TOWARDS A SUPPLY CHAIN ONTOLOGY OF INFORMATION LOGISTICS WITHIN PROCESS INDUSTRY ENVIRONMENTS

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Abstract. Process industries are nowadays involved in extended supply chains (ESC), which leave aside the traditional company-centric view of the supply chain (SC). The CAPE community has done many contributions in this domain, mainly proposing mathematical models to tackle the optimal infrastructure design of the SC and to address the SC planning and scheduling problems. Most approaches assume that the required data is always available. However, in many cases, this statement is not true: companies belonging to the same SC use different contents and formats for a given information entity to be shared. Even worst, they may have distinct views of a certain business process in which they participate. Therefore, there is a need for specific contributions focusing on the design of information logistics (IL) processes; processes that must be able to feed the mathematical models with proper data coming from the ESC. The SC Council (http://www.supply-chain.org/) presented a general framework for the SC management, named SCOR (Supply Chain Operations Reference Model). It is a business process reference model that provides a standard description of SC planning and operational activities. Thus, these tasks could be described and communicated, providing the basis for SC improvement. However, SCOR has some limitations and it is necessary to extend it in order to obtain a system of consistent concepts that could be used by all the actors and components of an ESC.

In order to tackle the consistency problem, this contribution proposes the design of an ontology that provides the foundations for the specification of IL processes in ESCs associated to process industries. The proposed ontology tries to formalize and extend the SCOR model concepts in order to overcome their limitations. This ontology is a first step towards achieving a standard description of SC design and management processes.

Keywords: Supply Chain Management, Ontologies, SCOR Model.

1. Introduction

Nowadays, there is a real need to track and trace product-related information in extended multi-company supply chains, either for management or optimization purposes or just for the observance of products liability requirements. The extended supply chain (ESC) context emphasizes the importance of information logistics (IL) as a key issue for integration. IL processes make accessible to the business performance management, level task-specific and relevant information coming from production and business processes, management processes as well as from external sources (e.g. suppliers and customers data) (Melchert and Winter, 2004). The role of IL processes is to interlink business process management cycles and to mainly support the monitoring and communicating activities in a supply chain (SC).

Therefore, information logistics has as premises to make accessible the right information, with the right content and quality, at the right time and at the required “place”. Thus, the supply chain management (SCM) poses not only the problem of the efficient administration of material inventories and flows but also the challenge of the efficient storage and flow of the associated information.

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The CAPE community has done many contributions in the SC domain, mainly proposing mathematical models (i) to tackle the optimal infrastructure design of the SC and (ii) to address the SC planning and scheduling problems. Most contributions assume that the required data is always available, specially when dealing with the second problem that appears at the operational level on a day-to-day basis. However, in many cases, this statement is not true: companies belonging to the same SC use different contents and formats for a given information entity to be shared. Even worst, they may have distinct views of a given business process in which they participate. Therefore, there is a need for specific contributions focusing on the design of information logistics processes; processes that must be able to feed the mathematical models with proper data coming from the ESC.

The SC Council (Stewart, 1997) presented a general framework for the SCM, named SCOR (“Supply Chain Operations Reference Model”). SCOR is a process reference model for SC management. It is based on the consideration that all SC tasks and activities can be assigned to five fundamental processes - plan, source, make, deliver and return – and, thus, it simplifies the visualization and analysis of networks. Therefore, it is a good starting point for the communication among SC stakeholders. However, it has some limitations and it is necessary to extend it in order to obtain a system of consistent concepts that could be used by all the actors and components of an ESC in a process industry environment.

In order to tackle the consistency problem, this contribution proposes the use of the ontology technology, which is discussed in the next section. The proposed ontology, called SCOntology, provides the foundations for the specification of information logistics processes in ESCs associated to process industries. The ontology is introduced in Section 3, where the concepts and relationships that are necessary to describe, measure and evaluate a SC are discussed.

2. Towards a Supply Chain Ontology

Even though many ontology definitions exist, the classical one was proposed by Gruber (1993): “an ontology is a formal, explicit specification of a shared conceptualization”. A conceptualization refers to an abstract model of some phenomenon in the world, which identifies the relevant concepts of that phenomenon. Explicit means that the type of concepts used and the constraints on their use are explicitly defined. Formal refers to the fact that the ontology should be machine-understandable. Shared reflects the notion that an ontology captures consensual knowledge; so, it is not restricted to some individual, but accepted by a group. Therefore, the construction of an ontology for SCM would provide a framework for sharing a precise meaning of information exchanged during the communication among the many stakeholders involved in the SC.

