The Knowledge Reuse in an Industrial Scenario: A Case Study

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***Abstract*—Many recent research works have investigated the potential of an Ontology-based approach to support the standardization of the information in industrial scenarios. A key success factor in this regard is the effective and efficient reuse of existing knowledge sources because the building of new ones from scratch is an expensive and time-consuming activity. Although there are many advantages for reuse in the knowledge engineering, the topic is not explored in depth and the current state of the art in this field demands further investigation. The study introduced in this paper addresses the applicability of an approach to knowledge reuse based on the combination of existing techniques and methods proposed in the literature. Specifically, the experimentation has been carried out in the context of the ongoing European research project Apps4aME, where an automated framework for knowledge reuse has been tested and validated, focusing in particular on the food knowledge domain. The paper summarizes the main results of the research work and includes the emerging issues as well as some proposals to overcome them.**

Keywords-knowledge reuse; ontology engineering; semantic matching.

I. Introduction

Reuse is an intrinsic practice in traditional engineering fields. The designers of different disciplines, from mechanics to electronics, apply it successfully whenever they build a new component, thus saving cost and time and improving the overall system quality. In this regard, an important example in the context of electronics is the reuse of standard components with well-documented and well-defined interfaces during the design of electrical circuits. Contrary to the traditional disciplines of engineering and despite intense efforts, reuse remains an underexplored and not standard process of the knowledge engineering. In this area, the key resources that can be reused are the reference models, which represent an abstract framework to understand significant relationships between defined concepts related to a specific domain, by developing consistent specifications.

Nowadays, a large number of reference models, covering a wide range of domains, are available in literature and can be considered a valid starting point for the knowledge reuse. In particular, at this stage, it is essential to refer to the state-of-the-art technical standards covering different domains, e.g., the Industry Foundation Classes (IFC), the Standard for the Exchange of Product model data (STEP), and the International Society of Automation standards (e.g., ISA-95). In fact, they contribute to enable a comprehensive conceptualization of the represented domains, thus simplifying the communication and collaboration between the involved actors. The ability to perform effectively and efficiently knowledge reuse plays also a crucial role in the development of ontologies, which are one of the most debated topics in data modelling research community because they represent a potential solution to the problem of standardization of information [1][2]. In the context of ontology engineering, reuse of existing reference models has several advantages. First, it reduces the cost and the time required for the conceptualization of specific domains from scratch [3]. Moreover, it increases the quality of newly implemented ontologies as the reused components have already been validated. Finally, it avoids the confusion and the inconsistencies that may be generated from multiple representations of the same domain; thus, it strengthens the orchestration and harmonization of knowledge [4].

A lot of efforts has been devoted towards the application of knowledge reuse in the field of ontology engineering. In this regard, Pinto and Martins [5] have analyzed the process from a methodological point of view, thus introducing an approach that comprises several phases and activities. Moreover, the European research project NeOn proposed a novel methodology for building ontology which emphasizes the role of existing ontological and non-ontological resources for the knowledge reuse [6]. However, some open issues still remain, especially with regards to the difficulty of dealing with the extreme formalisms heterogeneity of the increasing number of models available in literature [3]. The absence of an automatic framework for the rigorous evaluation of the knowledge sources is also a severe limitation to overcome. Finally, some sub-processes of the reuse process have been defined and formalized only at the theoretical level. Therefore, it is essential to carry out the experimentation within practical cases.

This paper presents an extended feasibility study of an approach to knowledge reuse based on the combination of existing techniques and methods proposed in the literature. The approach has been tested on the real industrial case of the Romanian company CarmOlimp, where existing knowledge sources have been explored for the development of new ontologies in the Food domain, thanks to the contribution of domain experts. Through the analysis of a real case study based on empirical evidences, the idea behind this study is to encourage and support the reuse of existing reference models, enhancing its real-world usability and identifying the challenges to make this practice a viable alternative to the development of ontologies from scratch.

The reminder of the paper is structured as follows. Section II describes the CarmOlimp case study, whereas Section III introduces and illustrates the knowledge reuse framework. Finally, Section IV draws the conclusions, summarizing the major findings and the future steps.

