A SUPPLY CHAIN ONTOLOGY CONCEPTUALIZATION WITH FOCUS ON PERFORMANCE EVALUATION

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Keywords: Ontology, Supply Chain Management, Performance Evaluation, Metrics.

Abstract: Organizations all over the world are increasingly aligning in Supply Chains (SCs) in order to perform more efficiently and to achieve better results. This contribution presents a SC ontology that aims at conceptualizing and formalizing this domain knowledge. Its goal is to: a) enable a better understanding among the various stakeholders & b) set the basis for an effective information sharing and the development of integrations tools. The ontology introduces concepts associated with the SC structure, functions, resources, and management issues. Since one key component of management is performance assessment, which must be done along the whole SC, the proposed ontology focuses on performance evaluation issues.

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. This allows to better communicate and to attain a genuine integration of the activities executed by the different functional areas and/or companies. This challenge has motivated several research efforts that addressed the development of models aimed at describing the elements and processes associated with a supply chain, as well as tackling specific SC integration problems. Beamon (1998) presented a review of the models that have been proposed for the analysis and design of the SC. However, the only de facto standard is the Supply Chain Operations Reference (SCOR) model (SCOR, 2007). Although this model is a good starting point for communication among SC stakeholders, it provides a slender modelling of processes, resources and the relationships among them; so, its formalization becomes a requirement for a more comprehensive usage of the model.

Furthermore, performance evaluation is an important supply chain management issue since it provides significant information to make decisions and to assess results. Thus, it can be seen as a basic prerequisite for improvement.

In recent years, research on SC measurement has increased significantly. This is reflected by the growing number of contributions that have been reported (Beamon, 1999; Brewer and Speh, 2000; Lambert and Pohlen, 2001; Hausman, 2002; Kleijnen and Smits, 2003; Gunasekaran et al., 2005; Gaiardelli et al., 2007; Bhagwat and Sharma, 2007). Nevertheless, most of these proposals do not consider the fact that a measurement system may involve different companies along the SC, and that this issue could yield semantic problems when information is shared by these distinct enterprises or by different organizational areas.

Additionally, many contributions have put forward several metrics, but their specification is neither clear nor complete. Therefore, in most cases it is difficult to distinguish what is supposed to be measured and how measurements must be done. For example, the metric identified as 'Number of stockouts', proposed by Beamon (1999), is defined as 'Number of requested items that are out of stock', but it does not specify which period must be covered (a week?, a month?, a year?), neither the 'location' where it must be measured (concerns a company?, the whole supply chain?), nor the items being

C. Böhm A., P. Leone H. and P. Henning G. (2008).
A SUPPLY CHAIN ONTOLOGY CONCEPTUALIZATION WITH FOCUS ON PERFORMANCE EVALUATION.
In *Proceedings of the Tenth International Conference on Enterprise Information Systems - ISAS*, pages 402-409
DOI: 10.5220/0001718004020409

considered (all the products?, a product family?), etc. Another relevant issue is that there are many contributions which introduce valuable information to help managers in the administration and operation of an appraisal system. However, this matter is just undertaken in different works in an isolated fashion and using dissimilar terminology. In consequence, there is a need to manage precise definitions; thus, leading to a universal understanding of the SC domain and measurement concepts, as well as a proper interpretation of the shared information.

Considering all these challenges, this proposal aims at contributing towards the formalization of the SC domain and its evaluation system. Since ontology-based models are expressive and minimize interpretation ambiguities (Kim and Fox, 2002), the goal of this paper is to propose an appropriate SC ontology, named SCOntology. It provides a first conceptualization of the SC structure, functions, performance and management concepts. A special emphasis is made on measurement and evaluation aspects. Regarding this last issue, an ontology would enable to make suitable comparisons, which otherwise could not be done without interpreting the relevant concepts in the same way.

In the next section the proposed ontology is presented and an example on its application is discussed. In section 3, conclusions are drawn.

