The Methodology of Modeling the Decision-Making Process for Planning the Logistics Supply Chain

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Abstract In this work it is proposed a Methodology to model the Supply Chain (SC) Collaborative Planning (CP) Process, and particularly its Decisional view. This Methodology is based on a Framework whose main contributions are the following, (1) the consideration of not only the Decision View, the most important one due to the Process type, but also three additional Views which are the Physical, Organisation and Information ones, closely related and complementing the Decision View; and (2) the joint consideration of two interdependence types, the Temporal (among Decision Centers belonging to different Decision Levels) and Spatial (among Decision Centers belonging to the same Decision Level) to support the distributed Decision-Making process in SC where several Decision Centers interact among them in a collaborative manner.

Keywords Methodology · Collaborative planning · Distributed Decision-Making · Decision view

1 Introduction

In recent years, many works have emphasized the importance of the Supply Chain Management [1–6] In this context, processes, traditionally developed in an intra-Enterprise level, should be adapted to be designed and executed by different enterprises, separated and with distinct characteristics, but at the same time

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belonging to the same Supply Chain. In that sense, processes are becoming more collaborative.

Among those processes, in the present work, one of the most relevant ones, the Operations Planning Process, which in collaborative contexts is commonly known as CP Process, is approached.

There are several literature definitions about the CP Process concept. The CP is defined in [7] as the coordination of planning and control operations across the Supply Chain, i.e., production, storage and distribution processes. Another definition, which has been useful is that of [8], in which several Decision Levels are identified, from the most strategic through the programming level, and in which the Operations to be planned, managed by different "entities" of the SC collaborating among them are placed.

From [8], CP is defined as a SC decentralised (distributed) decision-making process in which different decisional units (or Decision Centers) have to be coordinated to achieve a certain level of SC performance. But this coordination is narrowed to a tactical level (Aggregate Planning) and to a tactical-operational one (Master Plan).

Therefore, neither the strategical level (design) nor the most operational one (programming/sequencing) is included in our definition. In this CP context, as it will be explained later, the interdependence relationships among the different Decision Centers are of special relevance, either among those placed in the same "decision level" (spatial interdependences) or in different (temporal interdependences).

On the other hand, the design, analysis, adaptation, monitoring, control and improvement needs of the CP Process are becoming higher, which has led, mainly since the beginning of this century, to the publication of many works addressing the importance of its modeling, from multiple points of view: functional, analytic, etc. Nevertheless, for an efficient and effective modeling, it is essential to take into consideration all the aspects influencing it as well as the relationships among them.

This justifies the development of a Methodology, which based on a Framework, aims to model this SC CP Process in an integrated manner. The Framework presents all the organized aspects and concepts allowing the Methodology application [8–12]. In [13] a Framework which addresses two main contributions regarding the previous ones is proposed.

Firstly, it integrates four different Modeling Views, as they are Physical, Organisation, Decision and Information ones and their relationships. That facilitates the development of integrated models of the CP Process, leading to more realistic and versatile models, being able to be applied to complex SCs. Particularly, the proposed Framework uses the Decision View as the main one, but complemented and enriched with other Views, since the CP Process implies to take decisions about Resources/Items (Physical View) taking part of a determined Organisation in which the different "entities" are more or less integrated (Organisation View). Besides, the SC activity generates and needs some information (Information View) in order to be able to take decisions or planning.

Secondly, the Framework stresses the importance of Distributed Decision-Making contexts [14], in which the CP Process is embedded, explicitly considering at the same time two interdependence relationships types, Temporal (among Decision Centers belonging to different Decision Levels) and Spatial (among Decision Centers belonging to the same Decision Level).

It is also important to remark that such Framework is not only conceptual, but also analytical, since it includes either all the necessary aspects to conceptually model the CP Process (Macro-Level) or the aspects to facilitate the formulation of Analytical Models as an aid to the Decision-Making of the CP Process (Micro-Level).