II. THE CARMOLIMP CASE STUDY

Modern enterprises have to face the challenge of handling a large amount of data, which are expressed in different and heterogeneous formats and are also distributed in various sources, while aiming at improving the effectiveness and the quality of their production processes [7][8]. This problem is relevant also for the Romanian company CarmOlimp that plays the meat market covering a large part of the meat production chain with a wide range of products (e.g., fresh meat, processed meat, dairy products, etc.). Since the effects of globalization are forcing this company to adapt its market to lower prices and high quality, it is needed to optimize its planning and monitoring activities to reduce the time for distribution, improve its packaging and optimize the monitoring of the meat temperature. The performance of such business process can be improved if they are supported by interoperable software tools. Semantic web technologies can be adopted to develop interoperable approaches [9] supporting the collaboration between all the involved actors and resources, while taking in consideration the storage of data [10], data definition via proper meta-models [11] and the inference of new knowledge [12].

The first step towards the realization of an ontology-based approach consists in the creation of an ontology, which is a common shared representation of the objects and their relationships and is intended to be used by the apps involved in the scenarios. The problem of developing comprehensive data models for various domains has already been addressed by researchers and a large number of them is available in literature. In the belief that their reuse could greatly reduce the costs of a new implementation, the next section introduces a framework that aims at identifying relevant data models for the formal conceptualization of a generic industrial case, while using CarmOlimp as a reference case study.

III. THE FRAMEWORK

The proposed framework requires as input a conceptual representation of the data model that highlights the hierarchy of concepts and their logical relations together with useful metadata description (target model). This representation can be the result of several interviews with the company's stakeholders and can be expressed in several languages, e.g., plain-text, XSD (XML Schema Definition), UML (Unified Modelling Language) Class Diagrams, E-R (Entity-Relationship) diagrams, etc.

As shown in Figure 1, the framework requires the contribution of two different figures: domain experts and knowledge engineers. The domain experts are people who have deep knowledge of a specific domain, whereas the knowledge engineers are employed to elicit and translate this knowledge in terms of ontology axioms. The contribution of both occur during the whole process and comprises three phases, which are briefly summarized as follows:

- identification of the knowledge domains covering the target model;
- search for the candidate reference models related to each specific domain;
- selection of the proper models to be reused.

Each of these phases is described in the next subsections, showing also how it can be applied to the specific case of CarmOlimp.

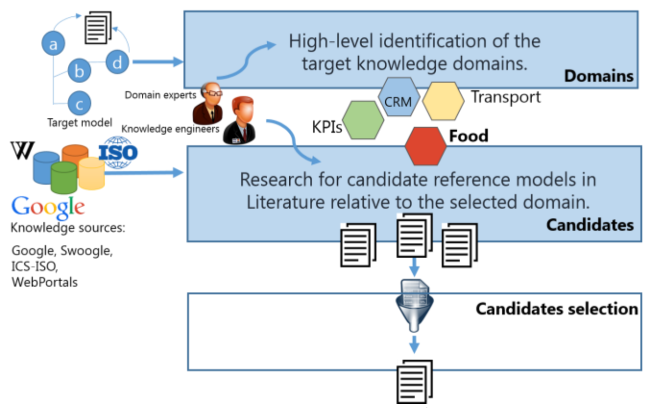

Figure 1. Framework workflow

A. *The first phase: the identification of the knowledge domains*

The first phase identifies the knowledge domains covering the target data model by a deep understanding of the concepts and of the metadata description within the case study. The contribution of domain experts is essential in order to clarify the meaning of some poorly defined concepts and to enable knowledge engineers to identify the right resources for this phase. Many of them are available in literature and can be used by knowledge engineers as a valuable aid to carry out the domains identification. The most important are the following:

1. Wordnet [13], a freely and publicly available large lexical database of English words.
2. General purpose or content-specific encyclopedia, e.g., Wikipedia and The Oxford Encyclopedia of Food and Drink in America.
3. Web directories, e.g., DMOZ (from directory.mozilla.org) and Yahoo! Directory.

4. Standard classifications, e.g., the International Classification for Standards (ICS) compiled by ISO (International Standardization Organization).
5. Other electronic and hard-copy knowledge sources, including technical manuals, reports and any other documentation that the domain experts may consider useful to identify the knowledge domains.