2 SCOntology

2.1 Methodological Approach

The development of SCOntology was based on the activities and construction life cycle recommended by METHONTOLOGY (Fernández-López et al., 1999). This methodology identifies specification, conceptualization, formalization and implementation activities as steps of the development process. In this contribution, only the first two phases are addressed. The specification entails the definition of the ontology purpose, degree of granularity and scope. In the conceptualization phase, the knowledge of the domain is organized and structured using external representations, which are independent of the implementation languages and environments.

2.2 Specification

In order to specify the scope of the ontology, to identify the set of relevant terms to be captured and the relations among them, as well as to define the characteristics and granularity of the relevant concepts, a series of informal competency questions were defined. Some of them are shown below.

1- Which **organizations** participate in a **SC**?
2- Which **processes** executed in a certain **organization** are involved in a given **SC**?
3- How is a given **process** carried out? Which activities are involved in its execution?
4- Which are the strategic, tactical and operational **goals** of a SC?
5- How is a given **goal** monitored?
6- Which **metrics** can be used to assess the performance of the SC from a **customer/internal/ long term point of view**?
7- What does a specific **metric** evaluate?
8- How is a certain **metric** calculated/computed?
9- Which temporal interval does a **measure** cover?
10- Which is the most recent **measure** of a certain attribute of a given entity?

The most relevant terms to be represented are the ones highlighted in bold.

The main knowledge sources for the ontology development are the SCOR model (SCOR, 2007), the Coordinates enterprise modelling language, developed by Mannarino (2001), and the concepts and ideas that resulted from a critical analysis of other proposals on measurement systems.

The SCOR reference model is a general framework proposed by the Supply Chain Council that defines a language to represent the business activities associated with all phases of satisfying a customer's demand. In turn, the Coordinates language allows representing enterprise processes and their associated resources and products in an integrated fashion, considering any type of possible relations among them. It allows the analysis, representation and comprehension of an enterprise in terms of several dimensions.

2.3 Conceptualization

Many aspects need to be taken into account in a SC, such as the network of participating organizations, the different kinds of flows (material, information and money), the several operational and management strategies and practices, etc. Due to this complexity, it is quite important to have mechanisms to help analyzing this domain. Since all the domain concepts cannot be included in just one view, the proposed ontology considers the following perspectives: structural, functional, performance and management. This separation aims at clarifying the

model; however, these different viewpoints are interrelated, as they are part of the same ontology.

Figure 1 presents a UML diagram that includes the different SCOntology views, their associated concepts and relationships. Table 1 defines the main concepts. The Entity concept is introduced in this model in order to abstract any concrete or conceptual thing of interest in the SC domain. Nevertheless, this notion is specialized in SC Entity and SC Information Entity. The former represents the entities that are direct components of a SC, which are related to the SC structural and functional aspects, and the latter represents those entities involved in the SC description (SC meta information), which correspond to the SC management and performance information views.

