

# A semantic-based framework for RFID-assisted port supply chains

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**Abstract.** Knowledge Representation techniques can be used to annotate relevant products information during their lifecycle without depending on a back-end infrastructure, so enabling novel added-value services. In this paper, a port supply chain management framework – based on EPCglobal RFID protocol enhancements– is presented allowing semantic-based descriptions to be associated to tagged objects and goods also introducing innovative supply chain models. Effectiveness and feasibility of the proposal are supported by a case study about advanced delivery scheduling and product tracking in a port scenario.

## 1 Introduction

The ports market was historically an early adopter of RFID technology and today represents a proven growing field in the domain of tracking assets, such as freights and containers across multiple supply chain nodes. In particular, in Port Supply Chain (*PSC*) management scenarios, benefits of RFID include timeliness, accuracy and completeness also enabling a radio interconnection of *transponders* (hosting information associated to the goods to be identified) with *interrogators* (able to extract carried data). In the last years, several port authorities are mandating the adoption of interoperable technology solutions to real-time management and monitoring of maritime related items –such as trucks, chassis and cargoes– both to improve their availability and to reduce downtime in the usage life cycle. In fact, these systems provide the critical core information needed to execute advanced decision making on the movement of containers and other transport assets, aiming to improve current PSC solutions and thereby saving time and money. Several proposals can be found in literature. A survey about the application of RFID technology in different ports across the world is provided in [3]; the authors also suggest the use of data mining techniques to handle RFID data. In [4], PSCs are described as convergent points of both information flow (logistics chain) and material flow (supply chain). Moreover, [9], [1] and [11] describe RFID applications for real-time monitoring and transmission of containers and cargo information, in order to improve the efficiency and the fault tolerance of the port logistic operations through the usage of automatic loading plans

and optimal scheduling. Despite RFID results particularly useful for goods management during the delivery stage of a supply chain, the original identification mechanism based on simplistic “true/false” replies appears as too restrictive for advanced applications. Furthermore, RFID-based technology usually relies on a stable and fixed back-end which makes every solution only partially applicable to intrinsically volatile contexts. To really improve decision-making capabilities and information sharing, it is important to enable RFID-based run-time resource/service discovery facilities in decentralized and pervasive contexts such as port environment ones. The main goal is to process expressive requests, annotated in terms of shared and formal domain vocabularies, in each node of the PSC. Due to these reasons, the paper presents a complete knowledge-based framework exploiting annotated objects able to fully describe themselves in several PSC stages, without depending on a back-end infrastructure and adhering to the Ubiquitous Computing paradigm [10]. Canonical EPCglobal RFID identification has been extended [6, 2], providing semantic-based value-added services. Semantic Web languages, such as OWL<sup>1</sup>, are used for building the linguistic and semantic infrastructure underlying a networked and capillary exchange of information. RFID enhancements applied in the proposed PSC framework allow to: (a) develop a distributed, backward compatible data management system; (b) exploit semantic-based annotations accompanying and describing goods aimed at optimizing the reliability and sustainability of the whole supply process; (c) enable an advanced context-aware tracking of goods and a fully automated goods compatibility management in delivery.

The remaining of the paper is structured as follows. Section 2 illustrates the proposed framework and the system architecture while the example in Section 3 acts as a case study. Concluding remarks close the paper.

## 2 Proposed framework

The proposed framework extends classic supply chain organization and shipment models using techniques and technologies for smart tagging [6] and a semantic-based decision support. An RFID-based delivery management system is presented for detecting most suitable ship holds transporting specific goods by sea among different ports. Ship holds and product packages (tagged with RFID transponders) are described by an OWL-DL compressed annotation [8] according to a reference ontology. Ship hold descriptions include general transport specifications (*e.g.*, micro-climate and storage features or possible security measures) and information related to the load capability. Product package characteristics contain relevant item properties, delivery requirements and potential incompatibility constraints referred to other nearby products. A semantic-based matchmaking process has been adopted to enable an advanced goods allocation maximizing ship carrying capability. The process exploits non-standard inferences [5] provided by the embedded Mini-ME reasoning engine [7], to automat-

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<sup>1</sup> OWL Web Ontology Language, version 2, W3C Recommendation 27 October 2009, <http://www.w3.org/TR/owl2-overview/>

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**Algorithm 1** Greedy algorithm for product clustering.