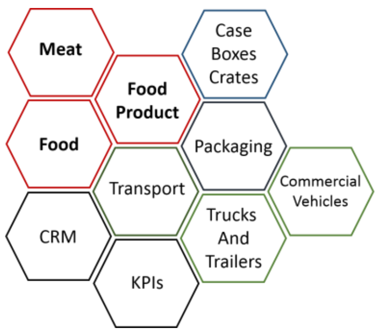

Figure 2. CarmOlimp knowledge domains

For the CarmOlimp case study, the knowledge engineers have identified the domains reported in Figure 2, which can be also mapped onto the following categories and sub-categories of ICS:

01: Generalities. Terminology. Standardization. Documentation:
- 01.040.03: Services. Company organization, management and quality;

03: Services. Company organization, management and quality. Administration. Transport. Sociology:
- 03.220: Transport
- 03.220.01: Transport in general;
- 03.220.20: Road transport;

17: Metrology and measurement. Physical phenomena:
- 17.200: Thermodynamics and temperature measurements;
- 17.200.20: Temperature-measuring instruments;

25: Manufacturing engineering:
- 25.040: Industrial automation systems
- 25.040.01: Industrial automation systems in general
  Key performance indicators (KPIs) for manufacturing operations management;

43: Road vehicles engineering:
- 43.080: Commercial vehicles;
- 43.080.10: Trucks and trailers;

53: Materials handling equipment:
- 53.060: Industrial trucks;
- 53.080: Storage equipment;

55: Packaging and distribution of goods:
- 55.020: Packaging and distribution of goods in general;
- 55.040: Packaging materials and accessories;
- 55.160: Cases. Boxes. Crates;
- 55.180: Freight distribution of goods;
- 55.180.20: General purpose pallets;

67: Food technology:
- 67.020: Processes in the food industry;
- 67.040: Food products in general;
- 67.120: Meat, meat products and other animal produce;

Since several domains have emerged during the analysis, the rest of the discussion will briefly overview their description and will focus mainly only on the food domain. This latter can be considered particularly significant for the analyzed scenario, as the core business of Carmolimp is meat processing.

B. Second phase: the search for candidate reference models

During this phase, knowledge engineers and domain experts continue to collaborate in order to identify the best tools and resources supporting the search for the relevant sources covering the selected knowledge domains. Within this study, the following sources were explored:

1. Specialized portals and websites within public or private organizations.
2. Search engines (e.g., Google, Bing, etc.), directory-based engines, e.g., Yahoo!, BOTW (Best of the Web Directory), DMOZ, etc., specialized semantic-based engines, e.g., Yummly (specialized on food), True Knowledge, etc.
3. Ontology repositories including: BioPortal, Cupboard, Schemapedia, Knoodl, etc., and search engines for semantic web ontologies, e.g., Swoogle and the Watson Semantic search engine.
4. Available standards and non-standard reference models that provide requirements, specifications, guidelines and characteristics of a service or a product (ISO standards, the IFC Industry Foundation Classes, Ansi/ISA-95, STEP, mentioned above, and the Core Product Model).

On the basis of these sources, the search has yielded a set of ten relevant candidates (Table II) for the food domain in the Carmolimp case study. They are the input for the next step of the framework.

C. Third phase: candidates selection

This phase identifies the best candidates for the formal conceptualization of the target model. The identification is performed by an initial qualitative analysis that yields the ranking of candidates according to some preference criteria. Afterwards, a linguistic analysis is carried out in order to identify the candidates which are conceptually closer to the target model (relatedness), by a measure of their similarity level.

Reference models can be rated according to relevant technical characteristics and other general information. The most important ones, considered in this study for the qualitative analysis of the sources, are shown in Table I and summarized in the following list:

(c1) **Model formality level.** It describes the formality of the conceptual model representation that can range from plain text to description logic-based languages.

(c2) **Model type generality**. It evaluates the model type from the viewpoint of its generality (upper-level model or application specific model).

(c3) **Model type structure.** It evaluates the model type from the viewpoint of its structure (simple classifications or taxonomies versus semantic enriched ontologies).

(c4) **Model language.** It describes the language used to represent the conceptual model, including RDF/OWL (Resource Description Framework/Ontology Web Language), graphic-based languages and pure text.

