Intelligent Wireless Manufacturing IT Methodologies and Technologies

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Abstract— **The Australian mining industry has introduced a new set of requirements on the construction industry in the fabrication and assembly of temporary dwellings for employees in rural areas. However, requirements such as rapid multi-site development, late customization, transportation and final assembly within very strict deadlines have resulted in many project failures and lost revenue. This paper outlines some proposals for the mining and construction industries that are seeking to develop new modes of operation which promote; multi-site development, track and trace visibility of manufacturing operations and their supply-chain.**

Keywords- Wireless devices and networks, manufacturing, ontology

I. Introduction

Rapid fabrication and assembly of temporary dwellings is a crucial requirement that is dictated by the fast moving Australian mining sector. However, requirements such as rapid multi-site development, late customization, transportation and final assembly within very strict deadlines have resulted in many project failures and lost revenue in the past. Such failures have led to the construction industry seeking to develop new modes of operation which promote;

- Optimization of the communication and process flows.
- Efficient data capture and visualization.
- Material flow monitoring and control monitoring.
- Assessment and tracking of timing information related to particular events and processes.
- Enforcement of project constraints while taking into account limitations of the resources available.
- Conformance and progression of a product's development against the proposed production plan and rules, regulations and standards.

Through our investigations we have defined two key areas of research to partially solve the above-mentioned problems. Firstly, multi-site development has been plagued with several communication and integration problems. Secondly, the software technologies and hardware devices that are required to undertake such projects are currently immature.

The solution to the requirements outlined above can only be met through new cutting-edge IT methodologies and technologies. The aims of our project are to produce a highly reconfigurable multi site production solution that addresses the issues of communication, coordination, situation awareness for multi-site manufacture and construction. Such a system must provide the following functions;

- Multi-site component-based development with varying levels of granularity that uses an increasingly iterative and hierarchical methodology with high degrees of re-configurability and automation.
- The use of cutting-edge technologies that offer complete track and trace visibility of all manufacturing operations and their supply-chain.

The paper is organized as follows; Section I provides background information. Section II discusses Multi-Site Development and Rapid Re-Configuration. Section III outlines Track and Trace Technologies and Section IV examines Manufacturing Ontologies. Section V Concludes the paper.

II. Multi-site Development and Rapid Re-Configuration

Most of the production engineering process models that are in existence assume a centralized approach to development. This assumption is also present in many of the current production engineering methodologies. However, there are many situations where such an assumption is inappropriate. We have noted that many technologies have not yet become mature to facilitate multi-site development. Process models, methodologies, technologies and approaches cannot be followed linearly in a multi-site development environment.

A recent trend for large project contracts is for the project managers or project directors to be in one place, and the team leaders and development teams to be spread across several countries or cities. As development projects proceed through the specification, design and implementation phases, the physical distance between development teams becomes a crucial issue if the specifications are not complete, are ambiguous or are continually evolving. It is crucial that smooth communication can take place to allow the project managers to monitor the progress and quality production, so that the whole project can be delivered on time and within budget.

Digital Object Identifier: 10.4108/ICST.ITREVOLUTIONS2008.5147
http://dx.doi.org/10.4108/ICST.ITREVOLUTIONS2008.5147

The following scenarios demonstrate the need for a multi-site distributed software development methodology:

- The clients and the developers may not be from the same region, city or even the same country. This could arise from the organization not being able to identify the best quality team in the local area, or the system contract being let through a tender process. The challenge is to get the model of development right, the specification and solution right and to ensure the end product meets the customer's needs.
- Since development in these environments employs a mostly adhoc component-based approach, the interpretation of components specifications can lead to incompatible components where the integration team who assembles the final product may find it hard to overcome technical difficulties without face-to-face communication.
- Quality measurement, component based testing, standards and procedures auditing, user acceptance and usability activities require intimate contact with users and well defined specifications.

However, existing methods for information based production engineering such as client server and blackboarding have not addressed the multi-site distributed production development environment. Amongst other things, they require:

- That the sites from which the data is entered are relatively fixed.
- That the production team members are collocated sufficiently to be able to communicate face to face to resolve issues and have a similar understanding of the underlying terminology and concepts and relationships within the domain.
- That the production team members are sufficiently computer literate in the software systems deployed.

Therefore, the need for this multi-site development is therefore of considerable significance.

