Reference Ontologies for Global Production Networks

Esmond Neil Urwin[1], Claire Palmer[1], Anne-Françoise Cutting-Decelle[2,6], Francisco Sánchez Cid[3], José Miguel Pinazo-Sánchez[4], Sonja Pajkovska-Goceva[5] and Robert Ian Marr Young[1]

[1]*Loughborough University, Wolfson School of Mechanical and Manufacturing Engineering, Loughborough, Leicestershire, U.K.*

[2]*Ecole Centrale de Lille, Cite Scientifique, CS 20048, 59651 Villeneuve D'Ascq Cedex, France*

[3]*Instituto Tecnológico de Informática, Camino de Vera s/n, Edif. 8G, Acceso B, CP 46022, Valencia, Spain*

[4]*Ainia Centro Tecnológico, Parque Tecnológico de Valencia, Avinguda de Benjamin Franklin, 5-11, 46980 Paterna, Valencia, Spain*

[5]*Fraunhofer Institute for Production Systems and Design Technology IPK, Pascalstraße 8-9, 10587 Berlin, Germany*

[6]*University of Geneva, CUI, ICLE, CH 1227, Carouge, Switzerland*

Keywords: Ontology, Standards, Interoperability, Global Production Network.

Abstract: The development and utilisation of flexible, reconfigurable Global Production Network organisations presents issues for the sharing and reuse of information and knowledge between systems and domains. The research approach put forward in this paper posits that manufacturing reference ontologies can provide the necessary underlying flexibility in a semantic-base to support interoperability. Moreover for that to be of real value to industry it needs to be commonly applicable across the breadth of manufacturing business and therefore be offered as a standard.

1 INTRODUCTION

As globalisation continues at a fast pace, Global Production Networks (GPN) are becoming ever more important to industry and commerce. By employing a GPN an organisation can become more adaptive to change, adopt technology at a faster pace, lower its costs (Coe *et al.,* 2008) and ultimately be more successful at fulfilling its customer and end user needs. Indeed it can be mooted that by utilising specific suppliers in target markets products can become more attractive to customers, this has often been the case for the aerospace industry. However, a GPN can expose organisations to a diverse range of risks. Utilising a network spread over a geographically wide area can induce perturbations, bringing about delays in communication and the sharing of information. Moreover the mere comprehension and utilisation of information between numerous and varied suppliers and systems within a network can sometimes be insurmountable without considering the different domains that each potential supplier works within. What this means is that the structure and definition of information is of paramount importance if interoperability is to be achieved. The concept of flexible and reconfigurable GPN highlights the need for improved interoperability standards and the development and application of reference ontologies to help overcome boundaries between different domains, cultures and languages.

Research presented within the literature has focused upon interoperability for enterprises and manufacturing, but less so upon interoperability for GPN (Panetto and Molina, 2008; Panetto, Goncalves and Molina, 2012; Young *et al.,* 2007; Borgo and Leitão, 2007). A number of manufacturing models have been developed for the purposes of semantic interoperability and the consolidation of production centric standards (Chungoora and Young, 2011; Chungoora *et al.,* 2012; Chungoora *et al.* 2013a) which aim to develop a basis for knowledge sharing between different domains.

Young *et al.* (2009) set out a manufacturing reference ontology developed from the Interoperable Manufacturing Knowledge Systems (IMKS) project. Aligned with this is the Manufacturing Core Ontology (MCO) presented by Chungoora *et al.*

Neil Urwin E., Palmer C., Cutting-Decelle A., Sánchez Cid F., Miguel Pinazo-Sánchez J., Pajkovska-Goceva S. and Young R..
Reference Ontologies for Global Production Networks.
DOI: 10.5220/0005026001330139
In *Proceedings of the International Conference on Knowledge Management and Information Sharing* (KMIS-2014), pages 133-139
ISBN: 978-989-758-050-5

(2013b). These approaches focus on ameliorating 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.

