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Semantic input/output matching for waste processing in industrial symbiosis

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ABSTRACT

Industrial symbiosis (IS) is a subdiscipline of Industrial Ecology that aims to bring together companies from different sectors to share resources, namely energy, materials, and water. The main goal of IS is to improve resource (materials, waste, energy) efficiency and lead to mutual environmental, financial and social benefits to participants.

In this paper we present a semantic approach for IS input/output matching. This approach is based on knowledge modelling and ontologies.

Ontologies are used to model all resources – waste, water, energy – along with details about their composition, characteristics (chemical and physical) and tacit knowledge about their flow.

The input/output matching algorithm presented enables the valorisation of resources through industrial symbiosis networks.

1. Introduction

Industrial symbiosis (IS) is a subdiscipline of Industrial Ecology that aims to bring together companies from different sectors to share resources, namely energy, materials and water (Chertow, 2004; Jacobsen, 2006). The main goal of IS is to improve resource (materials, waste, energy) utilisation and provide mutual environmental, financial and social benefits to participants (Van Berkel, 2010). Benefits are generated by the reduced intake of virgin materials, reduced amount of waste (Chertow, 2007) being landfilled, reduced emissions (Jacobsen, 2006), job creation (Chertow, 2007) and/or innovation (Van Berkel, 2010).

As demonstrated, IS is a knowledge-intensive discipline (Davis, Nikolic, & Dijkema, 2010). One of the key barriers in promoting IS is the difficulty in identifying new uses of waste (Chertow, 2007). Other main pieces of information required in promoting IS are the information about the composition of waste streams and the documentation of material flows (Allen, 2004). Consequently, the input/output matching is a significant tool in IS practice referring to formation of symbiotic networks (Chertow, 2000).

Tacit and explicit knowledge in a knowledge base about IS have been identified as a pre-requisite for the thriving evolution of IS into common practice (Grant, Seager, Massard, & Nies, 2010). Semantics and hence the opportunities offered by web technologies have been identified as potential solutions to mentioned barriers (Davis et al., 2010; Grant et al., 2010; Kraines et al., 2005).

In this paper we present a semantic approach for IS input/output matching. The approach is based on knowledge modelling and ontology engineering (Gruber, 1993). The use of ontologies allows modelling both tacit and explicit knowledge. It also offers standardisation in an off-market and off-spec subject, such as waste. The approach is formalised as a service and implemented as an automated web service (Cecelja et al., 2013), thus reducing costs for participants. Along with an appreciated comfort in using the service, automation also aims in motivating the participation of more industries and especially SMEs.

More specifically, ontologies are used to model the resources, i.e. waste, water, energy, along with details about their composition, properties (chemical and physical) and tacit knowledge about respective flows. Here, tacit knowledge is referred to as the knowledge captured from experience and professional intuition in waste treatment and industrial symbiosis by IS professionals. Material flows are identified from previous experience and domain expertise including IS, chemical engineering and process engineering, among others. Ontologies are also used for integrating processing technologies into a IS process in the form of the symbiotic network (Raafat, Trokanas, Cecelja, & Bimi, 2013). Knowledge modelling also allows for the pre-assessment of some of the environmental indicators of IS, hence enabling better screening and serving as a

