model. A SCAMM-CPA conceptual model**



tomatically fed on the demand information sent by the automobile assembler on a weekly and daily basis. The management of this process is in order to fulfil the automobile manufacturer requirement, because everything must be properly settled in order to accomplish with the car sequence in the tunnel. Thereafter, the MRP outputs are used as input information to control the component and finished goods inventory and to generate half-yearly net requirements plans. In order to see more detail in the description of this process, the author encourage to the reader to take advantage of the work of Hernández et al. (2008b), where this automobile supply chain process is describe in detail. Hence, the decentralized collaborative proposal applied to this supply chain will consider a negotiation process supported by multi-agent system, in order to promote the increasing benefit of the related supply chain nodes.

Hence, regarding to Figure 7, the behaviour of each agent can be defined in three types, the first one related to which an agent generate a call for proposal (CFP) message offers and receive proposals, the second one related to the reception of CFP and proposal and the generation of CFP messages as well, and the last one oriented to receive the CFP request and answer by accepting, refusing or proposing the CFP request. In addition, as three types of behaviours are to be considered, three types of agents are to be considered as well.

Each agent, depending on its level (customer, manufacturer or supplier), might consider the mentioned behaviours. The agents are briefly described as follows.

- **The customer agent.** The first one oriented only to generate the main necessities request, then their possible states are the follow: send proposal; wait for the answer. Thus, when the proposal is received, this agent must handle the content of the message and evaluate its requirements in order to know if another CFP will be necessary.
- **The manufacturer agent.** This second agent considers both, the generation and reception of necessities. Thus, this agent considers two activities at the same time. Depending on the collaborative horizon, this agent will be able to fix the problematic order which stays out of range regarding to the capacity. Then, by considering the selected value, the capacity problem will be fixed by forwarding the future orders to the present. Moreover, this agent represents the first tier supplier of the supply chain.
- **The supplier agent.** The supplier agent is oriented to receive the requirements from the first tier supplier in order to respond with the related ACL message. This answer may be of many types and,

from this answer, a secondary CFP negotiations process might be necessary in case of not getting a primary agreement when the capacity is exceeded in the orders. Its possible ACL message answer may be: ACCEPT, REFUSE or PROPOSE.

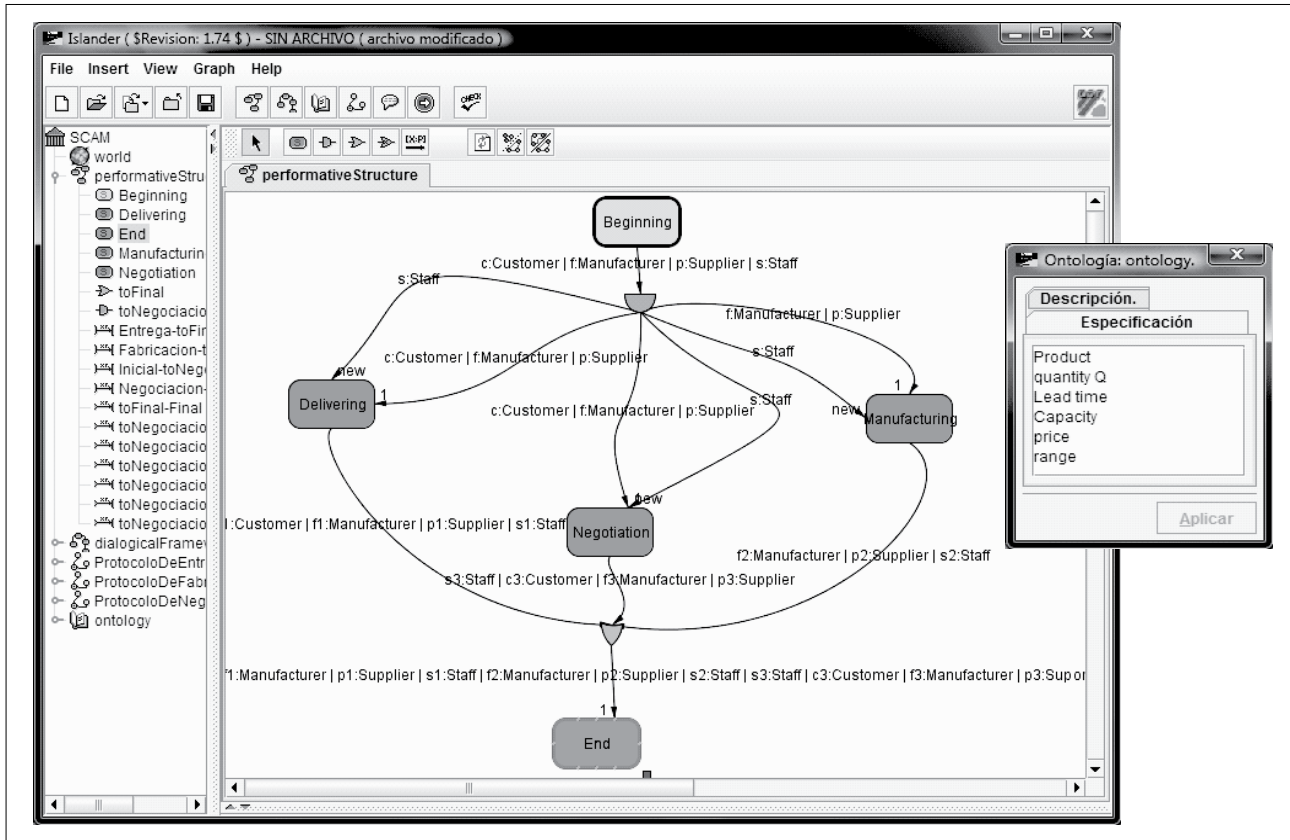
- **The agentDB agent.** To promote the decentralized decision-making process is important to share and to access as well the properly information. Then, this agent is oriented to take and transmit the information to the users by considering the related ontology's in the messages.