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**Algorithm:** *clustering* ( $(\mathcal{L}, \mathcal{T}, TH, P, )$ )**Require:**  $\mathcal{L}$  Description Logic; acyclic  $\mathcal{T}$ ; semantic threshold  $TH$ ;  $p_i \in P, i = 1, 2, \dots, n$  product concept expressions in  $\mathcal{L}$  satisfiable in  $\mathcal{T}$ ;**Ensure:**  $G = \{G_1, G_2, \dots, G_k\}$  set of product compatibility cluster.

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1:  $G := \emptyset$ 
2:  $k := 0$ 
3: while  $P \neq \emptyset$  do
4:    $k := k + 1$ 
5:   pick  $p_i \in P$ 
6:    $G_k := \{p_i\}$ 
7:    $C_k := p_i$ 
8:   for all  $p_j \in P, i \neq j$  do
9:     if  $(p_j \sqcap C_k)$  is satisfiable in  $\mathcal{T}$  AND  $\frac{\text{rankPotential}(\langle \mathcal{L}, p_j, C_k, \mathcal{T} \rangle)}{\text{rankPotential}(\langle \mathcal{L}, p_j, \top, \mathcal{T} \rangle)} \leq TH$  then
10:       $G_k := G_k \sqcap \{p_j\}$ 
11:       $C_k := \prod_{p_q \in G_k} (p_q)$ 
12:    end if
13:  end for
14:   $P := P \setminus G_k$ 
15:   $G := G \cup \{G_k\}$ 
16: end while
17: return  $G$ 
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ically detect a set of {products,hold} pairs taking into account both goods and shipping constraints expressed through the semantic annotations. Such a system aims to reduce response times in delivery planning, improve efficiency of product allocation and ensure products quality to destination. Particularly, the matchmaking ensures that: (i) products can be allocated only within holds fulfilling their transportation requirements, in terms of needed loading/unloading equipment and internal environmental conditions (*e.g.*, temperature, humidity, lighting); (ii) different products cannot travel together in the same hold if they have negative mutual effects. A typical case concerns *climateric* fruits (*e.g.*, apples), which can influence ripening of other fruits and vegetables. In the port collection areas (indoor/outdoor), mobile devices equipped with RFID readers are used for extracting data from good tags and from each hold of the docked ships. These data are decompressed and used for the subsequently steps. Given a delivery request, a semantic-based product allocation process is performed receiving as input the following data:

- the set of *products*  $P = \{p_1, p_2, \dots, p_n\}$  to be delivered along with their semantically annotated description (referring to the ontology  $\mathcal{T}$ ), required quantity  $q_i$  and destination;
- the set of available *ship holds*  $S = \{s_1, s_2, \dots, s_m\}$  with the relative annotations and freight capacities;
- the *threshold value*  $TH$  (with  $0 \leq TH \leq 1$ ), representing the maximum admissible semantic distance between two compatible products.

The product allocation strategy splits the problem into the following steps:

**1. Products clustering;** as described in Algorithm 1, products with similar requirements are gathered together in a set of clusters. In particular while  $P$  is not empty, a new cluster  $G_k$  is defined by a semantic description expressed as

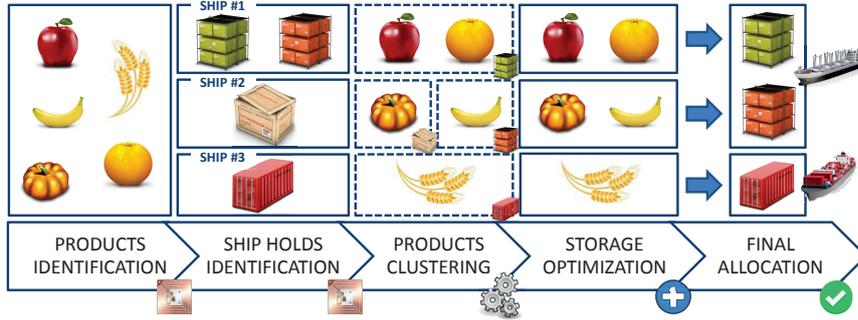


Fig. 1. Product allocation process.

