University of
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INTEGRATING META CYBERNETICS AND VIABLE SYSTEM MODEL FOR REDESIGNING COMPLEX SYSTEMS AND MANAGING EMERGENT BEHAVIOUR

A Thesis submitted by

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ABSTRACT

This study shows how intelligent systems, meta systems, and the meta cybernetics viable system model (VSM) can be combined to give a powerful methodology for studying and redesigning complex systems in project domain. By using the VSM, we describe how to define levels of recursion as well as identify and describe various systems. This study explores the possibility of integrating cybernetics meta-methodology and VSM with the application of meta systems reductionism to reduce the occurrence of negative emergent behaviour in project complex systems. The integration of fourth order emergent cybernetics model in meta - metasystems is of great value to the world of engineering. By integrating cybernetics and meta-methodology we can managed and or control system viability. In this approach, the role of individual systems, systems of systems (SoSs), and metasystems is recognised. The fact that a single system is deterministic and SoS is a stochastic system in which emergence is present is also elucidated. By integrating cybernetics VSM and meta-metasystems, the key parameters used to build an intelligent system are explored. The literature suggests that meta-metasystems provide superior capabilities by providing a governing structure that coordinates and integrates multiple systems. This thesis by publications reviews existing battle management systems (BMS) as systems of systems (SoS) research and highlights the need to develop complex structure thinking, cybernetics, depraved problem-solving and emerging behaviour analysis considering the relationship between complex and multi-structural systems. The system-thinking approach aims to organise and structure the problem-solving process by selectively handling details that can obscure the underlying features of a situation from a set of explicit perspectives. This study also aims to understand some challenges and opportunities in the design and development of future space vehicles, hybrid gas-electric cars, fully autonomous city driving, and prosthetic devices that allow the control of physical objects via brain signals. The basic design of structures and their parts covers all tangible and intangible object configurations. These objects create new movements to achieve unique goals and therefore suit the description of emergent behaviour.

CERTIFICATION OF THESIS

I Aleksandar Seizovic declare that the Doctor of Professional Engineering Thesis entitled *Integrating meta cybernetics and viable system model for redesigning complex project systems and managing emergent behaviour* is not more than 100,000 words in length including quotes and exclusive of tables, figures, appendices, bibliography, references, and footnotes.

This thesis is the work of Aleksandar Seizovic except where otherwise acknowledged, with the majority of the contribution to the papers presented as a Thesis by Publication undertaken by the student. The work is original and has not previously been submitted for any other award, except where acknowledged.

Date: October 2023

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Student and supervisors' signatures of endorsement are held at the University.

STATEMENT OF CONTRIBUTION

Paper 1 (Chapter 5):

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DEDICATION

To my wife Denise and son Christopher for their support and patience and to my sons and daughter (Michael, Daniel, and Rachelle) for understanding and being supportive.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS

ACP	Autonomous cyber physical (system)
ANN	Artificial neural networks
AS/NZS	Australian/New Zealand Standard
ABCANZ	American, British, Canadian, Australian, and New Zealand Armies Program
BMS	Battle management system
C3	Control, computation and communication
C4I	Command, control, communications, computing and intelligence
CBMS	Cyber Battle Management System
CPH	Cyber physical human (system)
CPS	Cyber physical system
CPS-NS	Cyber physical system – network soldier
CS	Constituent system
ECG	Electrocardiography
EDA	European Defence Agency
EUD	End user devices
EW	Electronic warfare
FMEA	Failure Mode and Effects Analysis
FMECA	Failure Mode Effects Criticality Analysis
FPS	Function and performance specification
FRAM	Functional resonance analysis method
GSA	General services administration
GST	General systems theory
GVA	Gross value added
HMI	Human machine interfaces
HQ	Headquarter(s)
HR	Heart Rate
IMEC	Interuniversity Microelectronics Centre
INCOSE	International Council on Systems Engineering
IoBT	Internet of Battlefield Things
ISO	International Organisation for Standardization

ISR	Intelligence, surveillance and reconnaissance
IT	Information technology
LAN	Local area network
LCC	Life cycle costing
LRV	Laws of requisite variety
M&S	Modelling and simulation
NCW	Network Centric Warfare
OI	Operative intelligence
OT	Operational technologies
PI	Process intelligence
PC	Personal computer
PERT	Program evaluation and review technique
S-ACP	Semi-autonomous cyber-physical
SEBoK	System engineering body of knowledge
SoS	Systems of systems
SoSE	Systems of systems engineering
SPAN	smartphone ad-hoc networking
SWaP	Size weight and power
TC	Tactical computer
TBD	To be determined
TRIZ	Theory of Inventive Problem Solving (translated from Russian)
UAV	Unmanned aerial vehicle
UK	United Kingdom
USAID	United States Agency for International Development
US/USA	United States of America
UWB	Ultra-wide band
VHF	Very high frequency
VSM	Viable systems model

CHAPTER 1: INTRODUCTION

1.1. Introduction – Background and context

In this introduction, we delve into the crucial role integrated methodologies play in the domain of ambitious engineering projects. The focal point is the realisation of methodological exploration through the application of cybernetics and meta-systems reductionism, as underscored by the insights of Holman et al. (2020). These projects, spanning various sectors such as infrastructure development, aerospace engineering, and advanced technological innovations, necessitate a cohesive approach to tackle multifaceted challenges effectively (Maier et al., 2022). As we embark on this exploration, it becomes apparent that seamless collaboration and the harmonisation of efforts are paramount for achieving overarching project objectives efficiently and with a high level of confidence (Helfgott et al., 2023; Ackoff, 2010).

The integration of methodologies is an essential factor for the success of large-scale engineering projects, encompassing realms from infrastructure development to cutting-edge innovations. This emphasis on collaboration serves as a cornerstone, fostering inclusivity and open communication within diverse teams (Garcia et al., 2021). The collaborative framework highlights the significance of risk management, modular design, continuous integration, standardisation, and performance monitoring as integral components of successful engineering endeavours.

These ambitious engineering endeavours, often spanning infrastructure development, aerospace engineering, or advanced technological innovations, require a cohesive approach to tackle multifaceted challenges (Maier et al 2022). With various systems and subsystems at play, the seamless collaboration and harmonisation of efforts becomes paramount to accomplishing any overarching project objectives efficiently and with a high level of confidence (Helfgott et al., 2023; Ackoff, (2010).

The integration of methodologies represents a cohesive strategy aimed at addressing the intricate challenges inherent in large-scale projects. This amalgamation of diverse perspectives forms a unified framework fostering collaboration, effective risk management, and system security.

Effective collaboration across diverse disciplines stands as the cornerstone of integrating methodologies. Engineering projects of significant scale and complexity involve teams with diverse areas of expertise, including civil engineers, mechanical engineers, electrical engineers, software developers, and more (Garcia et al., 2021). To ensure smooth coordination and cooperation, these teams must communicate openly, share knowledge, and work in synergy (Van Knippenberg et al., 2020; Adams, 2014). Emphasising a culture of inclusivity, where different perspectives are valued, contributes to the identification of innovative solutions and enhances problem-solving capabilities (Adams, (2011; Wolcott et al., 2021).

Proper risk management becomes a pivotal factor in the successful execution of complex engineering projects. With inherent uncertainties, unexpected events, and potential hazards lurking, diligent identification and systematic mitigation of risks are crucial to ensuring safety and security (Chapman & Ward, 1997; Cleland & King, 1983). Conducting comprehensive risk assessments across various aspects of the project, be it technological, environmental, or regulatory, enables proactive measures to address potential threats before they escalate (Esposito et al., 2023; Engwall, 2003).

The implementation of modular design and testing practices serves as an architectural advantage in large-scale projects. By breaking down the project into smaller, more manageable modules or subsystems, development and testing can occur independently (Wuni et al., 2020). This modular approach offers numerous benefits, including parallel development, more focused problem-solving, and easier maintenance. Additionally, it allows teams to integrate the components seamlessly, like assembling a puzzle, leading to a more robust and cohesive end product (Wuni et al., 2020).

Adopting continuous integration and testing practices keeps the development cycle agile and adaptive. Regularly validating work through automated testing, real-time feedback, and iterative development ensures that each component aligns with the project's requirements (Munteanu et al 2021). The early detection of integration issues and prompt corrective measures reduces the risk of costly disruptions during the later stages of the project, saving time and resources (Bordley et al., 2019; Tannir et al., 2019; Chapman & Ward, 1997; Cleland & King, 1983).

Standardising processes emerges as a critical aspect of integrating methodologies. This standardisation facilitates effective communication, reduces misunderstandings, and ensures consistency in approach and documentation (Jaskó et al., 2020). Having a shared set of practices enables smoother collaboration across teams and promotes a sense of unity, which is particularly crucial in projects involving a wide range of specialists with varying working styles and backgrounds.

Performance monitoring and optimisation efforts play an instrumental role in achieving efficiency and reliability. Continuously evaluating the performance of various subsystems and their interactions allows project teams to identify bottlenecks, anticipate potential inefficiencies, and optimise resource utilisation. This dynamic approach ensures that the project evolves with real-time feedback and adapts to changing requirements or unforeseen challenges (Sahadevan, 2023).

However, the integration of methodologies goes beyond technical aspects alone. It also demands a deep understanding of the broader context, encompassing social, economic, and environmental factors. Taking a holistic view that embraces complex systems thinking empowers project stakeholders to grasp the interconnected nature and interactions of the systems involved. The interplay of diverse elements in engineering projects can lead to emergent behaviours, some of which may prove advantageous, while others may pose unforeseen risks. Being proactive in anticipating and mitigating negative emergent behaviours becomes imperative to maintain project safety and security (Bordley et al., 2019; Tannir et al., 2019; Chapman & Ward, 1997; Cleland & King, 1983).

By embracing the practices of integrating methodologies and adopting a holistic approach, engineering teams can effectively collaborate, manage risks, ensure security, and successfully manage complex projects. As they navigate through the intricate landscape of engineering marvels, they prioritise safety and security throughout the entire development process, leaving a lasting impact on society, technology, and the world at large (Esposito et al., 2023; Engwall, 2003).

1.2. Research aim

The thesis' aims are to examine and understand the emergence and complexities of systems of systems (SoS) in complex project environments. The author applied the definition of SoS given by Dr Mark Maier (1998) and Maier et al.,

(2022) which emphasise the interdependencies and emergent behaviour that arise when multiple systems are integrated into a larger-scale system.

This research considered the challenges posed by structural, technical, directional, and temporal complexity in SoS management. A multi-methodological approach was deemed valuable in complex problem-solving due to its holistic understanding, diverse expertise, adaptability, resilience, reduction of bias and limitations, and iterative learning. By embracing this approach, the thesis aimed to enhance problem-solving capabilities and increase the likelihood of finding effective and sustainable solutions. Lee and Miller (2004) devised and documented a multi-methodological approach combining systems dynamics with critical project management to simulate a multi-project environment that focuses on interactions between projects (Tolk et al., 2021; Howick et al., 2006). SoS is a collection of task-oriented or dedicated systems that pool their resources and capabilities to create the latest, most complex system that offers additional functionality and performance, rather than simply being the sum of constituent systems (Kazakov et al., 2021).

1.2.1. Interconnected systems achieving a larger objectives

Even though several definitions are available in the literature, the author has chosen to apply Maier's (1998) definition of SOS. Dr Maier is a renowned systems engineer, and his definition emphasises the emergent behaviour and interdependencies that arise when multiple systems are combined. It is a higher-level concept that describes the integration and coordination of multiple independent systems into a cohesive and unified whole. In this context, a system can be defined as an entity composed of interconnected components that function together to achieve specific goals. Examples of SoS can be found in various domains, such as transportation networks, power grids, healthcare systems, and military operations, where the integration of diverse systems is essential for achieving the desired outcomes.

1.2.2. Objectives

Examine emergence and complexities of Systems of Systems (SoS)

Investigate the interdependencies and emergent behaviour within SoS in complex project environments. Apply Dr. Mark Maier (1998) and Maier et al., (2022) definition of SoS to emphasise the integration of multiple systems into larger-scale systems.

Address challenges in SoS Management

Identify and analyse challenges posed by structural, technical, directional, and temporal complexity in SoS management. Develop insights into the unique issues associated with managing systems within a larger, interconnected framework.

Utilise a multi-methodological approach

Employ a multi-methodological approach for comprehensive problem-solving.

Leverage the holistic understanding, diverse expertise, adaptability, resilience, and iterative learning inherent in the chosen approach.

Enhance problem-solving capabilities

Explore how the multi-methodological approach enhances problem-solving capabilities in dealing with complex systems. Increase the likelihood of finding effective and sustainable solutions through the chosen research methodology.

Apply Lee and Miller's (2004) multi-methodological approach

Implement a multi-methodological approach combining systems dynamics with critical project management, as devised by Lee and Miller (2004). Simulate a multi-project environment focusing on interactions between projects within the SoS framework.

Define and understand Systems of Systems (SoS)

Adopt Dr. Maier’s (1998) and Maier et al’s., (2022) definition of SoS for a higher-level understanding of the integration and coordination of multiple independent systems.

Investigate SoS as a concept where diverse systems are combined into a cohesive and unified whole, achieving objectives beyond the sum of constituent systems.

Apply methodological integration in project management

Strategically combine various methodologies for effective project management. Address project-specific factors such as size, complexity, organisational culture, and industry requirements in the integration process.

Promote cohesiveness and avoid conflicts

Approach the integration of methodologies with care to maintain cohesiveness. Emphasise clear communication, collaboration, and a shared understanding among project team members to avoid confusion and conflicts.

Recognise the importance of collaboration and harmonisation

Highlight the significance of seamless collaboration and harmonisation of efforts in achieving overarching project objectives with confidence. Embrace a collaborative approach across diverse domains, including infrastructure development, aerospace engineering, and technological innovations.

1.3. The research innovation

The research proposed in this thesis represents a ground breaking endeavour poised to reshape the landscape of project management. This pioneering exploration combines a variety of engineering (Figure 1) digital twin technology, agent-based modelling, cybernetics (specifically, viable system theory), and the study of emergent behaviour in SoS. Its aim is to push the boundaries of existing knowledge by embracing innovative methodologies and cutting-edge technologies (McMeekin, 2019). This research offers robust solutions that address inherent limitations in traditional approaches. It unlocks fresh insights and advantages for managing complex engineering projects and solving complex problems with confidence.

Central to this research is the integration of digital twin technology and introducing a component that empowers project managers to create virtual replicas of physical systems for real-time monitoring and analysis (Chapter 8). This facilitates data-driven decision-making, troubleshooting, and performance optimisation. Additionally, agent-based modelling introduces a dynamic simulation approach, enabling the exploration of various scenarios and their impacts on project dynamics.

By amalgamating these advanced technologies with cybernetics principles, this research aims to construct highly adaptive and self-regulating systems, adept at responding effectively to evolving conditions (Seizovic et al., 2022).

The examination of emergent behaviour in SoS holds particular significance for large engineering projects, where numerous interconnected systems coexist. Understanding the intricate interactions among these systems and their resulting emergent behaviours empowers project managers to anticipate challenges and harness synergies more efficiently.

This research incorporates the perspectives of experts and peers through Delphi analysis, as detailed in Chapter 8. This adds a practical and real-world dimension to the research, enriching the proposed methodologies and making them more adaptable and effective in the context of real engineering projects. The fusion of methodologies, complex systems thinking, cybernetics, and the viable system model presents a robust and comprehensive approach to the management of large and complex engineering projects. By embracing innovative technologies and adaptive principles, organisations can elevate their project management capabilities, enhance the likelihood of project success, and contribute to advancements in the field of engineering (Fernandez et a.,l 2022).

A thorough review of relevant literature in the field reveals that the research idea proposed in this study has received minimal exploration or discussion in previous studies dating back to the early 21st century (see Chapter 3).

The methodology defined in the introductory chapter is "Methodological Integration". This involves strategically combining various methodologies for effective project management. The integration is driven by factors such as project size, complexity, organisational culture, and industry-specific requirements. It emphasises incorporating principles and practices from different methodologies to strike a balance between agility and structure, optimising project execution. Examples include adopting iterative development, feedback loops, and continuous integration from agile methodologies for flexibility while incorporating elements from traditional project management methodologies to ensure proper governance, documentation, and risk management. The integration process should be approached carefully to maintain cohesiveness, prevent confusion, and avoid conflicts. Clear communication, collaboration, and a shared understanding among project team members are deemed crucial for successful implementation. It underscores the importance of seamless collaboration and harmonisation of efforts to efficiently achieve overarching project objectives with confidence.

The additional or different methodologies introduced and applied in this study, namely digital twin technology, agent-based modelling, cybernetics and the analysis of emergent behaviour in SoS, offer ground breaking concepts and approaches that have not been widely applied in prior research (Mihai, et al., 2022). These methodologies address the limitations and gaps in traditional methods, providing fresh insights and potential advantages. They have the capacity to yield distinct, new, or more precise results compared to conventional approaches. The utilisation of Delphi analysis, as elucidated in Chapter 8, in a published article titled "BMS and future soldier system", reveals the support and real-world perspectives of experts and peers in the field. This research on BMS, detailed in Chapters 5 and 6, is grounded in the wisdom of knowledgeable individuals who assess its novelty based on their expertise and familiarity with existing literature on BMS SoS (Patra et al 2022).

Tatikonda and Rosenthal (2000) have defined technological novelty, particularly in the context of product development projects, as the originality of the technologies employed, as opposed to their familiarity (Haleem et al., 2021). A higher degree of technological novelty often corresponds to increased task uncertainty. Moreover, scholars have ascribed varying contextual meanings to the terms 'uncertainty' and 'complexity.' For instance, Williams (2005) considers uncertainty as a dimension of complexity, while Tatikonda and Rosenthal (2000) suggest that complexity contributes to uncertainty (Haleem et al., 2021).

On the contrary, Baccarini (1996) emphasises that the extent of complexity varies, depending on factors such as size and uncertainty (Mikkelsen, 2020). Thus, a project cannot be examined in isolation from its surroundings or history. Additionally, understanding the context alone is insufficient for prescribing a method; instead, the method for managing a project is shaped by the context, emerging through interactions between the actors and the environment.

To address the question of whether a multi-system framework can be established and the factors that positively influence such an endeavour, it is imperative to define ‘project complexity’, a concept intrinsically linked to the researcher's ontological stance. Mikkelsen (2020) and Baccarini (1996) have explored two distinct perspectives of project complexity: 'systems theory' and 'difficulty' perspectives. From the systems theory viewpoint, complexity can be operationalised in terms of differentiation and interdependency. Mikkelsen (2021) and Williams (1999) refer to this dimension of complexity as structural complexity. Hüttemann (2021) and Hüttemann (2004) highlight that ontological emergence entities must possess new properties, behaviours, and laws that are autonomous from and irreducible to the sum of individual properties, behaviours, and laws of their parts (Hüttemann, 2021; Garson, 2006; Hüttemann and Papineau, 2005).

1.4. Thesis statement

The integrating methodologies approach leverages the strengths of different methodologies, addresses emergent behaviours, and establishes effective communication and control mechanisms throughout the project lifecycle. By adopting this integrated system, organisations can enhance their project management capabilities and increase the likelihood of successful project outcomes.

1.4.1. Value of the research

Lately, interest in SoS engineering has been on the rise. Examples of SoS applications include military command and control, computerised communications, and information (C4I) systems (Gu et al., 2000; Pei, 2000); intelligence, surveillance, and reconnaissance (ISR) systems (Manthrope, 1996); intelligence collection management systems (Osmundson et al., 2006); and electrical power distribution systems (Niet et al., 2021; Casazza & Delea, 2000). System complexity is a challenge for systems engineering and architectural design of numerous SoS, particularly those that interact with financial systems such as transportation logistics networks, communications networks, and energy delivery networks (Kornbluth et al., 2021; Motter & Lai, 2002).

In the mentioned study in Chapter 5, the researcher developed a complex project systems methodology that integrated numerous complex systems thinking tools into the project systems and management process (Hughes, 2020; Sage, 1977). Despite the wide use of systems theory in the field of project management and in systems integration (Locatelli, 2023; Geraldi, 2020; Soderlund, 2004; Morris, 2012), there is a lack of discussion on the use of cybernetics in complex projects systems and management as well as most of the completed research works

(Krippendorff, 2019; 1986), which includes but is not limited to Marie (2020), Chernyakhovskaya (2019), Awuzie and McDermott (2013), Saynisch (2010), Piney (2008), Turner (2006), and Britton and Parker (1993).

The research presented in this study has significant value in advancing the understanding of complex project frameworks, addressing negative emergent behaviours, and the viable system model (VSM), which only controls the system variety described in **Appendix A**. The findings have implications for future research direction, policy-making, and practical project management, ultimately leading to improved safety, security, and performance of large and complex engineering projects (Rezk et al., 2020; Ríos, 2010).

1.5. Impact and implication

1.5.1. Complex project frameworks and their impact on future research, policy and practice

To understand complex project frameworks and their impact on future research, policy, and practice, we examined negative emergent behaviour phenomena in SoS and addressed the associated challenges of interdependence to ensure safe and secure project delivery. This research underscores the need for further exploration in this area, with the aim of advancing and implementing such frameworks in real-world scenarios.

1.5.1.1. The implications of this research extend beyond academic realms

The implications of this research extend beyond academic realms because they have practical significance and real-world applications. While academic research contributes to expanding knowledge and theoretical understanding, the findings and insights derived from this research on complex project frameworks and negative emergent behaviours have direct and tangible implications for various stakeholders involved in engineering projects (Post et al., 2020). Below is a list of reasons why the implications go beyond academia:

- Practical relevance: The research addresses challenges that project managers, engineers, and practitioners encounter in the real world when dealing with complex projects. By providing insights into negative emergent behaviours and offering metasystem frameworks, the research directly impacts how projects are planned, managed, and executed in practice.

- Safety and security: Engineering projects can have significant safety and security implications. Understanding negative emergent behaviours and how they can arise in SoS enables project teams to proactively identify potential risks and take preventive measures to ensure the safety and security of the project and its stakeholders.
- Innovation and progress: Applying the metasystem frameworks to complex projects can lead to innovative solutions and more efficient project management practices. This research empowers project stakeholders to think critically and holistically about project frameworks, fostering progress in the engineering field.
- Policy and regulation: Policymakers and regulators can use the research findings to inform the development of policies and guidelines that enhance project safety and resilience. The research can influence industry standards and practices, thereby impacting how projects are executed on a broader scale.
- Industry adoption: The practical applicability of the research makes it attractive to industry practitioners. Project management professionals can incorporate insights and frameworks into their projects to achieve better outcomes and mitigate potential risks.
- Economic impact: Engineering projects, especially large and complex ones, often involve substantial financial investments. Understanding and addressing negative emergent behaviours can lead to cost savings by avoiding project disruptions and delays.
- Risk mitigation: By recognising interdependencies and potential negative emergent behaviours, project teams can develop contingency plans and risk mitigation strategies to handle unexpected challenges more effectively.

Understanding and addressing negative emergent behaviours in complex projects can inform future research efforts, shape policy decisions, and transform project management practices. Policymakers can leverage these findings to establish guidelines and regulations that enhance project safety and resilience. Practitioners, including project managers and teams, can apply the metasystem frameworks to proactively address challenges and optimise project outcomes (Midgley, et al 2021).

The research's implications extend beyond academia because they offer practical solutions and insights to address complex project challenges. By impacting project safety, innovation, regulation, and industry practices, this research contributes directly to the successful execution of engineering projects and their positive impact on society, the economy, and the environment

1.6. Thesis overview

1.6.1. Outline

Chapter 1: Introduction
Chapter 2: Synergising methodologies and cybernetic insights for enhanced project management in complex systems
Chapter 3: Literature review and additional information in Appendices C, D and E.
Chapter 4: Theoretical and conceptual framework
Chapter 5: Paper 1. Emergent behaviour in the Battle Management System, published.
Chapter 6: Paper 2. Cybernetics and Battle Management System (BMS) and its application to the network soldier, published.
Chapter 7: Paper 3. Cyber–physical systems, systems of systems, and emergent behaviour. Cyber Battle Management Systems (CBMS) are considered as systems of systems (SoS) and their emergent behaviour is presented, wherein the viable system model.
Chapter 8: Delphi group and system simulation based on cyber-battle management system (CBMS) and its application to the network soldier, described in **Appendix A** and **Appendix B.**
Chapter 9: Discussion
Chapter 10: Conclusion
Appendix A: Systems of Systems and digitial twin
Appendix B: Cybernetics – BMS and the application to the network soldier
Appendix C: ICCPM webinar

Appendix D: Engineers Australia – Integrated Project Engineering Congress (IPEC)

Appendix E: Presents a research literature summary

Appendix F: Identify relevant authors

Appendix G: Presents relevant databases used in this research

CHAPTER 2: SYNERGISING METHODOLOGIES AND CYBERNETIC INSIGHTS FOR ENHANCED PROJECT MANAGEMENT IN COMPLEX SYSTEMS

2.1. Cybernetic insights for enhanced project management

Cybernetics, the study of communication and control in complex systems, provides valuable insights into managing and regulating the behaviour of interconnected systems. It offers a framework for understanding the feedback mechanisms and control loops necessary to maintain stability and optimise performance. By applying cybernetic principles, project teams can establish effective communication channels, feedback loops, and control mechanisms to monitor and regulate projects while ensuring that they stay on track and meet safety and security requirements.