This paper sets out an approach being developed by the EU FP7 FLEXINET project for the development of reference ontologies from which to base the flexible re-configuration of globalised production networks. This takes into account the potential types of interactions that are necessary between multiple systems across multiple enterprises. The main aims of the FLEXINET ontological research are the following, (i) document key semantic concepts, knowledge constraints and inter-relationships in the context of globalised production networks, (ii) structure and formally model concepts, relationships, constraints and related facts to provide an underpinning environment against which specific network configuration designs can be evaluated and (iii) develop methods for ontology querying from which to evaluate the compliance of potential production network configurations from both OEM and SME perspectives.

2 GLOBAL PRODUCTION NETWORKS: THE NEED FOR REFERENCE ONTOLOGIES

In competitive and time sensitive market places, organisations are tasked with providing product-service solutions that can achieve and maintain competitive advantage. They must be able to react to change and to understand the balance of possible options when making decisions on complex multi-faceted problems. A major part of the development and delivery of such commodities is the application and use of Information Communication Technologies (ICT) to enable the sharing, use and reuse of information and knowledge between different and often disparate groups of people and systems in different domains. Currently problems are still encountered when trying to share information between systems and people as organisations' ITC systems and software tools have different ways in which information and knowledge is represented, formatted, stored, sorted and accessed relative to their business domain, requirements and needs. Thus the aim of achieving interoperability between such systems and tools for the supposed seamless interchange and exchange of information both within and between organisations is ostensibly an arduous and problematic challenge to address. To tackle and achieve this, improved semantic communication is needed by way of developing and applying reference ontologies to the problems at hand and use standards to support these to enable a common and shared basis with which to allow systems to interoperate more effectively.

Fettke and Loos (2003) define a reference model as *'a model representing a class of domains*' and describe it as a *'blueprint for information system development'*. They are used to designate *'standardized technical architectures'* (ISO, 1994), applying reference models can accelerate the development of ICT systems and structures, decrease costs, risks, modelling time and increase modelling quality (Fettke and Loos, 2006). Standards present a common format or vocabulary with which to exchange data between systems. At present there are a number of international standards being developed by ISO/TC184/SC4 and ISO/TC184/SC5 which focus upon interoperability, for example ISO 15531-44:2010 and ISO 11354-1:2011. These concentrate upon enterprise and manufacturing interoperability, per se there is a need for standards that address the sharing of information between systems and domain boundaries, to which ISO SC4 cites the need for formal ontologies. The research approach put forward in this paper posits that manufacturing reference ontologies can provide the necessary underlying flexibility in a semantic-base to support interoperability. Moreover for that to be of real value to industry it needs to be commonly applicable across the breadth of manufacturing business and therefore be offered as a standard.

3 THE FLEXINET APPROACH

FLEXINET aims to support decision-making in the early design of global production network configurations based on the implementation of new complex technologies. FLEXINET will apply advanced solution techniques to the provision of a set of Intelligent Production Network Configuration Services that can support the design of high quality manufacturing networks, understanding the costs and risks involved in network re-configuration, and then mitigating the impact of system incompatibilities as networks change over time. These are fundamental requirements for high quality decision-making in the early design of intelligent manufacturing system networks. These innovative concepts will enable a fast and efficient response to market variations and be easily adaptable across industrial sectors. The FLEXINET concept is illustrated in Figure 1 below.

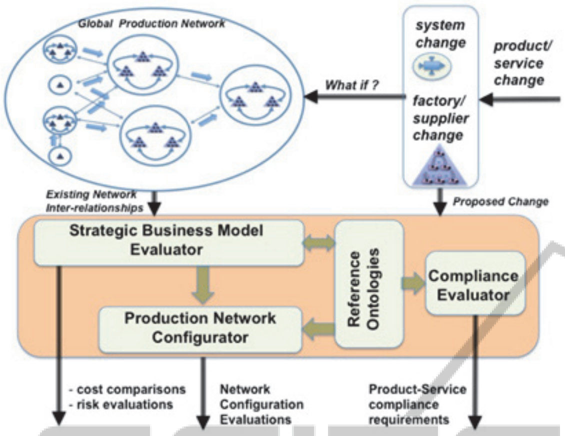

Figure 1: The FLEXINET Concept: Intelligent Production Network Configuration Services.