(c5) **Model provenance.** It evaluates the model from the viewpoint of its origin, thus giving higher rates to standards or conceptual models authored by influential scientific groups.

(c6) **Model license.** It evaluates the availability of the conceptual model (open data-model versus proprietary and licensed models).

A higher rate will be given to formal models because the aim of the framework is to reuse existing models for a formal conceptualization of the target model.

TABLE I. CRITERIA FOR THE QUALITATIVE ANALYSIS

Criteria	Values					
Model formality level (c_1)	Formal model (first order logics-based)	Semi-formal model (RDF, XSD, graphics-based)	Informal model (text-based)			
Model type generality (c_2)	Upper level model	Domain model	Application specific			
Model type structure (c_3)	Ontology	Taxonomy	Glossary	Classification		
Model language (c_4)	OWL	RDF	UML	E-R diag.	XSD	Text
Model provenance (c_5)	Public or private standardization organizations	Non-stand. research groups	Private companies	Other		
Model licence (c_6)	Open license	Proprietary				

TABLE II. CANDIDATES FOR THE QUALITATIVE ANALYSIS

Reference model	Source	Formality (C_1)	Generality (C_2)	Structure (C_3)	Language (C_4)	Provenance (C_5)	License (C_6)
National Cancer Institute Thesaurus Food product ontology	[21]	Formal	Domain	Ontology	OWL	Non-stand. Research	Open
AGROVOC	[22]	Semi-formal	Domain	Ontology	RDF	Non-stand. Research	Open
Linked Recipe Schema	[23]	Semi-formal	Domain	Ontology	RDF	Other	Open
BBC Food Ontology	[24]	Semi-formal	Domain	Ontology	RDF	Other	Open
LIRMM	[25]	Semi-formal	Domain	Ontology	RDF	Other	Open
The Product Types Ontology	[26]	Semi-formal	Application	Ontology	RDF	Non-stand. Research	Open
oregonstate.edu Food Glossary	[27]	Informal	Application	Glossary	Text	Other	Open
Eurocode 2 Food Coding System	[28]	Informal	Domain	Classification	Text	Non-stand. Research	Open
WAND Food and Beverage Taxonomy	[29]	Semi-formal	Domain	Taxonomy	Text	Private companies	Proprietary
Food technology ISO Standard	[30]	Semi-formal	Domain	Taxonomy	Text	Stand. Organiz.	Proprietary

With regards to the type generality, a domain model is more appropriate than upper level ontologies and application specific ontologies, because the latter may be too specific or too generic for the purpose of this study. The preferred model structure is Ontology because it generally provides logical links between concepts, thus adding more semantics to the data model than simple taxonomies and other types of classifications. The preferred representational language is RDF [14] and OWL [15] because the target model will be realized in those languages. With regard to the provenance, models delivered by standardization organizations or well-known research groups will be preferred to those produced by non-standard or unknown organizations. Finally, only open data models are passed onto the linguistic analysis, because their free availability is a mandatory requirement in this evaluation. Table I reports the values corresponding to the preference criteria mentioned above (with rates decreasing from left to right). On the basis of the criteria previously defined, a comparison of the set of pre-selected models is carried out. In order to facilitate the analysis of the technical characteristics, a synopsis of the main outcomes of this study is reported in Table II. In view of these results, the knowledge engineer has selected the following candidate to be promoted for the linguistic analysis: National Cancer Institute Thesaurus, AGROVOC Ontology, BBC Food Ontology, Linked Recipe Schema and LIRMM Food Ontology.

The linguistic analysis uses WordNet and some of its APIs (Application Program Interfaces) [16] for estimating the linguistic matching measures between the target model and the candidate models. In WordNet, nouns, verbs, adjectives and adverbs are grouped into sets of cognitive synonyms (synsets), each expressing a different concept [17]. The synsets are interlinked by conceptual-semantic and lexical relations, thus realizing a graph-based structure where synsets are nodes and lexical-relations are the edges.