2.1.1. Enhancing complex engineering project management by use of VSM

Cybernetics, which explores communication and control within complex systems, provides valuable insights for managing interconnected systems effectively. The VSM proves to be especially useful in ensuring the safe and secure delivery of complex engineering projects. VSM structures an organisation or project as a system composed of interacting subsystems, each with its autonomy and control mechanisms. The VSM empowers project teams to construct a resilient and adaptable project structure capable of effectively responding to changes and challenges. This approach capitalises on diverse methodologies, addresses emergent behaviours, and establishes robust communication and control mechanisms throughout the project lifecycle (Hossain, 2020).

2.1.2. Mastering complexity in large-scale engineering projects

Addressing complexity in large-scale engineering projects can be accomplished by introducing complex systems thinking and cybernetics, such as the Viable Systems Model (VSM), through the development of a metasystem framework. This approach allows for a holistic understanding of intricate project structures, the identification of potential undesirable emergent behaviours, and the creation of metasystem frameworks that ensure the safe and reliable project delivery (Tabilo et al., 2023). Additionally, it helps tackle challenges associated with interdependent systems, fostering effective communication, control, and adaptation both within individual systems and across interconnected systems (Chapters 6 and 7). To effectively manage the intricacies of behaviour within SoS and stochastic systems, it is crucial to integrate the principles of complex systems thinking and leverage cybernetic concepts like the VSM, especially within deterministic system contexts. Stafford Beer's VSM offers an analytical framework for understanding and governing complex systems, encompassing the analysis of a system's functions, communication, and inherent control mechanisms. Complex systems thinking acknowledges the intricate interrelationships, dependencies, and emergent properties within a system (Hy¨otyniemi, 2006; Clarke, 2020). Efficiently managing behavioural phenomena in SoS or stochastic systems necessitates embracing complex systems thinking and applying cybernetic concepts, such as the VSM, exclusively within the deterministic system domain. The VSM equips us with the tools to comprehend and regulate complex systems by scrutinising their functions, communication channels, and control mechanisms. SoS projects entail multiple systems collaborating to achieve common objectives (as discussed in Chapters 5, 6, and 7).

Understanding the relationships between these systems is crucial for managing complex projects and reducing unfavourable emergent behaviours. The application of complex systems thinking, cybernetics, and the VSM enables project managers to analyse interconnections, communication channels, and dependencies among systems. Furthermore, it aids in identifying potential sources of conflict, information gaps, and misalignments that could lead to negative emergent behaviours These approaches empower project managers to navigate the intricacies, interdependencies, and uncertainties inherent in complex projects, ultimately leading to more successful outcomes (Hy¨otyniemi, 2006; Clarke, 2020). By addressing these challenges and promoting effective collaboration and coordination, project managers enhance the overall performance and reliability of SoS (Chapter 8).

The viable system model (VSM) is a specific cybernetic model that can be particularly useful in the context of delivering complex engineering projects. The VSM helps structure an organisation or project as a system of interacting subsystems, each with autonomy and control mechanisms (Tannir et al., 2019). This model enables project teams to distribute decision-making authority appropriately, allocate resources efficiently, and ensure that each subsystem operates effectively while contributing to the overall project objectives. By implementing the VSM, project teams can create a resilient and adaptable project structure that can respond effectively to changes and challenges.

Incorporating cybernetics and the viable system model (Figure 1) adds an extra layer of adaptability and resilience to project management. The viable system model emphasises organisational autonomy and the ability to self-regulate, making it well-suited for managing complex projects with diverse subsystems. These cybernetic principles can facilitate effective communication and control mechanisms, ensuring that the project stays on track and adapts to changing circumstances. The emphasis on organisational autonomy, self-regulation, and effective communication and control mechanisms makes the VSM a valuable tool for managing SoS (Jackson, 2020). Analysing SoS using the VSM enables project managers to better understand the dynamics and interactions within these complex structures, leading to more effective decision-making and improved project outcomes.

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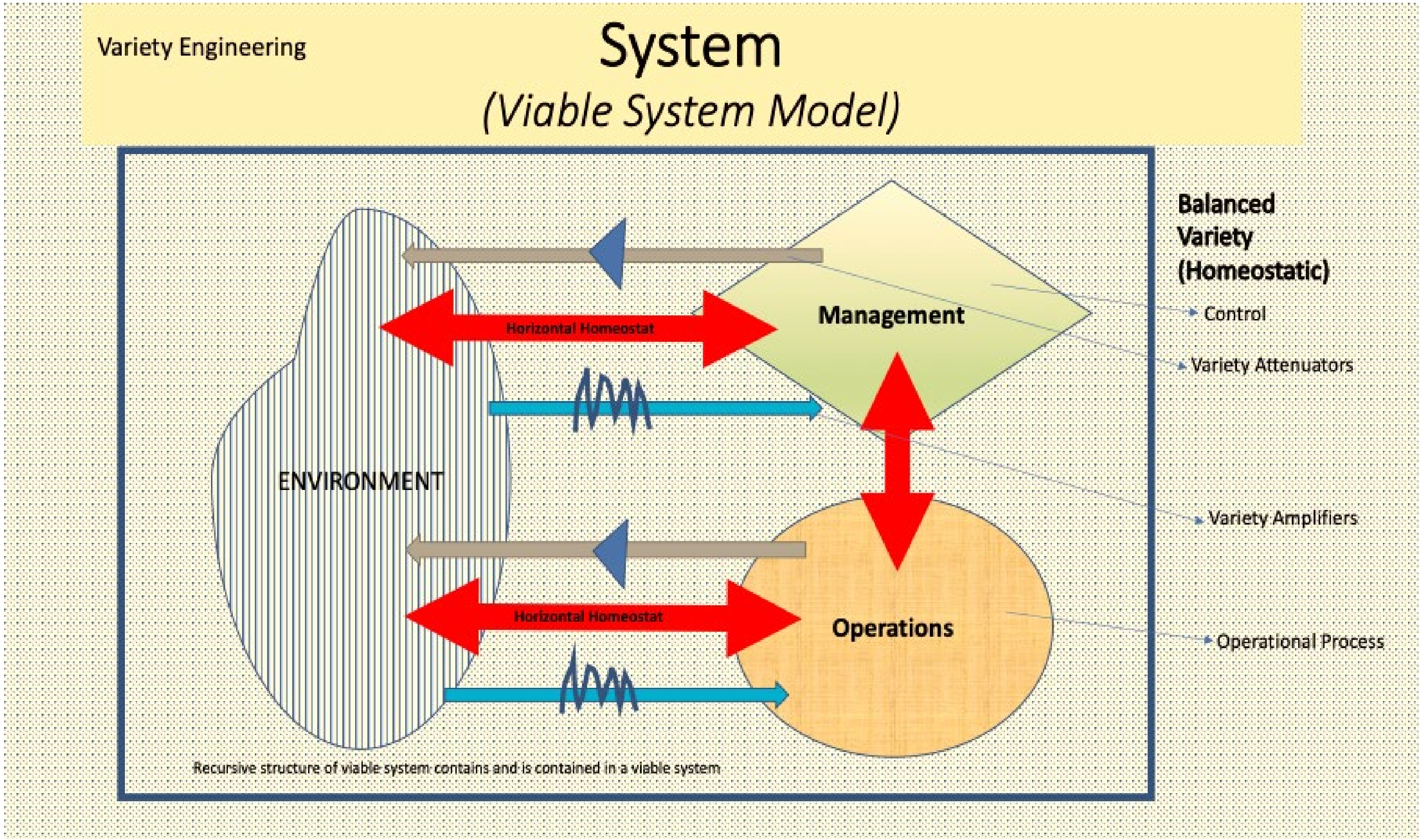
Figure 1

System, variety engineering and Viable System Model (VSM) (Jackson, 2020; Bordley et al., 2019; Tannir et al., 2019)



Overall, the integration of methodologies, combined with complex systems thinking, cybernetics, and the viable system model, presents a robust and comprehensive approach to tackling the challenges of delivering large and complex engineering projects. By blending the strengths of different methodologies, project teams can effectively address various aspects of the project, fostering seamless coordination and harmonisation. Complex systems thinking enables project stakeholders to understand the intricate interconnections and interactions within the project's systems. By taking a holistic view, they can anticipate emergent behaviours, both positive and negative, that may arise during the project's execution. This proactive approach empowers teams to identify potential risks and opportunities, allowing for more informed decision-making and risk mitigation strategies (Bordley et al., 2019; Tannir et al., 2019).

2.2. Methodological integration

2.2.1. Strategic integration of methodologies for effective project management

The integration of methodologies is driven by factors such as project size, complexity, organisational culture, and industry-specific requirements (Ríos, 2010). By incorporating principles and practices from various methodologies, project teams can strike a balance between agility and structure, thereby optimising project execution (Patrício et al., 2021). For instance, adopting iterative development, feedback loops, and continuous integration from agile methodologies enhances flexibility and adaptability, while incorporating elements from traditional project management methodologies ensures that proper governance, documentation, and risk management occurs (Bordley et al., 2019; Tannir et al., 2019). The integration of methodologies should be approached with care to maintain cohesiveness and avoid confusion or conflicts. Clear communication, collaboration, and a shared understanding among project team members are crucial for the successful implementation of a customised approach.

2.3. Complex systems in engineering projects

2.3.1. Strategic management of complex interconnected systems

When dealing with intricate projects, especially in the context of large-scale engineering endeavours, it is imperative to consider Systems of Systems (SoS), referring to a network of interconnected systems working collectively to attain higher-level objectives (Ríos, 2010). Managing SoS necessitates a comprehensive grasp of interactions and interdependencies between distinct systems. Embracing complex systems thinking empowers project stakeholders to pinpoint potential adverse emergent behaviours and proactively apply mitigation strategies. Systems theory, complexity theory, cybernetics, and reliability concepts offer invaluable frameworks and tools for managing both traditional and SoS projects (Conner, 2020; Adams, 2011). Consequently, employing complex systems thinking and integrating cybernetics concepts enhances the understanding and management of behavioural phenomena in complex systems (Holland, 2007). This approach promotes holistic perspectives, nonlinear dynamics, resilience, adaptability, hierarchical structures, and careful consideration of system boundaries and the environmentally crucial aspects for effectively managing intricately interconnected systems (Ríos, 2010).

2.4. Evidence in complexity

2.4.1. Key evidence in the field of complexity

In the field of complexity, cybernetics, and SoS research, key evidence is crucial for understanding and studying complex systems effectively. The type of evidence sought may differ based on the research question, methodology, and objectives of a particular study. However, there are some common sources of evidence that researchers often utilise in these fields. The case study in Chapter 6 titled *"Cybernetics and Battle Management System (BMS) and its application to the network soldier"* provides in-depth analyses of real-world examples of scenarios involving complex systems and SoS. By examining specific cases, researchers can gain valuable insights into the dynamics, interactions, and emergent behaviours of these systems. The case study involved collecting qualitative data through interviews, observations, document analysis, and real-world experience.

2.4.2. Interdisciplinary foundations for complex project

2.4.3. Unravelling complexity: Systems theory, complexity, cybernetics, and reliability in traditional and systems of systems (SoS) projects

The principles of systems theory, complexity, cybernetics, and reliability are not limited to conventional projects; they also hold significant relevance in the context of Systems of Systems (SoS) projects. These concepts provide a comprehensive framework for comprehending and effectively managing the intricacies inherent in both project types. To maintain the quality, credibility, and value of research, a rigorous set of standards and criteria was meticulously applied to evaluate the adopted research methodologies (Chapters 1, 2, 3, 8 and 9).

SoS represents an amalgamation of interconnected systems that pool their resources and capabilities, resulting in a more intricate system with enhanced functionality and performance. Within the domain of SoS, emergent behaviour refers to the system's capability to perform functions and tasks that transcend the boundaries of any individual component system. These behaviours manifest as properties of the entire SoS and cannot be localised to any specific component. The classification of SoS is predicated on operational and managerial independence, rather than factors like complexity or geographical distribution (Dridi et al., 2020).

The challenges inherent in SoS development primarily revolve around fostering and enabling collaboration and coordination, as opposed to solely addressing complexity or distribution issues. Adhering to stringent research criteria serves to bolster the credibility and value of research findings, thus contributing to the expansion of knowledge in the field and facilitating evidence-based decision-making practices. It is worth noting that while different disciplines may exhibit variations in terminology or specific criteria, the overarching objective remains consistent: establishing a robust and reliable research process.

Complex project systems exhibit noteworthy characteristics such as emergence, self-organisation, and self-modification. Understanding the behaviour of complex systems necessitates recognising the property of emergence; it cannot be solely deduced from studying individual components in isolation. The concept of project system complexity is a recurrent theme in various studies, particularly in the context of SoS projects, which often display nonlinear and nonintuitive behaviours, thus posing challenges for predictability by managers and engineers (Garcia, 2020; Sterman, 1992).

Despite frequent references, project complexity, as highlighted by Mikkelsen (2021) and Baccarini (1996), has not received adequate attention. As project complexity escalates, diverse perspectives are needed, prompting consideration of a cybernetics perspective (Tannir et al., 2021; Robb, 1984). Cybernetics deals with the integration of complex systems and their adaptability to external environments (Rezk et al., 2020; Ríos, 2010). Notably, models like the Viable System Model (VSM) within cybernetics manage variety and involve mutual interactions and feedback among lower-level actors, resulting in dynamic structures (Hy¨otyniemi, 2006).

However, the advent of neo-cybernetics shifts the focus towards directly studying emergent models, rather than solely relying on physical first-principle models (Hy¨otyniemi, 2006; Clarke, 2020). Neo-cybernetics, as a contemporary extension and evolution of traditional cybernetics, delves into emergent behaviours, self-organisation, and the dynamics of complex systems in ways that transcend the traditional boundaries of cybernetics (Chapters 5 and 6). It underscores the importance of studying emergent models and patterns directly, acknowledging that complex systems often exhibit behaviours arising from intricate interactions and relationships among their components (Lambiotte, 2019).

2.5. Multi-methodological approaches for solving intricate challenges in project management

In this section, the text discusses the difference between deterministic and stochastic systems in the context of complex project systems. For the systems to meet their purpose, another complex SoS needs to be established (Bar-Yam, 2017; 2004a), i.e., the system of maintenance and its support (Dyson, 1997). This system has components, such as human skills, machine learning, measures of performance, tools, knowledge, and facilities and two main subsystems: social and technical (Dyson, 1997). The social system describes the functions and behaviours that humans apply to and the technical system describes the technological functions and behaviours that deliver the required purpose (Dyson, 1997).

2.5.1. Deterministic system

In a deterministic system, the behaviour of the system is predictable and is a consequence of the interactions and relationships between system elements rather than the behaviour of individual elements. The focus is on factors such as reliability, performance, cost, durability, and economics. However, understanding complex systems requires considering multiple factors that interact and contribute to the overall system behaviour. The behaviour of the system as a whole is the result of the interactions of its components, and issues like completeness and order of the system elements need to be considered; there are several factors, such as reliability, performance, cost, durability, and economics, that need to be considered. However, the factor that enabled complex systems remained elusive; the factor that describes a ‘complex system’ could not be established. There remained some gaps in the understanding of what transpired, but answers to the query “what they are” also remained elusive. However, upon considerable investigation, something emerged. It was not a single factor that could be applied across the life span of a complex system; rather, it was a multi-faceted factor that could account for the complex system in a complex environment. Considering the various permutations and combinations of the components of the system, it was obvious that issues such as their completeness and order need to be considered. Michael Polanyi’s (2015) statement: “We know more than we can tell” is an appropriate description of the situation (Asher, 2019). The total behaviour events of the combined systems working alone or collectively must be visible from the strategic requirement of system performance to the implementation of the system to sustain the purpose (Polanyi et al., 1997). This means that these concepts should be used to understand and manage those parts of an SoS or stochastic system that are predictable and well-understood. This approach can help create a stable foundation for managing the system's behaviour.

2.5.2. Stochastic system

In a stochastic system, the behaviour of the system is unpredictable. Stochastic systems introduce randomness and uncertainty into the system, and the emergent behaviour cannot be determined based on the behaviour of individual elements alone. In such systems, vertical recursion is applied to manage unpredictability. The study explores the integration of cybernetics, such as the VSM, to manage variety and control negative emergent behaviour in stochastic systems. The visibility of emergent behaviour in a SoS is crucial for its management. Operators need to identify the physical manifestations or results of emergent behaviour, regardless of whether they are visible, such as broken or invisible parts, or tolerance drift. The relationship between the purpose of the system and its performance serves as an identifier of emergent events.

This thesis explored the possibility of integrating cybernetics, such as VSM, to manage variety with the application of meta-systems reductionism to SoS such that the negative emergent behaviour is recognised and controlled. Variety, a concept in cybernetics, is managed through Ashby's law of requisite variety, which states that the variety of the controller must be equal to or greater than the variety of the situation or environment. Reducing incoming variety and increasing internal variety is essential for a productive working system to match the external variety of the environment. VSM is proposed as a governing framework to manage variety in the SoS. The concept emphasises the need for a structured approach, such as the VSM and complex systems thinking, to manage behavioural phenomena within complex systems. By focusing on deterministic system levels and acknowledging the inherent complexity of these systems, organisations and projects can enhance their ability to achieve shared goals and manage emergent behaviours effectively in SoS.

The visibility of emergent behaviour in SoS can be described through several questions:

- **What** is/are the physical results/manifestations of the presence of emergent behaviour?

When the behaviour is not identified, it could result in catastrophic system failure or degradation of performance. The physical results could either be visible, such as a broken part, or be invisible, such as the tolerance drift of a component. The operators must be able to interpret what they see. For example, can they see a pattern in the data? Can a failed part be restored to its original state? The relationship between purpose and performance is an identifier of an emergent event (Menčík, 2016).

- **What** is/are the implication(s) of the existence of the presence of emergent behaviour?

The presence can be identified through data analytics. Management systems have methods to measure technical and social performance at both the operational and maintenance levels (Dyson, 2019; 1997). Strategic, operational, and technical goals are set, and the performance is measured against these parameters. Emergent behaviour in components such as time are candidates for intensive management to identify and mitigate the impact (Menčík, 2016).

- **Where** does emergent behaviour occur/take place?

The emergent behaviour can be observed at numerous locations. In some cases, it is data interpretation and identification of a cyber threat or vulnerability. Skills required for finding these patterns are difficult and need a deep knowledge of the equipment's normal state and a way to describe its relationship (Menčík, 2016). The emergent behaviour of the reliability of equipment can be observed through maintenance rates (Dyson, 2019). Reliability is an overall identifier of the source (Zio et al., 2011). Emergent behaviour can also occur at common points such as power supplies and errors in training programs. Furthermore, it can be caused by error creep as well.

- **How** is emergent behaviour manifested?

Emergent behaviour can manifest at any time or in any event. For example, when a system is repositioning, or re-tasking and the change is not according to the specifications. Simulating designs can aid in identifying unexpected emergent behaviours. Other manifestations include response time variations, loss of accuracy, threat management, and operator capability or skill.

The scope of all aspects of SoS involves an indeterminate number of possible emergent behaviour events. These can happen at the purpose strategy level or at the purpose implementation level. Emergent behaviour should be anticipated even if it cannot be identified in the first instance. Emergent behaviour, positive or negative, is that element of systems engineering that should improve capacity and capability.

Maintenance of system elements is driven by managing the emergent behaviour (Dyson, 2019; 1997).

2.6. Cybernetics and systems

2.6.1. Cybernetics theory and complex systems

The integration of a fourth-order emergent cybernetics model in meta-metasystems is of great value to the world of engineering. By integrating cybernetics and meta-methodology, an author can manage and / or control the system viability. The researcher recognised that a single system is deterministic and VSM is the deterministic system and so variety is controlled. Integration of cybernetics (VSM) and meta-metasystems is possible, and the researcher explored the key parameters used to build an intelligent system by managing the variety. The fourth-order cybernetics system is either difficult or, perhaps, impossible to conceive, and it unavoidably defies certain principles at the lower orders (Yolles, 2021). The integration of a fourth-order emergent cybernetics model and meta-metasystems (higher-order cybernetics) can provide valuable insights for engineering. Fourth-order cybernetics, also known as emergent or liquid cybernetics, deals with how a system redefines itself and immerses itself into its environment. It involves considering elements such as centrality, contextuality, goals, operations, viability, design, and information in systems theories (D’Andreamatteo et al., 2015; Cannon, 1932). The cybernetics methodology, often referred to as the “new paradigm”, allows for the visualisation of relationships in phenomena (Ríos, 2010). Through cybernetics management by Beer in 1959 (Vahidi et al., 2019), we aimed to examine the theory of critical system thinking and cybernetics methodology (Yolles, 2021).

2.6.2. Variety in cybernetics theory

Ashby’s Law of requisite variety is represented in the Variety formula:
V(C) >= V(S), where the variety of the controller (C) must be equal to or higher than the variety of the situation (S; Environment).

In pragmatic business terms, the internal variety of a productive working system must match the external variety of the environment (situation). Therefore, it is not only mandatory to reduce the incoming variety but also to increase the internal variety to reach the requisite variety. Typically, this means that we need sufficient resources, capabilities, and time to solve customer problems in a given situation. Viable systems management is proposed as a governing framework that can be applied in the system where the number of subsystems represents the SoS. The network soldier system is a deterministic system in which the behaviour is predictable and horizontal recursion is applied to reduce variety.

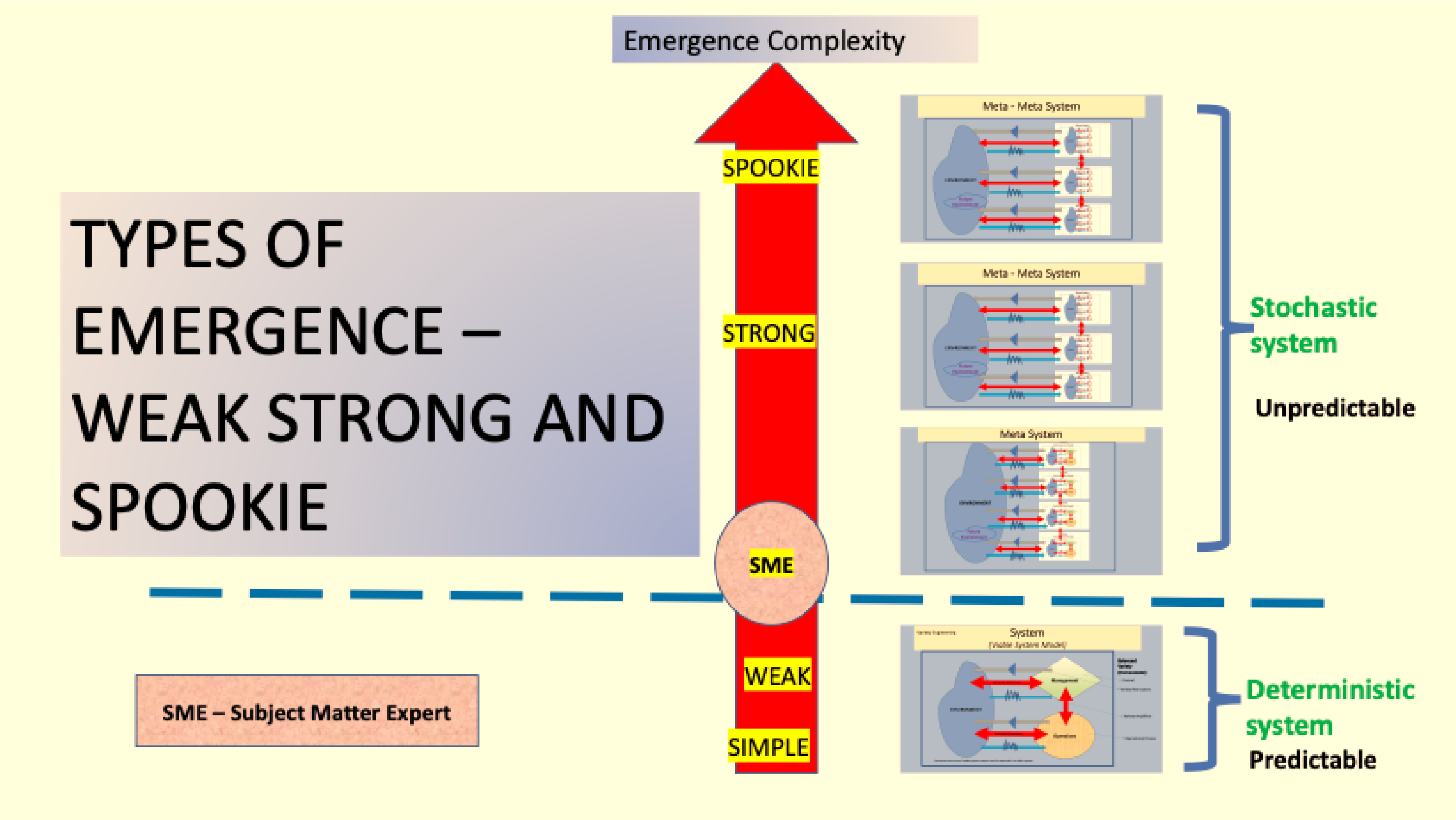
2.7. Emergent behaviour

2.7.1. The emergent behaviour of complex systems

The term 'emergence' frequently engenders confusion in both scientific and philosophical discourse, as it encapsulates at least two distinct concepts: strong emergence and weak emergence. While both concepts hold significance, it is imperative to make a clear distinction. Weak emergent properties pertain to properties of a large system that can be predicted or derived by computationally analysing the interactions among the system's constituent parts. Conversely, strong emergent properties of a system are deemed unpredictable through computational analysis of the interactions among its constituents.