FLEXINET takes the view that new manufacturing business modelling methods are needed that can model business cases and identify the critical network relations that underlie the business operation. Such methods and models are essential to the ability to define both the production network knowledge that must be captured and the queries that must be made if new business configuration possibilities are to be evaluated. Product servitisation adds to the complexity of this problem as the relationships between product lifecycles and service lifecycles also need to be understood and their impact on production system networks specified within the resulting business models.

4 DEVELOPMENT OF REFERENCE ONTOLOGIES FOR GLOBAL PRODUCTION NETWORKS

The first step taken has been to underpin the development of the FLEXINET reference ontologies with a clear and systematic methodological approach. A mixed methods (Creswell, 2008) approach is being used by combining a multiple case study approach (Yin, 2009) together with the application of the knowledge engineering methodology of Noy and McGuiness (2001). The multiple case study approach consists of three industrial case studies covering three different industrial domains. Information and knowledge has been elicited from these cases and is being analysed to focus upon the key global production network concepts that are of interest to the industrial project partners. As part of this approach, work from the IMKS research project, MSEE research project and existing international standards are being assessed and explored for applicability within the GPN domain to utilise them where possible. The reference ontologies that have been produced as part of the IMKS project have been semantically expressed in common logic (a first order logic language expression) and formally tested in knowledge sharing and interoperability experiments, hence these have been corroborated and validated. Additionally Hastilow (2013) has produced some interesting ontological research looking at Manufacturing Intelligence, to which an initial appraisal of this shows that there could be a high level of applicability to the GPN domain.

One of the main facets of the FLEXINET project will be to develop a set of reference ontologies from which to base the flexible re-configuration of globalised production networks taking into account the potential types of interactions that are necessary between multiple systems across multiple enterprises. This will result in a clear understanding of the types of concepts involved in the reconfiguration of product-service globalised production networks and the constraints that must, or may, be considered when reconfiguring a network. The resulting knowledge formalisation, extended with a fact base, developed in Common Logic, will support network design by providing answers to “what if” queries that can be used to compare alternative potential network configurations. These comparisons will identify the extent to which interacting systems in the network comply with the conceptual interaction requirements inferred from the developed ontologies. Figure 2 shows the initial FLEXINET Ontological approach, the premise being that enterprise ontologies must be built from a common base for ease of construction, effective interoperability and flexible re-use. This is illustrated by the upper three reference ontology levels those of (i) the Systems Foundation Ontology, (ii) the Manufacturing Systems Core Concept Ontology and (iii) the Product-Service Production Ontology. The next two ontology levels represent (iv) the Sector Specific Concepts and (v) the Enterprise Specific Concepts. For each of these ontology levels there will be a set of mapping rules, integrity constraints, relationships and functions, together with a taxonomy of classes.

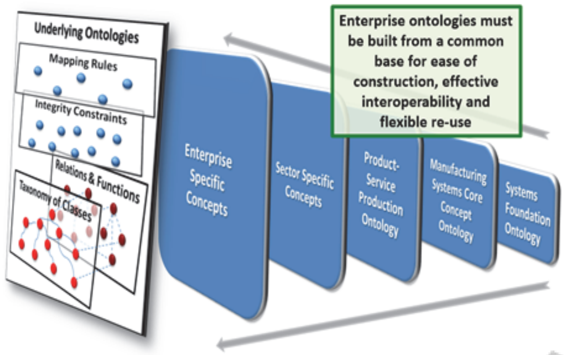

Figure 2: The FLEXINET approach to ontology development.

Subsequent research work has further developed and refined the reference ontology approach which is exemplified in Figure 3. Six levels have now been defined. Levels one to five represent the FLEXINET reference ontology. The core foundation ontology or level zero represents foundation concepts that are relevant to all domains. The concepts within this level have been derived from the Highfleet Upper Level Ontology (ULO) (Highfleet).

