Available online at www.sciencedirect.com

ScienceDirect

Procedia Computer Science 61 (2015) 128 – 132

Procedia Computer Science

Complex Adaptive Systems, Publication 5
Cihan H. Dagli, Editor in Chief
Conference Organized by Missouri University of Science and Technology
2015-San Jose, CA

An Information-centric Approach to Engineering and Manufacturing Cyber Physical Systems in the Defense Industry

George L. Ball[a]*, Christopher (Kit) Runge[b], Leslie Peoble[c]

[a,b,c]Raytheon Company, 1151 E. Hermans Rd., Tucson,85712, USA

Abstract

Engineering approaches to product development in the aerospace and defense industries still engender aspects of board-based design and prototype development. Cultural inertia pushes back on the reality that products need to be rapidly developed and produced at lower costs in order to be competitive. Aircraft manufacturers have had some success using model-based design and computer simulations to eliminate prototyping, but cyber physical weapon development is still highly dependent on past engineering experience and the development of working prototypes. This paper discusses how a model-based, information-centric environment can accelerate the design of new systems. Central to this paradigm shift is the introduction of information models to complement product models. The overall goal of information-centric product development is the reduction of the traditional engineering semi-sequential process and an over-reliance on extremely precise requirements and risk mediation. In the new model, all engineering and manufacturing processes are represented as simultaneous, asynchronous events which constitute a very complex and dynamic environment.

© 2015 The Authors. Published by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).
Peer-review under responsibility of scientific committee of Missouri University of Science and Technology

*Keywords:*information systems; complexity reduction; engineering process

1. Background

In the defense industry, the development of new technologies is driven primarily by the U.S. Department of Defense and the requirements are based on current or emerging threat scenarios. The desire to have the “newest” and

* Corresponding author. Tel.: +1-520-545-6829; fax: +1-520-746-2103.
E-mail address: George_Ball@Raytheon.com

1877-0509 © 2015 The Authors. Published by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).
Peer-review under responsibility of scientific committee of Missouri University of Science and Technology
doi:10.1016/j.procs.2015.09.172

"best" weapon has tended to encourage "design from scratch" using the latest technology. This approach leads to significant investments in R&D and development times on the order of decades. The aerospace and defense industries have long sought more use of model-based engineering (MBE) practices as a way to shorten development time and reduce cost. However, modeling systems that comprise thousands of parts is a very complex undertaking. Component interactions and dependencies are an n-squared problem for impact analysis and therefore untenable except in small, very well bounded domains.

Our ongoing research into an information-centric engineering environment (Ball and Runge[1,2]) has indicated a need for information models and architectures to complement the component models in order for model-based design and manufacturing to achieve its promise. Our premise has been that a model-based environment that enables concurrent cross-disciplinary analysis and decision-making needs to identify and leverage the "informational intersections" within the cyber physical product development space. Those intersections naturally fall into a structure similar to the product itself.

2. Complexity in Aerospace and Defense Product Development

The authors have identified three primary characteristics that contribute to the long product development lifecycle: sequential processes, the necessary involvement of numerous engineering domains, and ambiguous and arbitrary decomposition of complex systems to enable human understanding.

Regarding sequential processes, the American Aerospace and Defense Industry has evolved over decades to enable customer oversight of the design processes, in large part due to that fact that the customer traditionally *pays* for the design process, not just the end product. So, the rigorous and infamous Systems Engineering "V" emerged, and complex development programs were constrained to execute and be evaluated on their ability to demonstrate their adherence to processes that first resolved high level requirements, then detailed requirements, then preliminary design, then detailed design, etc. While there may have been value to this document-driven process forty years ago, it is arguably inefficient in the current digital information age.

In addition, many engineering/manufacturing companies segregate the engineering disciplines (e.g. mechanical, electrical, etc.) as an organizational convenience, and give them particular design aspects of the product on which to work. Each discipline tends to have its own language and way of doing things (e.g. tools), evolved to address the unique aspects of how each engineer does his/her job, dependent on the relevant product and phenomenology domains. Sharing information in this complex environment is particularly challenging. Brecher, *et al*[3]. describe engineering applications as a heterogeneous software landscape forming a heterogeneous information network.

