# SCONTO: A Modular Ontology for Supply Chain Representation

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**Abstract**. Supply Chain Management (SCM) involves coordinating and integrating material, information and money flows, both within and across several companies. The information associated with these flows is perceived differently by distinct companies, raising semantics-related problems. Industry 4.0 and the Digital Supply Chain initiative request a seamless integration. This implies achieving technical, syntactic, semantic and organizational interoperability. For several years, ontologies have been considered the key technology to achieve semantic integration. Therefore, this contribution presents SCOPRO, which is the main module of SCONTO, supply chain ontology. SCOPRO is an ontology that formally describes a supply chain (SC) at various abstraction levels, by specifying its associated business processes based on the SCOR de facto standard and by sharing a precise meaning of the information exchanged among the many stakeholders involved in the SC.

**Keywords**: SCOR model, Supply Chain, Ontology, Interoperability

## 1. Introduction

To efficiently operate a Supply Chain (SC), all its participants (suppliers, manufacturers, distributors, customers, third and fourth party logistics) must have an enhanced and common understanding of it. Reaching a shared vocabulary allows SC partners to communicate more efficiently, achieving a genuine integration of the activities executed by the different actors. This challenge has motivated several research efforts that addressed the development of models in two different directions. One of them has proposed models that describe the elements and processes associated with a supply chain. The other one has tackled specific SC integration problems.

Despite several models exist, the only de facto standard is the Supply Chain Operations Reference (SCOR) model (Supply-chain Council, 2012). It is a good starting point for communication among SC stakeholders because it provides slender modeling of business processes. However, neither the syntax nor the semantics of SCOR are well defined. In addition, resources and their relationships with processes are not explicitly captured. Therefore, the formalization of SCOR becomes a requirement for a more comprehensive usage of the model (Böhm et al. 2008).

In the last decades, ontologies appear as a tool to reach a semantic agreement. According to Gruber (1993), an ontology is a formal, explicit specification of a shared conceptualization. It captures the knowledge accepted by a community about a specific domain. In general, ontologies are expressed using not ambiguous and formal languages. Such formality allows a computer to interpret them and infer new knowledge.

After the rise of the Semantic Web, several SC ontologies implemented with these technologies appeared (Grubic and Fan, 2010). Some use linked data principles to represent traceability-specific domain knowledge in supply chains (Solanki and Brewster, 2016), as well as to improve and facilitate knowledge management among SC partners (Rodríguez-Enríquez et al., 2015). Other proposals formalize the SCOR model using OWL (Ontology Web Language), but in a partial fashion. Ontologies have been developed to support the knowledge management of supply chain operation (Zdravkovic et al., 2010), the alignment of strategic knowledge (Sakka et al., 2011), the modeling of processes (Grubic et al., 2011), or the simulation of SC processes (Fayez et al., 2005). In addition, there are proposals with the aim of describing SC partners and their relationships (Chi 2010), managing product data flows in the SC (Lu et al., 2013), and providing a core vocabulary for logistics. To infer or validate knowledge, some authors add rules and queries using SWRL (Semantic Web Rule Language) and SPARQL to their ontologies. Leukel and Sugumaran (2013) focus on the development of SWRL rules for the correct construction of threads, based on the articulation of SCOR's "Make", "Source" and "Deliver" processes. In turn, Petersen et al. (2016) propose the SCORVoc lightweight ontology, which provides a set of SPARQL queries that enable the evaluation of metrics and key performance indicators (KPIs) defined by SCOR.

In conclusion, several contributions whose aim is SC modeling exist, but none is complete and expressive enough to represent all the SC related concepts, such as its structure, involved organizations, business processes, resources and the roles they play in each process, as well as SC performance measurement and benchmarking notions. In addition, the existing proposals lack a semantic well-defined domain vocabulary. In consequence, there is a need to provide more comprehensive and formal definitions of the SC domain and its performance measurement/benchmarking concepts. This will lead to a common understanding of the field, as well as a proper interpretation of the shared information.

This proposal aims at contributing towards the formalization of the SC domain. The goal of this paper is to present SCOPRO, a SC sub-ontology, which is part of SCONTO, a comprehensive ontology based on the SCOR model. In the next section, SCONTO is concisely described to give place to a more detailed presentation of SCOPRO. Section 3 briefly illustrates SCOPRO´s application to a case study and Section 4 describes its evaluation from structural, content, consistency, and complexity perspectives. In section 5, conclusions are drawn.

## 2. Supply Chain Ontology (SCONTO)

The Supply Chain ONTOlogy (SCONTO) aims at describing supply chains having different features through a generic vocabulary. SCONTO is organized in three complementary sub-ontologies: SC processes (SCOPRO), performance evaluation (SCOBE) and benchmarking (SCOME), which are shown in Fig. 1. Despite its generality, SCONTO can be specialized to include more specific concepts. A similar approach has been followed regarding SC performance evaluation and benchmarking. The proposed ontology specifies the necessary terms to define an evaluation system that provides a common understanding to all the SC participants. Although SCONTO is defined in terms of the three modules mentioned above, this article focuses on the first one.

SCOPRO specifies the main concepts that are needed to capture the essence of a supply chain by formalizing and extending the SCOR reference model (Supply Chain Council, 2012). SCOPRO includes the basic terms that represent the SC structure, its processes and associated resources, the resource roles, as well as the relations among these concepts. In addition, SCOPRO makes explicit the organizational units that participate in a SC, their organizational components and roles, as well as the way these units are linked to processes.

An ad-hoc methodology based on well accepted principles has been proposed for the development of SCONTO. It has the following main stages:

1. *Requirements specification*; this stage identifies the scope and purpose of the ontology.
2. *Conceptualization;* which organizes and converts an informally perceived view of the domain into a semi-formal specification using UML diagrams and OCL specifications.
3. *Implementation;* stage that implies the codification of the ontology using a formal language.
4. *Evaluation,* step at which a technical judgment of the ontology quality and usefulness with respect to the requirements specification, competency questions, and/or the real world is made.

It is worth mentioning that these stages are not truly sequential. In fact, ontology development is an iterative and incremental process. If deficiencies are detected at any stage in the process, it is possible to return to any of the previous steps to make modifications and/or refinements.

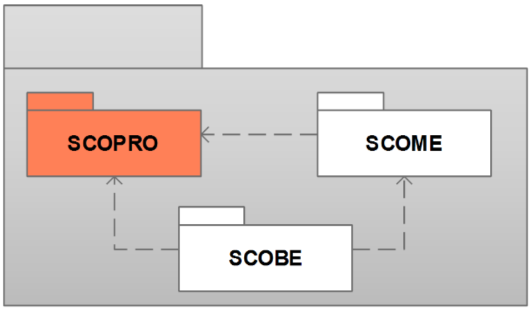


Fig. 1. SCONTO organization

### 2.1 Supply Chain Process Ontology

As already mentioned, SCOPRO integrates concepts representing the SC structure, as well as the business processes and resources involved in its operation. This ontology is presented in the following paragraphs using textual definitions, UML diagrams, and tables. The tables introduce concepts, relationships, and constraints that are expressed in natural language. Due to space limitations, the OCL specifications (OMG, 2014) of the textual constraints are not included in this article. The conceptualization of SCOPRO could be implemented in several languages. In particular, an OWL2 (W3C, 2004) implementation was made, which can be found in https://industrialonto.github.io/SCOPRO/OnToology/SCOPRO.owl/documentation/index-en.html.

Figure 2 presents an UML class diagram showing the SCOPRO main concepts, which are organized around three perspectives, labeled as structure, process and resource dimensions. The model includes the "SC Entity" concept, which is a generic and abstract notion representing every entity of a SC.

#### 2.1.1. SCOPRO - Structure Dimension

This perspective comprises the terms that are identified when conceiving the SC as an extended organizational network, including the roles that the organizations play in it. The main concepts belonging to this dimension are: *Supply Chain*, *Organizational Unit*, *Organizational Unit Role* and *Functional Area*.