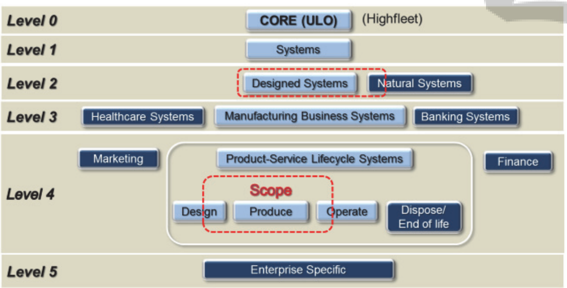

Figure 3: The FLEXINET reference ontology levels.

One aim of the FLEXINET project is to develop a reference ontology by applying a heavyweight ontological approach, this being the Knowledge Frame Language (KFL) which is based upon common logic (ISO/IEC 24707:2007). The approach is being realised by utilising the Highfleet Integrated Ontology Development Environment (IODE) which is enabling the ontologies to be queried and applied to the end user needs to develop solutions. This approach will ameliorate levels of semantic representation and definition, with a view to enabling a common base for seamless interoperability.

The FLEXINET levels each inherit concepts from the respective level above but, also provide concepts to the level below; each of the levels becomes more specialised or domain specific. The FLEXINET scope is highlighted in Figure 3 by lighter coloured domain boxes in the five levels. The dotted lines in levels two and four illustrate that the project's scope extends into natural systems at level two and design and operate at level four. These domains are therefore being considered and studied but not in totality.

Level one concerns systems and possess a set of concepts that enable any system to be represented. Level two is focused upon designed systems and natural systems. Banathy's (1992) classification has been applied to aid the specialisation of the level one 'systems', to which designed systems represent anything man-made, for example manufactured goods, information or knowledge. Alternatively natural systems represent anything natural, such as living organisms, planets and the universe. Level three provides a further specialised view, the main focus being upon manufacturing business systems. These in turn are specialised in level four by way of Product-Service Lifecycle Systems (PSLS). FLEXINET is focused upon global production networks which are viewed as a specialisation of a PSLS, the scope of these being focused upon 'produce' but also considers aspects of 'design' and 'operate', these are related the view of a product lifecycle. Level five represents the end user specific domains and related case studies.

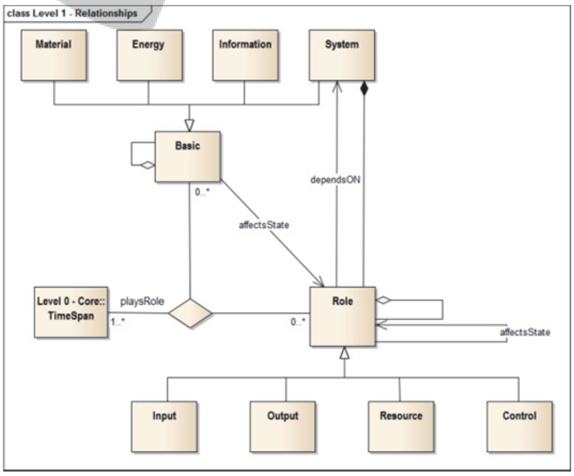

Figure 4: The FLEXINET Level 1 'systems' reference ontology.

The level one 'systems' ontology is illustrated in Figure 4, using the Unified Modeling Language (OMG) to model the concepts and relations needed to specify a system.

Within this level are two parent concepts, those being 'basic' and 'role', together with a level zero inherited concept that of 'timespan'. Basic as a concept (Mizoguchi *et al*., 2012) is independent of system and context, to which an instance of it retains its identity, some examples of basic are material, energy and information, 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. As per Figure 4 the UML states that a basic can be comprised of basics, an example of this being the basic 'bread' being composed of the materials 'wheat', 'yeast', 'water' and 'salt'. A TimeSpan includes the first and last instants of a date and all the instances in between (Highfleet).

A role is transitory and depends upon a context. An example of the key 'roles' applied to a 'designed system' is an IT System in which input roles are played by the basics 'information' (for example in the form of keyboard signals and numbers), output roles are played by 'information' (e.g. in the form of monitor signals and numbers), the resource role is played by a basic 'person' (a Natural System) who acts as the operator and control Roles are played by the material 'control unit' and the information 'analysis algorithm'.