III. CUTTING-EDGE TRACK AND TRACE TECHNOLOGIES

Recent advances in wireless technology have enabled the development of low-cost wireless solutions capable of robust and reliable communication and user interaction. International standards such as the IEEE 802.11a/b/g [1][2][3][4] for wireless local area networks and the IEEE 802.15.4 [5] for low-rate wireless personal area networks, as well as numerous RFID (radio-frequency identification) specifications, have enabled applications such as wireless networking, wireless sensing, monitoring and control, and wireless asset and personnel tracking. Wireless technology has the potential to be beneficial to the manufacturing industris in many regards [6]. Eliminating the need for cables can contribute to reduced installation and operating costs, it enables installations in remote and hostile areas, and it allows for cost-efficient temporary and mobile installations that can capture and display data in the field. This provides great visibility for both development and management teams in a dynamic multi-site environment.

In order to achieve our aims we employ Digital Pen and Bluetooth Technologies. These technologies have been chosen over client site workstations and PDAs. We have found that PDAs are not suitable to manufacturing environments because of the following properties;

- Complicated to use
- Require user training
- Relatively unreliable
- Easy to break
- Limited battery life
- Limited screen real-estate

Digital pens allow the user to digitally capture handwritten data while in the field. Such pens typically look and operate like a regular pen and can be used as such. However, digital pens require a virtually invisible special digital pattern to be printed on each page which uniquely identifies the form that is being used, what is being written, where it is written and when this has occurred. Handwriting recognition software imports handwritten notes as typed text in specific fields / areas. For security purposes, each pen has a unique identifier which allows recorded information to be traced back to its source. Therefore, with the appropriate wireless Bluetooth networks and compatible mobile telephone, it is possible to digitize existing field forms and have data that is stored in enterprise databases as it is being written. It is then immediately available on backend systems around the world providing comprehensive and timely production visibility. Digital pens offer the following benefits;

- **Transparent Transition and Acceptance –** The paper forms required by digital pen solutions require imperceptible changes; they replicate existing paper forms and documents almost exactly. Therefore, digital pens can be flexibly deployed at virtually any sites because they are infinitely easy to use and they require no training. Digital pens can employed in the presence of employees with relatively poor computer literacy without any formal training. Users continue to perform their roles while transparently structuring and digitally preserving everything they write.
- **Electronic Forms –** Structured written information is electronically transmitted to a central database where it can be accessed as required. Time-critical data availability aids management decision making and reaction to manufacturing requirements.
- **Data Backup -** Digital pens and paper creates both printed and digital records of forms that can be accessed by authorized personal while maintaining an appropriate paper-trail. Reporting and compliance is maintained.
- **Physical Proportions -** Digital pen and paper is less physically intrusive than laptops or PDAs.
- **Paper Trail and Traceability -** The digital pen and paper can each have unique identifiers which enable the pen to track and identify signatories. Information is

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traceable back to a specific pen and data is time-stamped for added accountability.

- **Cost -** Digital pen and paper for forms processing are cheaper than equivalent computers or mobile devices. With a relatively modest investment and minimal instruction, companies could achieve significant cost savings, and streamline processes.
- **Reliable, Durable Performance –** Digital pens are simple and highly reliable and durable. They offer great battery life.
- **User Interface -** As a result of the their digital paper interface, an A4 page offers equivalent screen real-estate as a static A4 sized computer screen.

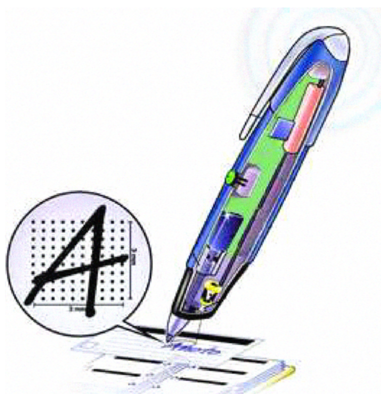

Figure 1. Digital Pen and Paper

Manufacturing may require thousands of parts and processes that must conform to certain specifications, performance characteristics and standards. Often, such parts and their use is developed and governed by third-party companies that reside in different countries. Digital forms allow users to quickly visualize component specifications and complete reports. This information is fed into a central system where managers and other concerned parties monitor production and react to manufacturing requirements. Digital pens may monitor the production process and the movement, flow, storage and consumption of materials and general production performance.

IV. MANUFACTURING ONTOLOGIES

Changes are inevitable during development projects; such activities are continuously confronted with an evolving specification problem. If these changes are not properly tracked and traced or maintained, this would impede the development and third party integration of components.