Finally, our research has shown that many engineering projects initially decompose the end product somewhat arbitrarily into a set of "sub-systems" identified by product function (e.g. propulsion or suspension). This decomposition often provides constraints, which, in theory, should enable product design. Lin and Chen[4] stated it this way: "*The main objective of product design is to meet the functional requirements. Given the alternatives in the selection of materials, product configuration, the required manufacturing and assembly methods, and costs, design needs to satisfy various constraints imposed on these selections*." Unfortunately, the decomposition of complex cyber physical products often leaves product form ambiguous and assumes that the inherent complexity of component integration can be addressed at a later stage. Consequently, the engineering of each of the sub-systems in isolation (or near isolation) induces re-work and delay due to unanticipated changes or interactions within the system when the subsystems are reintegrated.

3. Enabling good decision-making amidst complexity

The complex web of information flow across organizational structures, engineering disciplines, and different product areas, coupled with the inherent asynchronous timing of component design and reintegration, drives decisions that invariably lead to mistakes and rework. The authors have focused on developing a concurrent, multidimensional engineering and manufacturing environment that will support rapid conceptual design, engineering, manufacturing, and fielding of complex, cyber physical systems with an overall reduced development lifecycle. The key is recognizing the duality of complexity and good decision-making. Our approach is predicated on managing complexity, rather than eliminating it, with sophisticated information management.

Our initial research in this area (Ball and Runge[1]) led to a conceptualization of an information system that could transform model-based engineering of complex cyber physical systems. Fundamentally, the system enables the development of physical products (i.e., products that have physical form), and as such, must present a consistent product representation across all engineering disciplines (e.g., a 3-D model of the product). The system includes a library of multi-level, multi-fidelity product and process models, all validated against a known, maintained, and validated repository.

Our current research has been addressing two other aspects of the concept. First, the system must be designed to handle very large concurrency of interactions between engineering disciplines. Second, ontology will provide the unambiguous representation about what a product/component is, its attributes, and relationships to other products/components, in part to maintain context for the information. Information is usable for targeted decision-making only when it remains in context. For example, the thermal gradient of a specific metal (rate of temperature change with displacement from a reference point) may not be very useful for the software engineer but may be critical to the electrical engineer if the circuit card he/she is designing is to be next to a large heat source.

4. Mechanizing and automating information flow

During the product development process, timely sharing of decisions is critical. Information generation, modification, transport and consumption, often resulting from decisions, can be viewed as digital events, not unlike the events that have become the focus of so many Internet of Things discussions. We define a digital event as any event that can be detected by non-human means and recorded in a form that identifies (at a minimum) the time, source, and type of event. In order to make those events usable for subsequent decision-making, our approach is to encapsulate them as messages which are managed by the information system.

Our current information system implementation for this strategy is based on the Hadoop stack which consists of the Hadoop file system and a growing number of applications that can be used to manipulate the data streams. The implementation we are using provides several key capabilities necessary to make an information-centric approach usable to the engineering and manufacturing communities.

The system architecture includes the following capabilities: messaging, stream processing, unconstrained data storage formats, and multiple processing paths for user consumption. The event environment is driven by various engineering tools and processes (e.g. CAD, simulations, test equipment, etc.) as well as sensors that record environmental factors such as temperature, humidity, shock, and vibration.

Capturing the data being generated across the organization in the form of events is the first step in complexity management. Making sense of the data streams in a manner that is usable in the product development lifecycle still requires unravelling a complex system of both correlated and uncorrelated data.

4.1 Information Association

One of the objectives of the information system in reducing information complexity is to not overwhelm the users. The amount of information that a system of this type makes available can easily render the system useless if the user cannot find the right information within a desired time frame. Consider the average query on a typical internet search engine. Entering the text string 'UAV guidance system' into a search engine could result in almost two hundred thousand returns with potential answers to the query. Users generally assume that the first 10-20 hits must contain the answer they are seeking, but this may an erroneous assumption.

In making sense of the information driving the product development lifecycle within a typical defense manufacturer, that query may not result in much usable information. For instance, if the user is interested in thermal failures of inertial measurement units (IMU), the first assumption being made is that all devices which accomplish the task of an IMU are also identified as being an IMU. This may not be the case. For example, the command and data handler (C&DH) for a satellite might be a custom built unit or a simple processor bought off of Amazon for $50. The unit purchased online is not very likely to be identified by the manufacturer as a satellite computer processor.

This is where ontology comes into the picture. In our system concept, all components are described through ontology. The association of the information model with the component model (ontological description with the CAD drawing for example) allows the user to find the desired information regardless of how the object may have been described originally.