**Definition 1**: An Organizational Unit (OU) represents the enterprises or enterprise components that participate in the SC operation.

Each *Organizational Unit* can take part in more than one supply chain playing different roles (producer, supplier, distributor, etc.). Therefore, SCOPRO represents the role that is played by an OU in a specific SC through the concept *Organizational Unit Role*. Optionally, an OU can be related to one or more *Resource Role* and to one or more Functional Areas by the associations that are shown in Table 1. Regarding this table and the following ones, it is worth noting that each association is only included in the table of one of its end concepts. In addition, the constraints appearing in some of the tables are described in natural language.

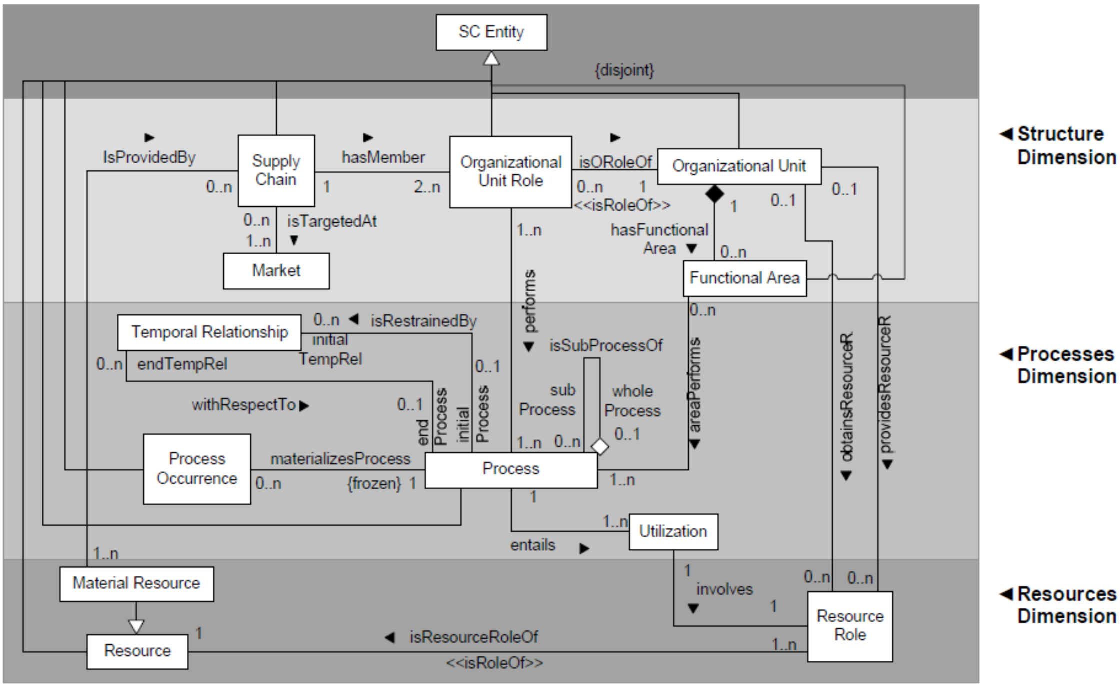


Fig. 2. SCOPRO main concepts

In order to specify the internal organization of the SC participants, the OU class is specialized into:

- *Dependent Organizational Unit*: is an OU that is a subordinate of another one, without losing its administration and functions. This concept is further specialized into any business entity, branch, or subsidiary of an enterprise or company.
- *Independent Organizational Unit:* is an autonomous OU to which belong, if any, all divisions, subsidiaries, branches, or other organizational components of a business. An *Independent OU* may be a company, a society, or an enterprise.

Table 1. *Organizational Unit* class relationships

| **Relationships** | |
|---|---|
| *hasFunctionalArea* | It is optional. If exists, it relates an OU with one or more Functional Areas. |
| *obtainsResourceR* | It is optional. It specifies which organizational unit has a resource available once the resource participation in a process ends |
| *providesResourceR* | It is optional. It indicates the organizational unit responsible for making available a resource for its use in a process |

**Definition 2.** An *Organizational Unit Role* represents the functionality assumed by an organizational unit when participating in a given supply chain. The *isRoleOf* association, which is shown in Fig. 2 and Table 2, between *Organizational Unit* and *Organizational Unit Role* classes agrees with the *isRole* generic relationship defined by Olivé (2007). In consequence, an instance of *Organizational Unit Role* is always the role of the same individual belonging to *Organizational Unit.*

In addition, SCOPRO specifies the following role types:

- *Primary Producer Role*: it is assumed by an organizational unit that carries out activities related to the primary production, such as agriculture, livestock, fishing, mining, fossil fuels extraction, etc.
- *Secondary Producer Role*: role that is played by an organizational unit when performing activities where raw materials or intermediate products are transformed into higher-value products.

*Customer Role:* a role that is performed by an organizational unit that carries out activities related to the purchase of goods for use, consumption or exploitation.

- *Service Provider Role:* a role that is played by an organizational unit that only performs activities related to transportation, marketing, storage, etc., that add value to a product without transforming it in a physical and/or chemical way.

The functional organization of work within organizational units is captured through the *Functional Area* and *Functional SubArea* concepts.

Table 2. *Organizational Unit Role* class relationships and constraints

| Relationships | |
|---|---|
| *isRoleOf* | Relates an *Organizational Unit* with one or more roles that the OU plays within a specific Supply Chain |
| *performs* | Links an *Organizational Unit Role* with one or more Processes that the OU carries out. |
| Constraints | |
| If an *Organizational Unit* performs through a certain role some part of a complex process, it will also execute such complex process | |
| All the roles that carry out a process have to belong to the same supply chain to which such process belongs. | |
| An OU playing a *Primary Producer* or *Secondary Producer* role can take part in any business process except in the *Deliver Retail Product* one. | |
| An OU playing the *Service Provider* role can perform any process except the *Make process*. | |
| Every organizational Unit playing as a Customer cannot participate in the *Make*, *Deliver* and *Deliver Return business processes.* | |

**Definition 3.** The *Functional Area* class captures the function-based work division that often occurs within organizations. This concept is further specialized into Purchasing, Production. Logistics, Marketing, Sales, R&D and Finance, based on the functions defined by Lambert (2008a). Table 3 presents the relationships in which this concept participates and its restrictions.

Table 3. *Functional Area* class relationships and constraints

| Relationships | |
|---|---|
| *areaPerforms* | Represents the link between a functional area of an organization and the SC process in which this area participates. |
| *hasFunctionalArea* | Specifies the link between a Functional Area with one or more Functional Subareas. |
| Constraints | |
| The range of an *areaPerforms* relationship is restricted to instances of the *Process Element* class. | |
| If a functional area belonging to an organizational unit executes a *Process Element*, then an Organizational Unit Role associated with such Process Element has to exist. | |

**Definition 4.** A *Functional SubArea* is a grouping of activities that are part of a *Functional Area* and that deals with a type of common tasks within the functional area of which they are part. Table 4 presents the relationships in which the *Functional SubArea* concept participates and its restrictions.

Table 4. *Functional SubArea* class relationships and constraints

| Relationships | |
|---|---|
| *subAreaPerforms* | Specifies the link between a *Functional SubArea* of an OU and one or more *Tasks* belonging to the process in which this subarea participates. |
| Constraints | |
| If a functional subarea belonging to an OU performs a task, then this task has to be linked to some role of such OU. | |

**Definition 5**. The *Supply Chain* class represents a network of *Organizational Units* (OUs) that transforms or adds value to materials, ranging from raw materials sourcing, to the final product distribution in specific markets. The relations in which this class participates and its constraints are listed in Table 5.

Table 5. *Supply Chain* class relationships and constraints

| Relationships | |
|---|---|
| *isTargetedAt* | Links a *Supply Chain* with at least one *Market*. |
| *isProvidedBy* | Relates a *Supply Chain* with at least one *Material Resource* |
| *hasMember* | Connects a *Supply Chain* with two or more organizational units playing a specific role |
| Constraints | |
| Each SC must have at least a member playing the primary producer or secondary producer role | |

**Definition 6**. A *Market* is a set of actual and potential buyers that are grouped together because they share certain distinctive characteristics.