Sometimes, emergent behaviour in complex projects can result in unexpected and undesirable outcomes in areas such as intelligence, cyber security, administrative and management software systems, wireless networks, and project management. Emergent behaviour is imperative for the development of a framework to deliver large and complex engineering projects safely and securely and to produce new insights and practical steps to improve the success of complex projects. Emergence can be summarised as a characteristic of a system, wherein properties appear at the system (macro) level that were not explicitly implemented but arise dynamically from the interactions between entities at the component (micro) level (Maier, 1998 and Maier et al., 2022). The interactions that might result in emergent behaviour manifest themselves at the interfaces between systems, between systems and operators, or between systems and project software development elements. Project software in an environment allows the participants to successfully combine and analyse network data with more sophisticated algorithms and techniques in the operational environment.

Figure 2
The classification of emergence complexity type (Mittal et al., 2015; Rainey et al., 2015; Yolles, 2021)



Emergent behaviour in a complex project is not based on a theoretical understanding because that is independent of experience, and it is challenging to clearly recognise, analyse, and validate where the emergent behaviour exists. The emergence exists in the project, primarily owing to ambiguous aspects that cause complications. The researcher focused on understanding how and why major projects succeed or fail. Additionally, the researcher also determined whether a system can be modelled and simulated to minimise the occurrence of disasters and accidents in complex engineering projects. General systems theory (GST) can be applied to both traditional and SoS projects (Söderlund et al., 2019; Soderlund, 2004).

Numerous techniques exist to detect emergence, ranging from statistical analysis to formal approaches. For this thesis, variable-based methods (O’Toole et al., 2014; Chan, 2011; Holland, 2007) were the most appropriate choice. The literature on crisis highlights that they occur for a reason and that most often the reasons are either ignored, covered up, or not recognised at all (Loosemore et al., 2020; Loosemore, 2000). They are events, i.e., before occurrence and being acknowledged, that are observed to have a low probability of occurrence but a high potential impact and are rarely accompanied by contingency plans. These types of situations are perhaps best tackled using an emerging strategy (Tennent, 2020; Mintzberg et al., 1998). Miller and Olleros (2000) argued that successful projects are not selected but are shaped (Dewulf et al., 2020).

Some generic examples of failure modes by Meier (2008) focus on projects within the U.S. federal intelligence and defence agencies; they found numerous early warning signs that occurred frequently in these projects.

Fromm (2005), Holland (2007), Bonabeau et al. (1995), and Emmeche et al. (2000) agreed that the notion of emergence involves the existence of levels in the system. Williams (2005) argued the need for developing a theory of project behaviour, as there have been few empirical positivist studies of projects (Williams et al., 2019).

Therefore, emergence can be summarised as a characteristic of a system (Maier et al., 2022). The properties which appear at the system (macro) level are not explicitly implemented and arise dynamically from interactions between entities at the component (micro) level (Singh et al., 2017). By classifying emergent behaviour using Fromm's taxonomy and by the development of a suitable framework, a platform for simulating and analysing behaviours in multi-agent systems can be formulated (Mittal, 2017). The taxonomy of different types of emergent behaviours is based on the relationship between these macro and micro levels (O'Toole et al., 1998; Clarke, 2014).

2.8. Complexity, cybernetics and biomimetics

Complexity is caused either by interdependencies and uncertainties (Williams, 1999), human-oriented social aspects (Stacey, 1995), or behavioural complexity. In addition to internal complexities such as technology and interfaces of existing systems, external complexities such as stakeholder relationships (Pryke & Smyth, 2006) lead to challenges in understanding and assessing project behaviour. Remington and Pollack (2007) discussed several types of complexities and tools to address the various elements in complex systems (Morcov et al., 2021; Williams et al., 1999).

Biomimetics[1], also known as biologically inspired design, offers another avenue for project management. By studying natural systems, biomimetics provides models, processes, and procedures for systems thinking, conception, design, architectures, lifecycles, and survival strategies.

Although cybernetics allows the study of complex systems and there is significant value in this endeavour (Robb, 1984), there have been no thorough studies on project management and cybernetics (Ríos, 2010). Therefore, the field of project management must reinvestigate its origins and explore other streams of management studies. (Morris et al., 2011).

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[1] "Behaviometrics" is the word which is gotten from the expressions "behavioural" and "biometrics". "Behavioural" alludes to the way how the individual acts while biometrics is a quantifiable conduct used to check the personality of a person. Behaviometrics focuses on behavioural patterns rather than physical attributes. Related Journals for Behaviometrics Journal of Applied Computational Mathematic, Advances in Applied Mathematics, Biomimetics Biomaterials and Tissue Engineering, International Journal of Medical Sciences and Technology.

Table 1
What factors are part of combining ecology, biomimetics and biomimicry systems functions (Peer Review Table1, 221722688, Applied Artificial Intelligence, p. 91)

Factors:		
Systems thinking	Systems conception	Systems lifecycles
Systems architectures	Systems methodology	System survival strategies

2.9. Project management

Project management emerged from the defence sector, which emphasised systems thinking and system integration in the 1950s (Hughes, 1998; Hughes et al., 2020). However, currently, the emphasis has predominately been on the process, planning, and monitoring tools, such as program evaluation and review technique (PERT) and critical path methods (Morris, 2011), which became synonymous with the discipline. In the 1960s, several operations management practices such as life cycle costing, quality assurance, value engineering, configuration management, and work breakdown structure were added to the discussion on this discipline (Moradi et al., 2020; Morris, 2012; Fortune & White, 2006).

In the search for indicators that can serve as early warning signs for projects, the focus must be on sources that describe factors of project success and failure (Bushell, 2009). Descriptions of project success and failure factors can be found in literature on project management, a topic that has been extensively studied by several authors that include Pinto et al. (2021), Pinto and Prescott (1988), Kerzner (2013), Morris et al. (2011), as well as the famous IMEC study by Favari et al. (2020) and Miller and Lessard (2000) regarding large projects. Projects are subjected to uncertainty (AS/NZS ISO 31000:2018), and extensive literature exists on project risk management that focused on the aleatoric risks within the project and known epistemic risks (Esposito et al., 2023; Engwall, 2003). The lack of clear unambiguous goal leads to uncertainty, making the analysis of achieving these goals equally unclear (Salovaara et al., 2020; Linehan, 2004). Even when the goal is known, achieving the goal can be uncertain as participants make sense of the project and work towards project delivery (Blomsma et al., 2023; Barbosa et al., 2021; Engebø et al., 2020; Jensen et al., 2006; De Meyer et al., 2002; Weick, 1995). Evidence suggests that a critical foundation for safe and efficient operational capability and project control is essential for the integrity of systems, communication, control, computers, and information.

2.9.1. Project management, risk, and effectiveness

Samson suggested three definitions for project management (Zwikael et al., 2022; Samson, 2009): (1) the collective return referring to those in charge of the project; (2) the self-management exercised by individuals over personal projects; and (3) the task of planning, organising, coordinating, directing, and controlling both human and material resources in a project (Morris et al., 2011). The other tasks include monitoring, supervising, evaluating progress, and reporting to higher management of a project. Self-management is a process in which an individual plans, organises, and controls a project.

The line management tasks involve exercising direct authority and taking responsibility for the whole project from beginning to end. The task of monitoring comprises staff management, including advising and assisting senior management; exercising limited authority; accepting limited responsibility for monitoring, assessing, and evaluating progress; and reporting and undertaking general supervision of the project (Zwikael et al., 2022; Samson, 2009).

The term ‘project’ is defined as an intergraded and distinctively defined set of interrelated activities that have a definite start and finish and are designed to produce a product, machine, structure, system, or service collectively designated as a project (Zwikael et al., 2022; Samson, 2009). Most engineering projects involve one or more of the following sets of technical activities: investigation, research, development, design, construction, manufacture, installation, operations, commissioning, maintenance, and servicing. The task of supervising and managing engineering operations forms part of the responsibility of most engineers. For any project, the issues of quality, time, costs, and delivery dates are critical and are associated with the management of individuals and groups on the project (Zwikael et al., 2022; Stanitsas et al., 2021; Samson, 2009; Jensen et al., 2006).

Nearly all projects usually encounter risks and uncertainty in investment decisions that are attributable to several possible sources (Bordley et al., 2019;

Morris et al., 2011; Chapman & Ward, 1997). Probability of a risk is determined during the analysis of projects; however, because these probabilities are not objectively verifiable, they are generally subjective (Bordley et al., 2019; Tannir et al., 2019; Chapman & Ward, 1997; Cleland & King, 1983). Even when probabilities are used, the risks and uncertainties concerning the outcomes in question are not fully eliminated (Tannir et al., 2019); rather, they become uncertainties associated with the probabilities on which the analysis is based (Langfield-Smith, 2008).

In the case of large projects, project management can be considered as a form of mini-general management, wherein the engineer manager needs to exercise more general management functions (De Rooij et al., 2019). The project management is not only in charge of the operation and material resources, such as plant and equipment, material supplies, and finances, but also in charge of a team of diverse personnel that could include accountants; industrial relations specialists; technical suppliers such as surveyors, computer experts and engineers; technicians; tradespersons; and other project personnel (Daniel et al., 2023; Zwikael et al., 2022; Samson, 2009; Turner, 2006; Cleland et al., 1983).

The project activity can be described as an integrated and distinctly defined set of interrelated activities that have a delineated beginning and end. It is generally designed to produce a machine, structure, system, or service, and a combination of diverse activities are collectively designated as a project (De Rooij et al., 2019; Langfield-Smith, 2008). For any project, the issues of quality, time, cost, and delivery dates are critical and must be associated with the management of the individuals and groups engaged in a project. Successful project management depends on the understanding of the basic principles, concepts, techniques, willpower, leadership abilities, and the ability to cooperate with and gain the respect of people associated with the project (Mäkinen, 2020; Zwikael et al., 2019; Fortune & White, 2006; Marion & Uhl-Bien, 2001). The project manager can be involved with several different projects simultaneously (Juli, 2011). Valuable skills of the project manager include:

- Administrative credibility
- Political sensitivity
- Technical ability
- Leadership

A project manager is perceived as a third-order cybernetic system with both a negative and a positive feedback loop, bound to leadership qualities and having intelligence (Juli, 2011). In handling systems that are on the verge of chaos, a leader can enhance their mental model by identifying hidden patterns during the project and multiple equilibrium possibilities (Regine et al., 2000). Therefore, the project's risk is reduced by providing confidence to the manager to handle the uncertainties in the project (Pires et al., 2023; Langfield-Smith, 2008; Marion et al., 2001; Regine et al., 2000).

Management action based on 'linear thinking' leads to predictable results. Even though a certain order exists in the system, it can undergo a type of disorder or chaos when certain actions result in unpredictable behaviour (Daniel et al., 2022; Marion, 1999). However, a system may not be either completely predictable or chaotic. As a priori that predicts what actions lead to specific outcomes is not presented in the case of a complex project system, it remains in a state of order and disorder simultaneously (Heylighen, 1988).

CHAPTER 3: LITERATURE REVIEW

3.1. Introduction

This chapter provides a comprehensive literature review, navigating through the complexities of SoS and their projects. It integrates theoretical concepts with practical examples, offering insights into effective SoS functioning, emergent behaviours, and the evolving landscape of cybernetics.

The literature review provides an in-depth exploration of Systems of Systems (SoS) and their components, examining their configurations, functions, and emergent behaviours. The discussion highlights the importance of exosystemic states and metasystems within SoS, emphasising the significance of hidden states beyond the system boundaries. The chapter then explores the intricacies of SoS projects, revealing how minor differences among stakeholders can lead to diverse outcomes, contributing to the nonlinearity of the system. The concepts of exosystemic states, representing external factors influencing SoS behaviour, and metasystems, serving as higher-order cybernetic frameworks, are introduced to analyse hidden states and relationships. An examination of emergent behaviours in combined systems sheds light on the challenges and opportunities associated with SoS design and management. To address the complexity of projects, the chapter incorporates Norbert Wiener's cybernetics, proposing adaptive, self-organised systems with positive feedback as a means of managing chaos. The evolution of cybernetic thinking is explored, introducing fourth-order cybernetics and emergent cybernetics, which pose challenges in understanding systems that redefine themselves.

Chapter 3 outlines the approach taken in the literature review, focusing on the examination of the emergence process in complex project systems. The review is guided by the pillars of modern warfare and emergent behaviour in engineering SoS, with research manuscripts from Chapters 1, 2, 5, 6, and 7 informing this exploration. The qualitative research method is chosen to address complex system design through system thinking theory and cybernetics principles. Several authors, including Holland (2007), Fromm (2005), Bonabeau (2002), Emmeche et al. (2000), and Bonabeau et al. (1995), are cited to support the notion that emergence involves system levels.

The methodology includes Boolean literature review use, focusing on the application of SoS in battle management systems. Specific keywords and areas of research are identified for the Boolean analysis, such as SoS, emergence, cybernetics, systemic thinking, and risk mitigation. The aim is to investigate challenges and opportunities to integrate diverse systems for effective decision-making in combat scenarios. The process involves identifying relevant authors through a purposeful sampling approach and selecting databases and sources for literature review. The identified databases include PubMed, IEEE Xplore, ACM Digital Library, JSTOR, ScienceDirect, Scopus, and others. The literature review is summarised by organising findings through thematic analysis or categorisation to facilitate synthesis.

3.1.1. Components of SoS are configurations of tangible and intangible objects

Metasystems and emergent behaviour, safeguarding operational capability, and project control in complex programs

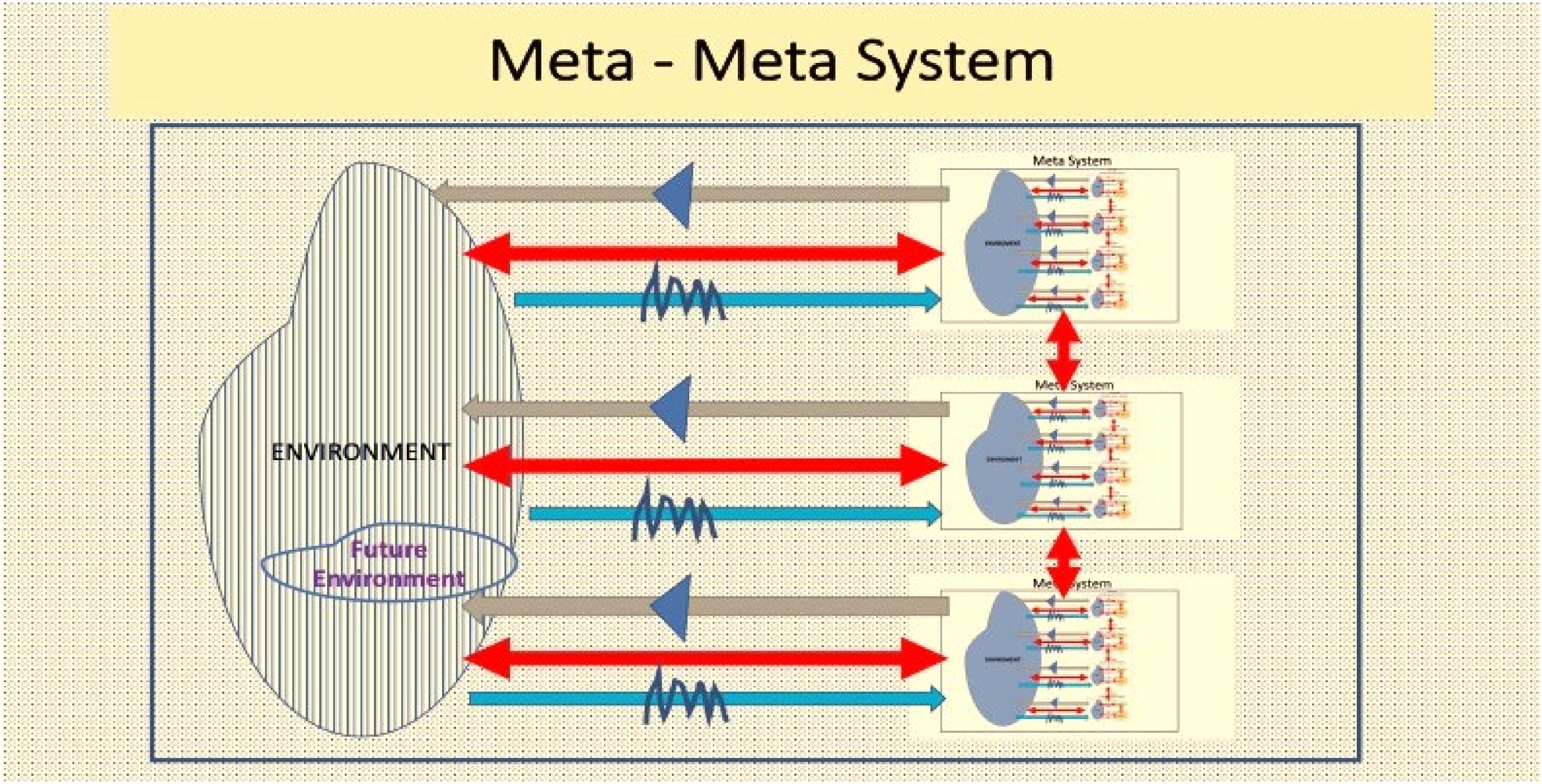
The SoS and the components of systems are configurations of tangible and intangible objects such as mechanical, electrical, electronic, software, knowledge, or natural objects. These objects perform functions and behaviours to meet a specified purpose and fit within the description of emergent behaviour (Maier et al 2022 and Mier 1998). In a complex project, the nonlinearity of the outcomes can be observed. For example, as every project progresses, even small differences between stakeholders (project’s attractors) can lead to substantially different solutions (or project designs). Even differences in the initial conditions can contribute to this chaos. Changes can take place even during execution, and complex projects are typically affected by deviations from plans. The temporary nature of the project organisation may also make it unstable.

3.2. Exosystemic states

3.2.1. Exosystemic states and meta system in SoS

Exosystemic states refer to hidden states that exist beyond the boundaries of a Systems of Systems (SoS). They are not confined solely to the system itself but encompass external factors and influence those factors that impact the behaviour and interactions of the SoS components. Exosystemic states can include various situational conditions, contextual factors, and external relationships that affect the functioning and performance of SoS (Bronfenbrenner, 2021; Djavanshir et al., 2015). On the other hand, the concept of a metasystem in the context of SoS refers to a higher-order cybernetic framework that explains the hidden states and relationships occurring within the system. The metasystem provides a way to understand the complex interactions and dynamics of an SoS by considering it as a subsystem embedded within a larger context. It enables the analysis and comprehension of emergent behaviours, feedback loops, and interdependencies that exist between the SoS and its external environment (Yolles, 2021; Djavanshir et al., 2015). This is explained in Chapter 8.

Figure 3
VSM system engineering (higher level abstraction diagram) (Bronfenbrenner, 2021; Djavanshir et al., 2015; Yolles 2021)



Although the objects provide a purpose, hidden states in various situations in such a system can be considered exosystemic (Bronfenbrenner, 2021). The metasystem can be used to explain the hidden states and relationships that occur in a system (Djavanshir et al., 2015). This relationship can be generalised to explain a higher order of cybernetics in relation to lower orders (Yolles, 2021).

Thus, an SoS of machines exists that must be designed, manufactured, and operated to deliver its purpose. An example is a communication SoS comprising satellites, land stations, submarine cables, facilities, etc., to enable household and business transactions, allow manufacturing, control autonomous vehicles in mines, or manage a battlespace. Another complex SoS is required to enable the systems to achieve their purpose (Yolles, 2021), i.e., the maintenance process and the associated support systems (Djavanshir et al., 2015; Hundt, 2006). Considering the various permutations and combinations of the elements of the system, issues such as their completeness and order must be considered[2]. The comprehensive behaviour events of the combined systems working alone or collectively must be visible from the strategic requirement of system performance to the implementation of the system to sustain its purpose. The combination of the maintenance process and the associated support system plays a crucial role in ensuring that the complex SoS can fulfil the intended purpose.

The aforementioned studies highlight the significance of a well-designed system of maintenance and support that integrates both social and technical aspects to ensure the effective functioning and longevity of complex SoS. In an SoS, it is crucial to identify the critical set of systems that affect the capability of the objectives of the SoS and help understand their interrelationships. An SoS can place demands on the constituent systems that are not supported by the designs of those systems. Combinations of systems operating together within the SoS contribute to the overall capabilities. Combining systems can lead to emergent behaviours more frequently than single systems. As in the case of single systems, the emergent behaviour of combined systems can also enhance or degrade the overall system performance (Preiser, 2019; Cilliers, 2002). In addition to the ability of systems to support the

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[2] In mathematics, combination and permutation are two different ways of grouping elements of a set into subsets. In a combination, the elements of the subset can be listed in any order. In a permutation, the elements of the subset are listed in a specific order.

functionality and performance required by the SoS, differences are observed among the systems in terms of the characteristics that contribute to the suitability of the SoS such as reliability, supportability, maintainability, assurance, and safety. The challenge in the design of an SoS is leveraging the functional and performance capabilities of the constituent systems to achieve the desired competence as well as crosscutting characteristics of the SoS to ensure that it meets the wide range of needs of all the users (Kockum et al., 2021; Cilliers, 2000).

3.3. The complexity and nonlinearity in complex projects

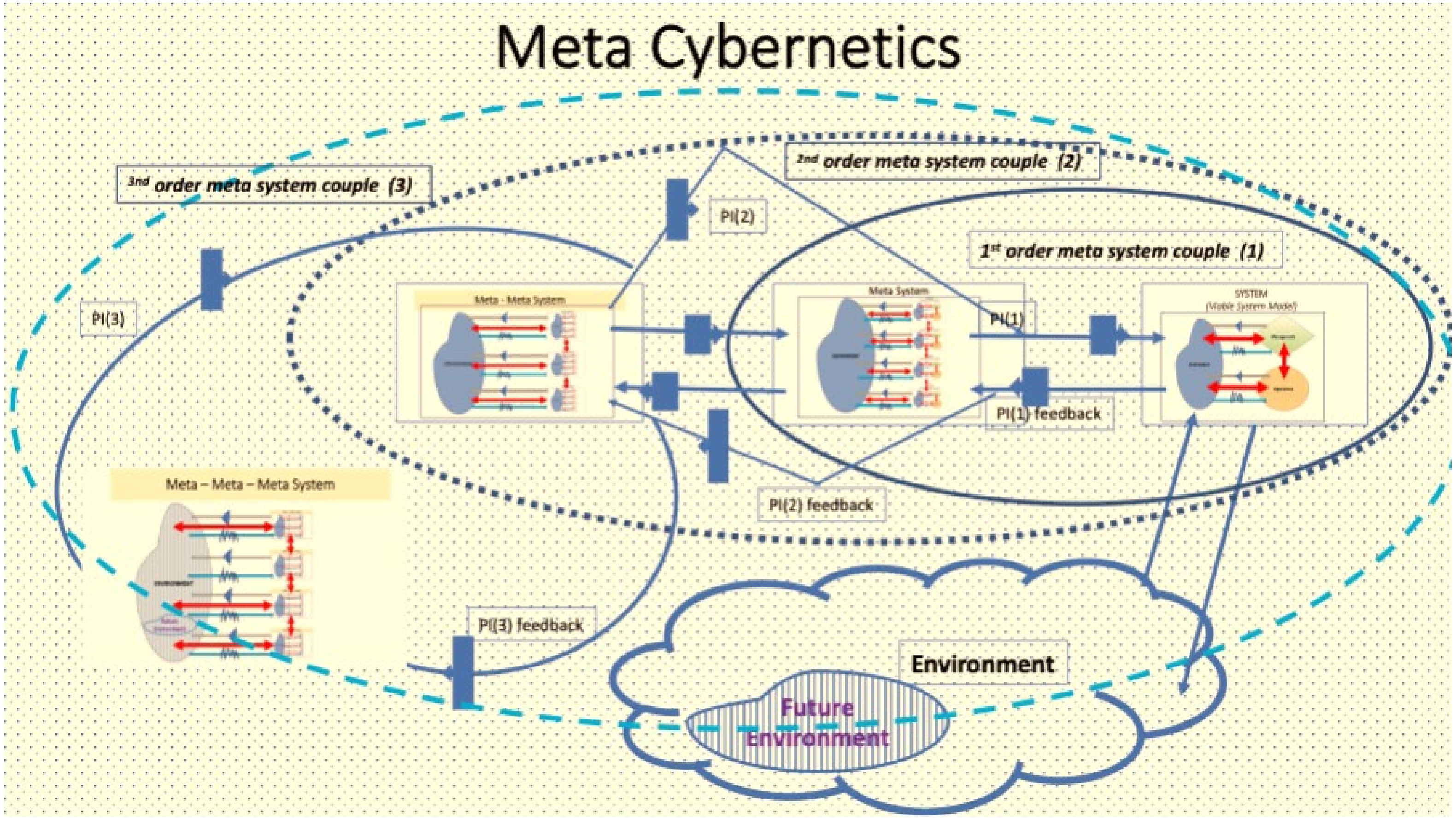
Norbert Wiener’s (1973) original cybernetics is associated with self-regulation and equilibrium stabilisation around specified goals primarily through negative feedback. Although this is an attractive proposition for project management, the complexity and chaos of projects are better reflected by nonlinear systems, wherein they are better managed in adaptive and self-organised distributed systems with positive feedback (Anderson, 2020; Marion, 1999).

