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Standardised semantic models to support the configuration of global production networks

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ABSTRACT: The configuration and deployment of global production networks, raises questions about the interchange of data and information between varied and different organisations, domains and systems. Standards should be an instrumental part of forming a basis to enable seamless interoperability, yet there is no clear support for global production networks. This paper sets out a reference ontology for global production networks being developed as a basis for interoperability between systems, with the potential for it to be developed as a standard.

KEY WORDS: Interoperability, standards, global production networks, ontologies.

1. Introduction

The subject of global production networks (GPN) is garnering attention as companies and organisations focus upon ways in which to innovate both their strategic and operational approaches to designing, manufacturing and delivering products and services to customers in ever increasing globalised world markets [1]. But, when trying to design, configure, deploy and re-configure GPNs, questions should be raised about the interchange of data and information between varied and different organisations, domains and systems. Generally GPNs are comprised of a set of geographically diverse and divergent organisations that will have different modus operandi, culture, approaches to business and potentially reside within different domains of interest. These therefore present potential problems to facilitating and deploying a fully working and effective global production networks, especially when a large number of these organisations exist within one, more importantly though, there is a fundamental factor to doing business in the 21st century that underpins all of this, that being the setup and configuration of information systems and the interactions between those different systems. Transferring data and information between different systems and companies can be fraught with difficulties, this can be because of the structure used to design and organise them but, also the meaning allotted to such structures.

One way to alleviate such problems is to apply a formal standards approach when designing data, information and knowledge structures. Standards should be an instrumental part of forming a basis to enable seamless interoperability, yet there is no clear support for global production networks. There are some examples of cross domain ontological research. Chungoora et al.[2] and Chungoora and Young [3] present the manufacturing reference ontology which was generated from research conducted within the Interoperable Manufacturing Knowledge Systems (IMKS) project. Furthermore, the Manufacturing Core Ontology (MCO) presented by Chungoora et al. [4] is associated with this. Both of these approaches focus on improving and enhancing the interchange of information and knowledge between multiple contexts and describe the organisation of relationships between concepts for manufacturing, assembly and design activities within an organisation.

The aim of reference models and standards is to designate technical architectures [5], Fettke and Loos [6] cite the ability of these to accelerate the development of information Communication Technologies (ICT), by decreasing development costs, whilst minimising the risks involved in such protracted exercises. The International Standards Organisation (ISO) technical committees ISO/TC184/SC4 and ISO/TC184/SC5 are currently developing international standards that focus upon interoperability, those being ISO 11354-1:2011 [7] and ISO 15531-44:2010 [8]. The need for a standard that addresses the sharing of information and knowledge across domains boundaries and between systems is still apparent, as these two standards focus upon enterprise and manufacturing interoperability. Furthermore, the Ontology summit of 2009 [9] (organised by ISO/TC184/SC4) explicitly stated that *'Ontologies represent the best efforts of the technical community to unambiguously capture the definitions and interrelationships of concepts in a variety of domains'*,

and therefore, *‘if the standards community is indeed serious about specifying such information unambiguously to the best of its ability, then the use of ontologies as the vehicle for such specifications is the logical choice’*. There are two international standards that are relevant to the development of a reference ontology for GPNs, these are ISO 10303-239 [10] industrial automation systems and integration (product data representation and exchange) and ISO 18629 [11] industrial automation systems and integration (process specification language). ISO 10303-239 is useful for supporting product lifecycles, and ISO 18629 is useful for capturing and representing process related meaning [12].

The definition of the proposed reference ontology for global production networks, presented in this paper, has been the subject of an on-going EU FP7 project (FLEXINET 608627) and a related IMS project called Configuration Services for Global Product Networks (CSGPN). The resulting model is under test in three manufacturing sectors: the pumps and valves industry; the white goods industry; the food and drink industry. Moreover, the proposed standard of ISO 20534:2015, which is entitled ‘Formal Semantic Models for the Configuration of Global Production Networks’ is being developed from this research. Currently, it is being progressed as a New Work Item within the International Standards Organisation.

This paper sets out a reference ontology for global production networks which is being developed utilising a set of industrial use cases developed within the FLEXINET project. The approach is based around the understanding that the developing GPN reference ontology could provide (i) an effective and flexible basis for enabling interoperability between complex multi-context systems and networks of systems and (ii) a potential foundation from which to generate new standards for the development of information and knowledge based systems to enable interoperability.

