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# Instrumenting the Acquisition Design Process: Developing Methods for Engineering Process Metrics Capture and Analysis

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## Abstract

There is a deficit of data on the detailed execution of design acquisition processes, data which is needed to truly understand and improve them. Simultaneously, the movement to digital engineering, and specifically model based engineering, offers a key opportunity to gather continual data needed to move acquisition processes forward. To address this issue, methods must be developed and implemented to capture key process metrics on the full product life cycle, which includes conception, design, development, and test. The engineering acquisition process should be instrumented, capturing engineering metrics at a level of granularity sufficient to provide actionable information to other acquisition programs. These methods would be implemented on a set of diverse engineering programs, utilizing internal engineering design tools, product data and life-cycle management tools, and manpower reporting systems to capture data. This paper first discusses a number of specific examples of process instrumentation undertaken by the authors, then concludes with recommended lines of research for fully instrumenting acquisition processes.

**Keywords:** Digital Engineering ROI; Acquisition Process metrics; Systems Engineering Data Metrics; Design Process Improvements

## Research Statement

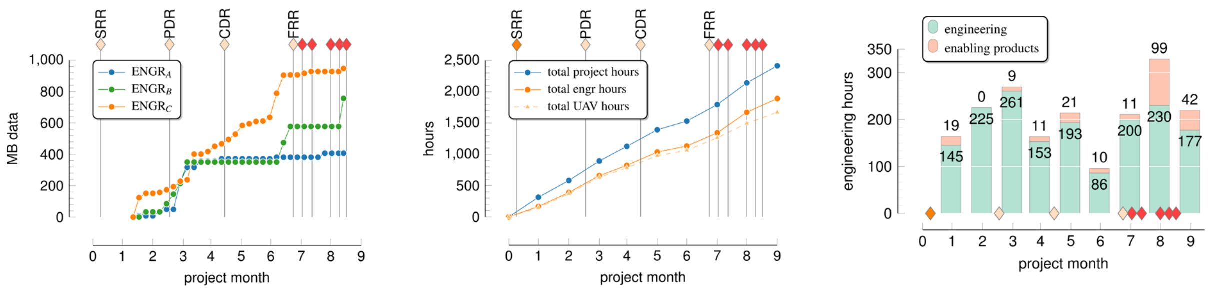
Fundamentally, the deep gathering of process metrics for large scale design efforts is not being done today. Processes must be measured and analyzed in order to improve. The three main roadblocks to gathering and sharing such data are (1) difficulties in data capture and categorization, (2) the proprietary nature of the data, and (3) a lack of emphasis from the community funding research on acquisition process improvement. Industry is historically unwilling and unable to provide design, schedule, and cost information at the level of granularity that can be analyzed to an actionable level. Cost, schedule, and design information provided by industry, per their contract requirements, is not at the level needed to decompose and correlate cost, schedule, and risk with design information. Additionally, there are minimal publications presenting metrics on design processes in the open literature, and those that do note the lack of data on which to base analyses.

## Technical Approach and Relevant Background

As a Department of Defense (DoD) designated University Affiliated Research Center, ARL conducts essential research, development, and systems engineering in support of our nation's priorities free from conflict of interest with industry. We have had hundreds of engineering design and development programs covering a broad spectrum of engineering domains and varying in levels of complexity. For example, we have designed and built UAVs in months (Miller et al., n.d.), and we have designed and developed highly complex undersea systems in years (Penn State, 2022). We have over 1,000 full-time engineers and utilize a broad set of engineering application tools including requirements management databases, MBSE, CAD, engineering programming tools, product data and life-cycle management systems, and software management tools. We have implemented both traditional systems engineering approaches and highly adaptable, accelerated acquisition approaches that are more commonly used in fast prototype programs.

In addition to our design and development programs, we have been performing core research in Systems Engineering (SE) and design methods for over 20 years. Topics in this research include systems engineering, model based engineering, multidisciplinary design optimization, decision making, sequential decision making, Set Based Design (SBD), conceptual trade space exploration, data visualization, uncertainty propagation, and more (Martin & Simpson, 2004a, 2004b, 2006; Miller et al., 2013; Stump et al., 2002, 2004, 2009; Yukish et al., 2018).