Currently, cybernetic thinking embraces the computerised assimilation of increasing information such that one can focus attention on specific (micro) segments of a larger system. In this process, problem decisions can be fragmented into smaller segments that are sequentially arranged in a linear path by conducting cybernetic inquiries using reductionist analysis of mass data. Additionally, this would dominate the industry and government policies as well as the promise of increased prediction and greater control with the advancement of increasingly more powerful computational assistance by smarter machines.

The fourth-order cybernetics system (emergent cybernetics) considers what happens when a system redefines itself. It focuses on the integration of a system within its larger, co-defining context. The fourth-order cybernetics system is difficult or, perhaps, impossible to conceive, and it unavoidably defies certain principles that make sense at lower orders (Yolles, 2021).

Figure 4

Fourth-order metasystem (emergent cybernetics) for VSM (Yolles, 2021; Leslie, 2021; Preiser, 2019; Chan, 2011; Holland 2007; O'Toole et al., 2014.



Fourth-order cybernetics acknowledges the emergent properties of complex systems. Emergence entails a greater complexity that reduces knowability and predictability. Therefore, a system will merge into the environment in which it exists. Emergence means “submergence” or “disappearance in, as if in, a liquid” (Yolles (2021). The distributed nature of fourth-order cybernetics is as follows:

- Who (or what) is capable of seeing a fourth-order system in its full complexity?
- In the fourth order, the discrete observer's boundaries become problematic.
- Who is sufficiently observant to notice all relevant changes as and when they occur?
- A single agent is unable to see enough – its standpoint is too fixed, partial, or out of date.

Emergence entails greater complexity that reduces the knowability and predictability. Therefore, a system will emerge into the environment in which it exists Yolles (2021). The higher-order cybernetics as defined by Yolles (2021) is the N+1 order cybernetics explained in Diagram 5 and in **“**Horizontal recursion in (*n + 1*)th order meta cybernetics”.

The orders of cybernetics defined by Zangeneh and Haydon (2004) are:

- “Fifth order: Cognitive coherence encompasses both an aspect of order (pattern establishment / viability of the system / teleonomy) and of balance”.
- “Sixth order: Constructive epistemology states that knowledge is not passively received, but actively constructed”.
- “Seventh order: Cognitive morphogenesis is the study of how forms of human behaviour originate; it can be applied to third- and fourth-order cybernetics”.
- “Eighth order: Rationality and languages are complements, the former is developed by the capacity of symbol creation and abstraction, but the latter could not subsist without thought coherence”.
- “Ninth order: Sociocybernetics can be defined as the interplay between third- and fourth-order cybernetics for the purpose of understanding human behaviour on an individual and collective scale, with the first- and second-order cybernetics functioning as complements”.

The key points are discussed while emphasising the importance of the theoretical framework, the components of SoS, the cybernetic approach, and the understanding of emergent behaviour in complex projects and systems. It highlights the **need for further research in the field** to address the challenges and complexities associated with managing SoS effectively and optimising their performance (Leslie, 2021; Preiser, 2019).

The significance of the literature review lies in its contribution to the understanding of the foundational principles, hidden relationships, emergent behaviour, and effective management strategies within metasystems and SoS. This understanding can spur future research, guide decision-making in system design and operation, and enhance the overall performance and safety of complex programs. The review also explores the foundations of operational capability and project control, which are critical for safe and efficient project management. By comprehending the underlying principles and factors that contribute to operational capability and project control, researchers and practitioners can develop strategies to enhance the performance and safety of complex systems.

This literature review delves into the critical foundation of a safe and efficient operational capability and project control within the context of metasystems and their emergent behaviour. The concept of metasystems is utilised to unravel hidden and unknown relationships that arise in SoS. Moreover, the review incorporates theories and research on managing complex programs with project management services. The significance of establishing a robust foundation for safe operations and effective project control in metasystems is emphasised by Crawford (2021). This review synthesises the available information, exploring the intricacies of metasystems, emergent behaviour, and the management of complex programs.

3.3.1. Introduction to techniques to detect emergence

In literature, several techniques exist to detect emergence and the most appropriate have been enumerated by Chan (2011), Holland (2007), and O’Toole et al., (2014). Such conditions in SoS are perhaps best tackled using an emerging strategy (Mintzberg et al., 1998). Miller and Olleros (2000) argued that successful projects are not selected but shaped. Some generic examples of failure modes by Meier (2008) focus on projects within the U.S. federal intelligence and defence agencies. Particularly, several early warning signs that occurred frequently in these projects have been documented by Yi et al. (2015).

3.3.2. The various theories and elements in SoS

The various theories and elements that have evolved are already established and very relevant to system emergent behaviour in complex SoS. Therefore, basic theory and research on judgment, decisions, and choices are the starting point for a general SoS framework. This study aims to understand how and why many major operations and projects fail and whether a management system can be developed to minimise the occurrence of failure in complex engineering projects.

The scope:

1. Conceptual understanding of systems of systems:
    - Definition and characteristics of SoS.
    - Differentiating SoS from individual systems and traditional systems engineering approaches.
    - Key principles and theories underlying SoS in the context of battle management systems.
2. Architecture and design of battle management systems of systems:
    - Architectural frameworks and models for SoS design in battle management systems.
    - Integration techniques for diverse and heterogeneous systems.
    - Interoperability standards and protocols for seamless communication and information sharing.
3. Interoperability and data fusion challenges:
    - Identifying and addressing interoperability challenges in battle management systems.
    - Data fusion techniques for integrating information from multiple systems.
    - Ensuring data quality, reliability, and consistency within the SoS.

4. Command and Control (C2) in battle management systems of systems:
   - C2 structures and mechanisms for SoS in battle management.
   - Decision-making processes and information fusion in dynamic combat environments.
   - Adaptive and resilient C2 approaches to handle system failures or disruptions.
5. Systems of Systems engineering approaches:
   - Methodologies, frameworks, and best practices for engineering SoS in battle management systems.
   - Verification and validation techniques for complex SoS.
   - Risk management and mitigation strategies are specific to battle management SoS.
6. Case study (Chapters 5 and 6) and practical implementations:
   - Analysis of real-world battle management systems of systems.
   - Lessons learned and success factors in implementing SoS in battle management.
   - Use cases demonstrating the benefits and limitations of SoS in battle management systems.

The specific scope and focus of this literature review within the broader field of systems of systems are defined and include application domains like Defence, Complex Projects, or specific aspects of SoS (e.g., design, integration, interoperability). This literature review aims to explore and analyse the field of SoS within the context of battle management systems. Battle management systems are critical components of modern military operations that encompass coordination, integration, and control of various interconnected systems to support decision-making and situational awareness during combat. The review will focus on identifying key research areas, challenges, and advancements related to the application of SoS principles in battle management systems.

3.4. Approach to literature review

3.4.1. The thesis approaches

The thesis will examine the nature, principles, operation, and outcome of the emergence process in a complex project system environment through the lens of the pillars of modern warfare and emergent behaviour in an engineering SoS by the research manuscripts published and noted in Chapter 1 and 2 and provided in Chapters 5, 6 and 7. The real-world scenario modelling and simulation are described in Chapter 8.

In the book titled "*Engineering Emergence: A Modelling and simulation approach",* L. Rainey (2015) describes the architecture and modelling of complex systems. According to Williams (1999), complexity is caused by interdependencies and uncertainties as well as by human-oriented social aspects (Stacey, 2007). Moreover, internal complexities which could include technology and interfaces to existing systems create difficulties, particularly in understanding and assessing project behaviour. Conversely, external complexities include stakeholder relationships (Pryke & Smyth, 2006). Remington and Pollack (2007) discussed the various types of complexities and the tools to address the various elements in complex systems. Other examples are the cause-and-effect tools that other authors and researchers have developed and used for diagnosing system faults (Williams et al., 2010).

3.4.1.1 Identification, selection, and analysis of thesis literature

The qualitative research method aims to address complex system design through the application of system thinking theory and cybernetics principles. The system thinking approach aims to simplify the process of thinking by selectively handling the details of the underlying features of a situation from a set of explicit perspectives (Ackoff, 2010).

Several authors, including Holland (2007); Fromm (2005); Bonabeau (2002); Emmeche et al. (2000); and Bonabeau et al. (1995), agree that the notion of emergence involves the existence of levels in the system, and thus, emergence can be summarised as a characteristic of a system. This property appears at the system (macro) level that is not explicitly implemented and arises dynamically from the interactions between entities at the component (micro) level (Sing, 2017). Fromm's taxonomy developed by psychologist Erich Fromm (Fromm, 2005), categorises different types of human orientations based on their relationship with others and the world. It offers insights into various psychological and social orientations that individuals may adopt. The taxonomy consists of five orientations: receptive, exploitative, hoarding, marketing, and productive. Using Fromm's taxonomy to classify emergent behaviour and create a suitable framework, a platform for simulating and analysing behaviours in a multi-agent system can be developed (Mittal, 2017). To establish the theoretical framework for modelling and simulation, it is necessary to first start the taxonomy of emergent behaviours. The most cited works to date that have explored the classification of emergent behaviours are Sing (2017), Johnson (2016), Holland (2007), Fromm (2005), and Bar-Yam (2004).

By utilising Fromm's taxonomy to classify emergent behaviours and create a suitable framework, a platform for simulating and analysing behaviour in a multi-agent system can be developed. To establish a theoretical framework for modelling and simulation, understanding the taxonomy of emergent behaviours is essential.

3.5. Boolean literature review use and methodology

The primary focus of this literature review is to investigate the application of SoS in the field of battle management systems. It aims to explore the challenges and opportunities associated with integrating and coordinating diverse systems for effective decision-making, situational awareness, and operational control during combat scenarios. The review will emphasise research papers, scholarly articles, and technical reports published in the last decade that specifically address the application of SoS principles and methodologies to battle management systems. The associated keywords and areas in which the research was conducted are listed in Table 2.

Table 2
Keywords and areas of research, by Boolean analysis (search strings).

Systems of Systems (SoS)	Problem-solving
Complex projects	Metasystems
Interdependent SoS	Emergent behaviour
Emergence	Complex programs
Variations	Managing complex programs
Cybernetics	Operational effectiveness
Systemic thinking	Decision-making
Meta-methodology model	System design
Resilience	Vulnerabilities
Optimisation	Risk mitigation

To summarise, the thesis explores the integral role of integrated methodologies in ambitious engineering projects, emphasising collaboration, risk management, modular design, continuous integration, standardisation, and performance monitoring. It delves into effective collaboration across diverse disciplines, the pivotal role of risk management, the architectural advantage of modular design, and the adoption of continuous integration and testing for agility. Standardising processes, performance monitoring, and optimisation are discussed, along with the holistic understanding of integration and the anticipation of negative emergent behaviours. The conclusion highlights the lasting impact of integrated methodologies on society, technology, and the global community.

Boolean search strings:

- AND
- OR
- NOT
- Parentheses ( )
- Quotation Marks " "

Boolean search strings keywords:

1. (Integration OR "integrated methodologies") AND cybernetics AND "meta-systems reductionism"
2. Collaboration AND ("seamless collaboration" OR "harmonisation of efforts") AND interdisciplinary
3. ("Pivotal role" OR "importance") AND "risk management" AND ("project execution" OR "project safety")
4. "Architectural advantage" AND "modular design" AND "testing practices"
5. "Continuous integration" AND "automated testing" AND "agile development"
6. "Standardizing processes" AND collaboration AND engineering
7. "Performance monitoring" AND optimization AND "efficiency and reliability"
8. ("Holistic approach" OR "systems thinking") AND integration AND engineering
9. ("Anticipating and mitigating" OR "negative emergent behaviors") AND proactive AND engineering
10. "Methodological integration" AND project management AND ("project size" OR "organizational culture")
11. ("Cohesiveness" OR "avoiding conflicts") AND "clear communication" AND collaboration
12. ("Importance" OR "significance") AND collaboration AND "harmonization of efforts"

3.5.1. Identify relevant authors with a summary (Appendix D)

The term "identify relevant authors" typically indicates the process of determining and recognising authors who have made significant contributions or have expertise in a particular field or topic of interest. It involves assessing the relevance and credibility of authors based on their qualifications, expertise, academic or professional background, publication history, and the quality and impact of their work. Identifying relevant authors is important in conducting research, literature reviews, and scholarly discussions as it helps to locate authoritative sources and perspectives on a given subject matter.

3.5.2. Identify relevant databases and sources (Appendix E)

Books and academic journals specific to the fields of systems theory, complexity, and cybernetics can also be valuable sources of information. Some notable journals include "Systems Research and Behavioural Science," "Complexity," and "Cybernetics and Systems". **Appendix E** presents relevant databases used in this research.

Professional conferences and proceedings: Attend or review the proceedings of conferences and workshops focused on systems theory, complexity, and cybernetics. These events often feature the latest research and insights from experts in the field, refer to Chapter 1and 2.

Academic databases: These databases contain scholarly articles, research papers, conference proceedings, and dissertations. Examples include:

- PubMed (biomedical and life sciences)
- IEEE Xplore (engineering and technology)
- ACM Digital Library (computer science and information technology)
- JSTOR (multidisciplinary subjects)
- ScienceDirect (science, technology, and medicine)
- Scopus (multidisciplinary subjects)

Government databases: Government agencies often provide valuable data, statistics, reports, and policy documents. Examples include:

- Commonwealth of Australia, Department of Defence, data
- Data.gov (US government data)
- Australia, other Commonwealth government data
- United Nations Statistics Division (international statistics)

Industry and market research databases: These sources provide market trends, industry reports, consumer behaviour data, and business insights. Examples include:

- IBISWorld (industry market research)
- Statista (statistics and market research)

- Gartner (technology and business insights)
- Euromonitor International (market research and analysis)

Online libraries and catalogues: These platforms offer access to books, publications, journals, and other reference materials. Examples include:

- University of Southern Queensland library (academic publications and books)
- Google Scholar (academic publications and books)
- WorldCat (global library catalogue)
- The Internet Archive (digital library of texts, audio, video, and more)
- Open Library (digital library with free access to books)

Specialised databases: Depending on the research topic, there may be specific databases tailored to that field. Examples include:

- ArXiv (preprints in physics, mathematics, computer science, and more)
- PsychINFO (psychology and behavioural sciences literature)
- LexisNexis (legal and news databases)

The literature review findings identify common themes, trends, challenges, and emerging research directions in SoS. Organising the findings through thematic analysis or categorisation to facilitate synthesis is considered and undertaken. A literature review in the field of SoS involves conducting a comprehensive review of existing research, publications, and scholarly works related to SoS.

Both qualitative and narrative analyses were performed in this study. The samples for qualitative research were drawn from an overview of systematic methods that was conducted on the literature from journals, books, and case studies. Although several qualitative research syntheses have recommended purposeful sampling for synthesising qualitative research, Patton (2002) is frequently cited as an authority on the topic of purposeful sampling.

Various techniques could be found in the literature to detect emergence, ranging from statistical analysis to formal approaches. However, the variable-based methods, such as those published by O'Toole et al. (2014); Chan (2011); and Holland (2007), were considered the most appropriate for this study. The emergent behaviour system consists of three general elements: agents, their interactions, and the environment. Each agent has a set of attributes that describe the state of the agent and numerous policies or rules that specifically define the agent's behaviour with respect to changes in its environment.

3.6. Research methods, analysis, and processes applied

The comparative analysis of approaches, methodologies, and frameworks used in SoS research reveals that different approaches, such as System-of-Systems Engineering (SoSE), Resilience Engineering, and Complexity Science / Network Theory, each have their own strengths and weaknesses in addressing the complexities of SoS. SoSE provides a structured approach while Resilience Engineering (RE) focuses on robustness and Complexity Science / Network Theory explores emergent behaviours. There are commonalities among approaches, and potential synergies can be achieved by combining elements of the different approaches. Performance evaluation in SoS research involves simulation, modelling, and empirical studies using metrics like reliability and scalability. Success factors include clear goals, effective coordination, stakeholder involvement, flexibility, and risk management. Critical factors include complexity, interdependencies, regulations, and funding. Current SoS research focuses on adaptive systems, decision-making, interdependency modelling, cybersecurity, and emerging technologies. Practical implications for practitioners involve collaborative governance, iterative development, resilience engineering, and consideration of emergent behaviours.

Policy recommendations include regulatory frameworks, collaboration, investment, and standards. Notably, research gaps do exist in standardised methodologies, human/social factors, ethics, sustainability, and advanced technologies, thus presenting opportunities for interdisciplinary collaborations as well as advancements in modelling and decision support systems. Overall, the literature review provides valuable insights that serve as a guide to practitioners, decision-makers, and policymakers involved in SoS development and governance.

The researcher viewed the functional resonance analysis method (FRAM) and Schwarz’s living system model which summarises the knowledge of complex adaptive systems compressed into a graphical generic metamodel. Schwarz defined it as a network of self-creation processes and firmly integrated it with relevant theory in complexity in a way that was not previously employed. The outcome illustrates how a complex and adaptive viable system can survive, maintaining an autonomous durable existence within the confines of its own constraints. The nature of viable systems means that they should have at least potential independence in their processes of regulation, organisation, production, and cognition (Schwartz, 2012). The functional resonance analysis method (FRAM) is yet another method that is used for building a model (Hollnagel, 2004 & 2012). The FRAM provides a way to describe outcomes using resonance arising from everyday performance variation. (Hollnagel, 2004 & 2012). FRAM focuses on understanding outcomes by studying everyday performance variation and identifying patterns of resonance within the system. Resonance refers to the alignment or synchronisation of system elements and their interactions. The FRAM helps uncover the system's behaviour, adaptive capacity, and factors influencing outcomes. It can be applied to various domains for improving safety and efficiency. In summary, the FRAM describes outcomes by examining resonance arising from everyday performance variation in complex systems. (Hollnagel, 2004 & 2012).

CHAPTER 4: THEORETICAL AND CONCEPTUAL FRAMEWORK

4.1. Theoretical framework for modelling and simulation of emergent behaviour (Appendix A)

To design a multi-BMS system, the first requirement is to explain how each system agent exists and acts in the environment, and this is represented in the behaviour ontology (Leslie, 2021; Linehan et al., 2006; Burbeck, 2004). Subsequently, the description is transformed and expressed in the language of the simulation engine and is provided as input for execution. There is no evidence suggesting that the emergent behaviour present in constituent systems[3] supports system design. The combinations of systems within the SoS contribute to the overall capability of systems in projects, operations, management, and physical assets. Combining systems can lead to emergent behaviours that may either improve or degrade the performance and additionally either decrease or increase costs.

In the system engineering body of knowledge (SEBoK), SoS is essential for providing capability objectives and understanding their interrelationships. Establishing the boundaries of an SoS can be difficult. The constituent systems of the SoS typically have different owners supporting defence organisational structures beyond the SoS management. In complex projects, there is a need to explore the relationship between two or more variables and the cause-and-effect relationships in SoS (Ablowitz et al., 2003; 2022). By examining these specific variables and relationships, we can relate to the emergence of complex systems in published papers that can be applied to complex SoS project frameworks.

To establish a theoretical framework for modelling and simulation, the taxonomy of emergent behaviours must be determined. Following is a list of authors who have explored the classification of emergent behaviours to date: Giammarco (2018), Singh (2017), Johnson (2016), Rainey et al. (2015), Holland (2007), Fromm (2005), Bar-Yam (2004), and Maier (1998); (Maier et al., 2022). Agent-based

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[3] Constituent systems can be part of one or more SoS. Note: Each constituent is a useful system by itself, having its own development, management goals, and resources, but interacts within the SoS to provide the unique capability of the SoS.

modelling and simulation demonstrate that emergent behaviour exists in a project's SoS. Furthermore, other applicable modelling and simulation (M&S) tools can be applied to a given SoS engineering application for determining emergent behaviour.

Dr Kristin Giammarco's paper '*Practical modelling concepts for engineering emergence in systems of systems*' in 2018, stated that "positive emergence is what remains after thoroughly exposing and removing negative emergence" and provides an n+-step algorithm for performing this. Emergent behaviour can manifest itself, as observed by the operator and software communication agents, and can interact with component systems as well as with one another. Large-scale disruptions can be intrinsic to the elements forming an SoS, especially those that display self-organised criticality. Today's modern digital world emphasises the sharing of relevant situational awareness information within and between project teams and across engineering levels.

There is no clear evidence of emergent behaviour in constituent systems supporting system design. Furthermore, there is no evidence suggesting that corporations are considering positive or negative emergent behaviour in SoS in architecture products contained in their capability development. It is difficult to establish the boundaries of an SoS because the constituent systems of the SoS typically have different owners and supporting organisational structures beyond the management of the SoS. To control the negative emergent behaviour, research should start at the early development of all the governing documents. As a result, positive effects can be achieved using simulation tools, modelling, and life cycle costing (LCC) analysis; therefore, emergent positive behaviour outcomes can be leveraged. Dr. Maier (1998); and Maier et al., (2022) described that the architecture of an SoS is composed of communications which is a nonphysical set of standards that enable communication among the components. In other words, SoS and its components consist of tangible and intangible objects such as mechanical, electrical, electronic, software, knowledge, or natural objects. These objects perform functions and behaviours to fulfil a specified purpose and exhibit emergent behaviour as defined by Maier (1998); Maier et al., (2022).