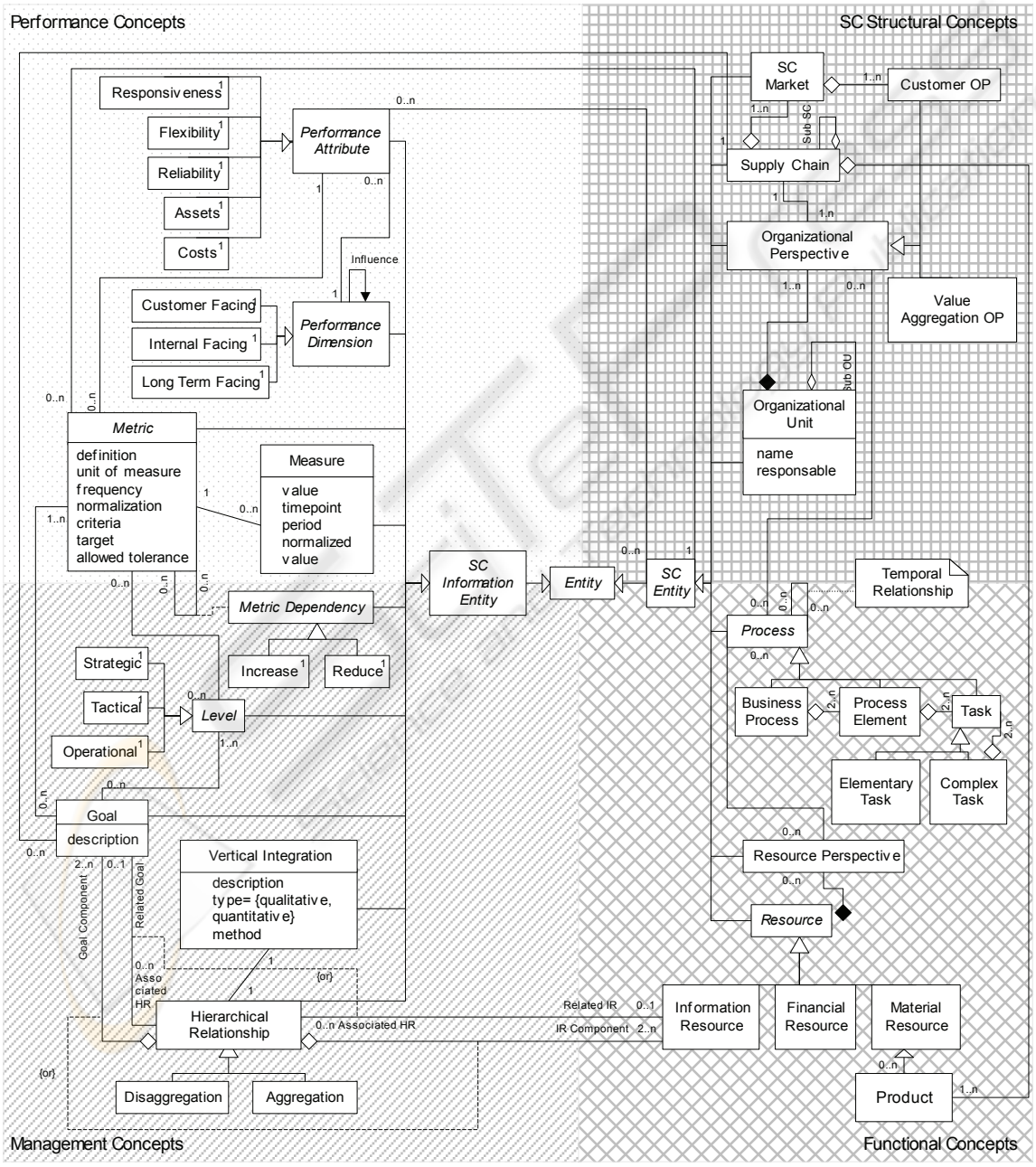

Figure 1: SCOntology. UML diagram.

Table 1: SCOntology. Main concepts description.