Although many methodologies have been proposed to build ontologies, each having different principles, design criteria and development stages, the approach of Grüninger and Fox (1995) has been selected for the development of the SCOntology. According to this approach a set of natural language questions, called competency questions, must be defined to determine the ontology scope. These questions and their answers are employed in the following step of the methodology, called conceptualization, which consists in extracting the ontology main concepts and their properties as well as relationships and axioms.
IL processes have as premises to access the right information, with the right content and quality, at the right time and at the required place. But which is the right information, the right content and quality for it, as well as the right time and place to access it? In order to define the scope of SCOntology, the previous generic competency questions are reformulated as follows: i) which is the required information for each SC process?; ii) which is the structure and content of each piece of information?; iii) which is the place to access it?; iv) which are the processes that provide it?; v) which are the processes that consume it?; vi) when is each information piece supplied?; vii) when is it consumed?, etc. Having posed and answered these questions, the conceptualization stage will help to organize and structure the acquired knowledge using a representation language that must be independent of both the implementation language and environment. In this contribution, the well-known UML language will be employed for conceptualizing the SCOntology.

3. Defining the Conceptual Model

3.1. Process related Concepts

The relevant concepts of SCOntology that arise when posing and answering competency questions are directly linked to the information associated to the ESC and the processes using it. They can be summarized as follows: (i) Information resources, defining the information and its structure; (ii) SC Processes, acting as information suppliers and clients; (iii) Locations, where processes are performed and the required information is needed, (iv) Relationships among processes and information resources, such as provider, consumer; (v) Relationships among processes, which allow tracing the information flow associated with particular workflows.

A good starting point to represent a framework able to answer competency questions is to consider an enterprise model. Though there are several models available, Coordinates (Mannarino, 2001) has been chosen because it allows representing the process and product views in an integrated fashion. The main concepts are shown in Fig. 1. According to this model, a Process is employed to represent a set of activities in terms of a set of resources that participate in different ways in order to achieve the process’ goals. As only certain aspects or characteristics of a Resource may be of interest to a given process, a particular perspective of the Resource (ResourcePerspective) is actually viewed by such Process. This fact is modeled by means of the Use Mode relationship that reflects the role that the Process plays in relation to the Resource Perspective. The following roles have been considered in this contribution: creates/eliminates (non-renewable resources), produces/consumes (renewable resources), modifies, uses, and employs (exclusive usage). The incorporation of these role types extends the SCOR original approach, which only considers input and output roles.

![Fig. 1. Supply Chain Conceptual Model Elements.](image)
As can be inferred from the previous paragraphs, processes relate among themselves indirectly by means of the resources they operate on. However, two processes can be directly linked through explicit temporal relationships. Furthermore, a Process can be described at different abstraction levels, according to the complexity of the activity that is being modeled. Hence, a process can be decomposed into subprocesses. Other concepts that take part in the model are: (i) the Organizational Unit one and (ii) the specialization of the Resource concept into Material and Information Resources.

This basic conceptual model is extended with the concepts introduced in the SCOR framework, which includes three levels of process detail. At Level One (see Fig. 2), SCM is defined in terms of the following integrated core processes: Plan, Source, Make, Deliver, and Return, spanning from the suppliers’ supplier to the customers’ customer, and all aligned with each company’s operational strategy, work, material, and information flows (Bolstorff and Rosenbaum, 2003). These processes, with the exception of Plan, are considered as execution type of processes (Execute); thus, they are the ones that represent raw materials acquisition (Source), transformation (Make) and product distribution to customers (Deliver). Return processes are associated with receiving any returned products, having two perspectives built into them: Delivery Return- returns from customers, and Source Return- returns to suppliers. It can be seen that Plan processes cover all activities for the preparation of future material flows; thus they perform the planning of the SC and the execution processes. In addition, SCOR includes a series of Enable elements for each of these processes. An Enable process is a one that prepares, maintains or manages information or relationships on which planning and execution processes rely.

Fig. 2. Supply Chain: Level 1 Model.

The five basic elements are further divided into process categories at the next level, called Level Two or configuration level. It defines the configuration of planning and execution processes using standard categories, like make-to-stock, make-to-order, and engineer-to-order, employed by companies to fulfill customer orders. The configuration is defined by the specification of which processes are used to move materials from location (organizational unit) to location. Thus, at Level Two, the five Level One process categories (Plan, Source, Make, Deliver and Return) are decomposed into thirteen SC execute process types and five plan process types (P1: Plan the whole supply chain; P2: Plan Source; P3: Plan Make; P4: Plan Deliver; P5: Plan Return). Furthermore, at this second level, Enable is also extended into five processes (EP: Enable Plan; ES: Enable Source; EM: Enable Make; ED: Enable Deliver; ER: Enable Return), one for each basic process. This
decomposition is shown in Fig. 3, including the aggregation association over the SCOR process class, which specializes the process-subprocess link introduced in Fig. 1.