Ontologies are a formal, explicit specifications of a shared conceptualization that are machine-understandable, explicitly defined abstract models that represent consensual knowledge that is widely accepted. Ontologies are concerned with all processes of component production from the stages of component requirements through verification and validation. They define concepts, abstractions, relationships and interactions as domain concepts and instantiations for manual or automated reasoning. These ontologies signify standardized project information which evolves to reflect a development environment. It fosters a seamless and virtual intra project environment of project data across sites and third party vendors / buyers. When coupled with multi-agent systems, ontologies allow greater ease of communication by aggregating the project knowledge with domain knowledge, and other concepts into a shared information resource platform that is distributed amongst the development team and others that reuse the projects artifacts. The ontology enables effective ways of distributing such knowledge. Reaching such a consensus of understanding is of benefit in a distributed and/or third-party component development environment.

With the use of Ontologies, project concepts, ideas and knowledge, development methodologies, tools and techniques are organized into an ontology that is used as the basis for explicitly classifying project concepts in a standardized way. We have merged Gruber's [7], Borst's [8], and Studer's [9] definitions of an ontology as a basis for our discussion here. Using such an ontology, it is possible to define concepts through uniquely identifying and identifying their specifications and their dynamic and static properties. Concepts, their details and their interconnections are defined as an ontology specification.

External entities may access this data in order to formally evaluate project details. Ontology compositions are typically formed from many interconnected components that are constructed in an iteratively layered and hierarchical manner.

Ontology research naming conventions vary (e.g. Ontology Commitment [10], [11], Ontology Version [12], Materialized Ontology View [13]. In general four aspects of multi-site development can be distinguished:

- **Information and Communication -** refers to the basic ability to gather, exchange and respond to information of any required form in the collaboration process between the parties involved.
- **Integrability -** relates to the ability of components from different sources to mesh relatively seamlessly and the ability to integrate these components to build the final product.
- **Coordination -** focuses on scheduling and ordering tasks performed by these parties.
- **Awareness and Cooperation -** refer to the knowledge of the production process of work being performed, progress achieved and decisions made by others.

An ontology framework enforces an agreement on how information should be organized, without losing any of the flexibility of allowing people to express and view parts in their own familiar expression language. The ontology driven architecture proposed reduces conceptual and terminological confusion by providing a unifying framework within an organization through:

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http://dx.doi.org/10.4108/ICST.ITREVOLUTIONS2008.5147

- **The normative model -** which creates a semantic for the system and an extendible model that can later be refined, and which allows semantic transformations between different contexts from different sites.
- **The network of relationships -** which can keep track of progress and monitoring quality and productivity from development teams in different locations
- **Creating consistency -** provides unambiguous definitions for terms in the production system.
- **Allowing integration -** by providing a normative model and integration of components developed in different places can be achieved.

The integration of a number of (existing) ontologies for other domains can be used to augment the functionality of any framework using the base ontology. This base ontology would in general terms overlap with external ontologies. These ontologies provide a distributed workflow technique across multiple sites with appropriate shared repositories, an ability to enforce pre-conditions and post-conditions on development activities and the artifacts developed, and task tracking with overall co-ordination. Multi-site issues are addressed through;

- Process Ontology develops a representation of the different types of processes involved in Manufacturing / Construction. Previously Taxonomies for manufacturing processes have been developed by Holland [14] and refined by Lastra [15]. These ideas were extended to an Ontology by Delamar [16]. These were largely relevant for mechanical production processes at a single site. Specifically they did not include manufacturing or construction activities nor did they allow specification of activities at multiple different sites.
- Product Ontology represents the different types of products or units that will result from the manufacturing / construction activity. They involve classification of the products by features as well as capturing the geometrical layout which is particularly important for construction. Here the relationships involved and the layout configurations are captured.
- Component Ontology provides a representation of all the components involved in the manufacture / construction activity at the different levels of granularity. As each large granularity component is likely to consist of subcomponents itself it is important that these are all represented within the ontology. Here, it is important to specify the functionality, geometrical aspects and the source of the component whether inhouse fabricated or externally sourced.

Each defined ontology conceptually represents the perceived domain knowledge through its concepts, attributes, taxonomies, relationships, and instances for manufacturing. Restrictions need to be applied to the above definitions in order to ensure that they are practically usable.

It is necessary to use a graphical representation of ontologies at a higher level of abstraction to make it easier for the domain experts to capture the semantic richness of the defined ontology and understand and critique each model In our previous work, we have developed such a notation [17] and utilized it successfully for the development of several ontologies including for the Trust and Reputation Domain [18] the Software Engineering Domain [19] the Disease Ontology [20] and the Protein Domain [21]. We intend to utilize this for our representation language for the modeling phase.