SCOntology View	Concept Name	Description
Functional View	Business Process	A structure of activities designed for action with a focus on end customers and on the dynamic management of flows involving products, information, cash, knowledge and/or ideas (Lambert et al., 1998).
	Financial Resource	Money, credit, etc. associated with a Process.
	Information Resource	Information involved in a Process.
	Material Resource	Physical thing that participates in a Process.
	Performance Information	Information involved in the evaluation of a SC Entity.
	Process	Activity or structure of activities intended to achieve a result, which entails the utilization of time, material, space, expertise or other resources.
	Process Element	Business Process component activity. In the SCOR model, it represents a level three process.
	Product	Individual or group of material resources resulting from a Process.
	Resource	Physical or conceptual means involved in a Process, as personnel, equipment, material, etc.
	Resource Perspective	A view of a Resource focused only on those aspects or characteristics that are of interest to a Process.
	Task	Process Element component activity. In the SCOR model, it represents a level four or a higher level process.
Management View	Aggregation	Hierarchical relationship that exists among an information resource, and other information resources of lower aggregation level.
	Disaggregation	Hierarchical relationship existing among an information resource and other information resources of higher aggregation level.
	Goal	A desired situation or general purpose toward which efforts are directed.
	Hierarchical Relationship	Relationship that exists among information resources of different degrees of granularity.
	Level	A management-based grouping associated with the scope and time horizon of decisions, actions or plans.
	Metric Dependency	Conditioning relationships between performance metrics.
	Vertical Integration	Specifies the way the information integration is tackled according with the hierarchical relationships among the information resources that are involved.
Performance View	Measure	Value that results from a measurement done by means of a given metric, as well as its normalized value.
	Metric	Method that allows evaluating a particular Performance Attribute of a SC Entity.
	Performance Attribute	Measurable property of SC Entities.
	Performance Dimension	Performance point of view. It is used to qualify Performance Attributes.
SC Structural View	Customer OP	View of an Organizational Unit corresponding to a customer role of a Supply Chain.
	Organizational Perspective	A given view that an Organizational Unit presents with respect to a SC in which it is involved.
	Organizational Unit	It might be a company, corporation, firm, enterprise or institution, or a part of it, having its own function(s) and administration, which supplies and/or acquires products or services.
	SC Market	Group of customers (Organizational Units with the role of customers in a given SC) that share some characteristics.
	Supply Chain	The network of business units, form original suppliers to end-customers, which transforms raw materials into final products, besides other value-adding companies such as logistics providers.
	Value Aggregation OP	View of an Organizational Unit corresponding to a value incorporating role in a Supply Chain.

2.3.1 SC Structural Concepts

The structural view includes Supply Chain concepts, along with the ones representing the various organizations which participate in a SC, and the roles these enterprises assume in different SCs. The main concepts of this perspective, such as Supply Chain, Organizational Unit (OU) and Organizational Perspective, are described in Table 1.

To reflect the fact that a given Organizational Unit (factory, warehouse, retail store) can participate in various SCs, the Organizational Perspective (OP) concept was included. It captures the different viewpoints that an OU presents with respect to the various SCs in which it participates. In a given SC, an OU could assume either the role of a customer or the one of a value aggregation node. Therefore, the Organizational Perspective concept is specialized into Customer OP and Value Aggregation OP.

Supply Chains are usually differentiated according to the characteristics of the delivered product/s and the diverse target markets. These ideas are captured by the association of the Supply Chain class with one or more Products and a SC Market. The Product class denotes individual or groups of goods having common characteristics. The SC Market concept represents a group of buyers of a particular good or service, and it is composed of Customer OPs.

2.3.2 Functional Concepts

The functional view is concerned with activities or processes performed in the SC and the means involved in them. The most important definitions are depicted in the Functional View section of Table 1.

As seen in Figure 1, Processes are hierarchically decomposed, as the basic structure of the SCOR model suggests, in at least three levels of detail, ranging from Business Processes (higher level) to Process Elements and Tasks (lower level). These can be Complex or Elementary, depending on if they are composed of other tasks or not.

Processes can be associated with several Organizational Perspectives and they can participate in various SCs. This is due to the fact that a given process could cross various functional areas and/or companies (when they are integrated) and, at the same time, it could also be executed to achieve results on different SCs. For instance, a Warehouse Delivery process can be done in the same way, involving the same resources and methods, for certain pharmaceutical and food product SCs.

Additionally, the execution of a given Process may depend on the temporal ordering defined among the Processes, represented in the model by temporal relationships.

Resources are also included in this view. Despite they are not functional in nature, resources are integrated in this perspective because they are closely related with functions. They not only are essential assets (as materials, equipment, personnel, etc.) associated with Processes, but also their availability can restrain the capacity to execute the Processes in which they participate. Resources can be physical or conceptual things and may assume different roles depending on the Process in which they participate. Therefore, in order to consider only those Resource characteristics that are of interest in a given context, the Resource Perspective class is defined.