A natural systems example is a tree. Input roles are played by the basics materials 'carbon dioxide' and 'water' and energy (solar) which also play resource roles for this system. Output roles are played by the materials 'glucose', 'oxygen' (both produced by photosynthesis) and 'water' (produced by transpiration). Control roles are played by the information 'concentration of carbon dioxide'", 'light intensity', 'temperature' (controlling photosynthesis), 'humidity' and 'wind strength' (controlling transpiration).

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 (Wieringa *et al*., 1995). For example, one person (instance of a Basic) can play two production manager roles, over two different time periods in two specific job roles. A basic can play more than one role at the same time (e.g. a person could be a production manager (context "manufacturing business") and a football player (context "sport").

As per the cardinality set out in Figure 4 for a basic 'affectsState' of a role, a basic does not have to play a role as they occur independently. Conversely a role does not have to be played by a basic, thus unfilled roles can exist, for example a person can leave the role of production manager, but the position of production manager can still exist and therefore be vacant.

The concept of system is a subtype of basic which provides the context of roles that are contained within it according to the 'composition' relation in the Figure 4.

Timespan represents the amount of time for a basic playing a specific role, this is modelled by the ternary relationship 'playsRole' For example in the context of a manufacturing organisation system, the basic 'spreadsheet' can play the role of Information during the TimeSpan of the system.

Input, output, resource and control are the four essential roles that represent a system. These follow the basic concepts of systems engineering and utilise views of information and material flows through systems in line with IDEF0 (PUB, 1993; POP*, 2006).

5 CONCLUSIONS AND FURTHER WORK

Knowledge elicitation and engineering are complex and time consuming tasks that utilise a large amount of resources to fulfil stated objectives successfully. The FLEXINET ontological research objectives are clear and succinct, that is to *'define reference ontologies from which to base the flexible re-configuration of globalised production networks'*. The domains of enterprise and manufacturing interoperability have garnered research attention over the past few years, but the subject of global production networks as of yet has very few examples of interoperability and reference ontology research work. Thus it is important to draw upon related reference ontologies and international standards to explore their applicability and develop consistent and representative reference ontologies for the design of globalised production networks for dynamically changing product-service systems.

This work highlights the need for well-defined higher level core or foundation ontologies that can act as a base for the generation and building of reference ontologies, not only for global production networks but other domains that are related and have potential for interoperation.

The work has defined a key element of the approach, which is the level 1 "systems" ontology. This is now in the process of being formalised and the programme of work is continuing to develop the subsequent levels of the reference ontology and then to test its applicability against our three manufacturing end users requirements.

ACKNOWLEDGEMENTS

The research leading to these results has received funding from the European Community's 7th Framework Programme under grant agreement nº NMP2-SL-2013-608627.

REFERENCES

Banathy, B. H., 1992. *A systems view of education: Concepts and principles for effective practice*. Englewood Cliffs, New Jersey: Educational Technology Publications.

Borgo, S., and Leitão, P., 2007. Foundations for a core ontology of manufacturing. *Integrated Series in Information Systems*, 14, pp. 751-775.

Coe, N. M., Dicken, P., and Hess, M., 2008. Global production networks: realizing the potential. *Journal of Economic Geography*, 8(3), pp. 271-295.

Chungoora, N., and Young, R.I.M., 2011. The configuration of design and manufacture knowledge models from a heavyweight ontological foundation. *International Journal of Production Research*, 49(15), pp. 4701 - 4725.

Chungoora, N., Gunendran, G. A., Young, R. I. M., Usman, Z., Anjum, N. A., Palmer, C., Harding, J. A., Case, K., and Cutting-Decelle, A. F., 2012. Extending product lifecycle management for manufacturing knowledge sharing. *Proceedings of the Institution of Mechanical Engineers Part B - Journal of Engineering Manufacture*, 226 (A12), pp. 2047-2063.

Chungoora, N., Cutting-Decelle, A-F., Young, R. I. M., Gunendran, G., Usman, Z., Harding, J.A., and Case, K., 2013a. Towards the ontology-based consolidation of production-centric standards, *International Journal of Production Research*, 51(2), pp. 327-345.