The ontology-based architecture is grounded on the notion of a base ontology sub-ontologies [22] or commitments [23] These sub-ontologies are used as independent systems (in functionality) for the various decentralized development teams. This would allow for a very versatile and scalable base for multi-site development. As our intention is to work with numerous sub-ontologies that provide custom portals for different expert groups to access information and communicate with other groups (at different locations) [24][25].

As an example, to resolve the component issues we outline the development of a base component ontology (Figure 2) which serves as a structure for an underlying knowledge base, allowing for full interaction, comprehension and customization between components. The Example Project Component Ontology model represents an example specification of a single project component and its interface. It specifies numerous exposed interfaces and their provided and required services in the form of static properties and dynamic operations.

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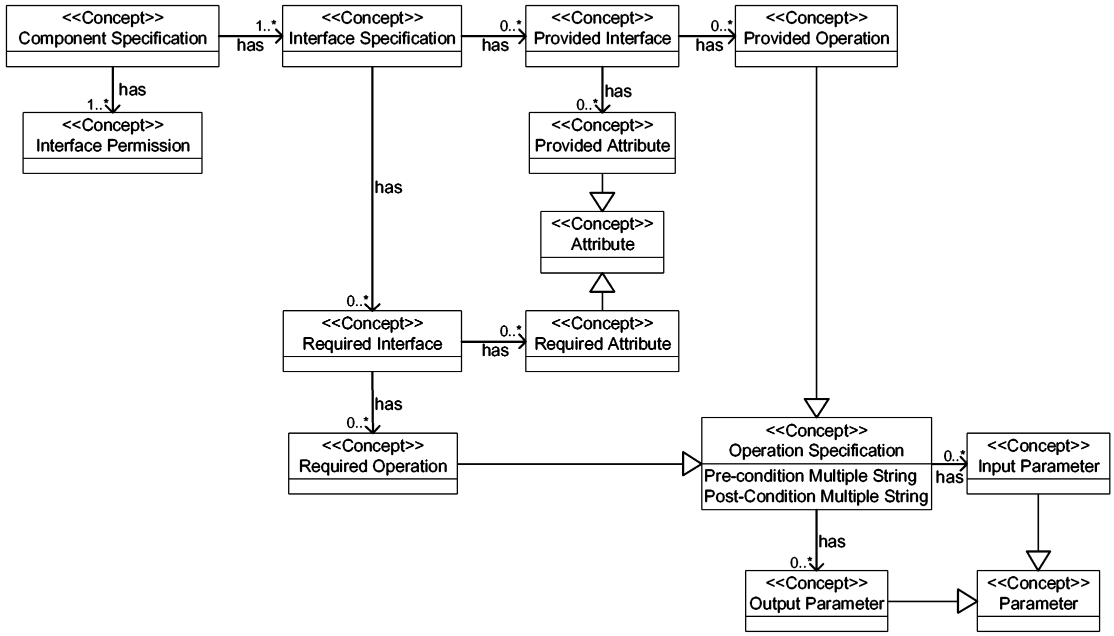

Figure 2. Component Ontology Model

V. Conclusion

The Australian mining industry has introduced a new set of requirements on the construction industry in the manufacturing of temporary dwellings for employees in remote multi-site areas with requirements such as rapid multi-site development, late customization, transportation and final assembly within very strict deadlines

This paper outlines proposals for the mining and construction industries that are seeking to promote; multi-site development, complete track and trace visibility of all manufacturing operations and their supply-chain and a high degree of re-configurability and automation. The proposals developed in this paper can be investigated widely to help Industry and Commerce to more effectively perform manufacturing tasks in multi-site environments and rural areas.

The tools and techniques will help avoid costly failures arising from communication, specification and management ambiguities while providing greater time-critical visibility for management decision making and reaction to manufacturing requirements.

References

[1] IEEE Computer Society, “IEEE 802.11-1999: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications”, Standard, July 1999.

[2] IEEE Computer Society, “IEEE 802.11a-1999: Highspeed Physical Layer in the 5 GHz Band”, Standard, Feb. 1999.

[3] IEEE Computer Society, “IEEE 802.11b-1999: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: Higher-Speed Physical Layer Extension in the 2.4 GHz Band”, Standard, Oct. 1999.

[4] IEEE Computer Society, “IEEE 802.11g-2003: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: Further Higher Data Rate Extension in the 2.4 GHz Band”, Standard, June 2003.

[5] IEEE Computer Society, “IEEE 802.15.4-2006: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low-Rate Wireless Personal Area Networks (LR_WPANs)”, Standard, Dec. 2006.