#	Product	Quantity (tn)
1	Navelina	200
2	Golden_Delicious	200
3	Cavendish	300
4	Caravelle	180
5	Wheat	3000

Table 1. Products to be delivered

#	Ship	Hold	Available Space (tn)
1	Ship <sub>1</sub>	Hold <sub>1</sub>	500
2	Ship <sub>1</sub>	Hold <sub>2</sub>	500
3	Ship <sub>2</sub>	Hold <sub>3</sub>	250
4	Ship <sub>3</sub>	Hold <sub>4</sub>	3200

Table 2. Available ship holds

the logical conjunction of individual item descriptions (which is satisfiable by construction). An item is added to the cluster  $G_k$  (line 10) if it is compatible with the other products in the group and the compatibility score is less than the similarity threshold  $TH$  (line 9). *Concept Abduction* [5] was used to discover conflict features between product requirements whereas good similarity was obtained exploiting *rankPotential* [5] measuring the semantic distance between the new element  $p_j$  to be added and the cluster description  $C_k$ , normalized w.r.t. the maximum *rankPotential* value for  $p_j$  (only depending on axioms in the reference ontology). If the item is added, the cluster annotation is updated with the description of  $p_j$  (line 11).

**2. Clusters allocation;** *rankPotential* is also exploited to perform a product/hold comparison and measure the semantic distance between clusters and holds descriptions. Each product cluster is allocated to the ship hold with the lowest score.

**3. Storage optimization;** finally, a storage optimization task could be performed to maximize space usage. If a ship hold is partially empty (*e.g.*, the total volume of a cluster is smaller than the hold storage space), pre-allocated products can be moved to other holds according to the compatibility scores previously defined. This task ends when all goods are allocated and each ship presents the minimum space waste.

### 3 Case study: Transport of goods in the Mediterranean

In order to better explain the proposed approach, the following case study is used as a real-world example. *An Italian food-service company exploits the semantic-based supply chain management process to assist products delivery and shipping*

in different ports. The company receives a delivery request, reported in Table 1, whereas the ship holds available for product transportation are shown in Table 2. The steps for products allocation are reported in Figure 1 and are described hereafter. Port operators, endowed with RFID-enabled handheld devices, can locally manage the allocation task, even by monitoring the automated system process behavior. For each tagged product, the following information is retrieved via RFID: (i) EPC code; (ii) unique identifier of the reference ontology; (iii) semantic-based annotation in compressed OWL-DL format, summarizing transport requirements. Descriptions of some goods follow as an example:

**Golden\_Delicious:**  $Apple \sqcap \forall Has\_Colour.Yellow \sqcap \forall Has\_Quality.Ordinary\_Quality \sqcap \forall Storage\_Temperature.Cold\_Temperature \sqcap \forall Storage\_Humidity.High\_Humidity \sqcap \forall Storage\_Oxygen.Natural\_Oxygen \sqcap Unripe\_Product \sqcap \forall Has\_Storage\_Equipment.ISO\_Pallet\_Rack.$

**Wheat:**  $Wheat \sqcap \forall Has\_Colour.Yellow \sqcap \forall Has\_Quality.Ordinary\_Quality \sqcap \forall Storage\_Temperature.Room\_Temperature \sqcap \forall Storage\_Humidity.Low\_Humidity \sqcap \forall Storage\_Oxygen.Natural\_Oxygen \sqcap \forall Storage\_Lighting\_Source.Indirect\_Light \sqcap \forall Has\_Storage\_Equipment.Bulk.$

Then ship holds should be filled with products that do not interfere each other causing a general quality loss. As described in Algorithm 1, the following steps are executed:

1. the process starts with the allocation of a new empty cluster ( $cargo_1$ );
2. the first product **Navelina** is added to  $cargo_1$ ;
3. the second product **Golden\_Delicious** is compatible with the  $cargo_1$  description and it is added to the group;
4. the subsequent good **Cavendish** is matched against to  $cargo_1$  but a semantic incompatibility is detected because the products are climacteric and so they can travel in the same cargo only if they are in the same ripening stage. In this case Cavendish is not added to the group;
5. **Caravelle** is also incompatible with  $cargo_1$ ;
6. finally, **Wheat** is not compatible with  $cargo_1$  due to conflicting storage requirements about temperature. Cold storage is required for fruit shipping whereas room temperature is suitable for transport of **Wheat**.