Chungoora, N., Young, R. I. M., Gunendran, G., Palmer, C., Usman, Z., Anjum, N. A., Cutting-Decelle, A. F, Harding, J. A., and Case, K., 2013b. A model-driven ontology approach for manufacturing system interoperability and knowledge sharing. *Computers in Industry*, 64, pp. 392-401.

Creswell, J.W., 2008. *Research design: qualitative, quantitative, and mixed methods approaches* (3rd Edition). Thousand Oaks: California, Sage Publications Inc.

Fettke, P., and Loos, P., 2003. Classification of reference models - a methodology and its application. *Information Systems and e-Business Management*, 1(1), pp. 35-53.

Fettke, P., and Loos, P., 2006. Using Reference Models for Business Engineering - State-of-the-Art and Future Developments, *Proceedings of the 3rd International Conference on Innovations in Information Technology*, Dubai, United Arab Emirates, November 19-21, pp.1-5.

Hastilow, N., 2013. An Ontological Approach to Manufacturing Systems Interoperability in Dynamic Change Environments. PhD Thesis. School of Mechanical and Manufacturing Engineering, Loughborough University, UK.

Highfleet Ontology Library Reference, 2014. Baltimore, MA, HIGHFLEET Inc.

Integrated ontology development environment (IODE). http://www.highfleet.com/iode.html (accessed June 2014).

ISO 11354-1:2011, Advanced automation technologies and their applications - Requirements for establishing manufacturing enterprise process interoperability - Part 1: Framework for enterprise interoperability. Genève, Switzerland.

ISO 15531-44:2010, Industrial automation systems and integration - Industrial manufacturing management data - Part 44: Information modelling for shop floor data acquisition. Genève, Switzerland.

ISO (1994). Information technology - Open Systems Interconnections - Basic Reference Model: The Basic Model, ISO/IEC 7498-1:1994(E), second edition, corrected and reprinted 1996-06-15. Genève, Switzerland.

ISO/IEC 24707:2007. Information technology – Common Logic: a framework for a family of logic-based languages. Genève, Switzerland.

Mizoguchi, R., Kozaki, K., and Kitamura, Y. (2012, September). Ontological analyses of roles. Federated Conference on Computer Science and Information Systems (FedCSIS), Wroclaw, Poland, September 9-12, pp. 489-496.

Noy, N. F., and McGuinness, D. L., 2001. Ontology Development 101: A Guide to Creating Your First Ontology, *Development*, 32(1), pp. 1-25.

OMG, 2012 OMG unified modeling language (OMG UML), superstructure and infrastructure version 2.4.1 [online]. Available from: http://www.omg.org/spec/UML/2.4.1/ [Accessed 26 June 2014].

Panetto. H., and Molina, A., 2008. Enterprise Integration and Interoperability in Manufacturing Systems: trends and issues. *Computers in Industry*, 59(7), pp. 641-646.

Panetto, H., Goncalves, R., and Molina, A., 2012. Enterprise Integration and Networking: theory and practice. *Annual Reviews in Control*, 36(2), pp. 284-290.

POP* Revised framework Work package – A1.8, 2006. Athena European integrated project no. 507849 public deliverable.

PUBs, F., 1993. Integration definition for function modelling (IDEF0). Federal information processing standards publication, 183.

Wieringa, R. J., de Jonge, W., and Spruit, P. A., 1995. Using dynamic classes and role classes to model object migration, *Theory and Practice of Object Systems*, 1(1), pp 61-83.

Yin, R. K., 2009. *Case study research design and methods*. Thousand Oaks: California, Sage Publications Inc.

Young, R. I., Gunendran, A. G., Cutting Decelle, A-F., and Gruninger, M., 2007. Manufacturing knowledge sharing in PLM: a progression towards the use of heavy weight ontologies, *International Journal of Production Research*, 45(7), pp.1505-1519.

Young, R. I. M., Gunendran, A. G., Chungoora, N., Harding, J. A., and Case, K., 2009. Enabling interoperable manufacturing knowledge sharing in PLM. *Proceedings of the Sixth International Conference on Product Life Cycle Management PLM09*, University of Bath, Bath, UK, July 6-8, Switzerland, pp.130-138.