This paper focuses on the Framework conceptual part, because the Methodology only aims to model the CP Process itself. However, although some necessary inputs from other Views (physical, and organisation) are pointed out, only the Decision View at a Macro Level, or what is the same, the Macro-Decision View is explicitly analyzed. The Decisional View is closely related to Decision-Making and therefore to activities of a decisional nature, which mostly define the CP Process. The Macro-Decisional View presents all the aspects which allow the Methodology to model the CP Process itself since a "conceptual" point of view, that is, defining all the Decisional activities and their interdependence relationships.

The rest of the work is arranged as follows. Section 2 describes the Methodology Framework as a whole while Sects. 3 and 4 focus in the Decision view and the Macro-Decision view respectively, this latter one explicitly approached to model the SC CP Process. Finally, in Sect. 5, some conclusions and further research are provided, some of them being currently carried out by this paper's authors.

2 Methodology Framework

As it was mentioned before, the CP process is mainly considered a decision-making process since most of the activities within this process are of a decisional nature. Nevertheless, CP decisions are made in a predetermined sequence (Decision View) on elements such as physical and human resources, and items (Physical View), which are specifically arranged (Organisation View), and specific information (Information View) is required to properly model the CP process. Therefore, there is a need to relate all these Views in order to get more realistic and integrated models of the CP process.

The Framework identifies the structure and the relevant features of any SC based on the four different views. By means of the Methodology, and based on the information provided by the Framework, all the necessary steps to model the SC CP process are indicated, in an intuitive manner.

A brief outline of each View is provided for clarification purposes:

- Physical View: identifies how a specific SC is configured, that is, the Resources and the Items about which the Decision-Making Process is being made.

- Organisation View: shows what the relationships among the resources represented in the Physical View are, an important aspect which strongly influences the Decisional View.
- Decision View: as it will be explained later in more detail, it is divided into two sub-Views: Macro-Decision and Micro-Decision Views. The first identifies what the "Decision Centers" are, their Interdependence relationships and the Decisional Activities making up the CP Process. The second, the Micro-Decision View, strongly influenced by the Macro-Decision View, identifies all the aspects that internally characterise the decision-making process of each Decision Center facilitating their analytical modeling.
- Information View: it may be considered as the "integrated view" as it collects and represents the necessary information from the other three Views to support the SC CP Process, which implies the information sharing among them.

In this paper, as it was previously indicated in the introduction, only part of the Framework which relates to the Macro-Decision View is detailed since the exposed methodology aims the SC CP process modeling from a "conceptual" point of view. Therefore, the Micro-Decision View will be just briefly outlined.

In Fig. 1 the Framework made up of the four Views: Physical, Organisation, Decision and Information is depicted.

This Framework feeds the Methodology (I), to "conceptually" model the SC CP Process itself (that is, the Methodology which is approached in this paper) and the