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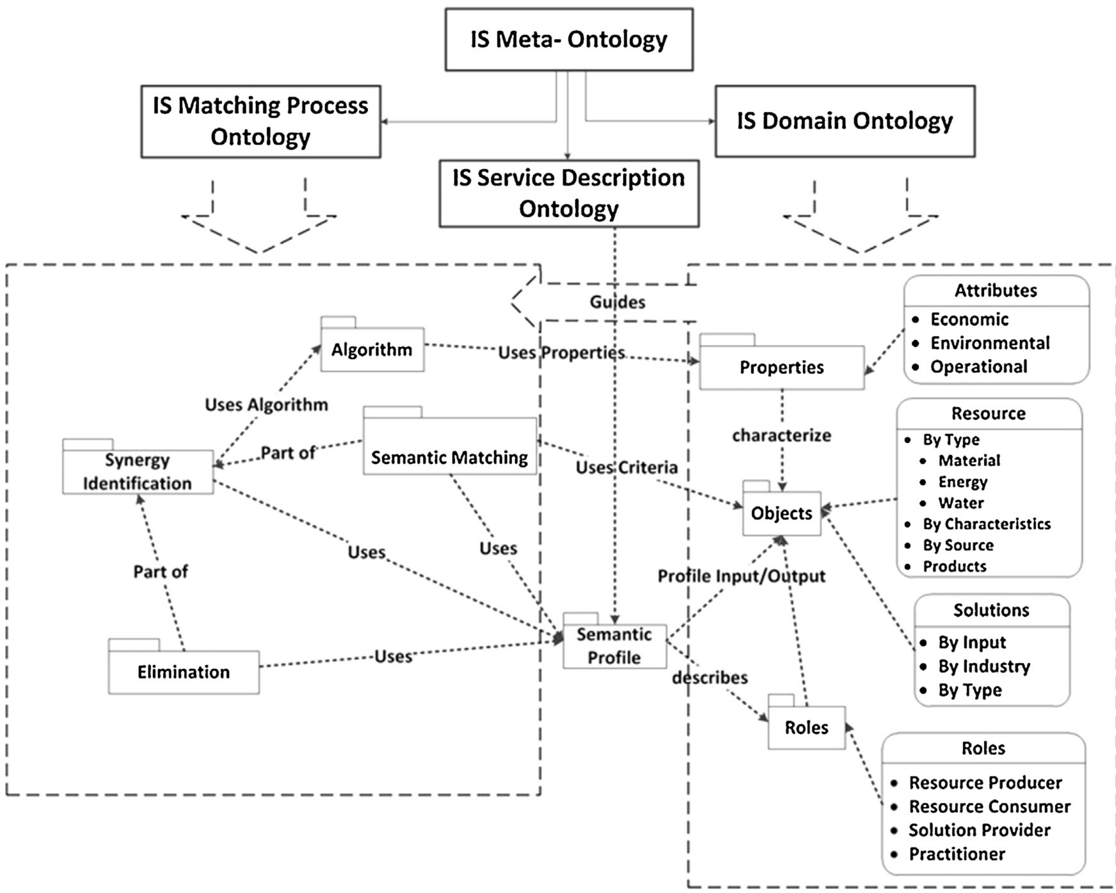

Fig. 1. IS ontology design.

useful decision making tool that further motivates participation (Trokanas, Cecelja, & Raafat, 2013).

2. Concepts and definitions

Ontological engineering is employed to model and formalise the knowledge in the domain of IS. The proposed ontology consists of three high level modules (Fig. 1): (i) IS matching process ontology, (ii) IS domain ontology and (iii) IS service description ontology. The three modules form the IS meta-ontology. This work proposes a fully functional IS domain ontology adjusted to description of respective resources participating in IS as well as matching of resources to form IS networks.

The IS domain ontology has four levels of abstraction (Singh et al., 2007; Sokka, 2011), as illustrated in Fig. 2. These levels contribute to ontology design levels as defined in Ratafia-Brown, Manfredo, Hoffmann, and Ramezan (2002) and include (i) meta-level which defines general purpose concepts of the ontology that can be applied universally and have no dependence on specific domains, (ii) top level providing abstract concepts of the domain as well as the top-level relationships between these concepts, (iii) domain level which specifies the domain of IS, and (iv) instantiation level which is application specific level with the user profile instances linked directly to the IS semantic service description ontology.

The IS matching process ontology (Fig. 1) incorporates concepts relevant to the process of screening the symbiotic networks, in particular algorithms and mathematical techniques adapted and created to fulfil requirements of semantic matching for potential synergies.

In order for the algorithms to perform, all participants need to be semantically described. For that the IS service description ontology is employed. More precisely, all IS participating resources have a semantic profile presented as instances of IS domain ontology which is then implemented as instantiation of the service description ontology.

2.1. Semantic description of resources

In order to accurately reflect IS practice, the *Resource* concept in the IS domain ontology (Fig. 2) acts as the point of reference for all semantic service profile descriptions and the synergy identification activities. To this end, the concept *Resource* refers to materials, waste, energy, product and water that a user provides or requires. The *Resource* concept consists of four different classification streams: (i) classification *bySource*, (ii) classification *byType*, (iii) classification *byProduct* and (iv) classification *byCharacteristic*. Classification *bySource* is implemented using both existing classifications, e.g. The European Waste Catalogue (EWC) (European Commission, 2000) and purpose-made classifications representing specific types of waste imposed by the application. These classifications are used for the registration of a waste as a *Resource* or by-products of a processing technology. The nonstandard nature of waste makes it difficult to compare different types, hence imposing the use of a more standardised classification defining the composition of the waste. Classification *byType* itself includes three categorisations: (i) *Materials*, (ii) *Energy* and (iii) *Water*.

Materials category is used to address the problem of standardisation. This classification was developed such that it inherently invokes similarity for concepts that have structural proximity in the ontology. For example, different types of biomass are