2.3.3 Management Concepts

The management view comprises management information about the SC. The most relevant concepts are defined in Table 1 and shown at the bottom left section of Figure 1.

Management information has different degrees of granularity due to various reasons, like error minimization, data availability, etc. In general, the information used at higher decision levels is more aggregated than the one employed by lower level activities. However, these information pieces are generally interrelated and it is very important to capture their links. With this aim, SCOntology has incorporated the Hierarchical Relationship concept, which makes explicit the participation of information in diverse Aggregation or Disaggregation relationships. The Vertical Integration concept denotes the manner in which the integration is performed in each Hierarchical Relationship.

The Goal concept is a useful management concept incorporated into the ontology. It has been established at different decision levels (Strategic, Tactical or Operational) for the proper management of SCs. Since it is essential to control Goals by means of appropriate Metrics, the attainment of a certain Goal can be monitored by, at least, one Metric. In addition, a particular Goal could be aggregated from or disaggregated into other goals. For this reason, specific links between the Goal concept and the Hierarchical Relationship one are included in the ontology (see Figure 1).

2.3.4 Performance Concepts

The performance perspective groups those notions associated with performance evaluation. The main

concepts are introduced in Table 1. They are also shown at the upper left section of Figure 1.

Supply chain entities (SC Entity in Figure 1), being elements that participate in SCs, could have performance attributes to be assessed.

It should be noted that a performance attribute of a certain SC entity can be evaluated by means of one or more metrics, each one having its own values. On the contrary, a Metric can only be associated with one SC Entity and one Performance Attribute. In order to prescribe which attribute and which SC Entity can be appraised with a given metric, the generic concept of metric should be specialized in particular metrics that assess the SC performance.

The values assigned to a certain Performance Attribute of a SC Entity in relation to a given Metric are represented in the ontology by the Measure class. These values can be obtained by actually doing a measurement, by benchmarking, or can be set as part of a SC design process; nevertheless, each value is always associated with a Metric.

The Performance Attribute concept is specialized in the following classes: Reliability, Flexibility, Responsiveness, Costs and Assets, following the guidelines of the SCOR model. In turn, performance attributes are categorized through the Performance Dimension concept, which characterizes them according to their scope. The SCOR model identifies two, the Internal Facing and the Customer Facing perspectives, which are focused on short-term assessment issues. The Long Term Facing perspective has been added to SCOntology to include a performance perspective concerned with the evaluation of actions performed to achieve future results, related with strategic and tactical issues.

Additionally, this proposal acknowledges that some performance evaluation frameworks, like the one proposed by Brewer and Speh (2000), based on the Balanced Scorecard idea (Kaplan and Norton 1992), identify links between pairs of different Performance Dimensions. These relationships indicate, in a qualitative manner, that if changes take place in a given performance dimension, they are expected to entail modifications in another one. This notion is included in the ontology as an Influence association between Performance Dimensions. For instance, the Long Term Facing dimension influences both the Internal and Customer Facing ones, whereas the Customer Facing dimension affects the Internal Facing one.

2.3.5 Application Example

With the purpose of illustrating the main concepts of the ontology, a simple case study is presented. Figure 2 shows a partial view of SCOntology, capturing some of the notions under analysis along with the instantiation of these concepts in order to represent a SC associated with a furniture enterprise and its corresponding evaluation. The constituents of this SC are the 'Oak Wonders' enterprise, the 'InWay Trucking' company and various retailers.

Oak Wonders (OW) produces and distributes oak home furniture: tables, beds, sofas, cabinets, wardrobes, etc., both in a standard format and in a tailored made one. It has outsourced the delivery transportation business and made a long-term contract with InWay Trucking (IWT), which is a 3PL that specializes in the haulage of different types of products, such as apparel, footwear and furniture. IWT is the linkage between OW and the retailers.