This paper presents the FLEXINET research project approach in section 2, the reference ontology for global production networks is presented in section 3, whilst section 4 sets out the conclusions.

2. The FLEXINET view

The approach to and premise behind the FLEXINET project is how to best design and facilitate networks of production systems that can be both flexible and interoperable. One of the main aspects within this approach is the ability to re-configure these networks when considering and introducing new technologies. Production networks can sometimes be spread over vast geographical areas comprised of diverse and divergent organisations. Therefore numerous factors can influence and affect such networks. FLEXINET therefore seeks to apply cutting edge techniques to the assessment of these factors so as to enable rapid re-organisation of those networks by considering potential scenarios where benefits and disadvantages (i.e. costs and risks) can be assessed and the implications those have for configurations of production network systems and how they change over time.

The FLEXINET research project contains three key end users, each of who are interested in understanding the impact of external demands, such as environmental regulations, on their business and most especially when related to the introduction of new product-service opportunities into their production network. Therefore, the availability, accessibility and usability of reliable data as well as the ability to use it for strategic and tactical decisions is of particular importance.

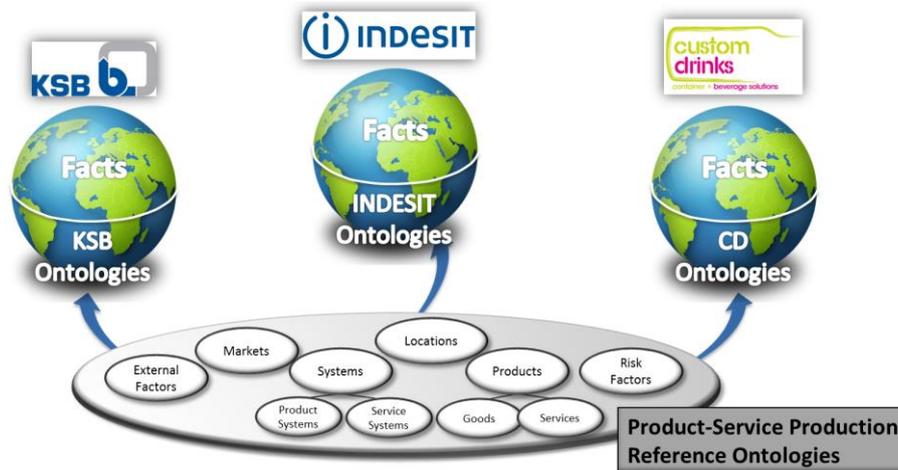


Fig. 1. Exploiting semantic models to create company specific knowledge bases.

Fig. 1 illustrates the FLEXINET approach to exploiting semantic models to create company specific knowledge bases relative to the end users. Three main software services are being actively developed to provide the environment for the assessment of risks and costs against potential network configurations. These are being supported by a reference ontology to enable the consistent representation and usage of product-service production information and knowledge across the platform. The three services are aimed at supporting strategic and tactical level decision making. The first is the strategic business model evaluator, as per its name it seeks to assess and evaluate cost comparisons and risk evaluations for higher level decision support, this considers strategic business interdependencies for product-service manufacture. The second of the services is the production network configurator which, is aimed at lower level tactical decisions. As its namesake is seeks to support the design and configuration of organisational and process aspects for the production network systems. The third service is that of the compliance evaluator. This studies both product and service lifecycle compliance issues when considering alterations to a production network system configuration, i.e. how do changes to a product or component affect related services in a product and vice-versa. The purpose of the underpinning reference ontology is to provide a standard basis from which information and knowledge can be represented and applied to reasoning processes for the generation of industry specific responses and solutions to the problems posed by the end user use cases.

The configuration of these service components is also aimed at improved integration between strategic and tactical business aspects to enhance the successful realisation of new business models. These configuration services, adaptable to suit multiple industrial sectors, will provide an understanding of the implications for the business of potential alternative production network configurations made necessary by product-service changes or new product-service requirements.

