

Hazard Analysis and Validation Metrics Framework for System of Systems Software Safety

James Bret Michael, *Senior Member, IEEE*, Man-Tak Shing, *Senior Member, IEEE*, Kristian John Cruickshank, and Patrick James Redmond

Abstract—Safety-critical software-intensive systems of systems require rigorous verification and validation to ensure that they function as per requirements. Unlike verification, validation is typically an ill-defined activity for software development. This paper presents a well-defined validation metrics framework which uses hazard analysis, and the derived software requirements for mitigating the identified hazards, as proxies in gauging the sufficiency of the software safety requirements early in the software development process. Moreover, traditional hazard analysis techniques are insufficient to deal with the complexity and size of systems of systems. This paper examines the nature and types of hazards associated with systems of systems and presents a new technique for analyzing one type of emergent hazard known as an interface hazard.

Index Terms—Goal question metric, goal structuring notation, hazard analysis, interface hazard, safety, software, system of systems, validation metrics.

I. INTRODUCTION

SOFTWARE has a growing, even predominant role in automating the decisions taken in safety-critical systems, including large-scale weapon systems (e.g., command of missile launchers via an engage-on-remote capability). Current and future generations of military capabilities require dependable systems of systems (SoSs) that integrate multiple software applications along with many physical systems. SoS must address all safety hazards before deploying the final system. One approach to risk management is Hazard Analysis (HA). HA techniques for SoS must address both the size and complexity of a SoS, and include defined practices that allow an engineer to keep pace with the evolution of a SoS over its lifecycle. These practices must cover the full scope of a SoS; they support both design and analysis to clarify what risks and hazards in a SoS may have been

overlooked. HA answers the question for a SoS, “What are the known and possible residual hazards in this system?”

Hazard Analysis, as applied in this paper, also plays an important role in the practice of Software System Safety; this practice depends on a set of management and engineering activities from the System Safety and Software Engineering domains. The intent is to identify, analyze, design, and track software mitigation and control of hazards and hazardous functions [1]. Effective analysis of the safety of software requires the engineer to work within the system context in which the software is executing. Therefore, the Software System Safety Engineering process typically starts with the System Safety Engineering activities to identify potential hazards at the System Engineering level. In this case, potential hazards and safety-critical functions are traced through high-level design and architecture, and ends with validation and verification (V&V) of software safety features required for controlling the hazard causal factors. (Readers can refer to [2] for definitions of error, failure, mishap, hazard, hazard causal factor and risk.)

In [3], Weaver identified the sufficiency of hazard identification and the adequacy of hazard analysis to identify software’s role in causing these hazards as two important considerations in constructing a safety case. He also advocated the use of traceability from the derived software safety requirements to the identified system hazards as an indication of the completeness of the set of software safety requirements. Measuring the affects of software on system safety is a relatively unexplored aspect of software engineering. In [4], Basili *et al.* presented an approach for developing software safety measures to gain early insights into potential safety problems and risks. While the metrics suggested in [4] cannot provide proof or validation of the software safety requirements, they can be used to identify potential weakness in the software system safety process and an associated likelihood that the system will not be safe.

This paper addresses the need for management to assess the adequacy of the software safety engineering process. It focuses on the contribution of software toward the safety afforded by SoSs and builds upon Weaver’s and Basili’s work by introducing a means for measuring the sufficiency of software safety requirements with a set of metrics derived from the hazard identification, hazard analysis, and requirements traceability artifacts. We present a Validation Metrics Framework for management to gauge the sufficiency of the software safety requirements early in the software development process. The framework describes a validation process in which the software safety engineering team acts as an advocate for safety on behalf of the stakeholders (Fig. 1). It complements the traditional methods of

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Table of Contents A Validation Metrics Framework For Safety Critical Software Intensive Systems

1. Understanding the eBook A Validation Metrics Framework For Safety Critical Software Intensive Systems
 - The Rise of Digital Reading A Validation Metrics Framework For Safety Critical Software Intensive Systems
 - Advantages of eBooks Over Traditional Books
2. Identifying A Validation Metrics Framework For Safety Critical Software Intensive Systems
 - Exploring Different Genres
 - Considering Fiction vs. Non-Fiction
 - Determining Your Reading Goals
3. Choosing the Right eBook Platform
 - Popular eBook Platforms
 - Features to Look for in an A Validation Metrics Framework For Safety Critical Software Intensive Systems
 - User-Friendly Interface
4. Exploring eBook Recommendations from A Validation Metrics Framework For Safety Critical Software Intensive Systems
 - Personalized Recommendations
 - A Validation Metrics Framework For Safety Critical Software Intensive Systems User Reviews and Ratings

- A Validation Metrics Framework For Safety Critical Software Intensive Systems and Bestseller Lists
- 5. Accessing A Validation Metrics Framework For Safety Critical Software Intensive Systems Free and Paid eBooks
 - A Validation Metrics Framework For Safety Critical Software Intensive Systems Public Domain eBooks
 - A Validation Metrics Framework For Safety Critical Software Intensive Systems eBook Subscription Services
 - A Validation Metrics Framework For Safety Critical Software Intensive Systems Budget-Friendly Options
- 6. Navigating A Validation Metrics Framework For Safety Critical Software Intensive Systems eBook Formats
 - ePub, PDF, MOBI, and More
 - A Validation Metrics Framework For Safety Critical Software Intensive Systems Compatibility with Devices
 - A Validation Metrics Framework For Safety Critical Software Intensive Systems Enhanced eBook Features
- 7. Enhancing Your Reading Experience
 - Adjustable Fonts and Text Sizes of A Validation Metrics Framework For Safety Critical Software Intensive Systems
 - Highlighting and Note-Taking A Validation Metrics Framework For Safety Critical Software Intensive Systems
 - Interactive Elements A Validation Metrics Framework For Safety Critical Software Intensive Systems
- 8. Staying Engaged with A Validation Metrics Framework For Safety Critical Software Intensive Systems
 - Joining Online Reading Communities
 - Participating in Virtual Book Clubs
 - Following Authors and Publishers A Validation Metrics Framework For Safety Critical Software Intensive Systems
- 9. Balancing eBooks and Physical Books A Validation Metrics Framework For Safety Critical Software Intensive Systems
 - Benefits of a Digital Library
 - Creating a Diverse Reading Collection A Validation Metrics Framework For Safety Critical Software Intensive Systems
- 10. Overcoming Reading Challenges
 - Dealing with Digital Eye Strain
 - Minimizing Distractions
 - Managing Screen Time
- 11. Cultivating a Reading Routine A Validation Metrics Framework For Safety Critical Software Intensive Systems
 - Setting Reading Goals A Validation Metrics Framework For Safety Critical Software Intensive Systems
 - Carving Out Dedicated Reading Time

12. Sourcing Reliable Information of A Validation Metrics Framework For Safety Critical Software Intensive Systems
 - Fact-Checking eBook Content of A Validation Metrics Framework For Safety Critical Software Intensive Systems
 - Distinguishing Credible Sources
13. Promoting Lifelong Learning
 - Utilizing eBooks for Skill Development
 - Exploring Educational eBooks
14. Embracing eBook Trends
 - Integration of Multimedia Elements
 - Interactive and Gamified eBooks

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