4.1.1. *Justification of meta cybernetics in system thinking*

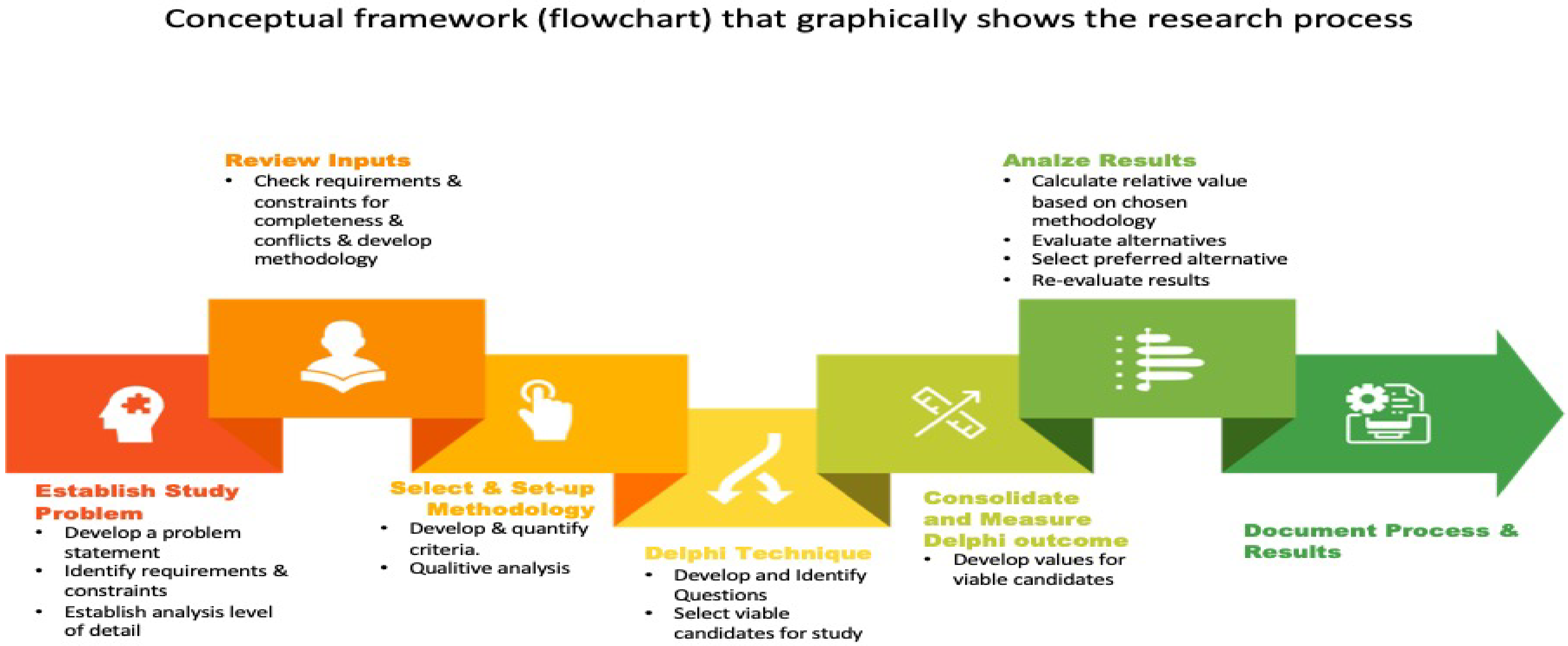
During the Second World War, mathematician Norbert Wiener (1961) and some respected professionals and colleagues developed a novel branch of applied sciences called information feedback systems or cybernetics (von Foerster et al., 1955). Meta cybernetics represents the higher-order cybernetics that arise in living system agencies. Agencies are complex and viable, and they require stability and uncertainty reduction to survive. Meta cybernetics is defined through a metasystem hierarchy and is mostly known through first- and second-order cybernetics (Yolles, 2021). Dynamic evolutionary metamodel analysis of the vulnerability of complex systems has severe consequences and has often been viewed as the core problem encountered by multilayer networks of complex systems.

Fourth-order cybernetics is called emergent cybernetics or liquid cybernetics, which considers what happens when a system redefines itself. It implies that a system will ‘emerge’ into the environment in which it exists. Notably, the axioms or elements of systems theories are defined as centrality, contextual, goal, operational, viability, design, and information (Galison, 1994). Through cybernetics management (Beer, 1959), this literature review aims to examine emergent behaviour through the theory of critical system thinking and cybernetics methodology (D’Andreamatteo et al., 2015; Cannon, 1932). The cybernetics methodology is called the “new paradigm” that has attracted numerous researchers and practitioners and introduced them to the discipline of systematic management (Ríos, 2010). Meta cybernetics refers to higher order cybernetics that are presented in living systems agencies that are complex (Yolles, 2021). Cybernetics is all about looking at relationships in phenomena. Emergent behaviour occurs in SoS that do not have relationships among the constituent members, and hence, emergent and very complex. Therefore, emergent behaviour simulation can be used to examine for the presence of emergence and explore ways to delete negative emergence such that only positive emergence remains. This is the route that needs to be followed for the development of the algorithm.

4.1.2. *Method of theoretical and conceptual framework analysis*

The significant difference between theoretical and conceptual frameworks is that the focus of theoretical frameworks is on broad analysis, whereas the focus of conceptual frameworks is on narrative analysis. Therefore, a narrative analysis method was used to analyse the content of the literature summarised in this paper. Narrative analysis involves a systematic review of the literature and summarising them to identify key themes, concepts, and theories. It aims to uncover the underlying narratives and meanings present in the literature. This approach allows researchers to gain a deeper understanding of the subject matter and to identify patterns and connections between different studies.

Figure 5
Conceptual framework



Qualitative methodologies and analyses were applied in this research to interpret all data (Cleland & King, 1983), which suggests that the analyses were focused on interpreting qualitative data rather than quantitative data. Qualitative analyses involve examining textual data such as interviews, observations, or written documents to derive insights and develop an understanding of the research topic. Additionally, it involves identifying themes, codes, and patterns in the data to generate meaningful interpretations. In the context of the paper, the theoretical and conceptual frameworks were analysed using a narrative analysis method. Moreover, this involved examining the literature and summarising its content to identify key concepts and theories. The analysis was qualitative in nature, focusing on interpreting the data to gain insights and understand the subject matter.

4.1.3. The explanation for excluded literature

In the project management literature, there are descriptions of project success factors and project pitfalls (Fortune & White, 2006). This topic has been extensively researched with significant work that included Pinto and Prescott (1988) and Kerzner (2013), and particularly for large projects, the famous IMEC study by Miller and Lessard (2000).

Particularly, in the governance of large and complex public projects, the emphasis is on accountability and transparency (Miller & Hobbs, 2005; Stewart, 2001). Walker et al., (2008) offered a “balanced scorecard” for projects, while Shenhar et al. (2001) presented the four dimensions of success. Nogeste and Walker (2008) described the dimensions of success and its priorities. Zwikael (2008a & 2008b) focused on project success, while Torp et al., (2006) focused on success factors.

Jergeas (2005) provided the approaches for project monitoring by identifying specific success factors in a project and measuring indicators. Kappelman et al. (2006) set up a list of early warning signs for IT project failure. Finally, a problem with assessing complex projects was observed (Cicmil et al., 2009; Williams, 2005), because understanding the relationship between events and outcomes is difficult (New England Complex Systems Institute, 2009; Simon, 1982). This means that complex projects often do not behave in the way they are expected to, and effects within complex projects are often time-delayed and thus take time to emerge.

Selected project management journals:

- *Project Management Journal*: Official journal of the Project Management Institute (PMI), featuring research on project management theory and practice.
- *International Journal of Project Management*: A leading journal publishing research on project management, organisational strategy, and project governance.
- *Journal of Modern Project Management*: Focuses on project management best practices, methodologies, and case studies.
- *International Journal of Managing Projects in Business*: Covers topics related to project management in a business context.
- *Project Management Research and Practice*: Publishes research papers, case studies, and reviews in project management.

Selected systems engineering journals:

- *Systems Engineering*: The journal of the International Council on Systems Engineering (INCOSE), addresses systems engineering principles, methodologies, and applications.
- *Journal of Systems Engineering and Electronics*: Covers research on systems engineering, electronics, and related interdisciplinary areas.
- *Systems Engineering Procedia*: Publishes proceedings from various systems engineering conferences and symposiums.

Project management organisations and websites:

- *Project Management Institute (PMI):* Provides resources, publications, and research reports on project management.
- *International Council on Systems Engineering (INCOSE):* Offers publications, conferences, and resources related to systems engineering.
- *Association for Project Management (APM):* Provides access to project management articles, webinars, and events.

The emergent behaviour of SoS is relevant to engineering and natural systems and is not well understood. Research evidence can be any systematic observation that establishes facts and reaches conclusions. This literature review aims to examine emergent behaviour through the theory of critical system thinking and cybernetics methodology (D'Andreamatteo et al., 2015).

4.2. Identified gaps in the literature

An introduction to systemic thinking and cybernetics and how they provide building blocks for the framework elements and the methods used in building a meta-methodology model are either unclear or not available. In this thesis, the author explores the behaviour of complex systems from the perspective of cybernetics. Cybernetics and systems thinking are identified as sources for a new problem-solving concept that is neither well-defined nor thoroughly understood. The thesis aims to investigate how systemic thinking and cybernetics can contribute to the development of a meta-methodology model by providing the foundational elements and methods necessary for its construction. However, it appears that there are currently uncertainties or gaps in knowledge regarding these specific issues.

Generally, there is a deficiency and lack of understanding on how to build a system of model frameworks and the ways to choose the right model to successfully implement a project. A project system is structured by the development of a conceptual framework, which combines systems methodologies and methods with the selection of the system. In a complex project, to establish a theoretical framework for modelling and simulation, it is necessary to establish the taxonomy of emergent behaviours first.

4.3. Synthesis of complexity

Within the realm of academic inquiry, a fundamental tool is the traditional literature review, which is an intellectual journey that involves the analysis of existing research work and the assimilation of knowledge accumulated in a particular field. For this thesis, the researcher undertook a meticulous examination of relevant scholarly articles, books, reports, and diverse publications. This endeavour was aimed at unearthing key concepts, elucidating theories, and extracting empirical evidence, all of which converge to support the researcher's overarching investigation.

A literature review, in its essence, operates as a scholarly compass, steering the researcher toward uncharted territories while also serving as a yardstick to measure against the landmarks of prior scholarship. By delving into the work of predecessors, the researcher establishes the present terrain of knowledge in the chosen field, thereby forging an informed path for their own research journey.

However, the tapestry of modern research is rich with vibrant threads of interdisciplinary exploration. The fields of complexity, cybernetics, and Systems of Systems (SoS) beckon researchers to cross boundaries, embracing an integrative perspective. In these dynamic domains, conventional silos of knowledge often yield to an amalgamation of diverse perspectives and methodologies. Researchers navigate this intellectual crossroads, drawing from various disciplines to form a holistic and multifaceted understanding of complex phenomena and intricate systems.

This interdisciplinary approach transcends the confines of one singular domain, enabling researchers to explore the multifarious dimensions of complexity more comprehensively. By weaving together strands of evidence from different realms, researchers are equipped to navigate the complexities of their subjects with a richer toolkit that unearths new insights, uncovers hidden connections, and approaches complexity with the nuanced perspective it warrants.

The management of complex project systems has been extensively studied by AlRiyami (2021), Pinto et al. (2021), Prescott (1988), and Kerzner (1987). Furthermore, the famous IMEC study by Miller (2005) and those by Mohammadreza et al. (2019), Lessard (2000), and Packendorff (1995) concentrated on large projects. This literature review includes various aspects of complex project system management.

A summary of the key points and themes addressed by these studies is as follows:

- Project success factors: Researchers such as Shenhar et al. (2001), Walker and Nogeste (2008), Zwikael (2008a; 2008b), and Torp et al. (2006) have focused on identifying the success factors in projects and highlighted the dimensions of success, priorities, and factors that contribute to project success.

- Early warning signs and project failure: Širovnik et al. (2022), Kivijärvi et al. (2020), and Kappelman et al. (2006) have assessed the detection method for early warning signs and symptoms of project challenges or failure. They emphasise the importance of identifying and addressing potential issues early on to prevent project failures.
- Governance and accountability: Governance of large complex public projects, as discussed by Miyamoto et al. (2020), Wikansari et al. (2020), Joslin (2019), Segon and Rowlinson (2008), Miller and Hobbs (2005), Stewart (2001), and Walker (1989), focuses on accountability, transparency, and using balanced scorecards for project assessment.
- Complex project assessment: Gajić et al. (2019), Cicmil et al. (2009), New England Complex Systems Institute (2009), Williams (2005), and Simon (1982) explored the challenges associated with assessing complex projects. They highlighted the difficulty in understanding the relationship between events and outcomes that lead to delays in complex systems and the need for comprehensive assessment approaches.
- Requirements for project assessment: Williams et al. (2019) and Samset (2009) described the requirements initially formulated for the United States Agency for International Development (USAID). These requirements focus on efficiency, effectiveness, relevance, impact, and sustainability in project assessment.

4.4. Complex project challenges

In the domain of managing large and intricate public projects, the focal points are firmly set on accountability and transparency (Miyamoto et al., 2020; Wikansari et al., 2020; Joslin, 2019; Segon & Rowlinson, 2008; Miller & Hobbs, 2005; Stewart 2001; and Walker, 1989). Notably, Wikansari et al. (2020) introduced a balanced scorecard for projects, while Shenhar et al. (2001) delineated four dimensions of success. However, assessing complex projects poses significant challenges (Cicmil et al., 2009; Williams, 2005) due to the intricate relationship between events and outcomes (New England Complex Systems Institute, 2009; Simon, 1982).

Furthermore, such projects often require time to reveal their complexities, and deciphering the causal connection between early indicators or incidents and eventual results proves to be neither obvious nor straightforward (Gajić et al., 2019). As complexity in projects continues to rise, they frequently deviate from anticipated timelines, resulting in delays.

Numerous studies have concentrated on identifying early warning signals for project challenges, commencing from the project's inception (Širovnik et al., 2022). This research zeroes in on the capacity of signals to pre-emptively detect failure both before and during the project, with particular attention to Ansoff's concept of “weak signals” (Boutout et al., 2020). The wealth of research in this domain is extensive (Venugopal et al., 2022). Williams et al. (2019) and Samset (2009) delved into the intricacies of the five requirements originally formulated for USAID in 1960, encompassing efficiency, effectiveness, relevance, impact, and sustainability. Collectively, the afore-mentioned studies have explored themes such as accountability, transparency, success dimensions, success factors, and the early identification of challenges in project management.

The journey of a researcher, marked by an exhaustive exploration of traditional literature and enriched by interdisciplinary currents, stands as a testament to the ever-evolving nature of academic inquiry. Through the fusion of conventional wisdom and interdisciplinary innovation, researchers can navigate the intricacies of our world while striving for deeper comprehension and insight.

The literature review on project management has unearthed pivotal findings from diverse studies. These studies have delved into topics including project success factors, early warning signs of project failure, governance, and accountability in large-scale projects, complex project assessment, and prerequisites for project evaluation. This review has underscored the significance of elements such as accountability, transparency, success dimensions, and the early detection of project challenges, all substantiated by contributions from noteworthy researchers and publications.

Beyond the literature review, valuable resources for further exploration have been provided, including a comprehensive list of project management journals, systems engineering journals, and pertinent organisations and websites. These resources offer a wealth of insights and information, enabling a deeper understanding of the topics discussed and providing diverse perspectives from experts in the field.

This discourse has touched upon the concept of emergent behaviour within Systems of Systems (SoS) and underscored the importance of comprehending systemic properties and employing meta-methodology in project system design for addressing complex problems. This emphasises the need for a holistic approach and the utilisation of appropriate methods and frameworks when managing complex projects within interconnected systems.

Overall, this research has shed light on the findings stemming from a literature review on project management. It has accentuated the significance of key factors, offering supplementary resources for further exploration. Moreover, it has underscored the importance of comprehending emergent behaviour in Systems of Systems (SoS) and the necessity of employing appropriate strategies to confront complex project challenges. By taking these factors into consideration and leveraging relevant resources, practitioners and researchers can enhance their understanding and practices in the domain of project management, particularly within complex and interconnected environments.

4.5. Multi-methodological approaches for solving intricate challenges in project management

The thesis discusses the significance of adopting multi-methodological approaches to address complex challenges in project management. Complex problems involve numerous interconnected factors and uncertainties, making it difficult to tackle them with a single method. Therefore, a multi-methodological approach is recommended to enhance problem understanding and improve the chances of finding effective solutions. One effective combination of methodologies is system dynamics and critical project management, which can be used to simulate and manage complex project environments. Integrating these methodologies provides valuable insights into managing complex project systems, understanding emergent behaviour, and solving intricate project management problems.

This thesis follows a thesis by-publication format, comprising a series of publications exploring various aspects of Systems of Systems (SoS) and complex systems. Each publication focuses on specific areas, such as emergent behaviour in battle management systems, the application of cybernetics in network soldier systems, and management approaches for complexity in project environments by Ramírez-Valenzuela (2021). These studies draw from relevant research to offer a comprehensive understanding of the subject and generate new insights.

The ultimate goal is to gain a comprehensive understanding of SoS and the complexities found in complex project environments. The studies by Ramírez-Valenzuela (2021), Nassar (2018), Koskela, and Howell (2002), and Packendorff (1995) contribute to this understanding by exploring various aspects of SoS, complex systems, and project management challenges. By examining the emergence, interdependencies, and behaviours of SoS, the thesis aims to make significant contributions to the fields of systems engineering and project management, highlighting the importance of adapting strategies and approaches based on project specifics to enhance the management of complex projects.

4.5.1. Emergent behaviour in the battle management system (Chapter 5)

The paper examines the distribution of information across warfighting networks using Battle Management Systems (BMS), which are employed by more than 30 countries. BMSs function like natural systems, where military assets act as autonomous agents guided by Defence doctrine rules. The system relies on subsystem reliability during interactions, but the countless possible interactions can lead to unpredictable outcomes, both positive and negative. Emergent behaviour can have unforeseen consequences in intelligence, cybersecurity, weapon targeting, and wireless networks. Given the increasing digitisation of systems, cybersecurity and data privacy are vital considerations. Understanding emergent behaviour is crucial for safely delivering large and complex engineering projects, generating new insights, and improving the success of such projects.

4.5.2. Cybernetics and BMS in the application of a network soldier system (Chapter 6)

The study explores Battle Management Systems (BMS) as complex Systems of Systems (SoS), focusing on information distribution in warfighting networks. The study proposes using the Viable Systems Model (VSM) as a governing framework for this system, with subsystems representing the SoS. The concept of meta cybernetics and metasystems, including BMS and their application to the network soldier, draws from earlier work by Yolles, Rios, Schwaninger, Lowes, and Sisti. The novelty lies in the application of meta cybernetics principles and the utilisation of Ashby's laws of requisite variety (2011) as well as insights from Yolles (2021).

4.5.3. Cyber-physical systems, systems of systems, and emergent behaviour (Chapter 7)

Cyber Battle Management Systems (CBMS) are considered as systems of systems (SoS) and emergent behaviour is present, where viable system model (VSM) only controls system variety.

This paper conducts a review of existing research on Cyber Battle Management Systems (CBMS). It emphasises the necessity of adopting complex systems thinking, and cybernetics, addressing wicked problems and emergent behaviour. The focus is on understanding the relationships between complex and multi-structural systems.

The systems-thinking approach discussed here involves the selective identification and understanding of associated systems, predicting their behaviour over time, and managing changes that could obscure the path to success. The paper also explores the potential integration of cybernetics meta-methodology and the Viable System Model (VSM) to mitigate negative emergent behaviour in complex systems. It clarifies that a single system is deterministic, while SoS is stochastic, which implies the presence of emergence. By integrating cybernetics, VSM and meta-metasystems, the paper delves into the key parameters used to construct an intelligent system. According to the literature, meta-metasystems offer superior capabilities by providing a governing structure that coordinates and integrates multiple systems.

The study's findings suggest that the meta-metasystem for CBMS has been developed to facilitate the design, execution, and evolution of SoS.

4.6. Complex project systems

In this thesis, the author delves into diverse theories and components relevant to emergent behaviour within complex project systems. The literature on the management of complex project systems encompasses a wide array of facets related to project success, early warning indicators of project challenges or failure, governance and accountability, complex project evaluation, and project assessment criteria. Numerous researchers, including Shenhar et al. (2001), Walker and Nogeste (2008), Zwikael (2008a; 2008b), and Torp et al. (2006), have concentrated on identifying success factors in projects, highlighting dimensions of success, priorities, and factors contributing to project success. Detecting early warning signs and signals of project challenges or potential failure has been examined by Kivijärvi et al. (2020), Kappelman et al. (2006), and Širovnik et al. (2022), underlining the crucial importance of early issue identification and resolution to avert project failures.

Governance and accountability in large, intricate public projects have been discussed by scholars like Wikansari et al. (2020), Miller and Hobbs (2005), Miyamoto et al. (2020), Walker (1989), Segon and Rowlinson (2008), Joslin (2019), and Stewart (2001). Their work has revolved around themes of accountability, transparency, and the use of balanced scorecards in project assessment.

The complexities associated with evaluating complex projects have been explored by Williams (2005), Cicmil et al. (2009), Simon (1982), New England Complex Systems Institute (2009), and Gajić et al. (2019), shedding light on the challenges of comprehending the intricate relationship between events and outcomes in complex project systems, often leading to delays and necessitating comprehensive assessment approaches. Requirements for project assessment, originally formulated for USAID, have been detailed by scholars such as Williams et al. (2019) and Samset (2009), focusing on efficiency, effectiveness, relevance, impact, and sustainability as essential dimensions of project assessment.

SoS projects are characterised by unpredictable emergent behaviour and can be fundamentally analysed through structured analysis. In contrast, chaotic projects are defined by their constant shifting, absence of manageable patterns, and perpetual turbulence (Sheffield et al., 2012; Snowden & Boone, 2007). The differentiation between complexity and chaos in projects reflects the levels of predictability and manageability.

CHAPTER 5: PAPER 1. EMERGENT BEHAVIOUR IN THE BATTLE MANAGEMENT SYSTEM

5.1. Observations on Paper 1

In the landscape of modern warfare, the utilisation of advanced technology has become pivotal for the effective functioning of digital armies. Among these technological advancements, Battle Management Systems (BMS) are a cornerstone for sharing critical situational awareness information. This paper sheds light on the profound significance of such systems, emphasising their role in facilitating the seamless exchange of vital data among soldiers, command headquarters, and a diverse array of military assets.

A fundamental paradigm shift in contemporary warfare has been the transition from analogue to digital communication. This transformation has been particularly conspicuous in the context of ongoing conflicts, such as the situation in Ukraine. Here, the adoption of IT-supported battlefield systems has not only revolutionised the way information is disseminated but has also brought unparalleled efficiency and effectiveness to military operations. The rapid evolution of communication technology has not only improved the accuracy and speed of information sharing but has also empowered military decision-makers with the tools to make informed and timely choices in the ever-changing dynamics of the modern battlefield.

This paper delves deeper into the core of the matter, focusing on the intricate workings and emergent behaviours that characterise BMS networks. These systems are akin to natural systems, where individual agents, such as ants and bees, follow simple rules to collectively achieve complex objectives. The challenge lies in understanding how these interactions among military assets within the BMS network can lead to emergent behaviours, some of which might be unexpected or unwanted.

5.2. Paper 1. Emergent behaviour in the battle management system

Published to Applied Artificial Intelligence

The papers are highly timely and relevant contributions to the literature. Given that these areas are emerging and constantly presenting unique avenues for research to engage in, it is clear that these studies are very important contributions in themselves to the literature. The studies are well-researched, appropriately backed by the extant literature, and provide useful insights and findings that inform future research and policy in equal measure.

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Emergent behavior in the battle management system

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ABSTRACT
Many countries including Ukraine use battle management sys- tems (BMS) like Delta that enable command to share situation awareness information; this study focuses on the distribution of information across a warfighting network. Similar to natural systems, where autonomous agents, such as ants and bees, follow a set of simple rules, a BMS is a network of bases and electronic warfighting platforms that have military assets as agents within the network, guided by the defense doctrine. The rationale for the workability of such a system is based on each subsystem being reliable when multiple subsystems inter- act. However, the potential permutations and combinations of interactions can cause unpredictable negative or positive feed- back loops, resulting in unpredictable and unwanted outcomes. The results of emergent behavior are unexpected and some- times unwanted in areas such as intelligence, and wireless net- works. Understanding emergent behavior is imperative in understanding complex engineering systems, and to present new insights, and take practical steps toward improving com- plex systems design and analysis. This paper presents the BMS and networks with examples of user-defined system integration of the network soldier concept. We believe that Ukrainian and other armies can directly benefit from utilising meta cybernetics, meta metasystem model analysis to control emergence.

Introduction

Modern digital armies are centered on sharing relevant situational awareness information within and between dismounted teams (soldiers) and beyond to other levels of command (headquarters or HQ) and flanking elements (mobile platforms and other assets). Previously, all communication and information were analogue and relatively inefficient in the theater of war. In the current wartime situation in Ukraine and the wide usage of IT supported battlefield systems, the chosen topic is very important to the Ukrainians and western world.

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The structure of the paper is the following: First, introduce the battle management systems (BMS) which focus on distributing information across a warfighting network and is basically explained. Secondly, the meta systems, meta methodology, meta cybernetics and emergent behavior in systems are explained and integrated in detailed diagrams presented. Next the state space framework and the polynomial nonlinear state space model are introduced. Finally, the proposed method is recommended for the BMS meta systems by meta cybernetics to control emergence.

Today, battle management systems (BMS) focus on distributing informa- tion across a warfighting network. BMS are a network of bases and electronic warfighting platforms. Military conflicts, especially those involving land com- bat forces, have recently grown rapidly (Chen et al. 2014). The rise of auto- mation in many systems and technologies presents complex operational environments that require a high level of collaborative, complex adaptive systems of systems (CASoS) solutions.