4.2 Analytics

With potentially thousands of events entering the system every second, real time analytics is necessary for identifying what could be meaningful information within the context of a specific consumer.

Event processors utilize a form of rules engine that generally uses the event source and type as the first filter to determine potential significance. The incoming event may trigger another event (e.g. an alert) that might result as an indicator to certain users of the system that there is something requiring their attention. In the type of system we are describing, there is an inherent potential for cascading event generation due to unknown relationships that the system identifies through implied associations derived from the ontology. This is an area for further research in non-deterministic systems.

In addition to the event streams, the information system also ingests a variety of data from numerous other sources such as enterprise resource planning (ERP) systems, test systems, product data management (PDM) systems, and quality control systems. These data are used to identify underlying associations that, when coupled with certain events, may indicate the need for preventative maintenance, or a potential for work assembly faults.

5. Discussion

The recognition that complexity cannot be eliminated from the engineering and manufacturing of complex cyber physical systems has resulted in some significant insights, including that the solution we are implementing is itself a complex system.

The accepted approach to managing information over the last five decades has been to reduce the amount of data being processed. The enabler for this has been the *a priori* assumption that only certain data were relevant. Relational database tables have always been an effort to reduce the amount of data handled by the system in order to make it manageable. The early constraints of hardware systems (e.g. storage and power) used to manage the databases were a contributing factor, but are no longer limiting factors.

The removal of the hardware constraints has allowed the adoption of systems that are more capable of managing the large data sets that are generated by ubiquitous computing systems around which modern life is built. Factories, cars, airplanes, refrigerators, all have the potential to send data into these repositories for use in decision processes.

In our current work, we are beginning to understand how the use of a complex computing environment (e.g. the Hadoop software stack) can make the complexity of information flow more manageable. Although the acceptance of complexity as an inherent aspect of the possible solution space has provided additional insights, it should be kept in mind that we are trying to find order in the chaos.

Some aspects of modern product development can leverage this acceptance of working within a complex information web. For instance, the capability to select certain data flows from the system to address equipment maintenance can be started quickly. Reaching the point at which the predictive capabilities are fully functional will require additional time and effort, as more of the information system is tapped for this particular decision process. In addition, it is not yet clear how the inclusion of large scale, high definition simulations and big data analytics will be incorporated.

Implementing a complex information environment based upon non-traditional technology within the existing framework of a modern company is problematic in itself. Since the implementation of an information-centric approach described in this paper is predicated on a multi-year strategy, the lack of immediate return on investment (ROI) is generally a major hurdle to be overcome. In addition, resistance can come from the IT department because of presumed increases in management and cost, and from the engineering and other functional areas due to required changes in work processes. Furthermore, and perhaps most significantly, the shift from “tool-centric thinking,” which assumes the next version of an engineering tool will naturally reduce the product development lifecycle, to “information-centric thinking,” is transformational and disruptive.

6. Conclusion

Our current research indicates that the potentially best approach to reducing the overall product development lifecycle is to not only accept the maxim that complexity cannot be eliminated, but also accept that an approach of increasing complexity might actually be part of the solution.

Decision makers want information but are as yet still not willing to accept that distilling the entire information ecosystem into a two line PowerPoint chart is not likely to ever become a reality. We have yet to develop machine reasoning capabilities that rival a human brain except in very special and constrained problem spaces. Our current research is directed at exposing the right information to the decision maker at the right time, and dealing with complexity is at the core of the problem.

References

1. Ball, GL, Runge, K. Producing Reusable Engineered Systems Through Ontology (PRESTO): An Information Sciences Approach to Architecture-driven, Model-based, Concurrent Engineering. In: Proceedings of the Autumn Simulation Multiconference 2012, San Diego, California, October 28-31, 2012.
2. Ball, GL, Runge, K. Producing reusable engineered systems through ontology: implementing an information sciences approach to architecture-driven, model-based, concurrent engineering. In: Journal of Defense Modeling and Simulation: Applications, Methodology, Technology 2014, Vol. 11(3) 219–226.
3. Brecher C, Ozdemir D, Feng J et al. Integration of software tools with heterogeneous data structures in production plant lifecycles. In: 10th IFAC workshop on intelligent manufacturing systems, Lisbon, Portugal, 1–2 July 2010.
4. Lin, C. and Chen, L.C. Constraints Modeling in Product Design. In: Journal of Engineering Design, 2002, Vol.13, No. 3, Pages205-214.