3. Towards a global production network reference ontology

Currently, the work within this paper is being put forward as a New Work Item within the International Standards Organisation (ISO), under the proposed standard of ISO 20534, which is entitled 'Formal Semantic Models for the Configuration of Global Production Networks'. The premise behind this, is, that for ease of construction, effective interoperability and flexible re-use, enterprise ontologies must be built from a shared base that utilises a common reference ontology wherever possible. A simple statement may describe the basis of generalisation: "A design of an ontology representing the core elements of a particular enterprise, will end up with a good number of elements that are not exclusive to this particular enterprise, but common to some other enterprises that operate in the same sector". For the sake of clarification, we use the word "element" to include "concepts", "relations" and "attributes" relating to an ontology.

Following this reasoning, it can be inferred that a subset of the elements that are common to a particular sector might be applicable or extrapolated to different sectors. In other words, some of the elements that are applicable to the Pumps Industry sector might be also applicable to the White Goods sector. Both sectors are part of the manufacturing industry, so we state that the concepts that are widely applicable to different sectors belong to the broader area of Manufacturing Industry, and not to a particular sector. In this area reside the elements that are specific to the manufacturing industry and you won't find in other types of industries, for example, Finance, Assurance, Construction, Mining and Agriculture.

However, even some of the elements identified for manufacturing industry might be applicable to other different man-made systems. In this case, they belong to the even broader area of Designed Systems. A limited set of elements that conform to a base knowledge shared among different systems that are under human influence or subject to human decision-making, whether dedicated to manufacturing or not. A limited set of general concepts and relations that are universally accepted and understood across industries and sectors.

FLEXINET is creating semantic models for each of the concept groups depicted in Fig. 2. But, the focus for the GPN ontology is upon production systems and more specifically, product production systems and service production systems.

The FLEXINET approach to creating a flexible re-configurable model of a GPN is to utilise a formal reference ontology. GPNs are widely applicable to a range of manufacturing areas, e.g. within FLEXINET white goods, food and drink, and pumps are considered. To enable ease of construction, flexible re-use across domains and interoperability the FLEXINET ontology is organised into five levels,

as illustrated in Fig. 3. Each level inherits concepts from and provides supplementary concepts to the level above, the ontology becoming more domain specific with each level.

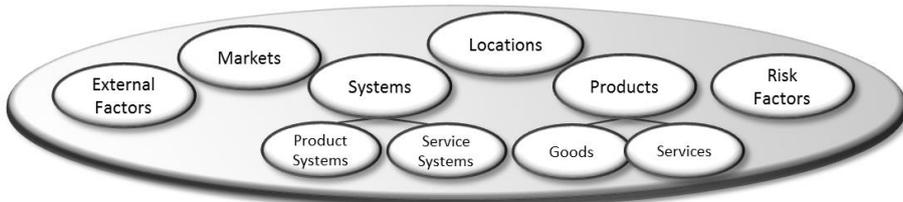


Fig. 2. The FLEXINET concept groups.

Level 0 Core contains highly general ontological concepts applicable to all domains and is based on the Highfleet Upper Level Ontology (ULO) [13]. Level 1 contains the minimal set of concepts that enables any system to be represented. Level 2 specialises systems into designed systems and natural systems using Banathy’s [14] classification. Designed systems represent anything man-made, for example manufactured goods, networks or knowledge. Natural systems represent anything natural, such as living organisms, planets and the universe. Level 3 focuses on manufacturing business systems which requires the capability to denote decision-making. A further specialisation is provided in level 4 into Product-Service Lifecycle Systems, implemented by FLEXINET as Global Production Networks. Level 5 represents specialist end user GPN application areas.

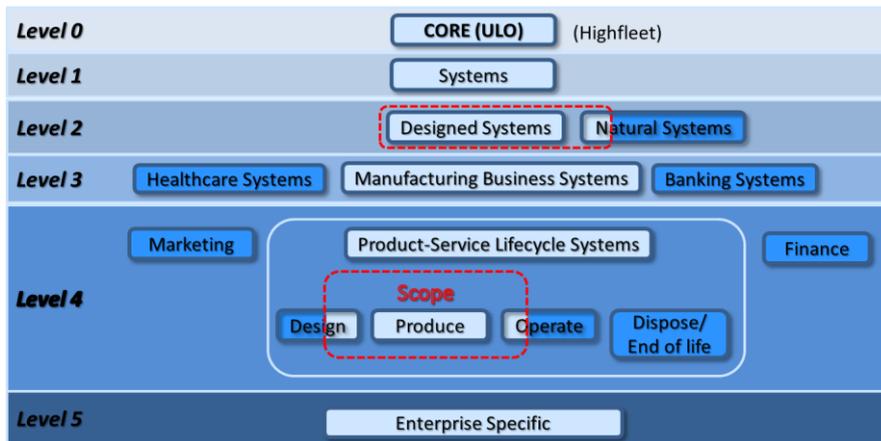


Fig. 3. Global production network reference ontology layers.