The business process configuration of this furniture SC and its associated evaluation methods, depend on the product line that is managed. Thus, from an OW viewpoint, the processes involved in supplying standard furniture to retailers include the storage of final products. On the contrary, no stock is kept for tailor made furniture. Similarly, metrics used to evaluate the performance of business units and processes are not the same for standard and custom built furniture. Due to these reasons, it is important to distinguish SCs according to their associated product and service.

This example focuses on one particular SC whose objective is to furnish small and medium size national retailers with standard wardrobes. This information is represented in Fig. 2 by the 'Standard Wardrobes SC' instance as well as by its links to the 'Standard Wardrobes Family' and to the 'Middle and Small Size National Furniture Retailers' objects.

All of the previously described companies are modelled by instantiating the Organizational Unit concept. Additionally, but limiting the analysis to only those elements associated with the standard wardrobes family of products, OW is composed of three OUs: one manufacturing plant and two distribution centers (the north and the south ones). Each of these OUs has a perspective involved in the standard wardrobes SC which is linked to the 'Standard Wardrobes SC' object.

With the purpose of exemplifying the application of the ontology to the evaluation of this particular SC, the 'Number of Monthly Stockouts' metric is proposed as a specialization of the Metric concept. This metric is an adaptation of the 'Number of stockouts' one, which was described in the first section of this contribution. The metric is appropriate for appraising an environment where

standard products are sold from stock. It is defined as the 'Number of requested items that are out of stock per month' and represents a method that allows evaluating the responsiveness of an organizational perspective, as indicated by its associations.

The 'Number of Monthly Stockouts' metric is instantiated, resulting in the following objects: 'Wardrobes Manufacturing Plant Metric', 'North Distribution Center Metric', 'South Distribution Center Metric' and 'Retailer Metric'. As seen, these metrics are involved in the evaluation of the responsiveness of specific OPs. Each of them has its own target value and an allowed tolerance.

Moreover, each metric shown in this example is related to one or more measures that represent the values of the responsiveness attribute for the different OPs being evaluated. Additionally, the measure instances capture further data about the measurement: the time point when the assessment was done and the period that was appraised. Thus, it is possible to trace how a performance attribute was evaluated, which metric was used, which were its values in diverse occasions and, in turn, which SC entity each measure evaluates. For example, it can be seen that the standard wardrobes manufacturing OP was evaluated twice, according to the 'Wardrobes Manufacturing Plant Metric', to assess its responsiveness. Its values were 30 and 25 items/month for the October and November periods, respectively.

