2012 EL Project Title and Number: Collaborative Requirements Engineering

Program Title: Systems Integration for Manufacturing and Construction Applications

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Summary: Production networks for complex engineered products and systems bring together participants who often have not worked together before. Their collaboration is impeded by differences in how each represents requirements and specifications, and by the lack of a systematic, standards-based means of communicating requirements. Resolving differences in requirements representation is costly and time consuming. The communication of design requirements is essential to the collaborative delivery of engineered products and systems. In many industrial settings, engineering processes use the vocabularies and measurements of product data sheets to convey requirements. A product data sheet is a concise description of the characteristics of a product, traditionally provided on a sheet of paper. Industry has initiated standards development projects that, in principle, could be extended to address these differences in requirements specification, if proven methods for requirements representation and correlation of terminology were available. However, the complexity of these standards makes commercial implementation and deployment daunting. This project will extend and apply formal methods of requirements representation and demonstrate a framework for collaborative requirements engineering of products and systems. In collaboration with industrial partners, the project will extend selected standards and test the use of these methods in industrial scenarios for the collaborative development of complex products and systems for manufacturing and physical infrastructure.

Objective: Apply and extend formal methods for requirements representation and demonstrate a framework for collaborative specification of complex engineered products and systems to improve the productivity of U.S. production networks. Test the methods in industry use cases and industry pilot projects by 2014.

What is the new technical idea? The project will use research and emerging standards in requirements engineering to develop the capability to communicate design requirements in collaborative systems design. The scope of systems addressed include systems supporting manufacturing and physical infrastructure and are characterized as requiring the ability to trace decision making through the processes of design, manufacture, operation, and maintenance. For example, as the design of a manufacturing system matures, the functional requirements for components or machinery may change and alternative products or interfaces may need to be considered. During the operational lifetime of a manufacturing system, exact replacement components are not always available, and identification of a suitable replacement must therefore reference the requirements the component serves. In these settings, product data sheets are a primary means to convey design requirements. Product data sheets are document-based representations that currently are not easily integrated with model-based engineering and systems engineering tools. The project will extend NIST-developed tools for ontology alignment, data integration and testing to develop the reference model and validation test suites. Success in catalog-based design settings will lead to application of the project's methods to configure-to-order and then engineer-to-order settings. (In a catalog-based design setting characteristics of components described by catalog entries (i.e., product data sheets) are matched to requirements. In a configure-to-order design setting, product characteristics are adjusted along established parameters to meet requirements. Engineer-to-order design allows the most freedom in formulation of a solution. In this design setting, a new solution is conceptualized in consideration of requirements, and the conceptualization is transformed to a concrete specification.)

In complex product and system design, knowing the system-wide consequences of a seemingly small change in a component can oftentimes be difficult. Further, parties working independently may make conflicting design commitments. When the trace from specification back to requirements is maintained, this record of rationale has enduring value to the lifecycle of the product. The project's strong industrial relationships and advances in the ability to represent requirements, reflected in emerging standards, make progress in these areas possible. Application of NIST-developed tools for validation of related technology improves our chances of success.

What is the research plan?

There are three research components to achieve the project objective: (1) develop methods of requirements capture and validation, (2) demonstrate these methods in draft standards and test cases, and (3) develop tools that will enable others to validate their application of these methods beyond the timeframe of the project's execution. The project will also undertake economics studies that will help prioritize future work.

Develop Methods of Requirements Capture and Validation

The project team will apply current research and emerging standards in requirements representation to develop methods for defining and communicating product design requirements in a property-based form. The project will establish a team of industry stakeholders to document challenge problems in collaborative requirements engineering

and relevant product data sheets and reference data libraries. The project will publish the challenge problems for review by industrial stakeholders. With this baseline documentation, the project will develop and validate the product data sheet ontology. An ontology is a formal description of concepts and relationships in some discipline or area of discourse. Ontologies may be used in engineering applications to enable software integration.