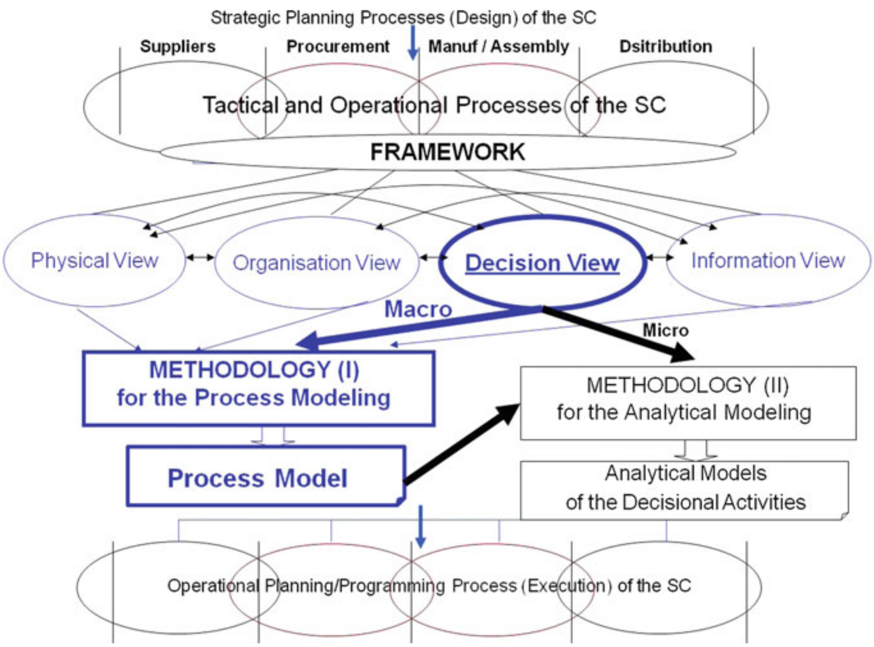

Fig. 1 Methodology framework for the modeling of the SC CP Process

Methodology (II) to develop Analytical Models in each of its Decisional Activities. This latter Methodology is not approached in the present paper.

3 Decision View Description

As it was pointed out before, the Decision View is divided into two sub-Views: Macro-Decision and Micro-Decision Views (Fig. 2).

The Macro-Decision View analyzes which Decision Centers are implied in the Decision-Making Process and, taking into account the Decisional Level where they are and their Interdependence Relationships (Temporal and Spatial), which are the Decisional Activities of the CP Process and their execution order. The former allows to set up the basis to respond to the following questions: (1) Who performs the Decision Activity?, (2) When is the Decision Activity performed? and (3) What is performed (at a Macro level) in the Decisional Activity?

Although only the Macro-Decision View is explicitly approached, it is important to briefly indicate some relevant aspects of the second, the Micro-Decision View, since some important inputs come from the first one.

The Micro-Decision View individually analyses each of the previous identified Decision Centres, aiming to set up the basis to respond to the following questions: (1) What type of specific Decisions are taken in each Decisional Activity (Decision Variables)? and (2) How is the Decision Activity (Decision Model and Input Information) performed? So, the Micro-Decision View presents all the necessary aspects to the detailed definition of the Decision Variables, as well as the Decision Model (made up of a Criteria and a Decisional Field/Constraints) and the Input Information (Fig. 2). Therefore, this Micro-Decision View, facilitates the development of Analytical Models as an aid for the Decision-Making Process in each Decisional Activity (and consequently in the Process as a whole), taking into consideration the Interdependence Relationships of the Macro-Decision View.

In the next sections only the Macro-Decision View is approached.

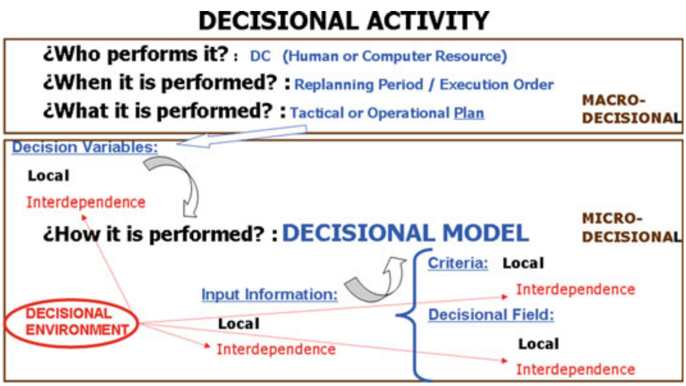

Fig. 2 Macro-decision and micro-decision views of the CP process

4 Macro-Decision View

The Macro-Decision View is made up of three main blocks: definition of the Decision Centers (DCs) implied in the CP Process, characterisation of the Interdependence Relationships (Temporal and Spatial) among the defined DCs and the identification of the Decisional Activities of the CP Process and their execution order.

4.1 Decision Centers

It is relevant to stress that the Macro-Decision View is based on the fact that the initial Decisional problem of the CP Process may be divided into several sub-problems, belonging to the various DC. At the same time, a collaborative context implies that those sub-problems are not fully independent but they are overlapped, and therefore, leading to Interdependence Relationships, either from a Temporal or Spatial points of view [15, 16].