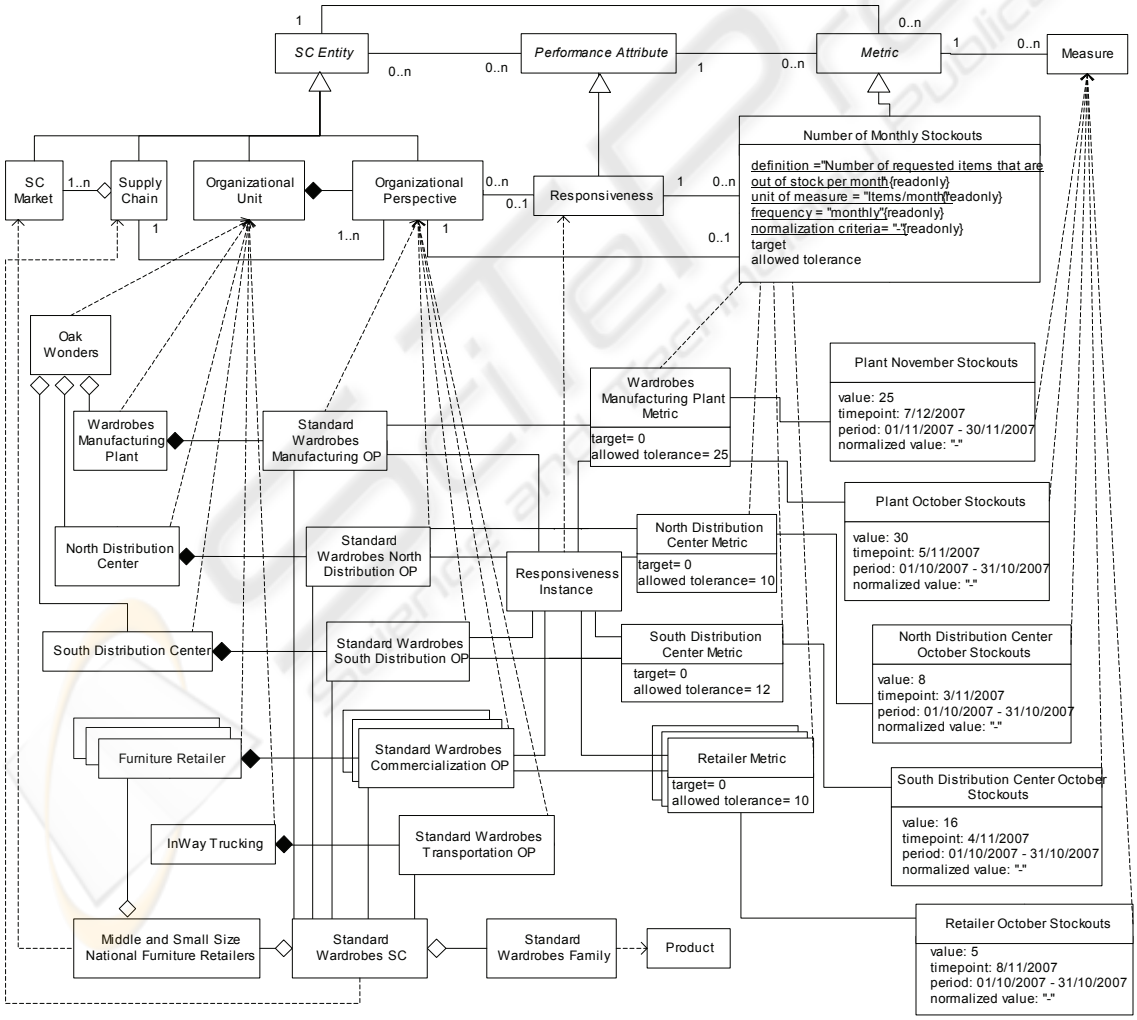

Figure 2: Metric specialization and instantiation example.

3 CONCLUSIONS

This paper presents advances in the development of an ontology, named SCOntology, that contributes towards the formalization of the SC domain and its associated evaluation system. SCOntology provides the basis for the description of the supply chain structure, its associated processes and evaluation system. In this way, it could lay the foundation for the development of a computational performance evaluation system. It adopts the process hierarchical decomposition structure of the SCOR reference model, which is nowadays a de facto standard. However, it enlarges it with additional concepts that allow to (i) render a more comprehensive enterprise model, and (ii) formally describe information composition or decomposition processes.

Regarding the evaluation system, SCOntology incorporates several performance evaluation management tools in a single framework. It allows the definition of different metrics and performance related concepts, including the measurement of performance attributes of distinct types of SC entities. Besides, classifications of metrics and performance attributes, relations with the SC's goals and their control, as well as important relationships between metrics and performance dimensions are some of the features that are incorporated in the ontology.

Future work entails representing SCOntology in OWL or in a closely related language. Once the ontology is fully defined, new defies will be tackled. One refers to the identification of mechanisms for collecting and managing the data needed to operate an assessment system in an actual dynamic environment. Another is related to the analysis and handling of performance information from a temporal perspective. One of the possible solutions to these challenges is the use of agent technology.

ACKNOWLEDGEMENTS

This work has been supported by CONICET (PIP 5915), UTN, UNL and ANPCyT (PICT 12628).

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