Specific to process instrumentation, in a project funded by the Rapid Response Technology Office under the Office of the Secretary of Defense, ARL instrumented the design, development, and test efforts of a 3D-printed UAV, and captured process metrics on two full product life cycles (Miller et al., n.d.). In this effort, we tracked engineering hours to progress a UAV design from requirements to development and test, and published resulting data repositories for use in other data mining and systems engineering research. Results from this effort showed relationships between team performance and design iterations, and how rapid prototyping methods, made available by 3D printing, accelerated the design process. An example of process data collected and related to design review events is provided in Figure 1.




(a) cumulative digital data generated by engineers (summed weekly)

(b) project and tasking hours accumulated per month

(c) engineering and enabling technology hours at the start of each month

Figure 1: UAV Design: Engineering Data Metrics

Another example project involved data capture and analytics within the shipbuilding industry through the Institute for Manufacturing and Sustainment Technologies. The project analyzed Production Bill of Material (PBOM) data from a major shipbuilder and created a configurable web-based Artificial Intelligence (AI) based software application to enable more rapid robust and accurate error discovery. In the shipbuilding industry, undetected PBOM errors lead to re-planning and/or production rework, which results in significant cost increases. Current error detection and resolution involves manual examination of data by planners and is often done retroactively. To decrease errors and the labor-associated costs, ARL created a configurable, web-based AI software application, which enabled more rapid, robust, and accurate error discovery. This effort involved data collection, data mapping and mining, requirements development, current state process mapping, AI model prototyping and testing, and development of a final custom rules interface for more targeted PBOM error detection. The initial data mining and mapping efforts on this project were challenging. The database was highly connected, but not all of the connections were useful, and the process of algorithmically mining similarities would mistakenly relate fields or user-entered data. Figure 2 is an example of initial connectivity among the database tables analyzed.

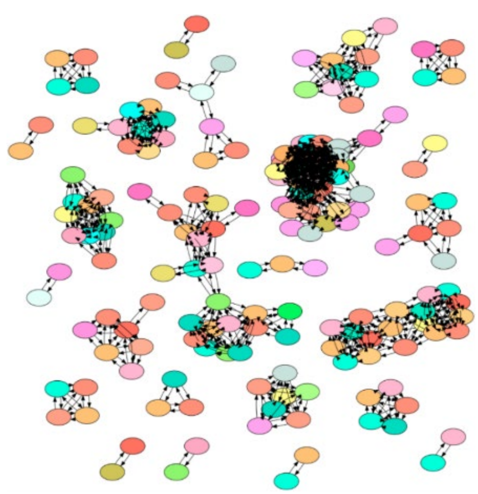


Figure 2: Example of Database Connectivity

Note: Colors Represent Different Tables, Nodes Represent Columns, Arrows Represent Inter-Table Relations

Several algorithmic approaches were developed and tested to automatically and correctly identify relationships among the data. One of the outcomes of this project was the development of a scalable and extensible mapping process by which complex data relations can be extracted from large data repositories to provide an automated platform for data analysis and the possible application of AI modeling techniques. These mapping processes directly enable applying AI techniques to analyzing extremely large datasets of design/manufacturing/acquisition-related data to make inferences on process performance, identify errors, and suggest actions for improvement.

ARL has been funded by the National Science foundation and Systems Engineering Research Center to research design decision support and SE design methods across a broad spectrum of topics. One topic focuses on treating design as a formal *Sequential Decision Process*, coupling Set Based Design (SBD) methods with Model Based Systems Engineering (MBSE), and developing new methods to progress through models of increasing levels of fidelity as the *consideration set* of possible solutions is narrowed (Miller et al., 2015, 2017; Yukish et al., 2018). In this research, we have developed qualitative and quantitative models of the decision process, and identified key data elements to capture in order to understand the state of an acquisition process. Conclusions from this research strengthen the need to better manage, maintain, and update design knowledge, and capture the state of the design in which decisions are made for later review and improvements (Yukish et al., 2018).