One example is the Delta real-time battle management system as part of the large-scale event Tide Spirit of the North Atlantic Treaty Organization (NATO). The Delta real-time battle management system (DBMS), which is designed to address an army's transformation from analogue to digital cap- abilities and provide military advantage in intelligent warfare situation aware- ness. DBMS provides a comprehensive understanding of the battlefield in real time, integrates information about the enemy from various sensors and sources, including intelligence on a digital map. These operations require agile systems of systems (SoS) that must be continually updated to meet the challenging pressures of the operational war environment. Ukrainian army and many others the major problem is the shortfall of operational control of units and to instantly relay information on enemy forces movement to other units and headquarters and includes friendly fire where soldiers are left vulnerable. This is explained in this paper DBMS and network soldier system and meta non linier model to solve problems.

In understand the non-linear model which is compared with other system representations, several examples are introduced, and the results are extended to create prediction error input-output models for multivariable non-linear stochastic systems. The graph theory is an important area in mathematics. A

is a graph-based representation representing a problem as a graph to provide a different point of view on the problem. A problem is much simpler when represented as a graph since it can provide the appropriate tools for solving it. Hence, a graph or network acts as an excellent modeling tool in representing several fundamental issues in the network, such as con- nectivity, routing, data gathering, mobility, topology control, traffic analysis, finding the shortest path and load balancing.

In mathematics the Lanchester (1999) presented a collection of joined ordinary differential equations known as the Lanchester equations (LEs); the roots of the LEs are process models for reducing strength or effectiveness in modern warfare (Engel and Gass 2001). They are a collection of differential equations describing the time dependence of the strengths of two armies, A (green force) and B (red force), as a function of time, c2n22 = c1n. Thus, the fighting strengths of both forces are equal when the products of the squares of the numerical strengths times the coefficients of effectiveness are equal (Chen et al. 2011). Osipov and Maksimov (2018) independently devised a series of differential equations known as Lanchester's Square Law (Engel and Gass 2001) to demonstrate the power relationships between opposing forces. With the design and development of BMS complex systems, under- standing differential equations is important. The Lotka-Volterra equations (Lanchester 1999) are used to model the dynamics of interacting "predator- prey populations" (Washburn et al. 2016).
An older example is the battle of Iwo Jima, where x(US) and y (Japanese) are the number of troops on the island, and r(t) is the rate at which the US troops landed (Rawson 2012). Experimenting with the model with different values of the parameters α and β or different reinforcement schedules would have resulted in different outcomes (Chen et al. 2014). The parameters α and β comprise units of opposing casualties per man per day of combat and were chosen to fit the record of all that happened (Washburn et al. 2016). The explanation is that US troops substantially outnumbered their Japanese counterparts during most of the battle.

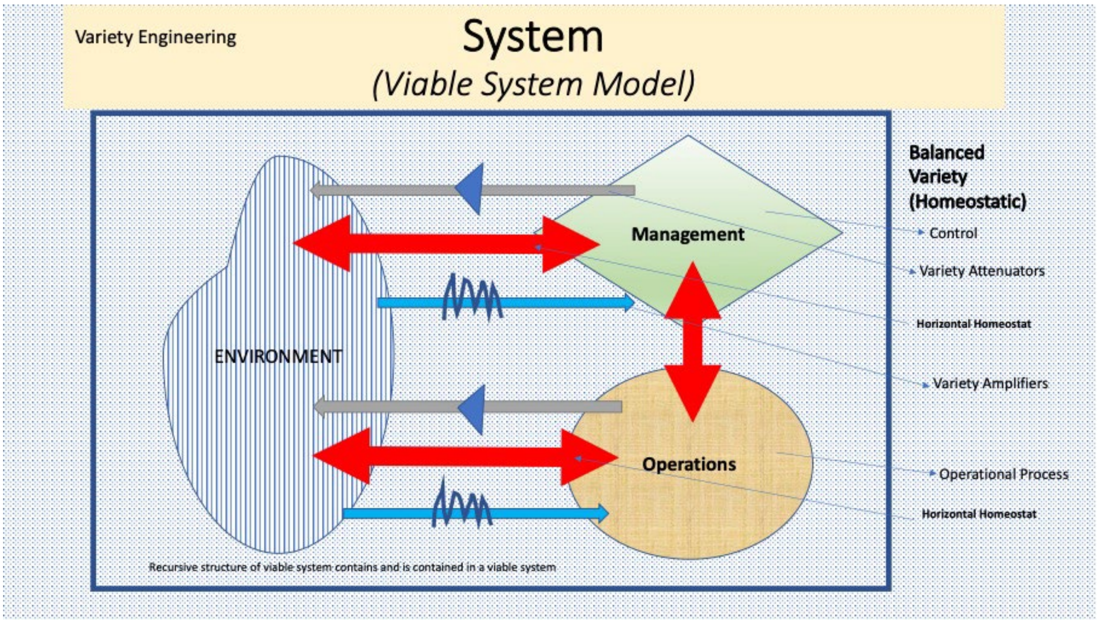

Diagram 1. Variety Engineering, System Incorporating viable system model (VSM)

The BMS is focused on the distribution of information across a network. Systems with numerous components are complex, and their intricate interactions are inevitable (Chen et al. 2014).

Examples include natural systems that range from animal flocks to socio-ecological systems and leading-edge engineering (artificial) systems, such as the internet and social networks. These systems are called complex adaptive systems (CAS) and exhibit behaviors from non-linear spatio-temporal interactions among multiple components and subsystems (Kaisler and Madey 2009). These interactions may lead to proper- ties that are often called emergent and cannot be derived from individual components. While numerous attempts have been made to define emergence (Holland 2007), consensus has not been reached on a general definition. Some of the most cited works to date that have explored the classification of emergent behaviors are by Singh et al. (2017), Johnson (2016), Holland (2007), and Bar-Yam (2004b). The System Engineering Body of Knowledge (SEBoK; 2020) describes emergent system behavior as a consequence of the interactions and relationships between system elements rather than the behavior of individual elements.

Many authors, such as Singh et al. (2017), Johnson (2016), Holland (2007), Fromm and International Society (2021), and Bar-Yam (2004a), agree that the notion of emergence involves the existence of levels in a system. Therefore, emergence can be summarized as a characteristic of a system. The properties appear at the system (macro) level, are not explicitly implemented, and arise dynamically from the interactions between entities at the component (micro) level (Singh et al. 2017). Moreover, using Fromm's (2021) taxonomy of emergent behaviours, it is considered that the development of a suitable framework should provide a platform for simulating and analysing behaviours in multi-agent systems (Rainey and Mittal 2015) as the taxonomy of different types of emergent behaviours is based on the relationship between these macro and micro levels (O'Toole, Nallur, and Clarke 2014).

BMS Behavior Phenomenon

A Theoretical View

Similar to natural systems, where autonomous agents, such as ants and bees, follow a set of simple rules, the system – in this case, a network of bases and electronic warfighting platforms – has military assets as agents within the network that are guided by defense departments (army, navy, and air force). Although each subsystem is reliable, when multiple subsystems interact, the potential permutations and combinations of interactions can cause unpredict- able negative and positive feedback loops, resulting in unpredictable and unwanted outcomes (Henshaw 2015). BMS Function and Performance Specification (FPS) is developed by Defence departments for contractors and provided to define and validate a set of requirements for BMS material systems (Henshaw 2015). Interactions that may result in emergent behavior will manifest at the interfaces between systems, between systems and operators, and between systems and BMS agile software development elements. Examples include developing stories/epics/feature designs (SEFDs) and a stable understanding of warfighting operations and strategies during combat (Loerch and Rainey 2007). The epic and feature designs are important to the development of BMS software; similarly, it is important to recognize the positive and negative emergent behaviours in software development. The physical result of emergent behavior in the BMS is a goal-seeking element that may have probabilistic, unanticipated behavior.

The results of emergent behavior are unexpected and sometimes unwanted in areas of intelligence, cybersecurity, weapons on target and wireless net- works, integrated power hubs, sensors, end-user devices (EUDs), tactical routers, and network-enabled technologies (O'Toole, Nallur, and Clarke 2014). During agile software development, positive emergent behaviours are a preferred choice, whereas negative behaviours are unwanted and should be eliminated, if possible. Software developed using agile processes can be analysed from the perspective of graph theory and based on cognitive science methods.

BMS software in a battlefield environment permits participants to successfully allow network data to be combined and analysed with more sophisticated algorithms and techniques in the operational environment. Emergent behaviour occurs in the communications systems interface, the configuration of the combat network for land-dismounted wireless networking, sensors, and systems that include human biosensors, targeting, shot detection, uncrewed aerial vehicles (UAVs), small arms digital sights, range finders, and data.

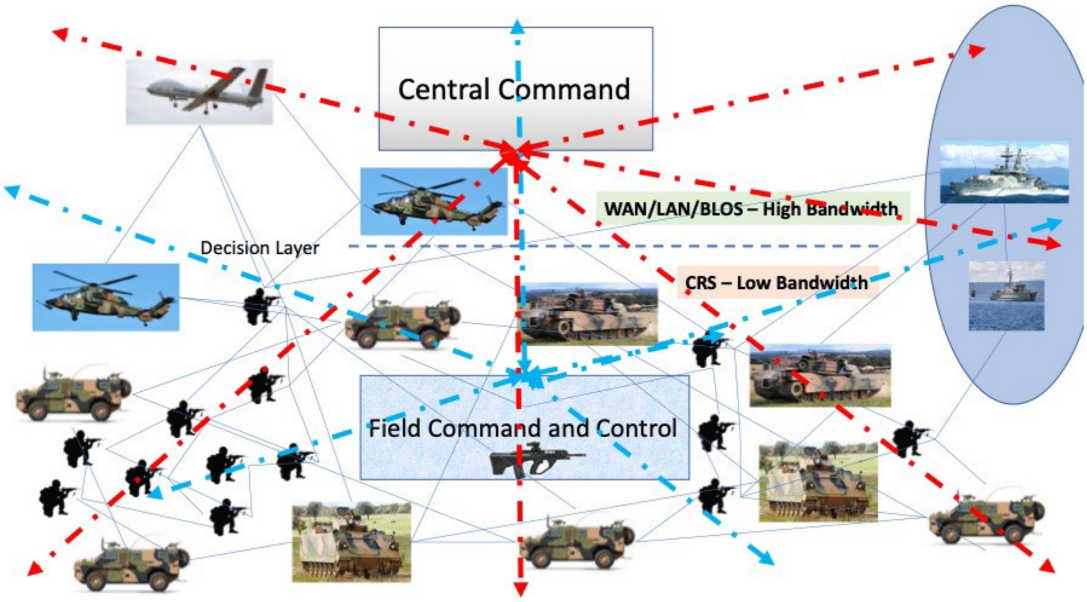

Diagram 2. BMS central command communication network

The emergent behavior in BMS is not based on a priori knowledge. The method used to analyze emergence in a real-time warlike hostile environment draws from the perspective of graph theory and cognitive science methods that are applied early in system development. At this stage, knowledge is independent of experience, and it is not easy to clearly recognize, analyze, and validate where the emergent behavior exists. However, agent-based modeling (ABM) and simulation to assess the presence of emergent behavior in BMS may be effective.

Literature Review and Taxonomy of Emergent Behavior

An extensive literature review suggests that the critical foundation to a safe and efficient operational capability is the underlying integrity of meta-systems of emergent behavior occurrence (Genesereth 1983).

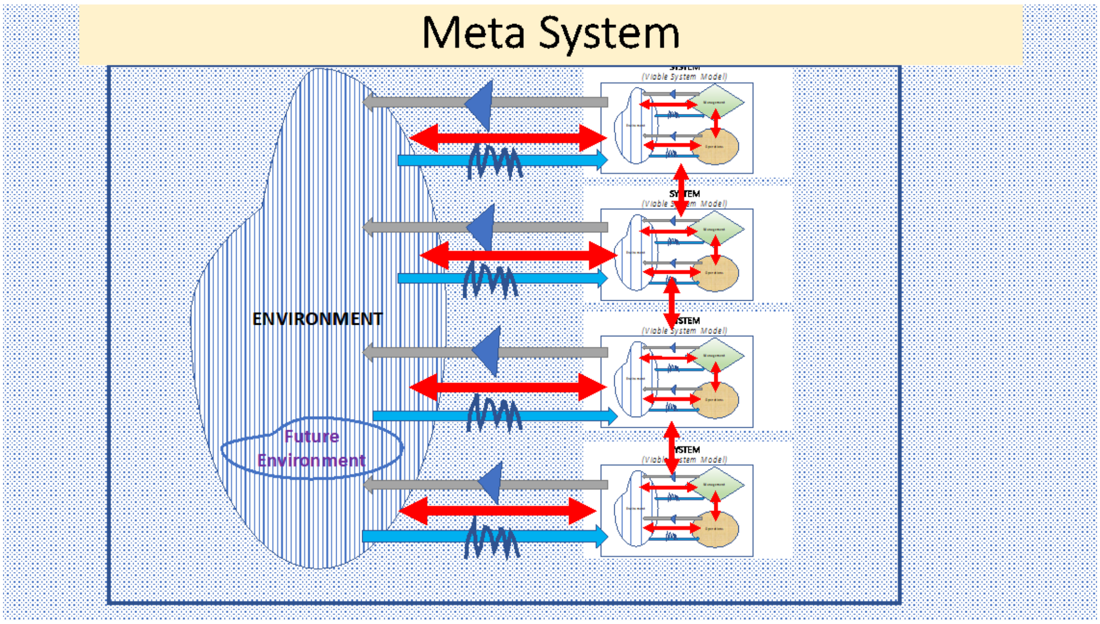

Diagram 3. Meta System incorporating System VSM

The literature suggests several techniques to detect emergent behaviour, ranging from statistical analysis to formal approaches. For the current study, variable-based techniques are the most appropriate choice (Chen et al. 2014; Holland 2007; O'Toole, Nallur, and Clarke 2014). The variable-based approach is used to design, develop, and implement information systems for BMS and many other SoS. Emergent behaviours in the SoS comprise three elements: agents, their interactions, and the environment. Each agent has a set of attributes that describe the state of the agent and several specified policies/ rules that define how the agent behaves with respect to the changes in its environment (Lee et al. 2018).

Emergent behaviour is often seen in computer systems such as the BMS; however, while it can appear in such systems, it is difficult to design. As large-scale behaviour results from unpredictable interactions among simple agents, there is no guarantee that any given set of simple agents will exhibit a particular kind of behaviour (Singh et al. 2017). Emergent behaviour often appears in large systems in the form of unexpected results, which are most often classified as “bugs” in the code. An example of this can be found in communication networks. In massively parallel computers, simple properties arising from interactions of simple rules lead to poor performance because of congestion in internal routing networks. However, these resulting bugs may exhibit emergent behaviour that can be put to interesting and unexpected uses as in the cases of Y2K, the Dhahran incident, and the Blue Screen of Death (BSOD) that occurred during a live Windows 98 presentation.

A mechanism of indirect coordination of agents that cannot communicate directly with one another but must engage indirectly through a medium is known as Stigmergy. Stigmergy is used to analyse self-organizing activities in various domains, such as robotics, society, and engineering (Adams et al. 2014). A network of computers allows the possibility of many kinds of emergent meta-level behaviours because computers interact in highly complex ways (Genesereth 1983). The emergent behavior found in computing contexts can be desirable and intentional (Burbeck 2007), or constitute malware, such as computer viruses, botnets, digital propaganda, and cyber-warfare, which are undesirable and problematic.

Gaps in the Literature

- Information on systemic thinking and cybernetics and how they provide building blocks of framework elements and methods used in constructing a meta-methodological model is unclear and lacking.
- As emergence is a property of the aggregate structures of warfighting systems and cannot be anticipated, to establish a theoretical framework for modeling and simulation, it is necessary to first establish a taxonomy of emergent behaviors, which is currently unclear.
- The Evidence is lacking on emergent behavior present in constituent systems that support the systems designs. Combinations of systems oper- ating together within SoS contribute to the overall capabilities. Combining systems can lead to emergent behaviors that may either improve performance or degrade it and may similarly decrease or increase costs.

BMS in Its Application to the Networked Soldier

Scenarios are used to reveal the dynamics of change and use these insights to arrive at sustainable solutions to the challenges at hand. They help stake- holders break through communication barriers and understand how current and alternative development paths may affect the future. The ability to illuminate issues and break impasses makes them extremely effective in open- ing new horizons, strengthening leadership, and enabling strategic decisions.

Therefore, it is reasonable to invite outsiders such as major customers, key suppliers, regulators, consultants, and academics into the process. The aim is to envisage the future broadly in terms of fundamental trends and uncertain- ties. First, line managers develop basic ideas, and then, staff, such as planners, develop the written versions, fill in the gaps, and find new data. Schwartz's (2012) meta-system and living system model summarizes most of the knowl- edge on CAS but, owing to its succinctness, it remains a generic graphic meta- model. Technological issues can be categorized as direct (e.g., "How will high- bandwidth wireless affect landline telephony?"), enabling (e.g., "Will X-ray lithography bring in the next chip revolution?"), and indirect (e.g., "Will biotech allow easy 'body hacking' and compete with more traditional forms of entertainment?"). Listing the driving forces is useful to look past the everyday crises that occupy our minds and examine the long-term forces that ordinarily operate well beyond our concerns. These powerful forces usually catch us unawares. Once these forces are enumerated, we can see that from our perspective, some of them can be considered "predetermined;" this is not exactly a philosophical stance but one describing how they are completely outside our control and will play out in any story we develop about the future. Not all forces are as evident or easy to calculate, but when we build our stories, predetermined elements figure in each one.

Cyber-Physical Systems and Next-Generation BMS in Its Application to the Network Soldier

The ability to interact with and expand the capabilities of the physical world through computation, communication, and control is key to future technolo- gical developments. Opportunities and research challenges include the design and development of next-generation airplanes and space vehicles, hybrid gas- electric vehicles, fully autonomous urban driving, and prostheses that allow brain signals to control physical objects. Increased efficiency of information or data flow alone changes the entire organizational construct within which the system operates. Directions for future research in Cyber Physical Systems (CPSs) are as follows:

- Standardized abstractions and architectures that permit modular design and the development of CPSs are urgently needed.
- CPS applications involve components that interact through a complex, coupled physical environment. Reliability and security pose particular challenges in this context – new frameworks, algorithms, and tools are required.
- Future CPSs will require hardware and software components that are highly dependable, reconfigurable, and in many applications, certifiable. Trustworthiness must also extend to the system level.

- Designing CPSs is challenging because:

(1) the vast network and information technology environment connected with physical elements involves multiple domains, including controls, communication, analogue and digital physics, and logic;
(2) the interaction with the physical world varies widely based on time and context; and
(3) using multi-domain models that capture such variability is critical to successful CPS design.

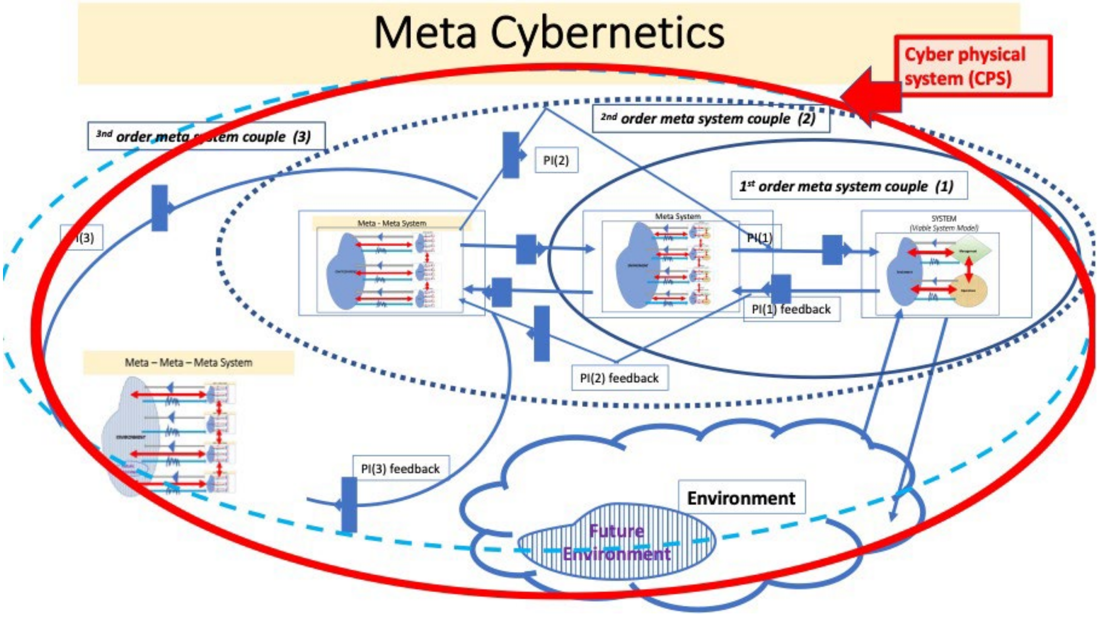

Diagram 4. Meta cybernetics and cyber physical system presentation coupled through use of cybernetics orders VSM and control of emergence.

CPSs link cyberspace with the physical world through a network of inter- related elements such as sensors and actuators, robotics, and computational engines. These systems are highly automated, intelligent, and collaborative. Examples of CPSs include energy-neutral buildings, zero-fatality highways, and personalized medical devices. CPSs require detailed modeling of the dynamics of the environment and a clear understanding of the interactions between the dynamics of the embedded system and its environment (Sage and Gass 2016).
The networked soldier CPS offers a good scenario for design and analysis because of the integration of BMS, process, computation, and networking, where embedded computers and networks can monitor and control the net- worked soldier's behavior and combat physiological monitoring systems with feedback loops in which the networked soldier's behavior and actions can affect computation and vice versa. Present-day CPSs integrate computation and physical processes to perform various mission-essential or safety-critical tasks.

Benefits

Wearable sensors for medical purposes (e.g., measuring temperature or heart rate) can be used to identify whether a soldier is in medical distress. In the past, it was not possible to obtain this information remotely unless the soldier radioed in and offered it. With this CPS connected to the BMS and tactical network, the condition can be identified before the soldier may even be aware of it, and an alert may be raised. If the alert is raised on an entire company, the system will "know" that a stressor of some kind is impacting the soldiers and some action is necessary. Data from a networked soldier can be used to simulate different scenarios for test and analysis purposes and identify areas where the safety and security of soldiers as a system or subsystem exist.

Analysis

Analysis is a process of examining possible future events by considering poten- tial alternative outcomes (sometimes called "alternative worlds"). The ideal scenario test is a credible, complex, compelling, and motivating story with an easy-to-evaluate outcome (Henshaw 2015). The research method is based on the methodological level in a system design, which applies to communication, control (cybernetics), and system thinking (Sage and Gass 2016). The application of cybernetics science in engineering is commonly used to analyze failures and systems accidents where a small error or deviation from the standard operating environment can result in a disaster (Sage and Gass 2016).

Smartphone Ad-Hoc Networking (SPAN) Mesh: The Local Network Topology and Future Soldier System's Physiological Concept Design

Networks are mathematical structures mainly used to describe complex systems like the brain and the internet. Therefore, in fundamental topological, structural and geometrical properties emerge complex geometry. Thus, characterizing the geometrical properties of these networks has become increasingly relevant for routing problems, inference, and data mining. Moreover, the nonequilibrium dynamic rules of these networks will generate scale-free networks with clustering and groups. These geometric networks are present and describe the technological system as well as biological and social. Graph theory works on treatable structures when we examine the difference between a network and a graph. The networks focus on data features like sparsity and inhomogeneities frameworks extension and the use of a classical random graph to a general class of inhomogeneous arbitrary graph model and a general framework for analyzing a large type of model.

Physiological Monitoring

The ability to remotely monitor the physical condition of each soldier in a dismounted unit has become an essential component of the unit's safety, efficiency, and effectiveness. The physiological monitoring system collects, stores, and transmits physiological data from the soldiers to the commander. The system comprises a set of wearables – minimally invasive sensors that collect data and monitor several parameters of the soldier's body, such as an electrocardiogram (ECG), a heart rate monitor (HR), and thermometers for core and skin temperatures – and an algorithm to collect, correlate, and distribute the data efficiently.