As shown in Figure 3, the linguistic analysis comprises three different steps. First, a list of terms is extracted from all the concepts of the candidate models and the target model. This process has been automatized using specific tools, e.g. XMI (XML Metadata Interchange) parsers, Ontology APIs including Jena, or Simple Access XML APIs, depending on the format used to represent the model. Then, all terms of the target model are compared to all those of each candidate model, in order to estimate the maximum Wu-Palmer [18] similarity between their synsets. This measure is calculated exploiting the Wordnet graph-based representation and indicates how much two terms are close to each other by counting the number of edges between them and also by taking into account their proximity to the root concept of the hierarchy [19]. According to Lin [20], Wu-Palmer similarity has the advantage of being simple to calculate, in addition to its performances while remaining as expressive as the others. Table III shows an example of these calculations performed for the National Cancer Institute Thesaurus and the CarmOlimp target model. Finally, after the Wu-Palmer measures are calculated for each pair of terms, the average similarity (i.e., the sum of the Wu-Palmer similarities divided by the number of analyzed pairs) has been estimated for each candidate.

TABLE III. EXAMPLE OF WU-PALMER MEASURES

		Target Model							
		Resource	Product	Meat	Beef	Salami	Trip	Client	…
National Cancer Institute Thesaurus	Food	0.625	0.706	0.923	0.857	0.800	0.533	0.375	…
	Product	0.571	1.000	0.706	0.533	0.500	0.632	0.632	…
	Meat	0.625	0.706	1.000	0.933	0.875	0.533	0.556	…
	Lamb	0.267	0.556	0.933	0.875	0.824	0.476	0.800	…
	Poultry	0.250	0.500	0.875	0.824	0.778	0.417	0.609	…
	Chocolate	0.533	0.571	0.857	0.800	0.750	0.400	0.353	…
	Drink	0.571	0.571	0.571	0.571	0.500	0.545	0.375	…
	…	…	…	…	…	…	…	…	…

TABLE IV. MEASURES CORRESPONDING TO THE SELECTED REFERENCE MODELS

Reference model	**100% Matching concepts**	**Wu-Palmer > 50% Concepts**	**Wu-Palmer total average**
National Cancer Institute Thesaurus	3	304	0.671
AGROVC Ontology	4	138	0.68
BBC Food Ontology	0	201	0.64
LinkedRecipe	0	227	0.67
LIRMM food Ontology	2	92	0.68

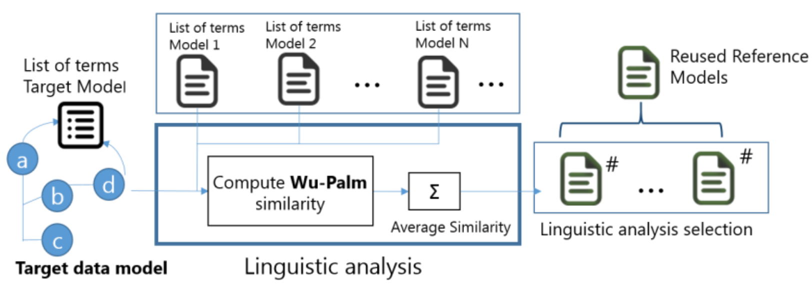

Figure 3. Selection process of the reference models

These measures are reported in Table IV together with the number of 100%-matching concepts and the number of concepts having a value of the Wu-Palmer measure greater than 0.5. The values of the average similarity are all very close and they range from 0.64 to 0.68. However, the National Cancer Institute Thesaurus proves to be the model more semantically related to the target model, since it has the largest number of 100%-matching concepts and the higher number of concepts having a value of the Wu-Palmer measure greater than 0.5.

A preliminary validation of these results has been performed by the domain experts through an empirical method based on their expertise. Moreover, this validation has been paired with an evaluation of the accuracy of the similarity scores with respect to some existing gold standards. This verification is currently under study.

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IV. Conclusion And Future Works

This work has demonstrated that an approach based on linguistic matching can help to identify the most relevant reference models that are available to cover concepts of the considered domain. Nonetheless, this approach still requires a significant amount of manual work, even when it deals with common and formal models. This requirement may be a severe limitation for a widespread adoption of the knowledge reuse, but it represents also a relevant technological gap to be addressed in future works by developing new methods and tools. Moreover, new similarity measures can be studied to improve the accuracy of the herein presented matching framework also with respect to some existing gold standards.

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