### 2.1.2. SCOPRO - Process Dimension

This dimension includes the concepts that are needed for a detailed description of processes. In particular, the terms required for defining processes and their sub-processes, the temporal relations among them, the resource participation in processes and the occurrences of the defined processes. Figure 3 presents the main classes of this dimension. In this figure the classes belonging to other dimensions are identified using their corresponding names.

**Definition 7.** A *process* represents an activity chain that is carried out in a SC to achieve certain results. A process execution implies the creation, modification, use or movement of several resources, which may be physical or conceptual ones.

In order to properly describe a SC, the business processes belonging to it should be modeled at different levels of abstraction. SCOPRO represents the process decomposition into more specific activities using the *isSubProcessOf* association., which is shown in Table 6. This table also presents the *materialize Process* relationship, which links a *Process* with one or more *Process Occurrences.*

**Definition 8**. The *Process Occurrence* concept represents a particular execution of a process in a given period.

Based on the SCOR model (Supply Chain Council, 2012), SCOPRO considers three different types of processes that are needed to model and analyze a SC. The three concepts that specialize the *Process* class are introduced in Fig. 4, and are labeled as *Business Process*, *Process Element* and *Task*.

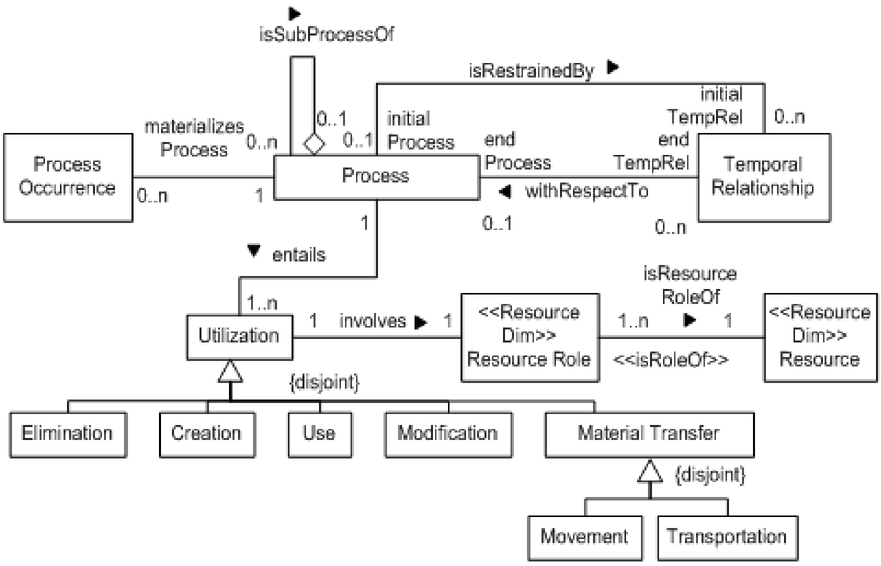


Fig. 3. Main classes of the *Process* Dimension

**Definition 9.** A *Business Process* is a type of process that is composed of value-added activities. It is designed for achieving a result having a significant impact on clients and in the efficient management of SC flows. Each *Business Process* is composed of *Process Elements.*

Table 6. *Process* class relationships and constraints

| Relationships | |
|---|---|
| *isSubProcessOf* | This association represents a *Process* decomposition into more specific activities. |
| *materialize Process* | It connects a *Process* with one or more of its occurrences. The semantics of this relation is the same one proposed by Olivé (2007) for the materialize association. |

| | |
|---|---|
| *isRestrainedBy* | This association represents a temporal relationship between a process and another one that restrains its start time. |
| *withRespectTo* | It represents a temporal relationship between a process and another one that imposes a limit on its end time. |
| Constraints | |
| If two processes are linked, then there is only one temporal relationship (atomic or composite) that connects them. | |
| Temporal relationships can be defined between business processes, between process elements or between tasks, but never between processes of different type. | |

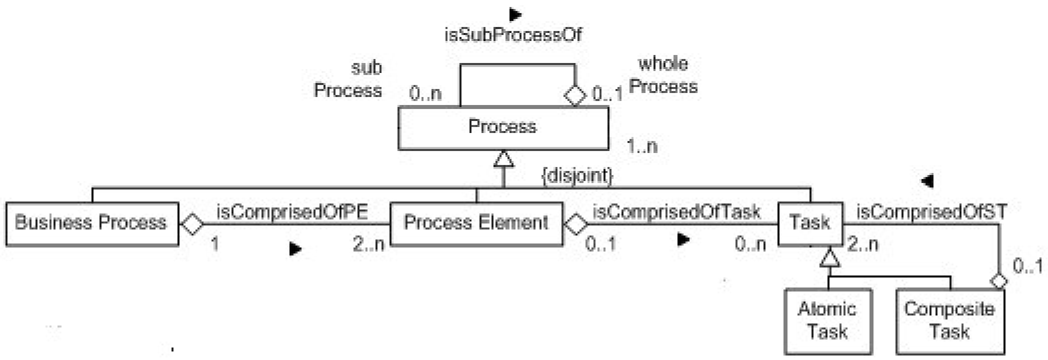


Fig. 4. SCOPRO - Process Dimension. Specialization of the *Process* concept

**Definition 10.** A *Process Element* is an activity or a logical structure of activities that is part of a *Business Process*. The detail level that is provided by the *Process Element* class allows the decomposition of a *Business Process* into specific operations but, at the same time, is general enough to describe activities that are valid for different types of supply chains.

**Definition 11.** A *Task* is an activity or a logical structure of activities that is part of a *Process Element* in a certain SC. For example, in a particular supply chain the process element labeled as "Schedule Product Deliveries" is decomposed into the following tasks: "Send material orders", "Coordinate delivery place and date." However, in other SC, in which the provider is responsible for monitoring and maintaining the client stock, the same process element is broken down into different tasks, like "Monitor stock inventory", "Send information to client" and "Propose delivery date and terms".

Table 7 presents the relationships associated with *Business Process, Process Element* and *Task*, as well as their constraints.

Table 7. Relationships and constraints of the *Business Process*, *Process Element* and *Task* classes

| Relationships | |
|---|---|
| *isComprisedOfPE* | It relates a *Business Process* with the *Process Elements* belonging to it. |
| *isComprisedOfTask* | It links a *Process Element* with its *Tasks.* |
| *isComprisedOfST* | It connects a *Composite Task* with one or more *Tasks* that are part of it. |
| Constraints | |
| Each *Business Process* is only composed of *Process Elements* | |
| Each *Process Element* is only composed of *Tasks* | |
| Each *Task* must be part of a *Process Element* or a *Composite Task*, but not both at the same time. | |
| An *Atomic Task* cannot be further decomposed | |

SCOPRO extends the *Business Process* and *Process Element* concepts using the vocabulary of the SCOR reference model (Supply Chain Council, 2010). This proposal recognizes as the main business processes of a SC the following ones: *Sources*, *Make* and *Deliver,* as well as the activities of material returns to providers (*Source Return*) and from clients (*Deliver Return*). The model also includes the planning of the operational activities related to material transformations and movements (*Plan*). As seen in Fig. 5, these processes are specializations of the *Business Process* class.

The SCOR reference model also includes a classification of the activities belonging to business processes. In SCOPRO, such activities specialize the *Process Element* class. As already mentioned, *Organizational Unit*s participate in supply chain processes playing several roles, which can be *Primary Producer*, *Secondary Producer*, *Service Provider* or *Client*. Each role implies that the organizational unit playing it performs a specific set of activities in a particular SC. If an *Organizational Unit* performs a *Process Element* or *Task*, then such OU also executes the *Business Process* from which the *Process Element* or *Task* belongs to. Therefore, constraining which business processes may be performed when adopting a specific organizational unit role, also restricts the process elements and tasks that such organizational unit can execute.