At this point, it is necessary, for a better understanding of the DCs definition, to show some concepts of the Physical and Organisation Views which are closely related to them.

In the Physical View "Stages" (Suppliers, Procurement, Manufacturing/ Assembly and Distribution), "Nodes", and "Arcs" are defined, which connect the dyadic Nodes and represent the flow of items from an origin to a destination node. Besides, each of these Nodes and Arcs perform the "Processing Activities" (Production/Operations, Storage and Transport).

In the Organisation View the "Organisation Centers (OCs)" are defined, which are responsible of the execution and control, and in some cases of the decision-making, of one or more Processing Activities previously identified in the Physical View. These OCs are placed in two "Organisation Levels" (tactical and operational).

From the Physical and the Organisation Views, in the Macro-Decision View the different DCs are identified. A DC corresponds to a "decisor" (human or computer resource), which in an automated manner or not, are responsible of the Decision-Making of one or more OCs. The made decisions (tactical and operational plans) affect the Processing Activities which were responsible for the OCs.

As in the Organisation View, in the Macro-Decision View two "Decision Levels" are also defined, each of them, Tactical and Operational formed by one or more DCs. This allows for the first approximation of how centralised or decentralised/distributed the Decision-Making Process in each of the Decision Levels are. This "decisional map" is the input to the second block, in which the DCs Interdependence Relationships are characterized.

4.2 Interdependence Relationships

Once the DCs in each of the Decision Levels are defined, a second block representing the type of Interdependence Relationships among them is stablished (previous works of [9, 14, 15] have been very useful). This is done either temporally (among Decisional Centers belonging to different Decisional Levels) or spatially (among Decisional Centers belonging to the same Decisional Level), which allows for the first approximation.

The fact that there exists more than one DC in certain Decisional Level imply that the decisions are not centralised (in this case from a spatial point of view), but does not imply that these are fully decentralised, but distributed (in case of collaborative contexts). This distributed Decision-Making (more or less hierarchical) is of special relevance when characterizing the DC Interdependence Relationships.

At this point, it is important to know how the Macro-Decision View and the Information View are related since these interdependence relationships require transmitting a certain type of information among DCs. Since a Macro point of view, this information may be of two different origins. In one hand, that information which comes from the decisions already taken by others DCs, and in the other hand, that which concerns certain attributes characterising different aspects of other DCs. These two types of information are known as Joint-Decision Making and Information-Sharing, respectively.

In Fig. 3, the Information View concepts needed to characterize the Interdependence Relationships between a “Top” DC (DC^T) and a “Base” DC (DC^B) are shown. First, DC^T sends Instruction (IN_k) to DC^B, which is composed of part of its previously made decision, which affects to DC^B (known as Global Variables-GV), and information, which may help in their joint coordination/collaboration Decision-Making Process (known as Global Information—GI). Before sending that IN, CD^T could have anticipated (ANT_k) some relevant aspects of DC^B in order to enhance the Process. Secondly, in non-hierarchical schemes, the DC^B could send back a counterproposal to DC^T within a Reaction (R_k). There may be several cycles k IN_k-R_k during the joint Decision-Making Process. Finally, both DCs “agree” and “implement” their decisions (Tactical or Operational Plans).

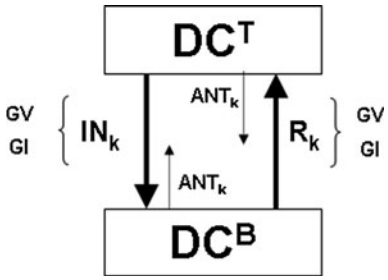

Fig. 3 Information view (macro) for DCs interdependence relationships

Based on the concepts explained in Fig. 3, the Macro-Decisional View characterizes the interdependence relationships among DCs within the description of 5 parameters, being each one of them, in turn, made up of several attributes (Table 1).

Finally, the concept of Decision Environment of a DC [17] is also defined, formed by those DCs which it has some kind of interdependence relationship with.