After the first loop, the following cluster is defined:  $cargo_1 = \{Navelina, Golden\_Delicious\}$ . During the process, the system can also show possible incompatible features among products by means of the *Concept Contraction* service [5] supported by the reasoning engine [7]. Outcome explanation is a very important feature provided by the proposed knowledge-based approach. The same process is repeated with remaining products to define other product clusters:  $cargo_2 = \{Cavendish\}$ ;  $cargo_3 = \{Caravelle\}$ ;  $cargo_4 = \{Wheat\}$ . Then, each cluster will be allocated on the more suitable hold. Let us consider the following hold descriptions:

**Hold.1:**  $\forall Storage\_Temperature.Refrigeration \sqcap \forall Storage\_Humidity.Controlled\_Humidity \sqcap \forall Storage\_Oxygen.Natural\_Oxygen \sqcap \forall Storage\_Equipment.ISO\_Pallet\_Rack \sqcap \forall Storage\_Lighting\_Source.Indirect\_Lighting.$

**Hold.2:**  $\forall Storage\_Temperature.Controlled\_Temperature \sqcap$

	<i>cargo</i> <sub>1</sub>	<i>cargo</i> <sub>2</sub>	<i>cargo</i> <sub>3</sub>	<i>cargo</i> <sub>4</sub>
<i>hold</i> <sub>1</sub>	0.133	n.c.	n.c.	n.c.
<i>hold</i> <sub>2</sub>	n.c.	0.279	0.03	n.c.
<i>hold</i> <sub>3</sub>	n.c.	0.133	0	n.c.
<i>hold</i> <sub>4</sub>	n.c.	n.c.	n.c.	0.019

**Table 3.** Ranking results between cargoes and holds

$\forall$  *Storage\_Humidity.Medium\_Humidity*  $\sqcap$   $\forall$  *Storage\_Oxygen.Natural\_Oxygen*  $\sqcap$   
 $\forall$  *Storage\_Equipment.ISO\_Pallet\_Rack*  $\sqcap$   $\forall$  *Storage\_Lighting.Source\_Indirect\_Lighting*.

First of all, a compatibility check is performed between cargoes and available holds. Also in this case, operators can show an explanation of contrasting features. Compatible results are then ranked by means of the *utility function* described below:

$$Rank(cargo_i, hold_j) = \frac{rankPotential(cargo_i, hold_j)}{rankPotential(cargo_i, \top)} \frac{residual\_space(hold_j)}{total\_space(hold_j)}$$

$rankPotential(cargo_i, hold_j)$  is the semantic distance between the  $cargo_i$  and the  $hold_j$  normalized w.r.t. the maximum semantic distance of  $cargo_i$ , whereas  $residual\_space(hold_j)$  is the available space in the  $hold_j$  after the allocation of the  $cargo_i$  normalized w.r.t. the overall space in  $hold_j$ . The pair with lowest score will be selected. According to the ranking results shown in Table 3, the cargoes will be arranged on the holds as follows:  $hold_1$  {Navelina, Golden\_Delicious};  $hold_2$  {Cavendish};  $hold_3$  {Caravelle};  $hold_4$  {Wheat}.

Finally, the system performs the storage optimization. In this case,  $hold_2$  and  $hold_3$  are partially empty with respectively 300/500 and 180/250 used/available space (tn). The system can rearrange cargoes after checking compatibility with both hold features and already stored product descriptions. For example, relaxing the constraint on the threshold value, *Caravelle* could be moved to  $hold_2$  despite it was not initially grouped with *Cavendish* because their similarity value (obtain through  $rankPotential$ ) exceeded the threshold value  $TH$ . The final allocation is:  $hold_1$  {Navelina, Golden\_Delicious};  $hold_2$  {Cavendish, Caravelle};  $hold_4$  {Wheat}. Moreover, a further approach can exploit Concept Contraction and  $rankPartial$  algorithms [5] to rank contrasting characteristics and to identify weakly incompatible products. In this case also partially conflicting goods can be delivered together to strongly reduce unused carrying space.

## 4 Conclusion

The paper presented a port supply chain model exploiting a semantic-based RFID enhancement to exchange information during different stages of the good life cycle and to enable a fully automated goods compatibility management in load composition. Benefits deriving from the adoption of such an approach have been proved with reference to a product delivery scenario in a generic fruit and vegetable market. Future developments will be performed to extend and improve the proposed approach, such as introducing advanced solutions to security issues specific for RFID.

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