The scope of FLEXINET is indicated by the white areas. At level 2 the project’s scope extends into natural systems as the interaction of people with GPNs is considered. At level 4 the main area FLEXINET considers is “Produce” (producing the product-service) but the scope also overlaps into “Design” (of the global

production network) and “Operate” as the operation of the product and the service needs to be considered in design.

The Unified Modeling Language (UML) [15] notation method has been used to represent the reference ontology for ease of comprehension and is presented herein. The overall approach of the FLEXINET project is to develop and implement the reference ontology using a heavyweight formal approach, this being the Common Logic [16] based Highfleet Knowledge Framework Language (KFL) [13]. This provides a highly defined semantic approach that has the ability to provide the best possible level of expressiveness available. By utilising the Highfleet software package and KFL code, the associated Highfleet ULO must be used to build the formal reference ontology.

3.1 Reference ontology level 1

Fig. 4 illustrates the level 1 ontology using the UML method, detailing the concepts and relations necessary to specify a system. The focus of this approach is the representation of a system and the extension and formalisation of the IDEF0 concepts [17]. There are two main parent classes at level 1, those of basic and role.

A Basic concept [18] is independent of the system or context, its definition does not depend on another concept and an instance of a Basic always retains its identity as such. Basics occurring at level 1 and can be classified as System, Information, Material or Energy. It is anticipated there will be other categories, a potential one being Feature. The ontology will be extended to include these further categories when necessary.

A Basic can be comprised of Basics, a System is a subtype of Basic and provides a context for the Roles it contains (shown via the “depends on” relation and the composition filled diamond in the Fig. 4). The definition of a Role depends on a context and an instance of a Role cannot exist without a context.

Roles may be comprised of Roles. The “playsRole” relation is transient, i.e. it exists for a certain time. A Basic plays a Role for certain TimeSpans, modelled in the ternary relation “playsRole”. Roles are played within a scenario, as such Scenario concepts are defined within the ontology in order to provide a method to describe multiple alternative instantiations of Global Production Networks. Additionally scenarios can be composed of scenarios. Within the widely known ontology analysis methodology OntoClean [19] Roles are modelled as concepts which are not essential to their instances (anti-rigid), a typical example provided being a student [20] (This vision of Roles is implemented within the Highfleet development environment as the metaproperty “MaterialRole”). However, this research takes the view that many Roles are essential to the System that incorporates them. In addition, to model the concept of an empty role (i.e. a vacant or required role) it is essential that a Role concept cannot cease to be (is rigid). This research captures the changeability of Roles through the playsRole relations which explicitly models the times in which individuals participate in a Role.