Thereafter, ontology's that this agent consider are the following: Product, quantity  $Q$ , lead time, capacity, price and range. This last one is oriented to the acceptance range in order to support the related negotiation process when it will be needed. In this case, the databases considered are MsAccess® as connectivity layer and MySQL (MySQL, 2009) as the information repository.

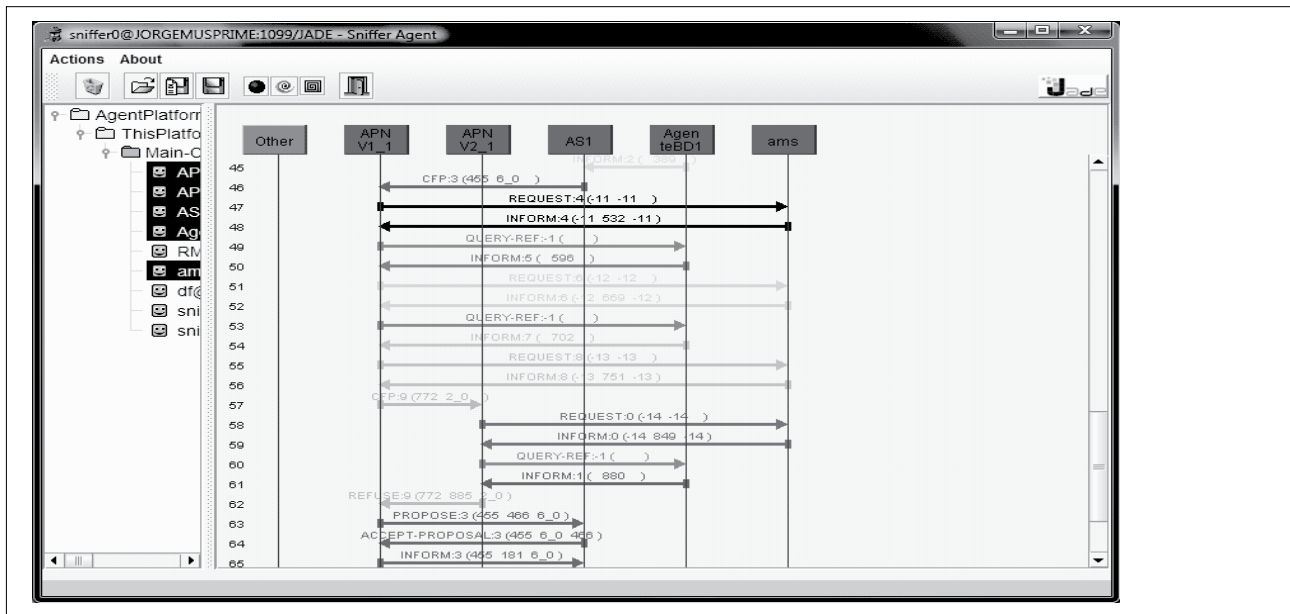
### **Application and preliminary results**

The electronic institution is supported by ISLANDER 1.74. TOOL (Figure 8). Then, this institution gives the foundation on which the "how" and "where" the agents will behave are defined, also the definition of the related languages that the agents will consider. Hence, as a first step, it is necessary the consecution of the performative structure. This structure (Figure 8) considers the states, scenes and roles that the agent will consider (as it has been shown in Figure 7). Thereafter, in this particular case, the roles that the agent will consider are: customer, manufacturer and supplier. Besides, the scenes in which they will be able to participate are the deliver, negotiation and manufacturing. The behaviour related to these scenes can be seen in Figure 6 as the state diagram of each agent. Next, the dialogue is defined in order to promote the conversation and understanding of the agents each other. Hence, the defined acceptable dialogues related to this case study are three. The first considers that an agent that participates with a role related with another will not be able to participate with the same role. The second one says that an agent may not participate with different roles at the same time. Finally, the third one establishes that, at the same time, an agent may not consider different roles. Thus, once the structure is defined, it is necessary to establish the protocol dialogues with which the agents will meet, talk and take decisions, This, as can be seen in Figure 8, also consider the related ontology's. In this case, in order to support it, the JADE library/platform has been considered, "where the call for proposal" (CFP) protocol has been considered (Figure 7).