Specification of the Methods in Draft Standards and Test Cases

The project will develop reference implementations of the product data sheet ontology encoded in a current or evolving systems integration standard, e.g., OMG ReqIF – (Requirements Interchange Form) or ISO 15926 with extensions to the ISO 15926 Reference Data Libraries. The project will demonstrate the use of the product data sheet ontology with these libraries to support collaborative requirements engineering for the selected challenge problems. The project will investigate configuration management principles and methods from aerospace, automotive, process, and defense industries for possible application to collaborative product engineering and downstream processes, e.g., testing, commissioning, operation monitoring and life cycle asset management.

The project will work with manufacturers of equipment, instrumentation, and automation and control systems to elaborate requirements for collaborative requirements engineering in various industrial contexts. The project is working with U.S. manufacturers and industry associations on these challenges, including Emerson, Flowserve, Honeywell, ITT and Johnson Controls. The project will combine these requirements into extensions to the product data sheet ontology and the ISO 15926 Reference Data Libraries. The project will work with industry partners and software developers to conduct trial implementations of requirements engineering and integration. After resolving issues identified in the trial implementations, the project will conduct a pilot project to demonstrate these new methods and new components of ISO 15926. The project will conduct similar analyses and testing for applying these methods to other systems specification and integration standards, e.g., SPie (Specifiers Properties Information Exchange) and ISO 10303-233(Systems Engineering).

Develop Testing Capabilities

The project will develop representative compliance methods and metrics for using the product data sheet ontology with ISO 15926 for collaborative requirements engineering and product specification. This will include developing templates and test suites for implementation of ISO 15926 and the federated use of reference data libraries. The project will develop and test these capabilities for at least one other systems integration standard, e.g., OMG ReqIF – (Requirements Interchange Form), SPie (Specifiers Properties Information Exchange) or ISO 10303-233(Systems Engineering). The project will extend the NIST conformance and integration testing tools to this new class of problems and will demonstrate on-line testing tools.

Economic and Productivity Assessment

The project will develop metrics, tools, and data for measuring productivity and identifying inefficiencies and improvement opportunities in the manufacture and installation of mechanical and electrical products and systems. The project will test the use of ASTM Standard Practice E 2691 on Job Productivity Measurement and expand the

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Major Accomplishments:

Recent Results: This is a new project. The project leverages results from our work in supply chain collaboration systems and model-based systems engineering.

- Denno, P. O., "Enabling a Model-based Systems Engineering Discipline", conference paper presented at International Council on Systems Engineering (INCOSE) International Symposium, 2008
- Denno, P. O.; Barkmeyer, E. J.; Neuhaus, F., "Use of Semantic Mediation in Manufacturing Supply Chains", book chapter in *Cases on Semantic Interoperability for Information System Integration*. Hershey: IGI Global, 2009
- Denno, P. O., "Trade Collaboration Systems", book chapter in *eBusiness Interoperability: Concepts, Opportunities and Challenges*. Hershey: IGI Global, 2010

Standards and Codes:

Standard	NIST Staff	Expected Outcomes
Object Management Group Requirements Interchange Form (ReqIF)	Denno	Industry and OMG adopt collaborative requirements engineering methods and product data sheet ontology for life cycle integration of requirements to the systems model. Demonstrated at OMG conference in 2014.
ISO TC184/SC4 - Industrial automation systems and integration -- ISO 10303-Part 233: Systems engineering data representation	Denno Palmer	Industry and ISO adopt collaborative requirements engineering methods and conformance testing tools across multiple standards to integrate and automate systems engineering. Industrial pilot project demonstrates in 2014 collaborative requirements engineering with the extensions to systems integration standards and federated use of reference data libraries.
ISO TC184/SC4 ISO 22745 - Open technical dictionaries and their application to master data	Palmer	Industry and ISO adopt common methods and testing framework for federated use of data dictionaries to integrate and automate production networks. Industry demonstrates adoption in best practices and software tools by 2014.
ISO TC184/SC4 ISO 15926 – Life Cycle Data for Process Plants	Palmer	Industry, API, ASME, EPRI, ISA and ISO adopt collaborative requirements engineering methods and conformance testing tools across multiple standards to integrate and automate production networks. Industry demonstrates adoption in best practices and software tools by 2014.
ASTM Standard Practice E 2691 – Job Productivity Measurement	Chapman	Industry adoption of ASTM E2691 by 2014 will result in significant productivity improvements through reductions in waste and rework and more objective benchmarks that will drive performance improvement opportunities for engineering processes.