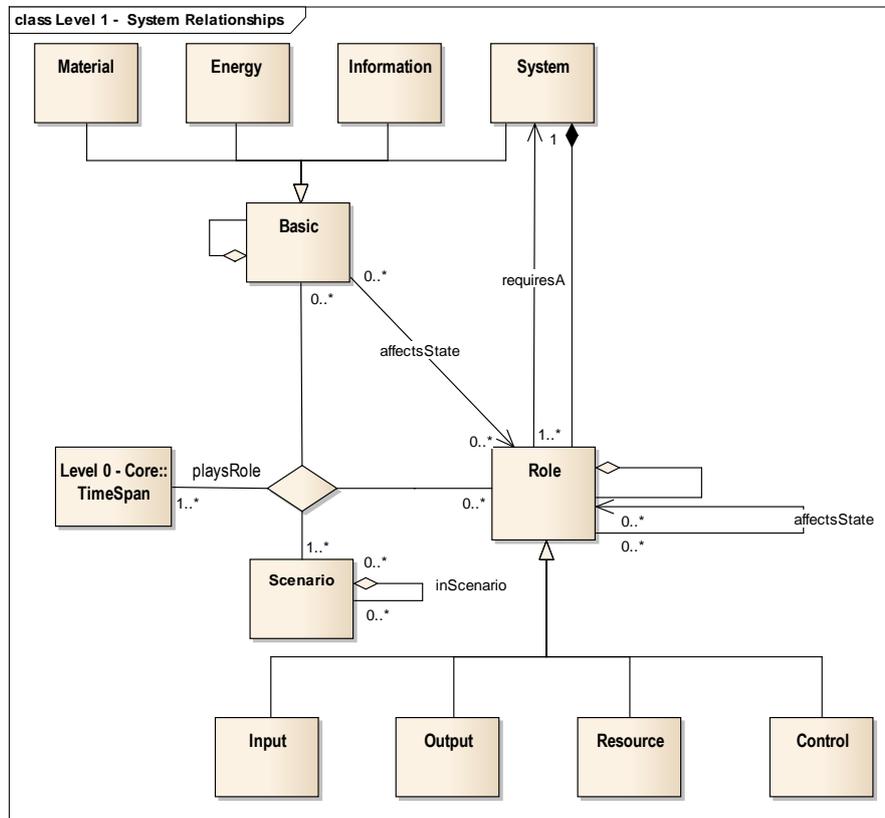


Fig. 4. Global production network reference ontology level 1.

This ontology level utilises the concept TimeSpan (inherited from Level 0) and contains two parent concepts: Basic and Role. A TimeSpan includes the first and last instants of a date and all the instants in between [21].

The modelling of Role as a specific concept is necessary to be able evaluate whether a system is capable of meeting specified requirements. The division of Basic and Role concepts enables the number of Role instances counted to differ from the number of Basic instances playing the Roles, see the Wieringa et al. [22] counting problem. A Basic can play more than one Role at the same time. A Role can be played by more than one Basic. There is no requirement for a Basic to play a Role (shown by the 0..* multiplicity next to the Role concept in Fig. 4). Role and Basic concepts exist separately and have separate identities. There is also no requirement for a Role to be played by a Basic, enabling empty Roles to be modelled. A Basic may affect the state of a role. Additionally a Role may affect the state of a Role.

The four key Roles that describe a system are input, output, resource and control. An input represents what is brought into and is transformed or consumed by the system to produce outputs. An output represents what is brought out from or is

produced by the system. A resource is used by or supports the execution of the system. A control is a condition required to produce the correct system output [17][23].

The final concept introduced at level 1 is that of Scenario. Scenario concepts are defined in order to provide a method to describe multiple alternative instantiations of system configurations that can be used to answer “what-if” questions. It is defined at level 1 in order to catch its relationship with Basics and Roles.

3.2 Reference ontology representation of a network

The UML diagram depicted in Fig. 5 illustrates the ontology design for the representation of a network for levels 1, 2, 3 and 4 (this is divided into levels of specialisation as per Fig. 3). Each level is specialised to represent more detail, hence, at Level 2 a network is represented, at level 3 a manufacturing network is represented, and at level 4 a global production network is represented.

The concepts that exist at Level 2 have been specialised from Level 1. To represent a network at level 2, the property of ‘network’ is a specialisation of system from level 1 (a subtype of Basic), additionally the property of a product is a specialised Role for the purposes of representation at level 2.

The key concepts at level 2 needed to represent a network (as per Fig. 5) are customer, supplier, product (which are subtypes of role), network (a subtype of system) and environ factors. For the purposes of FLEXINET, a product is a process output, A Supplier is “a party that supplies goods or services” [24], and a Customer is a “party that receives or consumes products (goods or services) and has the ability to choose between different products and supplier” [24]. Environ Factors are influencing factors from a System’s surroundings. For example, a production system will be influenced by surrounding production systems - a production system should not produce a product X, if X is produced by another production system nearby. Linked with these are two level 2 axioms:

- a network must contain more than one system
- a basic playing the role of an output must play the role of an input

The level 3 section of the ontology further specialises the properties used to represent a network at level 2, by progressing to the definition of a manufacturing network. The purpose of the level 3 aspect is to model and represent manufacturing processes and decisions. The concepts represented at the manufacturing business systems level 3 are manufacturer, manufactured product, manufacturing network, all of which inherit from their related level 2 concepts. Additionally, a gateway is represented to enable the ontology to support modelling of decisions regarding alternative process flows, this is a basic with at least one input and one output, based on the BPMN Gateway Process Element [25]. A Manufacturer is an “Entity that makes a good through a process involving raw materials, components, or assemblies, usually on a large scale with different operations divided among different workers” [24]. A Manufactured Product is a product that exploits or

consumes a raw material. A Manufacturing Network is a Network which is concerned with the design, finance or production of a Manufactured Product.