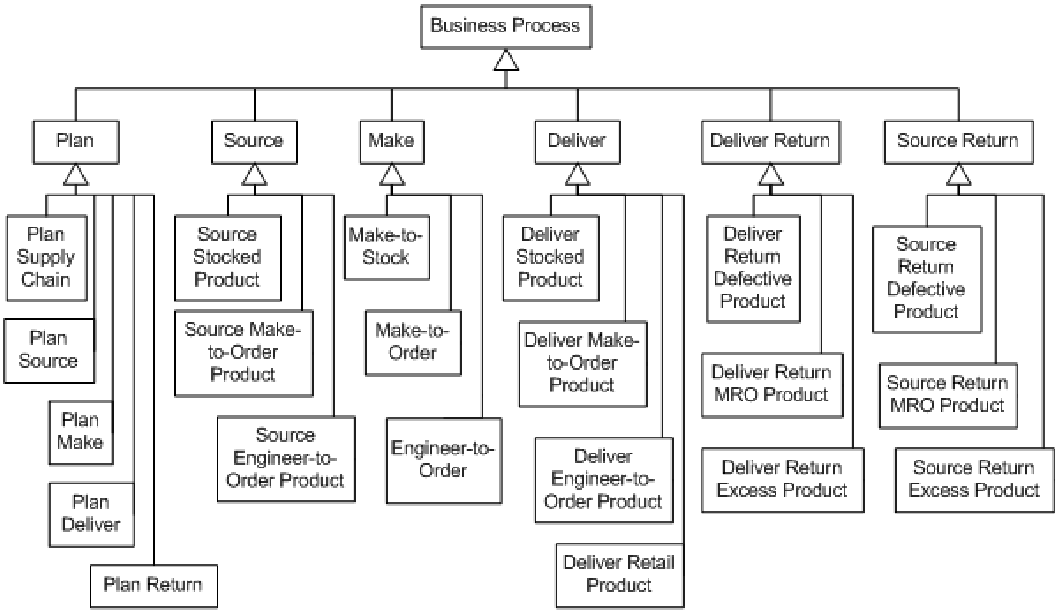


Fig. 5. *Business Process* class specialization

As seen in Fig. 3, SCOPRO introduces the *Temporal Relationship* class, which explicitly represents temporal links between two processes. In the following paragraphs, a refinement of such a concept is presented.

**Definition 12.** *Temporal Relationship* represents different constraints related to the partial order between the executions of two processes in a SC. To specify this class, this proposal uses the conceptualization developed by Allen (1983) that considers the time intervals in which the processes or activities are performed and the relations between them. Figure 6 introduces the different partial order relations associated with the execution of two processes.

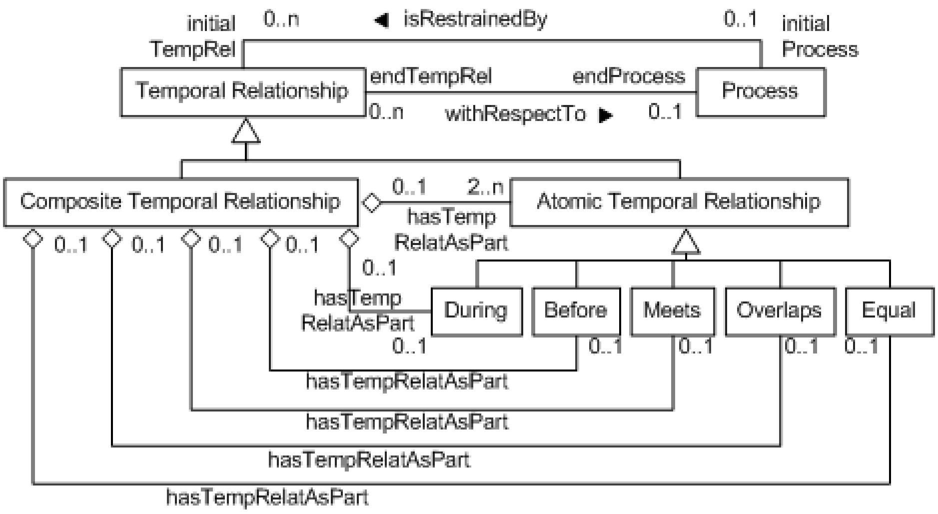


Fig. 6. *Temporal Relationships* in SCOPRO

As shown in Fig. 6, SCOPRO considers two types of temporal relation: atomic and composite ones. The former (Allen, 1983) includes the following subtypes:

- *Before than*: if the P1 process is executed before than P2, the time interval in which P1 takes place is previous to the P2 time interval. In other words, the end of P1 is prior to the P2 start time.
- *Meets:* if P1 meets P2, then the time interval in which P1 is executed ends at the same time the P2 activity begins. The end of P1 is equal to the start time of P2.

- *Overlaps*: If P1 overlaps P2, the start time of P1 takes place before the beginning of P2, but P1 ends while activity P2 is still executing. Therefore, the start time of P1 is prior to the beginning of P2 and the end time of P1 takes between the start and the end time of P2.
- *Equals:* If P1 equals P2, the time interval at which P1 is performed is the same as the one associated with the P2 activity. In other words, the start and end times of P1 and P2 coincide.
- *During*: If P1 is performed during P2, P1 begins after P2 starts and ends before P2 finishes.

The *Composite Temporal Relationship* combines different atomic temporal relationships as disjunctions. As seen in Fig. 6, a composite temporal relationship involves at least two atomic temporal relationships as parts.

**Definition 13**. The Utilization concept represents the way in which a process affects a resource that participates in a given component (subprocess, activity) of such process: *Creation*, *Elimination*, *Modification*, *Use,* and *Material Transfer* (See Fig. 3). This last type of utilization may occur inside a facility or between different ones. SCOPRO employs the *Movement* and *Transportation* classes, respectively, to represent these material transfer types. The *Transportation* class represents a material flow between two different geographic points. Table 8 presents the relationships associated with the *Utilization* class.

Table 8. *Utilization* class relationships

| Relationships | |
|---|---|
| *entails* | This relation links a *Process* with one or more *Utilization* types |
| *Involves* | It associates a *Utilization* type with the role that a *Resource* plays in such utilization. |

### 2.1.3. SCOPRO Resource Dimension

This dimension specifies the resources and the role they play when participating in processes. Figure 7 illustrates these concepts and their associations.

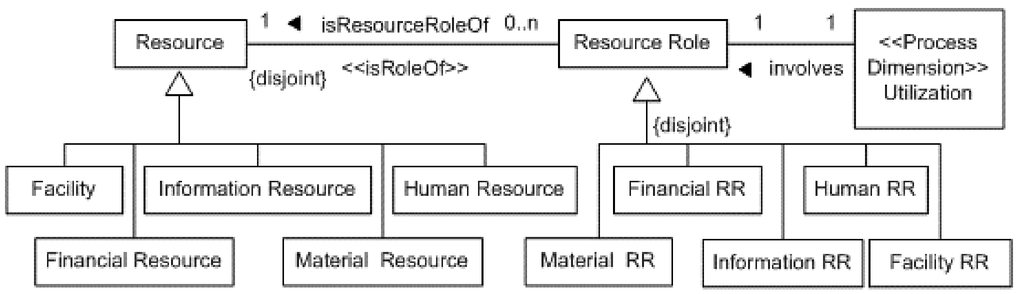


Fig. 7 Specialization of *Resource* and *Resource Role* classes

**Definition 14**. A Resource can be any type of physical or conceptual medium that participates in a process via one of its roles. This class represents resources that flow through the network (e.g., commercialized goods) and those that remain static (e.g., industrial plants). Supply Chain resources include buildings or facilities, material handling equipment, different types of products, information and financial resources, among others. Therefore, SCOPRO specializes the *Resource* class into the *Material Resource*, *Information Resource*, *Financial Resource*, *Human Resource* and *Facility* classes, which are further specialized.