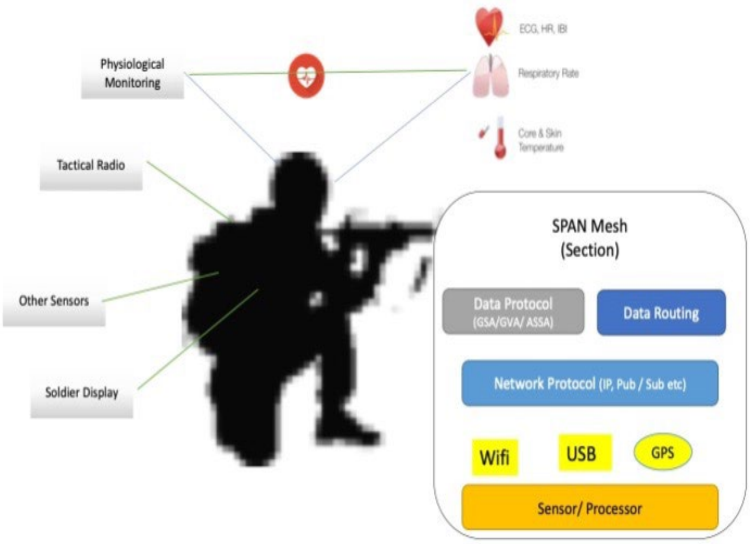

Diagram 5. Network soldier sensor and communication

Human-Machine Interface

Significant progress has been made in ensuring that the C4I computer and BMS software suit the needs of a dismounted soldier. Although the system has operational value for mission planning and situational awareness when on the halt, the current solution provides limited means for situational awareness while on the move. Additional technologies and solutions, such as voice control, in-ear earphones, and see-through glasses must be explored to provide a holistic solution that is usable during all phases of the dismounted soldier's mission. The soldier system must be sufficiently flexible to allow any combination of sensors, processors, user interfaces, and communications at different fitment locations to create an operational outcome.

System Modularity

The future soldier system is required to provide an optimized solution for several soldier roles in various mission types. The system must be modular and configurable to support multiple configurations using the same set of building blocks. Its ability to link soldiers in a section and with the broader army communication landscape is key to delivering the SPAN mesh networks (nodes).

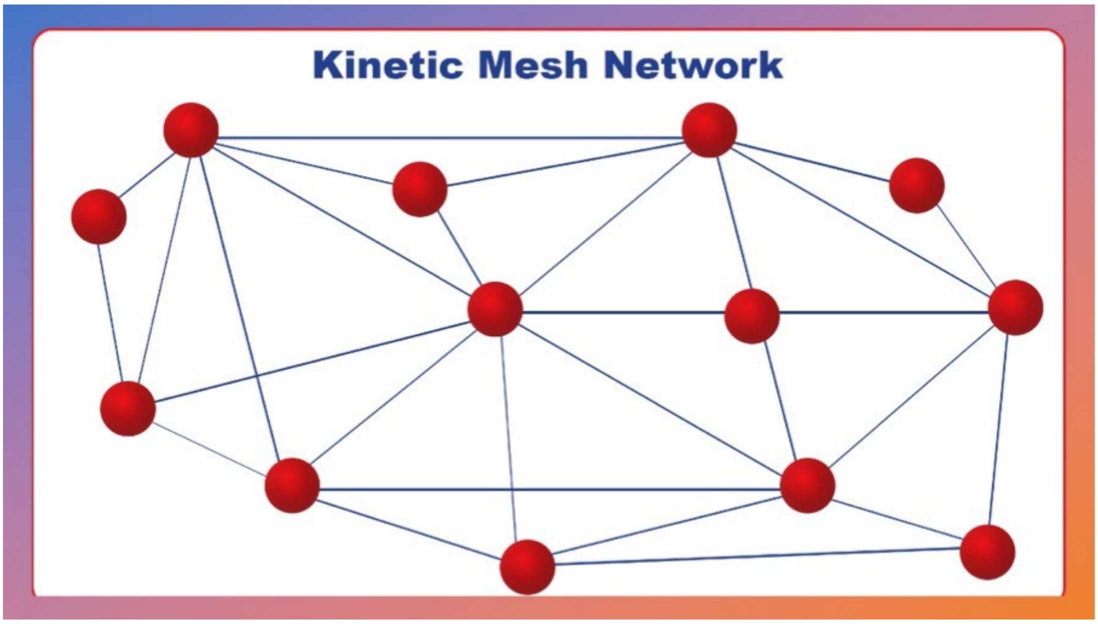

Diagram 6. Basic mesh network (kinetic)

The network needs to allow future support for the increasing range of sensors and field intelligence capabilities. The SPAN solution is an innovative mesh network for sharing data among soldiers in a section and between the command and the section. The mesh network will be built on a standardized technology platform and will support a set of standard data exchanges based on the generic vehicle (GVA) and soldier (GSA) architecture models. This will allow the SPAN mesh to provide a network for all sensors.

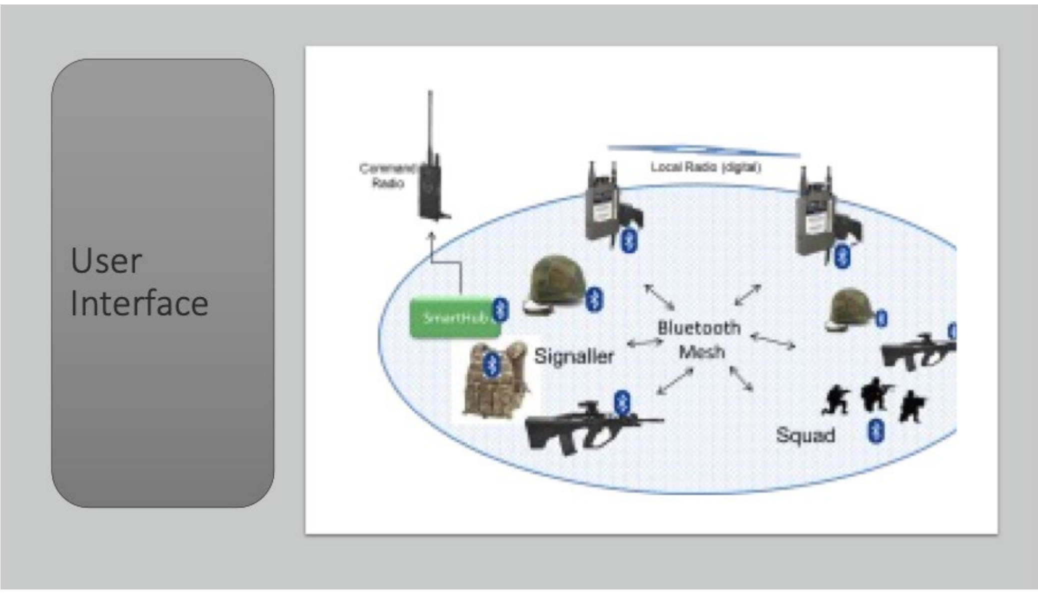

Diagram 7. Network soldier user interface

The SPAN mesh at the soldier and section levels will leverage several existing wireless technologies with new and evolving technology to create a low-power mesh network such as through Bluetooth/wi-fi and ultra- wideband (UWB). Creating a data standard over the mesh network will allow any sensor, device, or computer to connect as a node and collect or share data with other nodes in the network. The mesh network's routing capability would enable data to flow through the entire section. Thus, a dispersed section would still be able to share data through the links between individual soldiers over a significant distance. Due to the low size, weight, and power (SWaP) of these network components, many sensors can be self-contained and will not require a large separate power supply. The SPAN will be integrated with the broader army network by being connected to an existing very high frequency (VHF) network, broad- band, and future waveforms. Combining some of the existing radio knowledge with the new SPAN mesh and local higher capacity network will create a link with the army backbone network. A section commander, signaller, or vehicle can all carry the SPAN transceiver and tactical radio to allow this data exchange. With the creation of the SPAN mesh, multiple sensors can be fused to create higher-order information. Connecting sensors via the mesh networks to a processing capability in the BMS will allow combining and analysing network data with more sophisticated algorithms and techniques. Sensors such as shot and electronic warfare detection and range finders can be combined to create red tracks for sharing across the section and the wider BMS system. To create situational awareness, images and videos from local support can be integrated with ranger finders, BMS, and UAV data.

Cybernetics: “The New Paradigm”

During the Second World War, mathematicians Wiener (1961) developed a new branch of applied science, naming it the science of information feedback systems cybernetics (McCulloch and Foerster 1995). Fourth-order cybernetics is called emergent cybernetics and considers what happens when a system redefines itself. It implies that a system will “immerge” into the environment of which it is a part. The axioms or elements of systems theories are the centrality, contextual, goal, operational, viability, design, and information elements. Using cybernetics management (Beer 1972), this literature review examines emergent behavior through the theory of critical system thinking (D’Andreamatteo et al. 2019) and cybernetics methodology. The cybernetics methodology, called the “new paradigm,” has attracted numerous researchers and practitioners and introduced them to the discipline of systematic manage- ment (Sage and Gass 2016). Meta cybernetics represents the higher cybernetic orders in living system agencies (Yolles 2021). Agencies are complex and viable and require stability and uncertainty reduction to survive. Meta- cybernetics is defined through a metasystem hierarchy and is mostly known through first- and second-order cybernetics (Yolles 2021).

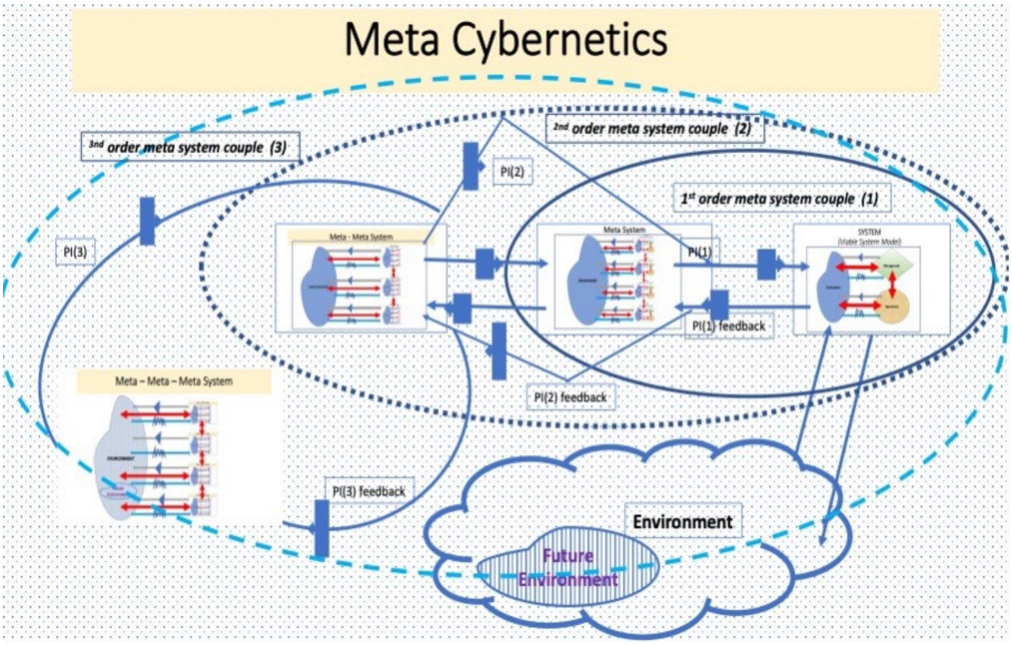

Diagram 8. Meta Cybernetics and coupled from 2nd – 4th order cybernetic.

Applying cybernetics management (Beer 1984) to complex systems analysis, this paper examines problem solving through the theory of critical system thinking (D’Andreamatteo et al. 2019) and cybernetics. Cybernetics began as a questioning of the ideas of systems in and out of control in first- and second- order behaviors. The law of requisite variety makes it clear that control has limits. When Ashby (1965) described first- and second-order effects, he was not thinking of autonomy or intelligent SoS, although he undoubtedly under- stood the possibilities of emergent behavior. Emergence, as a property of the aggregate systems of warfighting systems, cannot be anticipated (O'Toole, Nallur, and Clarke 2014). Simulations employing the same perceptual engines as found in vessels are currently being developed as experiments with different contexts by examining what is expected and unexpected and whether emergent behavior can be forecast within some limits of confidence (O'Toole, Nallur, and Clarke 2014).

Cybernetics and System of Systems

Cybernetics and systems science focus on complex systems, such as organisms, ecologies, minds, societies, and machines (Bar-Yam 2004b). They regard these systems as complex, multi-dimensional information system networks. Cybernetics presumes that some underlying principles and laws can be used to unify the understanding of such seemingly disparate types of systems (Sage and Gass 2016). The characteristics of cybernetic systems directly affect the nature of cybernetic theory, resulting in serious challenges to traditional methods. Some of these characteristics, as identified by Sage and Gass (2016), are:

- Complexity: Cybernetic systems are complex structures.
- Mutuality: The many components interact in parallel, cooperatively, and in real-time, creating multiple simultaneous interactions among subsystems.
- Complementarity: These many simultaneous modes of interaction lead to subsystems that participate in multiple processes and structures.
- Evolvability: Cybernetic systems tend to evolve and grow opportunistically.
- Constructivity: Cybernetic systems are constructive in that they tend to increase in size and complexity.
- Reflexivity: Cybernetic systems are rich in internal and external feedback, both positive and negative.

SoS Agent-Based Modeling and Simulation

ABM and simulation can demonstrate that emergent behavior exists in the BMS. Emergent behavior can be determined using ABM and simulation, or some other applicable modeling and simulation (M&S) tool applied to a given SoS engineering application (Lee et al. 2018). Designing a multi-BMS system first requires specifying how each system agent exists and acts in the environ- ment. This is represented in behavioral ontology (Burbeck 2007). This description is then transformed and expressed in the language of the simulation engine and provided as input for execution. There is no evidence of the presence of emergent behavior in constituent systems that supports systems design. Combinations of systems operating together within the SoS contribute to the overall capabilities and lead to emergent behaviors, which may improve or degrade performance and decrease or increase costs. In the System Engineering Body of Knowledge, SoS are important for capability objectives and understanding their interrelationships.

MITRE (2021) defines the SoS as a system with characteristics. It comprises a collection of systems, each capable of independent operation, that interoperate together to achieve additional desired capabilities. Maier (1998) defined SoS as operational and managerial independencies. These two independencies have distinguished characteristics in applying the term SoS. Therefore, any system that does not display these two characteristics is not SoS regarding its components' complexity or geographical distribution. The constituent systems of the SoS will have different owners supporting defense organizational structures beyond the SoS management. The SO/IEC/IEEE 21,839 (ISO/IEC/IEEE 2019) standard defines the SoS and constituent systems as follows:

Systems of Systems (SoS)—Set of systems or system elements that interact to provide a unique capability that none of the constituent systems can accomplish on its own. Note: Systems elements can be necessary to facilitate the interaction of the constituent systems in the SoS.

Constituent Systems—Constituent systems can be part of one or more SoS. Note: Each constituent is a useful system by itself, having its own development, management goals, and resources, but interacts within the SoS to provide the unique capability of the SoS.

Rainey and Jamshidi (2018) shared advice regarding setting a research objec- tive by choosing a given/specific SoS to explore for the presence of emergent behavior to identify it, understand what may constitute both positive and negative emergence, use Monterey Phoenix (MP) (https://wiki.nps.edu/display/MP/Monterey+Phoenix+Home) to remove negative emergence, and ensure that only positive emergence remains. The point, as stated above, is to consider one incident/venue to investigate from which general conclusions can be made that apply across the board/population of SoS (Rainey and Jamshidi 2018) This is further explained in Rainey and Jamshidi book, *Engineering Emergence: A Modeling and Simulation Approach* (Rainey and Jamshidi 2018), which describes architecture and modeling in complex systems. For analysis and modeling purposes, Rainey et al, (2015) recommended identifying SoS that require exploration for emergent behavior and explaining why this SoS was chosen for examination from which the conclusions can be drawn for all SoS (Loerch and Rainey 2007; Rainey and Jamshidi 2018).

In literature during the last decades, there has been a tendency toward nonlinear modeling in various application fields. An excellent starting point for nonlinear modeling is Jonas et al. (1995). However, a significant drawback is the lack of a general nonlinear framework. However, a class of nonlinear systems has intensively been studied and covers a broad spectrum of "nice" nonlinear behavior, namely the class of Wiener systems. This class of systems stems from the Volterra – Wiener theory (Rugh 1981; Schetzen 1981) and will be employed here as a framework to develop the initialization procedure of the Polynomial Nonlinear State Space (PNLSS) model. The network is a graph- based presentation of a problem (in many cases) and provides a different viewpoint to the analyst. This paper first presents the BMS and networks with examples of user-defined system integration of the network soldier concept. We believe that Ukrainian command and soldiers can directly benefit from integrating meta cybernetics, meta metasystem, and cyber-physical systems (Rainey and Tolk, 2015). For the systems of systems agent-based modeling and simulation in nonlinear devices and class systems, we proposed Volterra - Wiener theory, which can be used as a framework to develop the early procedure and initialize the polynomial nonlinear state space model.

In the following paper: *Practical Modeling Concepts for Engineering Emergence in Systems of Systems*, Giammarco (2018) states that positive emer- gence is what remains after thoroughly exposing and removing negative emer- gence and provides a five-step algorithm for executing the same. A dynamic evolutionary meta-model analysis of the vulnerability of complex systems can have severe consequences and is often seen as the core problem of complex systems' multilayer networks. To understand emergent behavior in SoS, MP facilitates modeling and simulation of systems of systems (SoS) across many application domains and enables exposure and control of associated emergent behaviors. With MP, the presence of emergence in a model of the SoS can be detected (MP also permits the modeling of an SoS) and negative emergence can be deleted such that only positive emergence remains. The upshot/impact of this tool is to preclude potential negative influences on the SoS and lead to potential force multipliers therein. Dr Kristin Giammarco developed the MP modeling tool that can detect the presence of emergence in a model of the SoS.

The key point is that MP provides a means and or capability to model and simulate the SoS. Most importantly, it facilitates the capability to examine for the presence of both positive and negative emergence. In addition, it facil- itates the deletion of negative emergence such that only positive emergence remains, integral because negative emergence can potentially be a significant detriment to the SoS' mission. Thus, it is a force multiplier for the SoS' mission (Rainey and Jamshidi 2018) As a powerful method for CAS model- ing, ABM has gained growing popularity among academics and practitioners. ABM demonstrates how the agents' simple behavioral rules and local interactions at the micro-scale can generate surprisingly complex patterns at the macro-scale.

Architecting Principles of Emergent Behavior

In 2013, Maier described the architecture of SoS to comprise communications and noted their nonphysical nature, constituting a set of standards that allow for meaningful communication among the components (Maier 1998). SoS and systems components are configurations of tangible and intangible elements, such as mechanical, electrical, electronic, software, knowledge, and natural objects. These objects perform functions and behaviors to meet a specific purpose and fit within the description of emergent behavior as defined by Maier (1998). The objects serve a purpose in their own right. However, such a system could be considered exosystemic in situations where there are hidden states. That is, the SoS of machines exist that must be designed, manufactured, and operated to deliver their purpose. An example is a communications SoS (such as satellites, land stations, submarine cables, and facilities) that aims to enable household and business transactions, manufacturing, the control of autonomous vehicles in mines, and the management of a battlespace. Within these SoS, their components are systems in their own right. For the systems to meet their purpose, other complex SoS must be in place. The components of this system include elements such as human skills, machine learning, measures of performance, tools, knowledge, and facilities. This system has two main subsystems: social and technical. Whereas the social system describes the functions and behaviors humans apply to a maintenance system, the technical system describes the technology functions and behaviors that deliver the required purpose (Rainey and Jamshidi 2018).

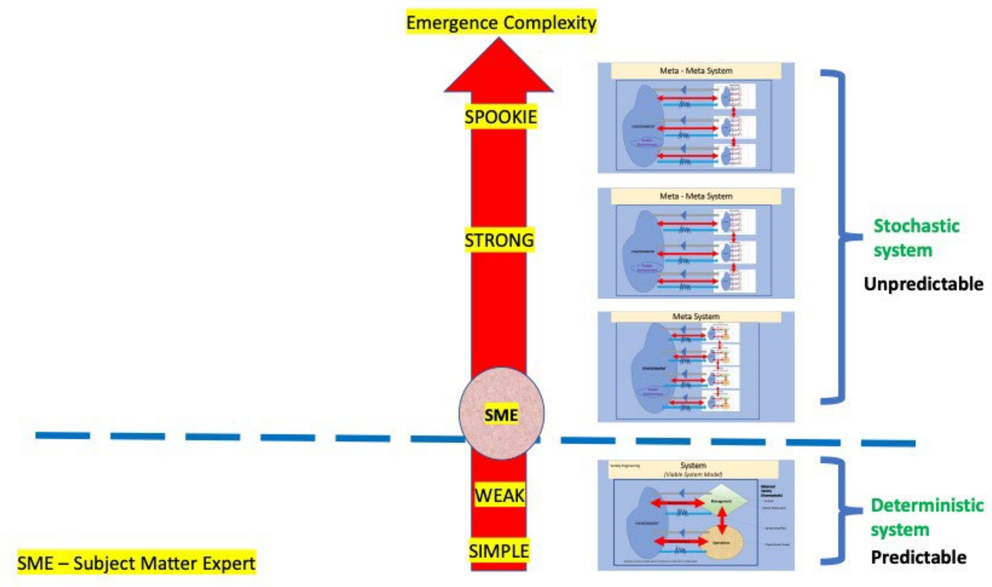

Diagram 9. Emergence complexity progress from deterministic to stochastic system

Considering the combination and permutation of systems elements or components, evidently, issues such as their completeness and order must be considered. Polanyi's statement that "We know more than we can tell (Lundberg 1949; Polanyi and Allen 1997) is an appropriate description of the situation. Several interacting systems exist, and because of relationships such as sneak circuits, there may be more going on in the systems than we can tell. The total behavior events of the combined systems working alone or collectively must be visible from the strategic requirement of system perfor- mance to the implementation of the system to sustain purpose. In the SoS, it is important to identify the critical set of systems that affect the objectives and to understand their interrelationships.

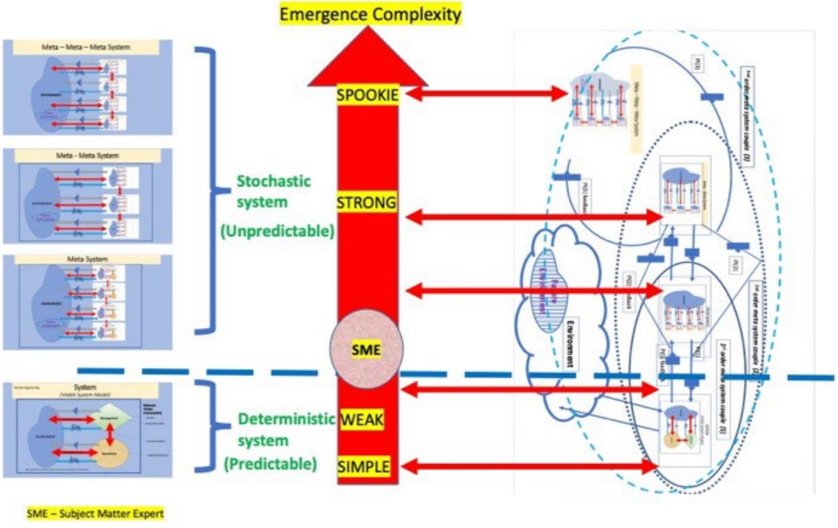

Diagram 10. Meta metasystem, meta cybernetics and emergence complexity incorporated

The SoS operating within other such systems contribute to overall capabilities. Combining these SoS can lead to more emergent behaviors than are usually seen in single systems. These behaviors may either improve or degrade performance. The challenge of design in the SoS is to leverage the functional and performance capabilities of the constituent systems to achieve the desired SoS capability. The crosscutting characteristics of the SoS ensure that they meet the broader user needs.

Findings

An Overview of the Research Evidence

The SoS emergent behavior is relevant to engineering and natural systems and is not well understood. Evidence may include any systematic observation to establish facts and arrive at conclusions. This literature review examines emergent behavior through the theory of critical system thinking (D'Andreamatteo et al. 2019) and cybernetics. In complex problem solving, we can assume that all systemic properties will be investigated; however, this is where the nature of the problem is revealed. Therefore, cybernetics and system thinking give rise to a new concept in problem-solving, which is currently not well defined, understood, or clearly tangible to the assessment of the opera- tions within engineering. In complex problem solving, we can assume to have all the systemic properties investigated, which is where the nature of a problem is revealed. The introduction of systemic thinking and cybernetics provides the framework elements and methods used to build the meta-methodological model that remains unclear or unavailable.

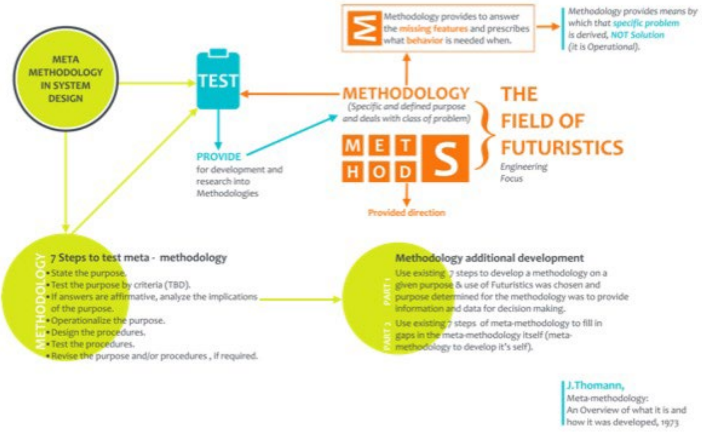

Diagram 11. Meta model methodology design by Thomann (1973).