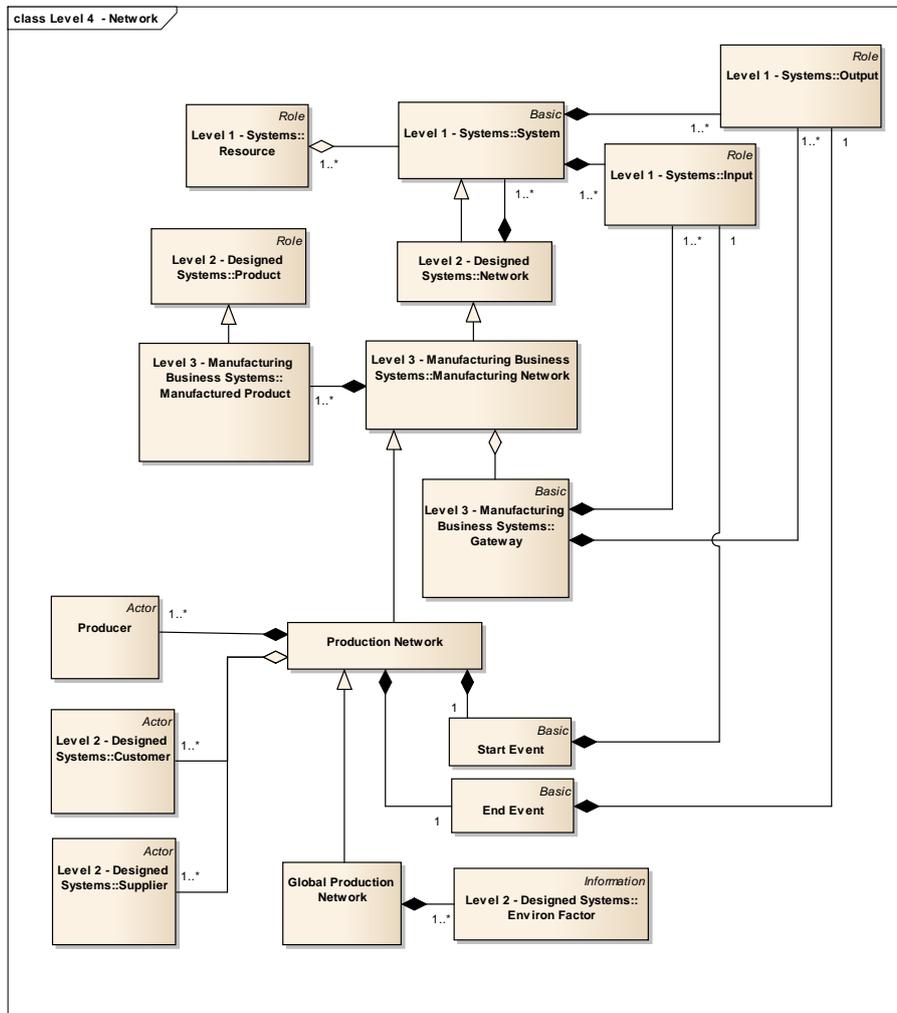


Fig. 5. Level 2 designed systems ontology concepts needed to represent a GPN.