**Definition 15.** A *Resource Role* reflects the participation type that a resource has in a given process. The same resource can play different roles in distinct processes. For example, a drill can be the final product of a production process and can be a tool in another one. SCOPRO specializes *Resource Role* into subclasses to represent more specific roles, and these subclasses are also further specialized. For example, *Payment* and *Proceeds* are a specialization of *Financial RR.* Similarly, *Responsible*, *Supervisor* and *Executor* are s*ubclasses of Human RR.* Table 9 presents the relationships associated with the *Resource Role* class, as well as its constraints.

Table 9. *ResourceRole* class relationships and constraints

| Relationships | |
|---|---|
| *providesResourcesR* | It states which is the OU responsible for making available a *Resource* for its use in a *Process* |
| *obtainsResourceR* | It specifies the OU that has a *Resource* available after the end of the resource participation in a given process. |
| *isResourceRoleOf* | It links a *Resource* with its *Resource Roles*. The stereotype <<isRoleOf>> in the association constraints that an instance of *Resource Role* is always connected to the same instance of |

| | |
|---|---|
| | *Resource*. In contrast, an instance of *Resource* can be linked to several instances of the *Resource Role* class. |
| Constraints | |
| SCONTO includes several specifications that state which are the roles that the different resources can play, and which are the utilizations that may be associated with them. Due to space limitations, it is not possible to describe all of these constraints in this table. | |

## 3. Case Study

This section illustrates the application of SCOPRO to represent an orange juice supply chain. This SC comprises three farms located in the Corrientes province of Argentina, which produce and pack oranges; the *CITRIX Company* that is the orange juice manufacturer, and the *ArgenTruck* company, which takes care of the material transportation between SC partners. Figure 8 illustrates this value chain in a very simplified way.

The *CITRIX Company* owns two production plants, the *BellaVista* plant *(FCojPlant)* and the *NaranUp* plant *(RojPlant)*, which are managed as separate business units. The *FcojPlant*, which is also located in Corrientes, manufactures frozen concentrated orange juice (*FCoj*). In turn, the *RojPlant,* sited nearby Buenos Aires, produces and bottles reconstituted orange juice (*Roj*). Finally, the *ArgenTruck* company provides transportation to and from the various farms, plants, resellers and retail stores.

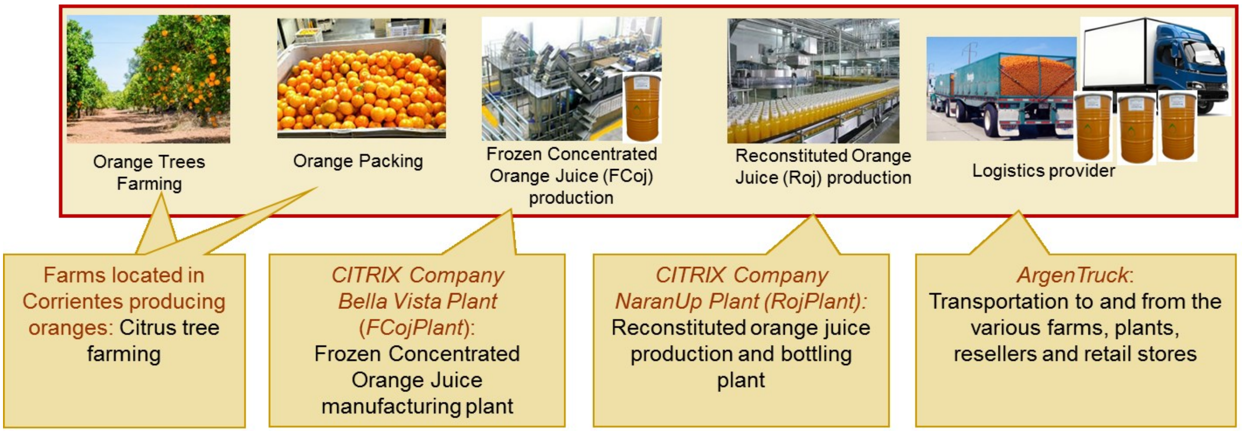


Fig. 8. Orange Juice Value Chain

Due to space limitations, only a small portion of the case study is addressed in this contribution. The delivery process associated with the distribution of frozen concentrated orange juice (*FCoj*) from the *Bella Vista* plant to the *NaranUp* one is represented. This process, which is carried out by both the *CITRIX Company* and *ArgenTruck*, is modelled through the *DFCoj* (Deliver frozen concentrated orange juice) business process, an instantiation of the *Deliver Make-to-Order Product* process that was presented in Fig. 5.

Figure 9 shows the decomposition of *DFCoj*, which is performed by the *CITRIXCompany Independent Organizational Unit* through its *FCoj production Primary Producer Role*. Similarly, *ArgenTruck* also participates through its *3PL Provider Role*. The figure depicts the seven *Process Elements* comprising the *DFCoj* business process; for instance, the *:Receive, Enter & Validate Order* one that is performed by the *CITRIX Company* and the *:Ship Product* process element, which is performed by *ArgenTruck*. The model also shows the various temporal relationships (e.g., *:Before*, *:Meets*) among the different process elements.

The *DFCoj* business process takes place because there is a sourcing need at the *NaranUp* plant, which employs frozen concentrated orange juice as one of its raw materials. In fact, there is a *SFCoj* (Source frozen concentrated orange juice) business process that is an instantiation of *Source Make-to-Order Product* (See Fig. 5), which is carried out by *NaranUp*. Both, the *SFCoj* and *DFCoj* processes represent, respectively, the customer and the provider views of the same business process. The *SFCoj* sourcing process includes ordering the frozen concentrated orange juice from the supplier, receiving the lot and transferring it to an area of the raw materials deposit of the *RojPlant*. In turn, *DFCoj* corresponds to the supplier vision for the same process, comprising the reception, management, and fulfilment of the frozen concentrated orange juice procurement order, as well as the product delivery to the *RojPlant.*

The *SFCoj* and *DFCoj* processes are shown side by side in Fig. 10, which captures the strong interactions that exist between these two processes. This figure presents the process elements belonging to both processes and the temporal relationships linking them. In addition, the model displays the resources that participate in each process element, the roles that the different resources play, and the way each process elements affects a given resource. For instance, it can be seen that the *:Procurement Order* resource participates with its *output* role in the *:Schedule Product Deliveries* process element, which is part of *SFCoj*. This process element affects the resource by creating it (*:Creation* in Fig. 10). It is important to note that the same resource also partakes through its *input* role in the

*:Receive, Enter & Validate Order* process element that comprises the *DFCoj* business process. However, in this case the *:Receive, Enter & Validate Order* process element uses the resource (*:Use* in Fig. 10).

The model depicted in Fig. 10 represents all types of resources that take part in the orange juice SC. For instance, it includes a portion of the flow of materials that occurs in such value chain. In particular, it shows the transport (*:Transportation* linked to the *:Ship Product* process element in Fig. 10) of the *FCoj material resource* from the *FCojPlant* to its destination, which is the *RojPlant*. It is also shown that this material resource plays the role of a load (*:Load* in Fig. 10) with regards to such transportation.

From the above description, it is possible to appreciate the close link that exists between certain supply chain business processes involving different organizations. The modeling of the process interactions is an essential step to achieve the semantic interoperability of the SC information, the design of information systems that support SC collaborative management, as well as the generation of information systems supporting materials traceability and allowing a comprehensive visibility of the SC information. In addition, this small example allows us to appreciate the important extensions that have been made on the SCOR model.

