

A Systems Engineering Approach to Requirements Elicitation and Management

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ABSTRACT

Effective requirements elicitation and management is a common need in supplier-OEM relationships, and continues to play a vital role in all aspects of the product development lifecycle. While traditional methods address the business goals for requirements and provide guidance in ensuring the accuracy of the “Descriptive-Prescriptive-Explanatory” outputs for requirements gathering and documentation, engineering organizations continue to encounter challenges with respect to capturing and communicating change, accommodating the addition of relevant design details and efficient propagation to inform development. These challenges become more difficult to overcome in mechatronic systems, which combine mechanical systems with integrated software.

As software development can produce an overwhelming volume of information that requires accurate tracking and proliferation, it cannot be effectively managed using traditional hardware-centric systems. This increased complexity introduced by software-intensive products pushes existing tools to their limits, making the efficient management of information critical to successful product delivery.

In this paper, we describe a systems engineering approach to requirements elicitation and management. As systems engineering focuses on the design and management of engineering projects over their lifecycles, it offers an interdisciplinary approach to dealing with the work-processes and tools that cover both the technical and information-based aspects of product delivery. More specifically, we will discuss; integration of existing tools processes, management of multiple sources of information, change management, strategies for process migration, and considerations for standards compliance.

CITATION: Perdikoulis, C. and Akers, D., "A Systems Engineering Approach to Requirements Elicitation and Management," *SAE Int. J. Passeng. Cars - Mech. Syst.* 5(4):2012, doi:10.4271/2012-01-2033.

INTRODUCTION

Effective product delivery is deeply rooted in the development of requirements that define what is needed to satisfy the product goals. While the business goals for these activities are well studied and follow mature processes, the practical methods in requirements gathering and documentation continue to challenge engineering organizations with respect to accurate articulation of need, capturing and communicating change, accommodating the addition of relevant design details and efficient propagation to inform development. Overcoming these challenges is particularly difficult in mechatronic systems, where the combination of mechanical systems and integrated software has introduced a level of complexity rarely encountered with hardware-centric system development.

Illustrated in [Figures 1 & 2](#), the complexity of engineering systems in production with respect to lines of code, features

and calibration parameters, continues to increase as next-generation products are brought to market.

As requirements generation is regarded as one of the most influential steps in product development with respect to the eventual success of a project [3], it is integral that the approach taken to elicit and manage mechatronic system requirements is fully integrated into the product lifecycle, from a systems engineering perspective.

Systems engineering focuses on analyzing and eliciting need, and articulating required functionality early in the product development cycle, while synthesizing design and validation to ensure that the entire product lifecycle is accounted for. Extending this paradigm to all aspects of the development effort, systems engineering facilitates a multi-disciplinary team effort, forming a repeatable development process that links development artifacts from the entire product lifecycle, from concept to end-of-life.

		< 1990	1995	2005
Hardware	Processor	8 bit	C196, 16 bit	TriCore, 32 bit
	Frequency	4 MHz	20 MHz	80 - 150 MHz
	Flash	10 - 100 kB	.25 - .5 MB	1 - 6 MB
	Sensors	10	17	25
	Actuators	14	22	31
Software	Lines of Code	20 000	44 000	690 000
	Features	1 800	3 100	5 200
Calibration	Parameters	1 000	1 800	7 200

Figure 1. Evolution of Complexity in Power Train Systems [1]

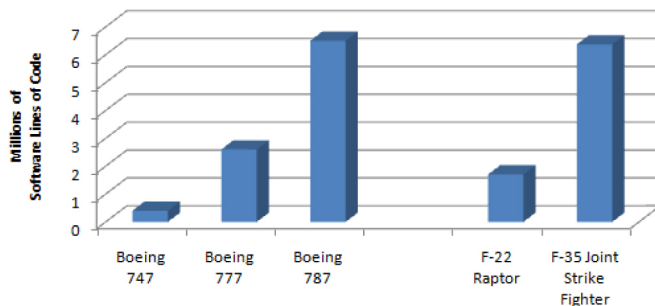


Figure 2. Evolution of SLOC [2]

The increase in complexity introduced by modern mechatronic systems has led to a number of common challenges in the area of Requirements Elicitation and Management, including:

Requirement inflation and complexity

Need to address all aspects of a multi-domain product delivery from hardware to software; functional and non-functional

Management and communication of requirements change

Evolving requirements need accurate articulation and coordinated proliferation to multiple groups and teams

Product repeatability

Need for an exact definition of a specific product to lead to its final delivery

Traceability of requirements for validation and reporting

Assurance that a requirement is met, despite inherent change, for process and quality assurance and reporting

This paper describes an interdisciplinary approach to requirements elicitation and management, dealing with the work-processes and tools that cover both the technical and information-based aspects of product delivery, and exploring integration strategies and considerations for standards compliance.

ENGINEERING EFFECTIVE REQUIREMENTS

Requirements capture the decisions made at project inception, and are designed to inform upstream and downstream artifacts that are encompass the product

lifecycle. Decisions made at the beginning of a project can have enormous implications later in the life of a system, if the consequences of the decisions are not well understood [4]. As such, gathering information from both a business and technical perspective and analyzing the intersections of technology that serve to deliver on the requirements, are the foundations of requirements engineering.

Challenges with Traditional Requirements Elicitation and Management Processes

Requirements engineering includes all of the activities within a product's lifecycle associated with requirements. Traditional processes distribute the activities among two main categories: Requirements Development and Requirements Management. Figure 3 provides a high-level overview of the activities and processes associated with requirements engineering.