[6] S. Petersen et al., “Requirements, Drivers and Analysis of Wireless Sensor Networks for the Oil & Gas Industry”, Proceedings of the 12th IEEE International Conference on Emerging Technologies and Factory Automation, 25-28 Sept. 2007, pp 219-226.

[7] T.R. Gruber, A translation approach to portable ontology specification, in: Knowledge Acquisition, 1993.

[8] W. Borst, Construction of Engineering Ontologies, Centre of Telematica and Information Technology, University of Tweenty, Enschede, The Netherlands, 1997.

[9] R. Studer, B. VR, D. Fensel, Knowledge Engineering: Principles and Methods, in: IEEE Transactions on Data and Knowledge Engineering, 1998.

[10] M. Jarrar and R. Meersman, "Formal Ontology Engineering in the DOGMA Approach," in Proc. Intl. Conf. on Ontologies, Databases, and Applications of Semantics, 2002, pp. 1238-1254.

Digital Object Identifier: 10.4108/ICST.ITREVOLUTIONS2008.5147
http://dx.doi.org/10.4108/ICST.ITREVOLUTIONS2008.5147

[11] P. Spynus, R. Meersman, and J. Mustafa, "Data Modelling versus Ontology Engineering," in Proc. 21st ACM SIGMOD Intl. Conf. on Management of Data, 2002, pp. 14-19.

[12] M. Klein, D. Fensel, A. Kiryakov, and D. Ognyanov. Ontology versioning and change detection on the web. In Proceedings of the EKAW 2002, pages 197–212, Siguenza, Spain, Oct. 2002. Springer.

[13] C. Wouters, T.S. Dillon, W. Rahayu, E. Chang, and R. Meersman, 2004, 'A Practical Approach To The Derivation of A Materialized Ontology View', Web Information Systems, Idea Group Press, Melbourne, pp. 191-226.

[14] N.J. Holland Feminist Interpretations of Jacques Derrida Published by Penn State Press, 1997 ISBN 0271016353, 9780271016351

[15] J.L. Martinez Lastra Dr.-Ing. Armando W. Colomb Domain Ontologies for Reasoning Machines in Factory Automation

[16] F. Delamare le Deist, Jonathan Winterton, What is Competence?, Human Resource Development International, Vol. 8 No. 1, March 2005.

[17] P. Wongthongtham, E. Change, T. S. Dillon, and I. Sommerville, "Ontology-based multi-site software development methodology and tools," J. Syst. Architect., vol. 52, pp. 640-653, 2006.

[18] E. Chang, T. S. Dillon, and F. K. Hussain, "Trust and Reputation for Service Oriented Environments -Technologies for Building Business Intelligence and Consumer Confidence" John Wiley and Sons, 2006 (400 pg).

[19] P. Wongthongtham, E. Chang, and T. S. Dillon, "Ontology Modeling Notations for Software Engineering Knowledge Representation," in Proc. Inaugural IEEE Intl. Conf. on Digital Ecosystems and Technologies, 2007.

[20] M. Hadzic, E. Chang, 'Role of the Ontologies in the context of Grid computing and application for the human disease studies', Proceedings of International Conference on Semantics of a Networked World-Semantics for Grid Databases, France.

[21] A.S. Sidhu, T.S. Dillon, and E. Chang, "Protein Ontology," in Biological Database Modeling, J. Chen and A. S. Sidhu, Eds. USA: Artech House, 2007, pp. 63-80.

[22] C. Wouters, T.S. Dillon, J.W. Rahayu, E. Chang, and R. Meersman, "Ontologies on the MOVE," in Proc. 9th Intl. Conf. on Database Systems for Advanced Applications, Korea, 2004, pp. 812-823.

[23] P. Spyns, D. Oberle, R.l Volz, J. Zheng, M. Jarrar, Y. Sure, R. Studer, R. Meersman: OntoWeb - A Semantic Web Community Portal. PAKM 2002: 189-200

[24] C. Wouters, T.S. Dillon, J.W. Rahayu, E. Chang, and R. Meersman, "A Practical Approach to the Derivation of a Materialized Ontology View," in Web Information Systems, Idea Group Publishing, 2004, pp. 191-226.

[25] M. Jarrar, R. Meersman: Formal Ontology Engineering in the DOGMA Approach. CoopIS/DOA/ODBASE 2002: 1238-1254

Digital Object Identifier: 10.4108/ICST.ITREVOLUTIONS2008.5147
http://dx.doi.org/10.4108/ICST.ITREVOLUTIONS2008.5147