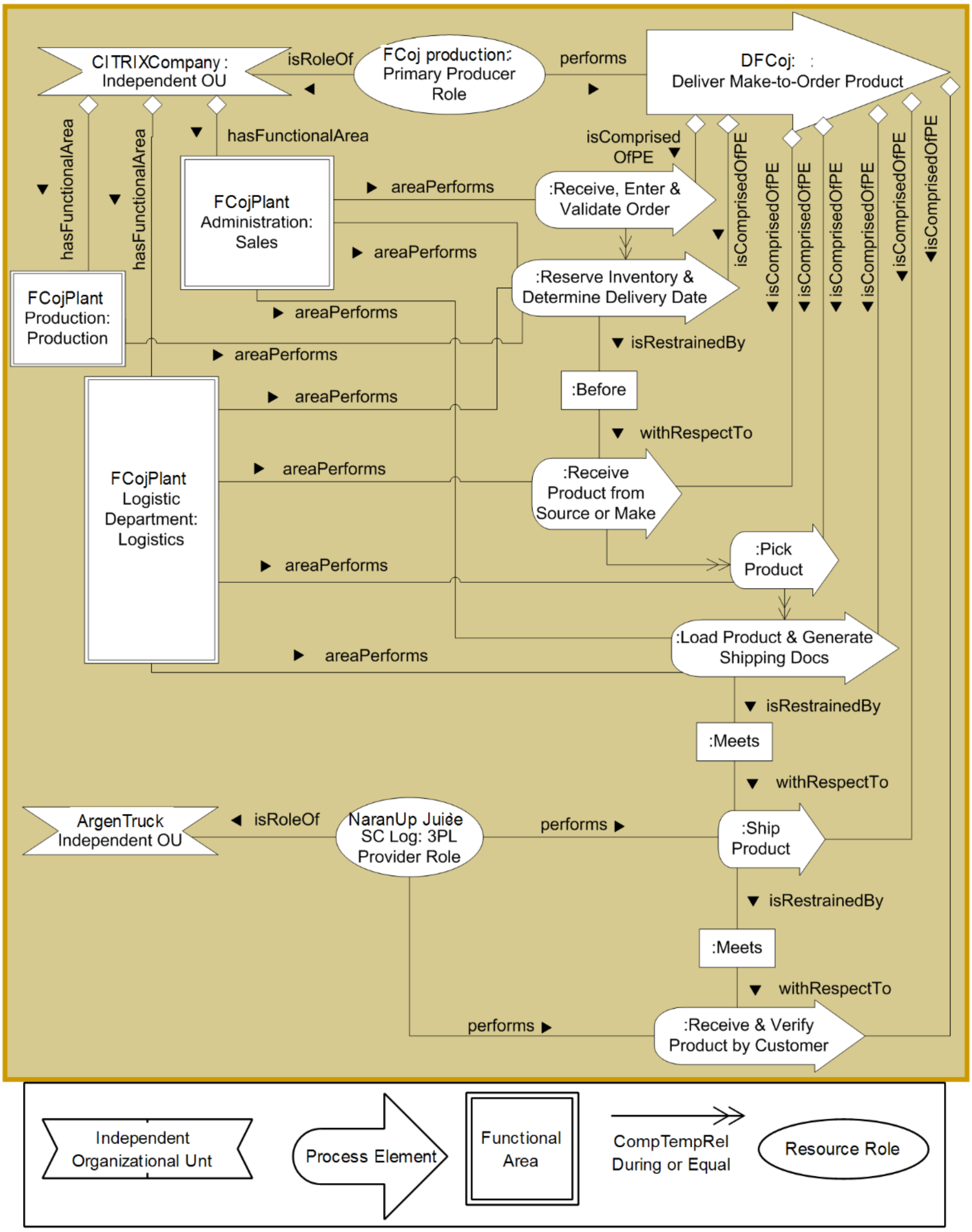


Fig. 9. Decomposition of the *DFCoj* Business Process

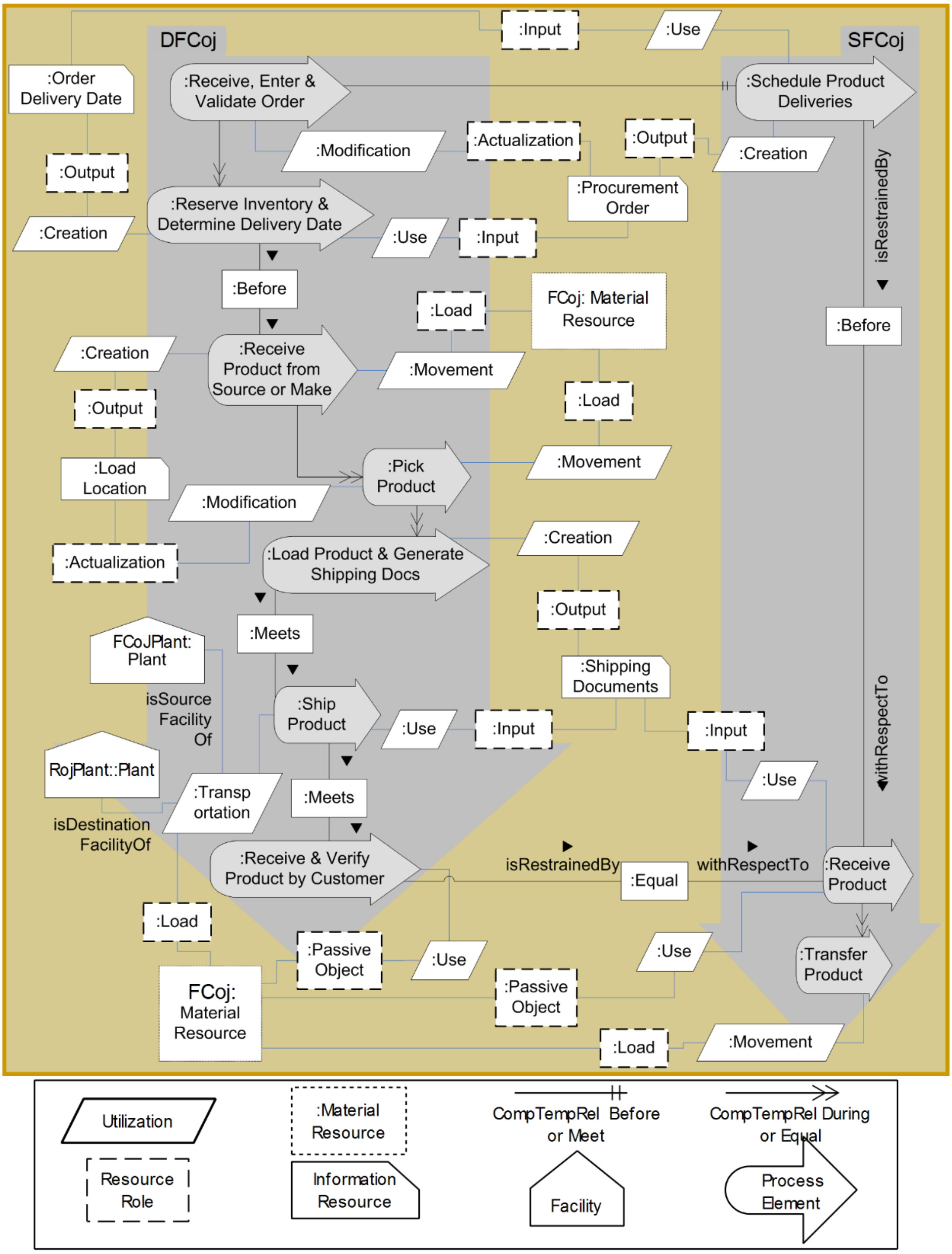


Fig. 10. Representation of *DFCoj* and *SFCoj* process elements, temporal relationships and resource flows

## 4. Ontology Evaluation

In order to evaluate SCONTO, aspects like content, structure, syntax and semantics have been analyzed. In such evaluation, the following methodologies and approaches have adopted:

- Ontoclean (Guarino and Welty, 2009) has been used to verify the correctness of the conceptual model structures
- A comparison with standards has been made to validate the ontology content depth and completeness.
- The tools available in the Protégé-OWL editor have been used to verify the consistency of the OWL implementation of the ontology.