Fig. 3 shows the specialization of Plan and Make processes. The Make Level Two process types (M1 – Make-to-stock, M2 – Make-to-order, M3 – Engineer-to-order) attempt to characterize how a company converts raw materials to work-in process to finished goods status. A level two Make process is guided by the planning made by a P3 process, therefore such P3 process has to be performed before the execution of the corresponding Make process. This temporal relationship is refined by the Planning link. The specialization of the Source, Deliver and Return processes was done in a similar fashion, though it is not shown due to lack of space.

Fig. 3. Supply Chain: A Partial View of the Level 2 Model.

Fig. 4 illustrates a partial view of the level two processes and their relationships with the associated information resources. In particular, P3 develops and establishes courses of action over specified time periods (Production Plan Information Resource) that represent a projected appropriation of production resources to satisfy production requirements, as service, cost, and inventory goals. For that, P3 uses Supply Chain Plans created by the P1 process, Delivery plans defined by P4, as well as Reserved Resources and delivery dates specified by delivery activities (D2 or D3).

Fig. 4. A Partial View of Relevant Information necessary to Perform some Level 2 Activities.

Level Three defines the business processes used to transact sales, purchase and work orders, return authorizations, replenishment orders, and forecasts. Fig. 5 shows a new class, Process Element, that represents those processes. A set of Process Elements defines a level two SCOR process. In the figure, it is possible to see the definition of the M1, M2 and M3 particular ones. At this level, the SCOR model defines work and
information flows. Thus, the workflow is specified by temporal relationships. As can be seen in Fig. 5, this link type is represented by customer-supplier relationships that define the roles of the associated Processes.

![Diagram of workflow relationships](image)

**Fig. 5.** Supply Chain: A Partial View of the Level 3 Model.

### 3.2. Performance Related Concepts

Control of processes belonging to a SC is crucial in improving its performance; one tool for doing control is measurement. To meet objectives, the output of the processes enabled by the SC must be measured and compared with a set of standards (Gunasekaran et al., 2004). A similar approach is followed by the SC Council that proposed a SCOR-based methodology which measures the performance of the SC and compares it to benchmark data from the market.

The primary use of SCOR is to describe, measure and evaluate SC configurations. The concepts presented in previous sections allow the description, while the concepts introduced in this section are oriented to measure and evaluate such SC configurations.

SCOR defines five generic performance attributes and three levels of metrics that can be used to evaluate the performance of the SC. **Level 1 Internal facing metrics** evaluate the performance of the organization as a whole, while **Level 1 Customer Facing metrics** measure the performance of the SC. **Level 2 metrics** check on the performance of level 2 SCOR processes, while **Level 3 metrics** evaluate the performance of process element within a level 2 process. Fig. 6 shows an example of the metrics used to quantify the responsiveness attribute at different levels.

![Diagram of metrics related to responsiveness attribute](image)

**Fig. 6.** Metrics related to the Responsiveness attribute.

The concepts related to SC performance are depicted in Fig. 7. It is shown that a SCOR process is evaluated by five Performance Attributes. Such attributes may be specialized in: Customer Facing metrics, Internal Facing
metrics which are specialized again in: **Reliability, Flexibility and Responsiveness** for the former and in **Cost and Asset** for the latter.

Each of these attributes is associated with a set of **Metrics** that indicate what to measure in order to give a real value to the attribute. In the example presented in relation to the responsiveness attribute, the associated metrics for level 2 indicate that the **Total item/product manufacture time** should be measured to evaluate the **responsiveness** of the M1 SCOR Process.

SCOR relies on variations and **refinements** of the level 1 metrics to measure the process at lower levels. But the breakdown of these metrics into the ones of levels 2 and 3 is not standardized. There are some metrics that can be computed by simple **calculation** from metrics at the lower level, but there are a lot of cases when this is not applicable. The proposed model, shown in Fig. 7 considers a class **Refinement** that can be specialized in **Calculation** and **Heuristic Refinement** classes in order to represent possible kinds of refinements between metrics.

![Fig. 7. Class Diagram for performance related concepts in SCOntology.](image)

As it was mentioned at the beginning of the section, in order to improve the performance of the SC, it is necessary to measure the company performance and then compare these values with benchmark data obtained from the market. In order to support this activity some concepts should also be introduced in the model. They are briefly described in the following paragraphs.