**FIGURE 8. Electronic institution agent-based model –Islander 1.74 IIIA-CSIC– An automotive supply chain application.**



**FIGURE 9. Structure/negotiation validation trough SNIFFER/JADE 3.6.1.**



Then, by considering all the internal agent structure supported by the electronic institution, the experiments were carried out through the JADE 3.6.1 platform. This platform, through the Sniffer agent (Figure 9), allows us to observe, and validate, the behaviours that each agent carry on. In this case, the

FIPA-ACLMESSAGES flow (among every agent) can be observed where the CFP protocols take place.

In addition, since de collaboration allows getting more visibility on the demand plans from the upstream nodes; this implies some improvements on the profits. Thereafter, the Figures 9 and 10 represent in the first

FIGURE 9. Requirement evolution by collaborating in the visibility of the demand plan.

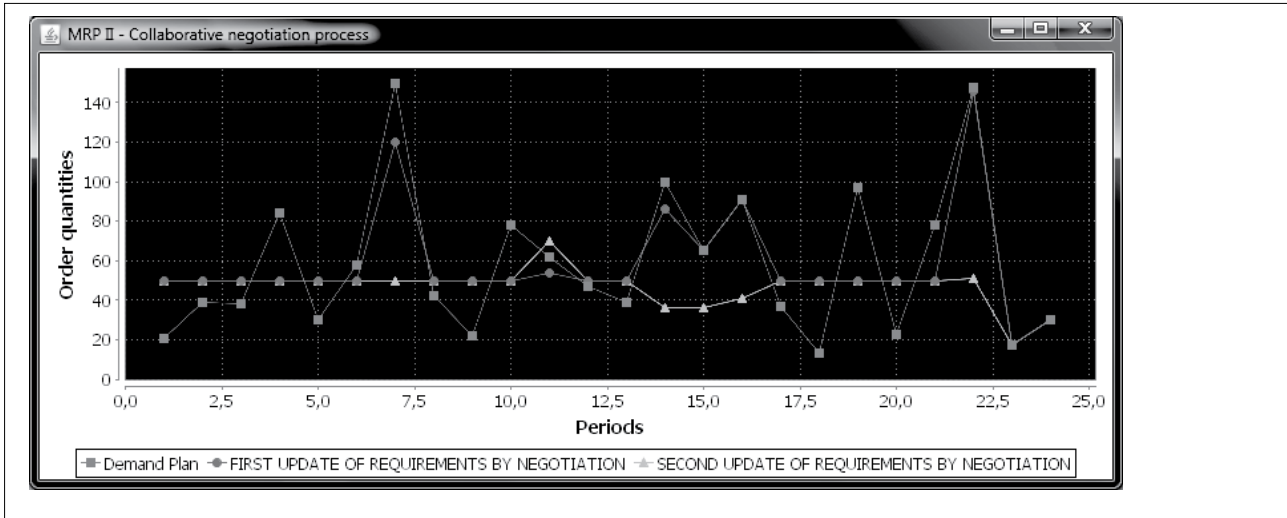
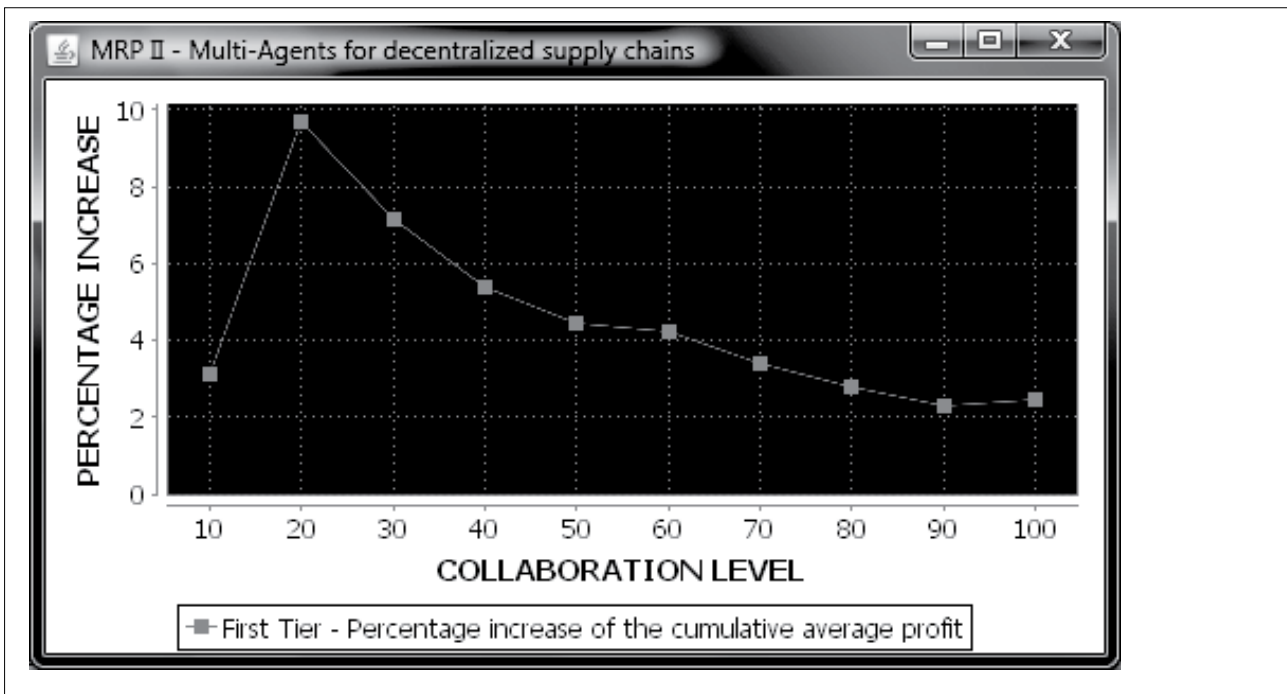