In addition, a set of metrics have been adopted to obtain a quantitative description of the proposed ontology.

### 4.1. SCOPRO structure evaluation

The OntoClean methodology has been employed to validate the structure of SCOPRO. This methodology allows analyzing the ontology concepts and their hierarchical relations based on rigidity, identity, dependency and unity properties.

A concept is rigid (+R) if its instances are necessarily instances of it in all times. If all its instances can stop being instance of a concept in any time, this concept is anti-rigid (~R). A concept is not rigid if some instances can stop being instances of it.

The identity property qualifies the ability to distinguish between different individuals which instantiate a concept. A concept has an identity criterion (+I) if each of its instances can be distinguished. Otherwise, it has no identity (-I). The identity property can be inherited. Therefore, it is necessary to identify when the identity property is inherited or is owned by a concept. In this last case, the concept supplies identity (+O).

Regarding the dependency property, a concept is constantly dependent (+D) if each of its instances needs another individual to exist. In this situation does not hold, it is independent (-D).

An individual is considered a *whole* if its parts are linked among them by a relation R, and they are not associated with any other individual. The parts of a whole may also be a whole. The Unity property refers to the problem of describing the way the parts of an individual are bound together as a whole. A concept carries unity (+U) if all its instances exhibit a common unity criterion. A concept carries no unity (-U) if all its instances are wholes but with a different identity criterion. A concept carries anti-unity (~U) if all of its instances are not necessarily a whole.

Ontoclean proposes to analyse the ontology taxonomy using a set of rules that can help identifying problematic modelling choices. Given two concepts A and B, such that B subsumes A, the following rules must hold:

1. If B is anti-rigid, the A must be anti-rigid.
2. If B carries an identity criterion, then A must carry the same criterion.
3. If B carries a unity criterion, then A must carry the same criterion.
4. If B has anti-unity then A must also have anti-unity
5. If B is constantly dependent on a concept C, then A must also be dependent on C
6. Each individual belonging to A has to instantiate a unique class providing the identity criterion

The following paragraphs present a brief analysis of the SCOPRO concepts considering these properties. The classes that have been identified as rigid or anti-rigid, unity or anti-unity and the dependent ones are the only classes that may violate the OntoClean rules. Therefore, they are the only ones that are included in Table 10.

In the SCOPRO ontology, the *Independent OU*, *Dependent OU* classes and their subclasses are anti-rigid because the organizational units can be instances of one or the other at different times. For example, an independent organizational unit may become dependent when a company buys another one.

The SCOPRO classes that provide an identity criterion have also been identified. For each of them, their subclasses have been analyzed to check if there is no other class providing an incompatible identity. Besides, the verification that each "leaf" class has an identity (either own or inherited) has been done.

The *Supply Chain* class has its own identity (+O) because it is possible to distinguish a given OU network from other ones and this condition is not inherited. Similarly, *Market, Process, Process Occurrence, Organizational Unit, Organizational Unit Role, Resource Role, Functional Area, Functional SubArea, Utilization* and *Temporal Relationship* classes provide identity (+O). Considering resources, *Facility* and *Human Resource* classes provide identity while *Material Resource*, *Information Resource* and *Financial Resource* do not (-O), because their instances do not share a unique identity criterion. Therefore, these classes should be further specialized.

Table 10. SCOPRO concepts and their classification according the OntoClean philosophical properties

| Property | SCOPRO Concepts | | |
|---|---|---|---|
| Anti-rigidity (~R) | *Independent OU* | *Dependent OU* | All *Facility* subclasses |
| Proper Identity (+O) | *Supply Chain* | *Market* | *Process* |
| | *Process Occurrence* | *Organizational Unit* | *Organizational Unit Role* |
| | *Functional Area* | *Functional Subarea* | *Utilization* |
| | *Temporal Relationship* | *Facility* | *Human Resource* |
| | *Resource Role* | | |
| No identity -I | *Material Resource* | *Information Resource* | *Financial Resource* |
| Unity (+U) | *Supply Chain* | *Process* | *Process Occurrence* |
| | *Functional Area* | *Functional Subarea* | *Utilization* |
| | *Temporal Relationship* | All *Organizational Unit* subclasses | |
| Without Unity (-U) | *SC Entity* | | |
| Dependence (+D) | *Supply Chain* | *Process* | *Organizational Unit Role* |
| | *Resource Role* | *Process Occurrence* | *Dependent OU* |
| | *Functional Area* | *Functional Subarea* | *Utilization* |

In turn, the *Independent OU*, *Dependent OU* concepts, and their subclasses inherit the identity from *Organization Unit* class. Similarly, *Resource Role*, *Process*, *Functional Area*, *Utilization*, *Temporal Relationship* and *Facility* classes, inherit their identity from their superclass (*Organizational Unit Role*).

To analyze SCOPRO under OntoClean unity-related rules it was necessary to identify the classes carrying unity criterion and to verify that their subclasses carry the same unity criterion. Also, it was required to check that the super classes of a concept having unity do not denote anti-unity. In SCOPRO, *the Supply Chain* class carries unity (+U) because it is possible to identify all the organizations belonging to each SC. The following classes also carry a unity criterion (+U): *Process, Process Occurrence*, *Functional Area*, *Functional SubArea*, *Utilization, Temporal Relationship* and all *Organizational Unit* subclasses.

OntoClean defines a class X as a dependent (+D) on another class W if each instance of X needs an instance of W to exist and the later instance is not part of the former. OntoClean states that all the subclasses of each dependent concept are also dependent. Table 11 shows the classes *Organizational Unit Role*, *Resource Role, Process*, *Process Occurrence*, *Dependent OU*, *Functional Area*, *Functional SubArea* and *Utilization,* which are considered as dependent concepts, and the classes on which they depend. All the subclasses of the class shown in the second column of Table 11 are also dependent (+D). Therefore, it can be concluded that the OntoClean rules regarding concept dependency are satisfied.

Since it was verified that the OntoClean rules have been fulfilled in terms of rigidity, identity, unity and dependence of its classes, it was determined that the SCOPRO conceptual models has an adequate structure.

Table 11. SCOPRO constantly dependent concepts

| Constantly dependent class (+D) | Depends on |
|---|---|
| Supply Chain | Organizational Unit |
| Organizational Unit Role | Organizational Unit and Supply Chain |
| Resource Role | Resource and Utilization |
| Process | Organizational Unit Role |
| Process Occurrence | Process |
| Dependent OU | Organizational Unit |
| Functional Area | Organizational Unit |
| Functional Subarea | Functional Area |
| Utilization | Process and Resource Role |

### 4.2. SCOPRO content evaluation

The ontology content evaluation has been carried out by comparing SCOPRO against a set of models considered as references in the domain, like IDEF 0, IDEF 3, ARIS, TOVE, among others. The analysis took into account whether a topic is treated or not in a proposal, as well as the depth of such treatment. For this, a score of 1 to 3 was adopted. It was scored 3 when a concept is modelled with precision appropriate to the domain, with a score of 2 if it is only vaguely modeled, and with 1 if the concept is mentioned by the proposal, but is not part of the model. Table 12 presents a summary of the evaluation results. When there is not enough information to demonstrate that a topic is addressed by a certain proposal there is a hyphen. It is important to mention that although 3 points have been assigned to certain proposals in a specific topic, an improvement in the treatment of such topic may be required in some cases.