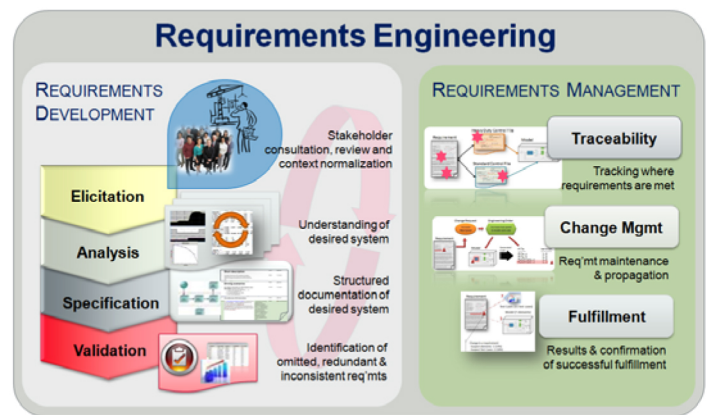


Figure 3. High-level Requirements Engineering Process

While requirements management is typically handled through structured process and formal reviews, requirements development is normally less prescriptive, with increasing formality introduced in the latter stages - specification and validation.

With products that are typically hardware-centric, these processes are effective and provide a thorough understanding of the product need, in addition to providing facilities to ensure that the need is satisfied throughout the development of the product. Requirements elicitation and analysis can normally be performed by a small group of qualified individuals, utilizing various elicitation techniques [5].

Mechatronic systems make these activities more complicated, insofar as the knowledge and expertise required to completely understand all the elements of the final desired result is typically spread out in different departments and engineering teams, and needs to be coordinated, reconciled and thoroughly analyzed before moving on to specification and validation. As products continue to grow in complexity, the challenges encountered in requirements engineering

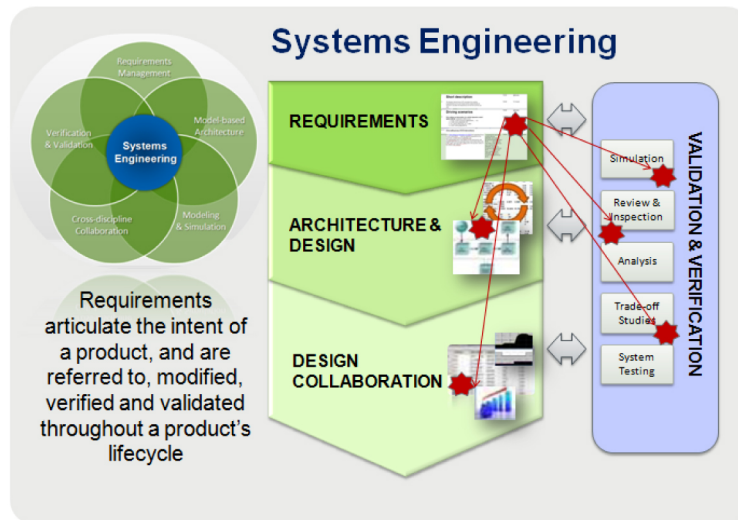


Figure 4. Systems engineering diagram

become more difficult to overcome, and new challenges begin to emerge:

Multi-domain applications lead to requirement inflation and increased complexity

The scope of what is captured in requirements has increased dramatically in mechatronic systems. System behaviour, human interface interaction, mechanical specifications and software service architecture are all informed by requirements covering multiple areas of expertise, including mechanical, electrical and software development. The domain-specific knowledge required to properly understand all elements of the desired final product requires collaboration and coordination among multiple individuals and teams, which can be time-consuming and prone to omissions, inconsistencies and redundancies.

Difficult to manage and communicate requirements change between Suppliers and OEMs

Different organizations typically operate under different development environments, use different tools and have uncoordinated project schedules and timelines. As such, communicating a desired final result to a Supplier, and their articulation of that need in such a way that the final result can be satisfied, is prone to miscommunication and inconsistencies. In addition, communicating and propagating change to requirements in a timely manner is generally handled manually and is dependent on clear communication, and consistent adherence to procedures. Implementing process models, reviews or change review boards help formalize the change process [6], but these manual solutions are resource intensive.

Inaccurate change capture during the product lifecycle leads to 'unique' products that cannot be recreated or reused

Once requirements are published and used to define upstream and downstream artifacts, capturing and maintaining the decisions and changes that are made

throughout the product lifecycle to ultimately deliver the final product is error-prone, and normally requires a considerable amount of documentation and manual consolidation of emails, meeting notes and technical review notes. Information is easily lost and as a result, valuable artifacts that could be reused in future projects are not properly identified as reusable candidates and recreating these products becomes time-consuming and difficult.

Costly and time-consuming to demonstrate traceability of requirements for validation and reporting

Integral to safety-critical system design, is the need to validate requirements throughout product development, and verify compliance through traceability. Without a requirements engineering strategy that centralizes engineering artifacts and facilitates connections to requirements and specifications, extensive manual effort is needed to develop compliance/governance reports [7].

Requirements Elicitation and Systems Engineering

As previously stated, systems engineering facilitates a multi-disciplinary approach to product development, forming a repeatable process that links development artifacts from the entire product lifecycle, from concept to end-of-life.

Focusing on the role of requirements in system engineering alone, the elicitation process is where the system is 'born' and the requirements management process is where the system 'lives'. Expanding on this analogy, the product lifecycle from the point of view of the system begins with requirements communication by the stakeholders. When the product itself begins to take shape and is in development, the requirements activities are predominantly management-focused.

Requirements elicitation has been defined as "the process of identifying needs and bridging the disparities among the involved communities for the purpose of defining and