FIGURE 10. Percentage increase of the cumulative average profit at the first supply chain tier.



place the evolution of the initial requirements (Figure 10, square dot) in order to adapt itself regarding to the capacity limitation (Figure 10, triangle dot). Secondly, they also represent the evolution of the percentage increase of the cumulative average profit (Figure 11, square dot), respectively, regarded to the collaboration level among the supply chain nodes. Thus, as can be seen, the main impact appears until the 40% or 50% of collaboration. Then it is possible to zoom up that, in order to promote the goodness of the collaboration, this percentage of visibility is only needed in order to increment the enterprise profit, and after that the profit will reminds almost stable.

### Conclusions

In recent years, the COP in a DSC-N environment is acquiring an increasing interest. In the most general case the COP implies a distributed decision-making process involving several decision-makers that interact and negotiate in order to reach a certain balance condition between their particular interests and those for the environment (DSC-N). In this context, the validity of the MAS to support the COP process modelling and the importance about having a methodology that could give support to the respective modelling, have been justified. According to this, a scientific literature



review has been made, which—as the main result—has shown the absence of explicit methodologies with the mentioned characteristics. With regard to this, the literature review has been divided into two blocks: the first one has presented some relevant authors providing the relevant aspects for the modelling of the COP and SCM processes. The second one has been oriented toward analysing those explicit methodologies for supporting the MAS based modelling of any type of problem under consideration. Obviously, the analysis of the reviewed literature has partially contributed to the phases of the SCAMM-CPA methodology and their contents.

Then a methodology to support MAS based process modelling enriched with mathematical programming models has been described. The proposed SCAMM-CPA methodology can be considered to be composed by three main action blocks: conceptualization (A, B and C phases), agent-based modelling (D, E, F and G phases) and the application (H and I phases), being as a central point (in order to fulfil the methodology main purpose), the agent-based modelling block.

The methodology has been contrasted with the reviewed literature. The results are that the proposed methodology is coherent with those aspects considered relevant by the authors, and it contributes with additional knowledge respect to certain deficiencies detected from the literature review. Therefore, it can be said that the SCAMM-CPA methodology synthesizes the existing knowledge and fulfils, as well as enriches, each of their phases with our own knowledge.

Finally, the future research lines are: 1) to study in a deep manner the proper agent-based tools in order to improve the current work, 2) to extend the present work to other collaborative fields such as forecasting

and replenishment, and hierarchical planning, 3) to apply the present methodology to other DSC-N sectors such as tile or textile ones such as the presented by Hernández et al. (2009), and finally, 4) extend the proposed modelling methodology in the automotive supply chain sector by considering the model of Mula et al. (2008), 5) to compare the proposed methodology with others methodologies that cover similar aspects by considering another approaches such as genetic and evolutionary algorithm fuzzy set and systems and non-linear programming.

## Acknowledgements

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