Table 12. Content included in different proposals in relation to business processes, enterprises and supply chains.

| | Process | Resource | Resource Flow | Temporal Information | Organizational Unit | Interorganizational Business Processes | SC Topological Structure | SC Management | SC Organizational Structure |
|---|---|---|---|---|---|---|---|---|---|
| IDEF 0[a] | 2 | 2 | 2 | - | - | - | - | - | - |
| IDEF 3 [a] | 3 | 2 | 3 | 2 | - | - | 2 | - | - |
| UML Activity Diagram[b] | 3 | 2 | 2 | 3 | - | 2 | 2 | - | - |
| BPMN[c] | 3 | 2 | 2 | 3 | - | 3 | 2 | - | - |
| CIMOSA[d] | 3 | 3 | 3 | 3 | 3 | 2 | 2 | - | - |
| GRAI-GIM[e] | 2 | 2 | 2 | - | 2 | - | - | - | - |
| ARIS | 3 | 3 | 3 | 3 | 3 | 2 | 2 | - | - |
| Enterprise Ontology[f] | 3 | 3 | 3 | 3 | 3 | - | 2 | - | - |
| TOVE[g] | 3 | 3 | 3 | 3 | 3 | - | 2 | - | - |
| SCOR[h] | 3 | 2 | 2 | 2 | 1 | 3 | 2 | - | 1 |
| GSCF[i] | 3 | 2 | 2 | 2 | 1 | 3 | - | 3 | 3 |
| SCOPRO[j] | 3 | 3 | 2 | 3 | 3 | 3 | 2 | - | 3 |
| - = topic not addressed 1= topic only mentioned 2= topic super partially modeled 3 = topic modeled with enough depth | | | | | | | | | |
| [a] US-ICAM, 1981; Mayer et al., 1995 - [b] OMG, 2007 - [c] OMG, 2011 - [d] Vernadat, 1992; Kosanke et al., 1999 - [e] Doumeingts et al., 1992 - [f]Scheer & Schneider 2005 - [g] Uschold et al., 1998 - [h] Fox and Grüninger, 1998; Grüninger and Fox, 1994 — [i] Cooper et al., 1997b; Lambert & Cooper, 2000; Croxton et al., 2001; Rogers et al., 2002; Croxton et al., 2002; Lambert, 2008b - [i] Supply-Chain Council, 2012 | | | | | | | | | |

The analysis has considered the following topics: i) Process; ii) Resource; iii) Resource Flows; iv) Temporal Information; v) Organizational Unit; vi) Interorganizational Business Processes; vii) SC Topological Structure; viii) SC Management; and ix) SC Organizational Structure. Although in some cases the first three topics are vaguely modeled, these topics are included in all the analyzed proposals.

SCOPRO has obtained the highest marks in topics (i) and (ii). In addition, it also models with enough depth topics labeled as (iv), (v), (vi) and (ix), and vaguely addresses topics numbered as (iii) and (vii). Since SCOPRO formalizes and extends the SCOR model, the analysis has shown that both proposals have building blocks for representing the same issues. However, since SCOPRO has incorporated several extensions, this ontology outperforms the SCOR model in the following subjects: Resource, Temporal Information, Organizational Unit, and SC Organizational Structure.

### 4.3. SCOPRO consistency evaluation

The three sub ontologies of SCONTO have been implemented with the ontology editor Protégé-OWL version 4.3.0. Therefore, the evaluation of the consistency of SCOPRO has been done using two reasoners provided with this editor, which are called HermiT 1.3.8 (Horrocks et al., 2012) and FaCT++ (Tsarkov and Horrocks, 2006). The latter is a description logic-based reasoner that permits satisfiability checking by means of tableaux algorithms (Baader et al., 2010). Hermit 1.3.8 allows satisfiability validation, using new algorithms developed in recent years based on hypertableaux calculations (Motik et al., 2009). Horrocks et al. (2012) state that these new algorithms generate a more complete reasoning in terms of data object properties and instance classifications.

The use of both reasoners allowed verifying the consistency of all SCOPRO definitions that have been implemented in OWL 2 (W3C, 2004). Therefore, it is considered that the syntax and semantics of the OWL 2 implementation of the SCONTO ontology are correct. In addition, the OWL implementation has been tested using OOPS! Pitfall Scanner (Poveda-Villalón et al., 2004). The results of this evaluation can be found in the following link: https://industrialonto.github.io/SCOPRO/OnToology/SCOPRO.owl/evaluation/oops.html.

### 4.4. Quantitative Metrics

Several methodologies, frameworks and metrics have been proposed to quantify the quality of ontologies (Yao et al., 2005; Gangemi et al., 2006; Tartir et al., 2010; Burton-Jones et al., 2005; Zhang et al., 2010; Yu et al., 2009; Manouselis et al., 2010). From the set of metrics proposed in the literature, the following subset has been selected to evaluate SCOPRO structural characteristics:

- NOC (Number of Classes), and NOR (Number of Relations) are simple counts of the number of classes and properties, respectively, defined in the ontology.
- NORC (Number of Root Classes) and NOLC (Number of Leaf Classes) metrics correspond to the number of classes without superclasses and classes without subclasses, respectively.
- RR (Relationship Richness), which is also called relation diversity, reflects the variety of relationships in the ontology. It is defined as the ratio of the number of non-inheritance relationships (P) divided by the total number of relationships, i.e. the sum of the inheritance relationships (H) and the non-inheritance ones (P)
- IR (Inheritance Richness) represents the average number of subclasses per class. It is computed as: FALTA
- DOSH (Depth of subsumption Hierarchy)¸ which is also called depth of inheritance, measures the length of the longest path from a given class C to the root class in an ontology subsumption hierarchy.
- AR (Attribute Richness) is defined as the average number of attributes per class. It is computed as the number attributes for all classes (ATT) divided by the number of classes (C).

The quantitative evaluation of SCOPRO has been done based on the information extracted by using the Protégé tool. The Thing OWL concept (superclass of all concepts in an OWL ontology) has not been considered to compute NOC, NOR, IR and AR. Table 13 shows the values of the adopted metrics that have calculated for SCOPRO.

Table 13. SCOPRO measures

| Metric | SCOPRO |
|---|---|
| Number of Classes | 200 |
| Number of Relations | 45+195 = 240 |
| Number of root classes | 5 |
| Number of Leaf Classes | 142 |
| Relationship richness | 45/240=0,19 |
| Inheritance richness | 195/200 =0,98 |
| Depth of the subsumption hierarchy | 6 |
| Attribute richness | 0 |

The result of the formula that computes the Inheritance Richness (IR) is a real number representing the average number of subclasses per class. The computed IR for SCOPRO is 98%. Such measure, together with the DOSH one, suggests that the proposed ontology is of a horizontal nature, which means that it represents a wide range of general knowledge. This was SCOPRO´s original aim, since it was conceived as general purpose ontology, capable to be specialized for different kinds of supply chains. In order to be reusable, the proposed ontology has to represent generic concepts common to different types of industrial organizations. Concept attributes describing particular characteristics of specific industries are out of the scope of SCOPRO. In consequence, the attribute richness metric value is equal to 0 attribute per concept. However, the amount of attributes per classes would increase as SCOPRO will be specialized to represent particular supply chains in the future. The Relationship Richness value is low; it implies that the hierarchy relationships overpass the other kinds of associations.

All these metric values give an idea about the characteristics and complexity of the ontology. However, the complexity measures provide no guarantee about the ontology quality, because there is no consensus or standard to compare with (Marquardt et al., 2010). The analysis of certain ontology characteristics, like usability and reuse, can only be measured and improved by using the ontology in different application contexts.

## 5. Conclusions

This paper presents the SCONTO ontology that contributes towards the formalization of the SC domain. SCONTO provides the basis for describing the supply chain structure, its associated processes, and evaluation system. This article just focuses on SCOPRO that is the main module of the ontology. This module includes and integrates the structure, process, and resource dimensions, emphasizing the SC processes knowledge. SCOPRO provides the following capabilities

- To describe supply chains that are composed of one or more enterprises.
- To represent the SC structure and the organizations that participate in it.
- To specify organizational processes and their decomposition into interrelated subprocesses.
- To define atomic and composite temporal relationships between processes.
- To describe resources, the effects that activities have on them, and the multiple functions they can fulfill in the SC processes.
- The explicit representation of material movements between SC partners.

This representation made it possible to establish a common vocabulary for all the SC actors, general enough to be valid in supply chains of different industries and having dissimilar sizes. Besides, SCONTO can be extended to allow its specialization to consider the characteristics of particular supply chains.

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