Table 1 Macro decision view/block 2—interdependence relationships

Parameters	Attributes
Interaction nature	*Temporal*: the interaction is produced among DCs placed in different decisional levels, that is, tactical and operational
	Spatial: the interaction is produced among DCs placed in the same decisional level
Interaction type	*Null*: no interaction exists. That means that DCs are taking their decisions myopically, that is, there are neither joint-decision making nor information sharing, or what is the same, there are neither IN nor ANT
	Hierarchical: an interaction exists. DC^T inicializes the jointly decision-making process by sending an IN to DC^B. In this case there is no R, so that the "jointly-decision" flow only goes in one direction
	Non-hierarchical: an interaction exists. DC^T (in this case it could be the DC which inicializes the jointly decision-making process) sends an IN to CD^B and in this case there is R. In fact, there could be several cycles k IN-R. This case is usual in negotiation processes
Objectives sharing	*Organizational*: This is the case when DCs aim to achieve a common goal, previously defined and agreed, but at the same time keeping its own goals. In that sense, they are interacting as if they were a "team", and they are really "collaborating". It is usual the utilization of fictitious incentives and penalties, even other kind of information (shared by means of GI), in order to warn the another DC which consequences has its decision in the overall common goal. In these contexts are usual the "agreements" instead of "formal contracts"
	Non-organizational: This is the case when DCs don't aim to achieve a common goal, but at the same time they understand that may benefit themselves of a jointly decision-making process. In that sense they are just "coordinating". It is usual the utilization of real incentives and penalties (shared by means of GI) and the use of "formal contracts". This "coordination" process doesn't seem suitable for medium and long term relationships
Anticipation degree	*Null*: no ANT exists. DC^T doesn't anticipate any component from the decisional model of DC^B (neither from the criteria nor from decisional field/constraints). The former doesn't imply that there is type of interaction is null, since at least there is an IN (with GV and probably GI)
	Non-reactive: an ANT exists. DC^T anticipates some components from the decisional model of DC^B, but only from its decisional field/constraints. It is called "Non-Reactive" because it doesn't depend on the IN
	Reactive: an ANT exists. DC^T anticipates some components from the decisional model of DC^B, but in this case either from its criteria or the decisional field/constraints. It is called "Reactive" because it depend on the IN. In practice, it is more complex to calculate it

(continued)

Table 1 (continued)

Parameters	Attributes
Behaviour	*Oportunistic*: This behaviour is common in non-organizational contexts, in which the DCs don't aim to achieve a common goal. Besides, not only attempt to achieve individual goals, but it doesn't exist fair play. Most of the cases come out real incentives o penalties which change the way the DCs behave
	Non-oportunistic: This behaviour is common in organizational contexts, in which the DCs aim to achieve a common goal and obviously there exist fair play. However, this "Non-Oportunistic" behaviour may also appear in "Non-Organizational" contexts

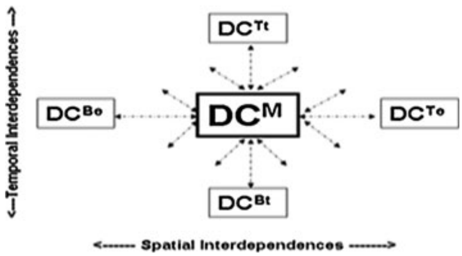

Fig. 4 Decision environment of a generic CD^M

However, the Macro-Decision View highlights the fact that the DC Decision Environment of a generic DCM is formed either by those which interacts temporally (DCTt, DCBt) or spatially (DCTt, DCBt) (Fig. 4).

4.3 Decisional Activities

In this third block, the necessary concepts to identify each of the Decisional Activities of the SC CP Process are defined, as well as their execution order, since in Collaborative context, they are all interconnected.