For level 3 there are seven axioms that exist describing a gateway, these are:

- a diverging gateway has only one input and 2 or more outputs
- a converging gateway has 2 or more inputs and only one output
- an inclusive diverging gateway has one input and two or more outputs
- an inclusive converging gateway has one default input and two or more inputs

- an exclusive diverging gateway inherits from an inclusive diverging gateway
- an exclusive converging gateway inherits from an exclusive diverging gateway
- a manufacturing network must contain the role manufactured product

The level 4 section of the ontology further specialises the ontology used to represent a manufacturing network at level 3, by progressing to the definition of a global production network. The concepts added at this level are Production Network, Global Production Network (GPN), Producer, Start and End. A Production Network is a specialism of a Manufacturing Network which is concerned with producing a Manufactured Product. A Global Production Network is defined here as a specialism of a Production Network which contains Roles played by globally dispersed Systems. A Producer is "a person or business enterprise that generates goods or services for sale" [26] and is a sub-type of Role. A Production Network is concerned with a production process which requires a Start and an End. An End prevents infinite loops forming in the Production Network by providing a breakpoint. For level 4 there are eight axioms that apply, these are:

- a production network must have a start event and an end event
- a start event is a specialised type of basic which has an output role only
- an end event is a specialised type of basic which has an input role only
- the basic playing the role of a product(-service) must also play the role of an end event input in a production network
- a production network must contain the role producer
- a production network will contain the role supplier
- a production network will contain the role customer
- a system playing a role within a GPN must have environ factors

4. Conclusions

The work set out in this paper has put forward a four layered ontological model to provide the basis for a reference ontology to define and support global production networks. It is encouraging that this is currently being developed as a New Work Item presently defined as ISO 20534:2015, 'Formal Semantic Models for the Configuration of Global Production Networks', which was accepted at the last ISO/TC184/SC4 meeting. This stipulates that there is benefit in approaching the subject matter in this manner.

Commercial organisations constantly deal with uncertainty when reacting to customer needs and trying to introduce new technologies. The three industrial end users involved within FLEXINET have expressed and reinforced this viewpoint by way of a set of developed end user requirements and a number of developed use cases (see Fig. 6). Therefore, to meet these demands of the industrial end users within the project requires formal semantic models that can represent the complex, dynamic and transient nature of global production networks. These are needed in

order to respond effectively to the flexible production requirements demanded by the increasing business need for rapid product-service change. These standardised reference models provide the foundation from which industry specific solutions can be adapted and provide a shared basis upon which all the parties involved can develop a common understanding.

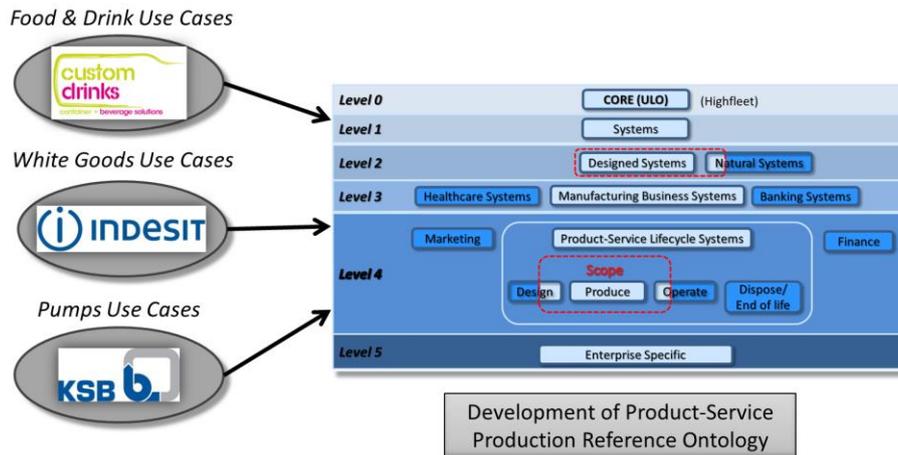


Fig. 6. Use case input into the development of the reference ontology.

FLEXINET has a clear ontological research objective, to 'define reference ontologies from which to base the flexible re-configuration of globalised production networks'. The definition of these standardised reference models has been the subject of an on-going EU FP7 project (FLEXINET 608627) and a related IMS project called Configuration Services for Global Product Networks (CSGPN). The resulting models are under test in three manufacturing sectors: the pumps and valves industry; the white goods industry; the food and drink industry.

Furtherwork will focus upon questions concerning (i) the ability of the reference ontology to sufficiently represent the three different manufacturing sectors represented by the industrial end users, (ii) definition of the key concepts and relationships within the reference ontology and (iii) to what extent can the rules and constraints be defined generally? Additionally, there will be effort placed upon validating the reference ontology approach. This will focus upon testing it utilising the end user use cases and results will be evaluated against the derived end user requirements. This will provide feedback and enable iterative development.

Acknowledgements

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