The **Measure** class represents the measured value corresponding to a specific metric. This concept is specialized, in values that are measured in a specific company (**Actual Measure** subclass) and values obtained from other enterprise benchmarks. (**From Market Measure** subclass). This last subclass is associated to the **Information Source** from which the benchmark data are obtained and it is also specialized into different possible values: i) **Parity**: value of the median of the statistical sample; ii) **Advantage**: value associated to the midpoint between **Parity** and **Superior**, and iii) **Superior**: value corresponding to 90th percentile of the population.

### 4. Extending SCOntology

SCOR was designed to support SC of various complexities and across multiple industries. The SC Council has focused on three process levels and up to now did not attempt to prescribe how a particular organization
should conduct its business or tailor its information flows. Every organization implementing SC improvements using the SCOR model will need to extend the model, using organization specific processes, systems, and practice.

Nevertheless, there are several architectures and standards to help i) organizing and integrating the decisions made by managers (business systems) and implemented by workers (manufacturing systems), and ii) specifying the information required to make those decisions, monitor their execution and control their implementation (Jones et al., 2000). One proposal is the ANSI / ISA S95.00.01-2000 Enterprise – Control System Integration standard (ANSI / ISA, 2000), known as ISA 95, which provides a model for exchanging data between business and manufacturing systems. Consequently, the concepts and relationships for the specification of information logistics processes in ESCs associated to process industries may be extended with ANSI / ISA S95.00.01-2000’s concepts. SCONtology proposes the use of such standard for specializing the Process Element and Resource (material and information) concepts.

According to ISA 95, the Material Resource concept introduced in Fig. 1 can be specialized into resources representing S95 Object Models: Personnel, Equipment, Material and Energy, and Process Segment. This fact is shown in Fig. 8, where the Information Resource concept is specialized into information resources representing the following S95 Object Models: Production Capability, Product Definition, Production Schedule, and Production Performance.

![Fig. 8. S95 Object Model extending Information and Material Resources.](image-url)

Furthermore, ISA 95 defines a set of activities for manufacturing operations which SCONtology uses in order to extend SCOR Level Three Process Elements concepts into a set of level four tasks. It is important to note that although the definition of level four tasks is out of the scope of SCOR, this reference model proposed that each organization that implements SCOR has to define models at this level. Models at this level describe how the process elements at level three are actually implemented in a particular organization.

An example of the proposed extension is presented in Fig. 9, where the Identify, Prioritize, and Aggregate Production Requirements (P3.1) process element is decomposed in three tasks: i) Generate Detailed Production Requirements From Sales Production Orders, ii) Highlight Specification Requirements for Non-Standard Requests and iii) Generate Production Order Entry in Scheduling File and Append Shipment Requirements. The figure also shows the application of the extension of resource concepts. The resources Delivery Plans and Reserved Resources, which were previously presented in Fig. 4 as a specialization of the Information Resource concept, are now presented as a specialization of the new Production Schedule Information concept introduced by the proposed extension (see Fig. 8).
5. An Example

The proposed SCOntology was implemented by adopting the OWL ontology language (http://www.w3.org/TR/owl-features/) and the Protégé 2000 ontology editor (http://protege.stanford.edu/). In order to test SCOntology, a refinery industry SC process (Julka et al., 2002) has been modeled. Fig. 10 shows a partial view of the three SCOR representation levels for the crude procurement process treated in this case study.

4. Conclusions

The SCOR model is a business process reference model that provides a standard description of SC planning and operational activities. Thus, these tasks could be unambiguously described and communicated among
supply-chain partners, providing the basis for SC improvement. It also defines a way to evaluate the performance of each participant in a SC, through the definition of performance attributes and metrics associated to process in each level. However, in its current version, the SCOR model is too abstract to be useful in real situations. One of its main drawbacks is the weak representation that information and data have, as well as the lousy modeling of their usage by means of the actual SC processes. Moreover, the sources of most information flows are Enable type of processes; but the SCOR model does not explicitly specify which are those processes and which information is employed in such data creation. Another problem of this high level of abstraction is that models at level 3 represents generic activities and do not allow the representation of particular characteristics of each industrial organization.

The SCOntology presented in this contribution formalizes and extends the SCOR model in order to overcome some of the limitations of SCOR. The proposed contribution uses the ISA 95 standard in order to obtain a tool that permits modeling processes with greater detail. Moreover, it resorts to a specialization of the Resources and of the Use Mode employed by a process to access resources. It also proposes a formalization of the concepts related to performance attributes, metrics, measures and the relation among them. Future work will involve specifying the information flows participating at levels 3 and 4 and testing the model with other case studies.

References

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