It is relevant to stress that DCs definition is not the same as the Decisional Activities identification, for instance the case of a non-hierarchical context negotiation process carried out by two DCs. Depending on the number of cycles in the Decision-Making process, a DC may lead to more than one Decisional Activity, as a result of its successive activations generating proposed decisions or plans. Therefore, it is important the sequence in which the different DCs execute or activate these Decisional Activities, obtaining Tactical or Operational Plans.

For each one of these plans two temporal characteristics may be specified, as they are the Replanning Period and Horizon (there is another important one, as it is the Planning Period, but is not relevant in the Macro-Decision View).

It is considered that two DCs placed in the same Decisional Level present the same Replanning Period and Horizon. In case not, there should be an initial effort to synchronize them. Within the Replanning Period is it possible to know when a DC placed in any of the Decision Levels should make its decisions, that is, when it has to be activated, leading, as it was commented before, to one or more Decisional Activities.

The former implies that all the Decisional Activities of the CP Process are activated periodically (as it usually happens with the Decision-Making in a Tactical/Operational level). Nevertheless, as there may be several of them being executed at the same time, their priority is based on which DCs are "top" ones (DC^T). The rules to consider a DC as a DC^T are as follows:

1. DCs placed in the Tactical Decisional Level are always activated before DCs placed in the Operational one and therefore the last ones are always considered "base" from a temporal point of view (the hierarchy seems obvious). In this case the Replanning Periods and the Horizon of the DCs placed in the Tactical Decisional Level are multiples of the DCs placed in the Operational one. Besides, these DCs placed in the Operational Level review their Operational Plans with a higher frequency (shorter Replanning Periods) so that the Decision-Making only matches in determined instants of time.
2. Given one of the two Decisional Levels (Tactical or Operational), a DC is activated before all the "Base" from a spatial point of view. The DC "top" is therefore activated just an instant before, despite sharing the same Replanning Period. This is often due to power-related issues.

5 Conclusions

The aim of the methodology (I) presented in this paper is to support the integrated modeling of the SC CP process, and particularly, the macro-decisional view.

This methodology (I), is, in turn, based on a framework, previously outlined but some of this paper's authors in [13], which presents all the organized aspects and concepts allowing for the methodology (I) application.

The main contributions of this proposed framework/methodology (I) are:

- The integration of four different modeling views: physical, organisation, decision and information, and their relationships. This facilitates the development of integrated models of the SC CP process, leading to more realistic and versatile models, and being able to be applied to any complex SC. Particularly, the proposed framework uses the decision view as the main one, but is complemented and enriched with other ones, since the CP process implies to take decisions about resources/items (physical view) taking part of a determined organisation in which the different OCs are more or less integrated (organisation view). Besides, the SC activity generates and needs some information (information view) in order to be able to take decisions or planning.

- The simultaneous consideration of two interdependence relationships types, temporal (among decision centers belonging to different decision levels) and spatial (among decision centers belonging to the same decision level), both typical from distributed decision-making contexts, in which the CP process is embedded. Besides, it is explicitly considered a set of parameters/attributes to characterize the DCs interdependence relationships.

It is also important to stress that such framework is not only conceptual, but also analytical, since it includes either all the necessary aspects to conceptually model the CP Process (macro-level) or the aspects to facilitate the formulation of analytical models in each of the DCs decisional activities identified in the CP process (micro-level). This paper focuses on the framework conceptual part, because the methodology (I) just aims to model the CP Process itself.

Finally, it is remarkable to highlight the lines of research which are being carried out by some of this paper's authors.

On one hand, the development of a methodology (II) [18, 19] which establishes the steps for the analytical modeling (based on mathematical programming) of each of the DCs decisional activities identified in the SC CP process. This methodology (II) not only takes into account the framework developed concepts (mainly in the micro-decisional view) but also the "conceptual" Model of the CP Process previously obtained within the application of the methodology (I). This methodology (II) assists the model maker in the process of defining the mathematical programming models of each DC by considering their previous characterized interdependence relationships.

By the other hand, the development of an informatic tool [20] which is based on the framework and both methodologies allows the execution of all the defined interrelated mathematical programming models and its validation.

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