As a UARC, we are currently involved with several DoD program offices helping them define their digital engineering strategy, and their roadmap to generating digital twins of their assets so that they can reap the benefits of a digital twin in the design, test, and sustainment phases of their projects. Digital engineering and digital twinning both will create reams of data across the breadth of programs, from conception to sustainment that can be exploited to gain insight into the processes and identify areas for improvement. The data gathered for process *improvement*, however, is not necessarily the same as the data gathered to support the process itself. The time to identify and ensure process improvement data is up-front in the development of digital engineering and digital twin infrastructures.

Digital engineering and digital twin thrusts provide the perfect opportunity to instrument the design process, collect and analyze process data, and delivery methods to the acquisition community for future data analytics and process improvement. Industry partners that develop engineering systems for the DoD are a rich target for process data collection; however, these organizations are historically unwilling and unable to provide design, schedule, and cost information at the level of granularity that can be analyzed to an actionable level. ARL has performed multiple cost analysis studies for NAVSEA with the intent of better understanding cost and schedule risk areas in order to make acquisition improvements (Bennett, 2011; Clark & Bennett, 2008). However, the cost, schedule, and design information provided by industry, per their contract requirements, was not at the level needed to decompose and correlate cost, schedule, and risk with design information. As expected, this information, at lower levels of detail, is industry proprietary. As a university-affiliated research center with strong ties to the DoD acquisition community, we can instrument our processes to collect, categorize, group, and analyze engineering data from our programs, and provide analytical results and lessons learned to the acquisition community for future improvements.

## Proposed Efforts and Expected Results

All organizations that strive to improve design processes will benefit from detailed, highly granular process data and the techniques to extract it from the Digital Engineering systems. Reducing defense acquisition cycle times has been a cornerstone goal of multiple DoD initiatives over the past several years. In addition, the OSD has published their Digital

Engineering Strategy, and requested all DoD components to develop digital engineering implementation plans that show desired outcomes. A crucial part of implementation success is showing improvement (reduced cost or schedules) from previous practice. To show improvement and to accelerate it, projects to support process instrumentation are needed.

Within the scope of these projects, the primary efforts should be to develop and implement data collection methods on engineering processes, update and improve methods based on initial data analysis, and provide these methods, analytics results, and data repositories to acquisition professionals, government labs, and industry. The projects should involve not just engineering design researchers, but also experts in business, contracts, legal, and logistics. Example relevant tasks for a research effort would include the following:

- Identify and categorize engineering tools and databases to be instrumented.
- Develop automated methods on these engineering applications to capture relevant data.
- Identify diverse engineering programs for initial design capture; collect and categorize historical data on the program and begin collecting data in real time. Choosing programs that have varying levels of design complexity and represent various engineering domains to assure methods are applicable across the larger engineering spectrum.
- Analyze data, identify data sensitivities and relationships, and modify methods as necessary.
- Analyze all data for statistical relationships and patterns.
- Provide data analysis results, lessons learned, data capture methods, and cleaned data repositories to Acquisition and Sustainment (A&S) for future implementation, study. and data mining.

In the initial stages, the acquisition instrumentation and analysis would be performed by dedicated researchers, as this is a nascent line of inquiry. In future phases of this work, the methods and processes should be transitioned to DoD acquisition programs and their industry performers to implement data collection methods *across all programs*, and implement developed process improvements, which will help reduce program schedule and costs.

The long-term objective of this line of research is to discover areas for acquisition engineering process improvements based on analysis of data on current and historical programs. The key tenet of the effort is **we cannot improve what we do not measure.** This tenet applies to every weapons system technology we acquire as they progress from basic research to developmental test, and on to operational test, at each stage rolling test results into improving the technology. This same dedication now needs to be applied to the acquisition processes themselves.

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