A meta methodology is a way of developing and testing a method for a specific, defined purpose. An overview of Meta-Methodology and how it was designed (Thomann 1973). To establish a theoretical framework for modeling and simulation, it is necessary to first establish a taxonomy of emergent behaviors, which is unclear thus far. Further, evidence is lacking on the emergent behavior that is present in constituent systems that support the system's design. Combinations of systems operating together within the SoS can contribute to overall capabilities. Combining systems can lead to emergent behaviors that may improve or degrade performance and decrease or increase costs.

Conclusion

This paper concludes that the concepts, ideas, theories, tools and general methodologies of nonlinear dynamics and complex systems theory show enormous, almost total, potential for not just providing better solutions for some existing issues of land combat, but for fundamentally altering our general understanding of the fundamental processes of war, at all levels. Indeed, the new science's most significant legacy may, in the end, be not just a set of creative answers to old questions but an entirely new set of questions to be asked about what happens on the battlefield. The central thesis of this paper is that land combat is a complex adaptive system. Land combat is a nonlinear dynamical system composed of many interacting semi- autonomous and hierarchically organized agents continuously adapting to a changing environment.

The BMS focuses on distributing information across a warfighting network and is a network of bases and electronic warfighting platforms. The rise of automation in multiple systems and technologies presents a complex opera- tional environment. Such environments require highly collaborative, CASoS solutions. Combining systems may lead to more emergent behaviors than is usually observed in single systems (Kaisler and Madey 2009). The emergent behavior is imperative in developing a framework to safely and securely deliver large and complex engineering projects to produce new insights and practical steps to improve complex project success (Juli 2011).

Emergence may be positive or negative and may take shape (types) in various systems that range from simple to complex. Therefore, a mechanism that provides a structured approach for analyzing and controlling such behaviors is required. We make a case for a framework to explore emergent behaviors in a multi-agent system (O'Toole, Nallur, and Clarke 2014). The aim is to demonstrate that if any emergent behavior system, that is, a complex (multi-agent) system exhibiting emergence, is represented formally using the developed framework, this would render it easy for a modeler to analyze and study the causal relationships between the micro and macro layers of the system. It is possible to use a case study to demonstrate how the BMS framework can be beneficial in implementing and classifying emergent behaviors using existing and known approaches in the literature. The challenge of design in the SoS is to leverage the functional and performance capabilities of the constituent systems.

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Table 1 – Peer Review 221722688 (Applied Artificial Intelligence) A revised earlier decision prior to final acceptance.

221722688 (Applied Artificial Intelligence) A revised decision has been made on your submission
Emergent behaviour in the battle management system
Karin Pils-Vorsteher
Editorial Assistant
Applied Artificial Intelligence
Comments from the Editors and Reviewers:

Reviewer 2: The authors have clearly defined their research goal in both the title and the summary. Clear messages were described. In the current wartime situation in Ukraine and the wide usage of IT supported battlefield systems, the chosen topic is very important. However, I'd read more details on the usage of AI in battlefield systems. It is sufficient for the the actual proposal, but I hope that this aspect will be more elaborated in a future article. This manuscript is a result of an ongoing research and more practical details will come into public in the future, therefore I can accept it as it is. The research question is clear and highlights an important aspect, the emergent behaviour. The research method is well-chosen and fits to the topic, moreover, validates the results, that are clear and accurate. There are no ethical concerns in the research. The conclusions can serve as a basis for future research. No tables or figures were used, that is a minor shortcoming.

The references are supporting the research and were used in in accordance to the requirements. The style and grammar of the manuscript are acceptable and follow the scientific requirements. I recommend the publication of this manuscript.

5.3. Links between Paper 1 and Paper 2

The linking theme between these papers is the exploration of advanced technology and its role in modern warfare, with a specific focus on Battle Management Systems (BMS) and their impact on information sharing and emergent behaviour within military systems. Both papers offer a comprehensive exploration of the evolving landscape of modern warfare in the context of advanced technology. They share a central theme of highlighting the profound influence of technological advancements on military operations, underscoring the transformative impact on how modern armies operate and communicate in the digital era.

The first paper zeroes in on Battle Management Systems (BMS), recognising them as a pivotal component of contemporary warfare. BMS plays a pivotal role in enabling the seamless exchange of vital situational awareness information among various military units, spanning from individual soldiers to command headquarters and a diverse array of military assets. This technology has become the linchpin for digital armies, serving as the linchpin for the efficient flow of critical data, ultimately enhancing the coordination and effectiveness of military operations. This paper underscores the transition from analogue to digital communication, a paradigm shift that has significantly influenced contemporary warfare. This shift is particularly pronounced in ongoing conflicts, such as those observed in Ukraine, where the adoption of IT-supported battlefield systems has revolutionised information dissemination. This transition not only enhances the speed and precision of information sharing, but also empowers military decision-makers with the means to make informed and timely decisions, enabling adaptation to the ever-shifting dynamics of the modern battlefield.

Paper 2 (in Chapter 6 below) delves into the complex domain of emergent behaviour within Systems of Systems (SoS), with a specific focus on the "Cybernetics Battle Management System and its Application to the Network Soldier" scenario. This paper extensively explores the mechanisms and various forms of emergent behaviour, building upon the foundational work of renowned researchers. The focus here is not solely on recognising and categorising emergent behaviours but also on comprehending how they manifest within SoS. The introduction of Yolles' (2021) meta-cybernetics framework is a key highlight, emphasising the roles of process intelligence (PI) and operative intelligence (OI) within systems and highlighting their significance in managing emergent behaviours. The paper emphasises that systems naturally adapt and emerge within their environmental contexts, with flexibility playing a pivotal role in controlling these systems effectively. To aggregate, these two papers shed light on the substantial impact of advanced technology on modern warfare. They elucidate how advanced technology facilitates efficient information sharing through BMS while also addressing the complexities of managing emergent behaviour within SoS. These papers provide valuable insights into how modern militaries navigate the intricate challenges brought about by technological advancements.

CHAPTER 6: PAPER 2. CYBERNETICS – BATTLE MANAGEMENT SYSTEM (BMS) AND THE APPLICATION TO THE NETWORK SOLDIER

6.1. Observations on Paper 2

This paper extensively explores emergent behaviour within the Systems of Systems (SoS) framework, specifically in the context of the "Cybernetics Battle Management System and its Application to the Network Soldier" scenario. It investigates the mechanisms behind emergent behaviour in SoS and categorises it into various forms, building on foundational work by researchers like Ashby, Maier, Rainey, and Tolk. The paper introduces Yolles' (2021) meta-cybernetics framework, emphasising the roles of process intelligence (PI) and operative intelligence (OI) within systems. It highlights the natural emergence of systems within their environmental contexts and the role of flexibility in control.

The study looks into managing variety within Cybernetics Battle Management Systems (CBMS) and explores the integration of cybernetics and the Viable System Model (VSM) to mitigate negative emergent behaviour in complex systems, using the Delphi technique to predict future events. The study aims to formally identify and analyse emergent behaviours in complex systems, enhancing the understanding of causal relationships between micro and macro layers. It refrains from discussing distributed battle management (DBM) solutions, which enhance communication between manned and unmanned platforms in communication-deprived environments.

Notable contributions include defining contextual specifications and a hierarchical structure for CBMS, essential for understanding emergent behaviour in the networked soldier context. It also outlines methods for adjusting system variety and introduces a system classification schema for developing network soldier systems within the meta-system.

6.2. Paper 2. Cybernetics and Battle Management System (BMS) in network soldier system application

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Cybernetics and Battle Management System (BMS) in network soldier system application

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Word count: 13288

Abstract

Countries use battle management systems (BMS) that enable commands to share digital situational awareness information. The background of the BMS complex system is by Maier definition a system of systems, and current research has focused on distribution of information across a warfighting network. In the network of electronic warfighting platforms where military assets are classified as agents and where multiple subsystems interact, potential permutations and combinations of interactions can cause unpredictable negative or positive feedback loops, resulting in unpredictable or unwanted outcomes, which is referred to as emergence behavior. The Viable Management System is proposed as a governing framework that can be applied in the system where the number of subsystems represents the SoS. The network soldier system is a deterministic system in which behavior is predictable and horizontal recursion is applied to reduce variety. The introduction of stochastics system like cybernetics battle management system (CBMS) is where the system behavior is unpredictable. The CBMS and its application to the network soldier is derived from previous schematics developed by Yolles, Rios, Schwaninger, Lowes, Sisti etc., and the originality is on the aspects of meta cybernetics and the use of laws of requisite variety by Ashby, 2011.

Keywords: defense; cybernetics; systems; communication; emergence; behavior.

1. Introduction

This paper aims to investigate and review emergent behavior with the Systems of Systems (SoS) structure and function and provide a system within the SoS in an application scenario, namely, "Cybernetics Battle Management System and its Application to the Network Soldier." Questions arise as to what is the mechanism/process generating emergent behavior in the SoS and what types of emergences are experienced? From a systems perspective, starting with Ashby, emergent behavior is stated to be the lack of understanding of the system. Maier proposed the taxonomy of emergent behavior, and Rainey and Tolk further explored Maier's taxonomy with the introduction of simple, weak, strong, and spooky emergence and called it the emergence complexity funnel, illustrating emergence behavior in deterministic and scholastic systems. Yolles presented the meta cybernetics, complexity, and recursion emergence cybernetic schematics, which entail greater complexity that reduces knowability and predictability. Therefore, a system will emerge into the environment in which it exists. In the meta cybernetics schema by Yolles, the process intelligence (PI) equates to operative intelligence (OI), and as cybernetics orders are coupled together, the systems (meta) with most flexibility will control the system (meta).

The structure of the paper is as follows: First, introduce the battle management systems (BMS) which focus on distributing information across a warfighting network. Secondly, the Delphi technique is introduced to conduct analysis which consists of a carefully structured 'scenario pilot test' with questions, asking participants to provide their view on the application of VMS in meta cybernetics SoS where we can provide control of SoS variety. Next, this will be further analyzed to clearly define the drivers and elements in CBMS control of variety. Finally, the method and Delphi group supportive proof is presented for analysis to control emergence in CBMS. This study explores the possibility of integrating cybernetics meta-methodology and VSM with the application of meta-systems reductionism to reduce the occurrence of negative emergent behaviour in complex systems. Delphi technique is applied in a system of predicting possible future events by considering possible alternative outcomes.

This study presents a "real-world application," which the current literature has not yet addressed.

The contributions of the current study are as follows:

- The requirement for the specification of context, criteria, and a system hierarchical structure in the schematic of the CBMS application to network soldier emergence behavior is outlined.
- Network soldier system variety attenuators and amplifiers to balance variety (haemostatics) use laws of requisite variety (in dealing with complexity in the environment.
- A schema of system classification is presented to provide the framework in which a network soldier system must be developed in the meta system to explore emergent behaviors in multi-agent systems (O'Toole, Nallur, and Clarke, 2014). This review helped to elucidate the challenges and opportunities in meta-metasystems schema design for SoSs.

The objective was to present if any emergent behavior was present in a system (i.e., a complex (multi-agent) system was exhibiting emergence), which can be represented formally using the developed framework (Singh et al., 2017). Then, a modeler could easily analyse and study the causal relationships between the micro and macro layers of a system (Bar-Yam, 2004). Those processes operate according to cybernetic principles and are conceptualized with schematics in the networked soldier's role in a larger SoS such as the battle management system (BMS); there may not be many actual examples available. To be genuinely useful for engineering systems, the schematics must be expanded into at least two fundamental categories: (1) a "discrete" schematic for time-limited operations that terminate, and (2) a “recursive” schematic for extended operations, during a set timeframe, which will not be covered in this study. Further, this study will not cover any form of the distributed battle management (DBM) solution described as disruptive new technology developed to provide timely and relevant information to the battle commander and soldier. The DBM is a semiautonomous software solution used to enable complex teamwork between manned and unmanned platforms in communication-deprived environments.

2. Battle management system (BMS)

The Dr Maier SoS definition is referenced in the paper titled, “Emergent Behavior in the Battle Management System (BMS).” Maier, in 1998, described the architecture of a SoS as communication. The architecture is nonphysical and has a set of standards that allow for communication among its components. The SoS and other components of the system are tangible and intangible objects that can be configured such as mechanical, electrical, electronic, software, knowledge, or natural objects. These objects perform functions and behaviors to meet a specified purpose, and they generally fit within the description of emergent behavior as defined in Maier’s paper on “Architecting principles for systems-of-systems” (Maier, 1998).

The BMS is an SoS with the mission of defending a continent; it focuses on the distribution of information across a network and is essentially a client-server software. The BMS comprises numerous components such as a tactical computer (TC), local area network (LAN), personal computers (PCs), and servers. A range of servers can be configured for several different platforms. The BMS is a mesh network in which information passes through multiple nodes. Land dismounted soldier wireless networking, sensors, systems, and data communications systems cover a range of wireless networks, integrated power hubs, sensors, end-user devices (EUDs), tactical routers, and network-enabled technologies. Some of these sensors include human biosensors, targeting, shot detection, unmanned aerial vehicles (UAVs), small arms digital sights, and range finders. Because of the complex web of interconnections within the BMS, emergent behavior can occur and cause problems. The aim is to investigate various theories and elements that are and can be relevant to system emergent behavior in a complex SoS. Therefore, the basic theory and research on judgment, decision, and choice are the starting points for the development of a general SoS framework.

3. Research conceptual framework

The conceptual framework and the system of concepts, assumptions, expectations, beliefs, and theories that supports and informs this research is a key part of proposal design. The conceptual framework is an analytical tool with several variations and contexts. It can be applied in different categories of work where an overall picture is needed. It is used to make conceptual distinctions and organise ideas (diagram 1). Strong conceptual framework captures something real and does this in a way that is easy to remember and apply.

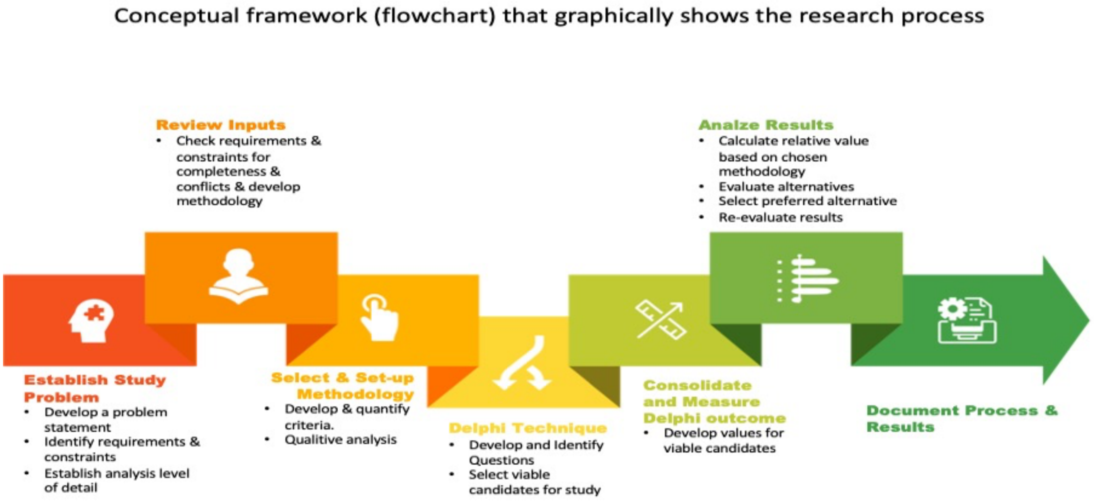

Diagram 1: Conceptual framework

The aim is to establish a conceptual system and framework and discuss issues related to understanding CBMS to eliminate or reduce the occurrence of negative emergent behaviour in complex SoS.

4. Literature review including assessment of gaps in existing knowledge

In the literature, many techniques exist to detect emergence, ranging from statistical analysis to formal approaches (Chan, 2011; Holland, 2007; O'Toole et al., 2014) and are the most appropriate choice. These types of conditions are perhaps best tackled using an emerging strategy (Mintzberg et al., 1998). Miller and Olleros (2000) argued that successful projects are not selected—they are shaped. Some generic examples of failure modes by Meier (2008) looked at projects within the U.S. Federal Intelligence and Defense agencies. He found a number of particular early warning signs that occurred frequently in these projects. For this research, VSM (Ashby 1965, 2011; Chan, 2011; Holland, 2007; O'Toole et al., 2014) is the most appropriate choice to control variety in SoS. The emergent behaviors system comprises of three general elements: agents, their interactions, and the environment. Each agent has a set of attributes that describes the state of the agent and a number of specified policies or rules that define how the agent behaves with respect to the changes in its environment. The SoS objects provide a purpose, and hidden states in various situations in this system can be considered exosystemic (Bronfenbrenner, 2021). The metasystem can be used to explain the hidden states and relationships that occur in a system, while the metasystem can help in explaining any unknown relationship that occurs within (Hundt, 2006 and Djavanshir et al., 2015). This relationship can be generalized to explain a higher order of cybernetics in relation to lower orders (Yolles, 2021).

Various techniques exist to detect emergence (Chan, 2011; Holland, 2007; O'Toole et al., 2014), and the types of conditions are perhaps best evaluated using an emerging strategy

(Mintzberg et al., 1998). Some generic examples of failure modes by Meier (2008) observed projects within the U.S. Federal Intelligence and Defense agencies. He discovered a number of particular early warning signs that occurred frequently in these SoSs. SoSs are characterized by unforeseen emergent behavior, and chaotic systems are where the relationships between cause and effect are impossible to determine. Others (e.g., Sheffield et al., 2012; Silva, at al., 2017 and Snowden and Boone, 2007) also referred to complicated and dynamic SoS (Stocchero, et al., 2022).

Complexity comes from interdependencies and uncertainty (Williams, 1999), but also from human-oriented social aspects (Stacey, 2007). Internal complexities, such as technology and interfaces of existing systems, bring difficulties in understanding and assessing project behavior. External complexities such as stakeholder relationships (Pryke & Smyth, 2006), Remington and Pollack (2007) discussed several complexity types and tools to address various elements in complex systems. Other examples of tools include the cause and effective tools that others have developed and used for diagnosing system faults (Williams et al., 1995). The VSM is proposed as a governing framework that can be applied where the number of subsystems represent the project parties (client, integrator, and suppliers) (Hildbrand, et al.2015 and Yolles, 2021, Hildbrand, et al.2015). Nevertheless, the application of VSM can also be used as a platform to enhance the integration and cooperation of project entities as it will set the communication channels among them (Burgess, et al. 2012, Natuzzi et al.2023 and Hildbrand, et al. 2015). The complexity and chaos of complex systems are better reflected by non-linear systems, which in turn are better manageable in adaptive and self-organised distributed systems with positive feedback (Yolles, 2021). Heikki Hy¨otyniemi, 2006 has introduces us to a new approach to complex systems or neocybernetics. The key parameters in a systemic viability must be controlled to ensure continued existence. The viability addresses how to design a system so that changes in the operational environment may be detected and affected to ensure continued existence (Morris, 2012).

5. Gaps in the literature

- The introduction to systemic thinking and cybernetics and how they provide building blocks of framework elements and methods used in building meta-methodology model is unclear or not available.
- To establish a theoretical framework for modeling and simulation, it is necessary to first establish the taxonomy of emergent behaviors.
- There is no evidence of the emergent behavior present in constituent systems[4] that support systems design. Combinations of systems operating together within a SoS contribute to the overall capabilities. Combining systems can lead to emergent behaviors that may either improve or degrade performance and decrease or increase costs.
- There is no clear understanding of how to test system methodologies while applying system thinking and steer and control theory described as cybernetics, which is the source of knowledge required to mitigate management and operational risk control (Ashby, 1965 and 2011, Kawalek et al., 1996).
- In complex systems, during problem solving, we can assume to have all the systemic properties investigated, and this is when the nature of a problem is indeed revealed.

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[4] Constituent systems can be part of one or more SoS. Note: Each constituent is a useful system by itself, having its own development, management goals, and resources, but interacts within the SoS to provide the unique capability of the SoS.

Therefore, cybernetics and system thinking give rise to a new concept in problem solving, which is not well defined and understood in relation to system development (Wiener, 2013 and Kawalek et al., 1996). The definition of schema is very similar to definition of system and the term schema describes the organisational pattern of thought. A schema identifies categories of information and the relationship between them and the metamodel can be observed as the framework. Metamodel becomes a schema which instantiated the database and provides a framework in which to build the development model of the system (Long et al., 2011).

6. Research methodology design, application, and results

The application of BMS networked soldier scenario is to capture and assess the risks and opportunities of the soldier operations; it is associated with specific sets of elements, particularly where the likelihood of failure occurrences are highly uncertain.

Scenario analysis using the Delphi technique is a system of predicting possible future events by considering possible alternative outcomes. The ideal scenario test is a credible, complex, compelling, or motivating story, the outcome of which is easy to evaluate. What formerly was a simple, top-down system has become a complex bottom-up modeling exercise, involving almost every function within the industries (Beer, 1984, Ashby 1965, 2011).

In the Journal of Socio-cybernetics 11 (2013), pp. 47 -73 51, by Mancilla, the cybernetics orders are defined and quoted:

1st order - Self-consciousness is the point of transition between lower and human cognition. The latter can be understood as the processing of information made by an autopoietic system in its interaction with its surroundings with the possibility of stating a purpose beyond self-sustainment.

2nd order - order cybernetics deals with the study of self-observing systems, which are both teleological and teleonomical; it studies cognitive machines, information processing mechanisms of the high order that have their basis within the neural network of human beings.

3rd order - Rationality can be individual, groupal and social. They can interact and be at odds with each other, when the latter happens there is a cognitive dissonance.

4th order - Hermeneutics from a cybernetic perspective can be seen from the perspective of patterns (order), proportions (balance) and the functional implementation of both (harmony).

5th order - Cognitive coherence encompasses both an aspect of order (pattern establishment/viability of the system/teleonomy) and of balance (proportion of the pattern/ optimality of the system/ teleology).

6th order - Constructive epistemology states that knowledge is not passively received, but actively constructed.

7th order - Cognitive morphogenesis is the study of how forms of human behavior originate; it can be applied to third and fourth order cybernetics.

8th order - Rationality and Languages are complements, the former is developed by the capacity of symbol creation and abstraction, but the latter could not subsist without thought coherence.

9th order - Sociocybernetics can be defined as the interplay between third and fourth order cybernetics for the purpose of understanding human behavior in an individual and collective scale, with first and second cybernetics functioning as complements.

Complex systems are defined as systems with numerous stakeholders, nonlinearities, multiple interdependencies, and feedback systems. Such problems require a multi-methodological approach because they are often not amenable to being solved with a single methodology. The process is one of a Systems of Systems (SOS), computation and networking, where embedded computers and networks can monitor and control the metasystem behaviour. Dyson and George (1997) stated that "the emergent behaviour is that which cannot be predicted through analysis at any level simpler than that of the system. Emergent behaviour, by definition, is what's left after everything else has been explained". Nevertheless, the application of VSM can also be used as a platform to enhance the integration and cooperation of project entities as it will set the communication channels among them (Burgess, et al. 2012 and Hildbrand, et al. 2015). The complexity and chaos of complex systems are better reflected by non-linear systems, which in turn are better manageable in adaptive and self-organised distributed systems with positive feedback (Yolles, 2021). Heikki Hy¨otyniemi, 2006 has introduces us to a new approach to complex systems or neocybernetics. The key parameters in a systemic viability must be controlled to ensure continued existence. The viability addresses how to design a system so that changes in the operational environment may be detected and affected to ensure continued existence (Morris, 2012).

6.1 Delphi technique

The Delphi technique relies on a panel of experts and is focused on a systematic, interactive forecasting method. This technique consists of a carefully structured ‘scenario pilot test’ with questions, asking participants to provide their view on the application of VMS in meta cybernetics SoS where we can provide control (Davidson, 2014). This will be further analyzed to clearly define the drivers and elements in CBMS control of variety.

The questions will be based on concepts from the pilot test scenario and backed by literature, designed to be asked in any order, allowing the researcher to follow the specific trajectory of the participant’s answers and to explore the emergent themes.

- The questions will be emailed to several professionals from organizations based in Australia. These professionals are from academia, military, and defense industry and the assumption is that they will provide similarity in their feedbacks.
- Test methodology by examining how the result of expert opinions compares with drivers/elements.
- What are the drivers, aspects, or elements for decision-making in each of the methodologies?
- From findings, formulate the new model. The system modeling is defined as a construction and development of the frames, rules, constraints, models, and applicable theories, modeling a predefined class of problems (Chang et al., 2014).

- Complete the feedback loop by returning to the new expert panel to test and validate the model (Weiner, 2013).

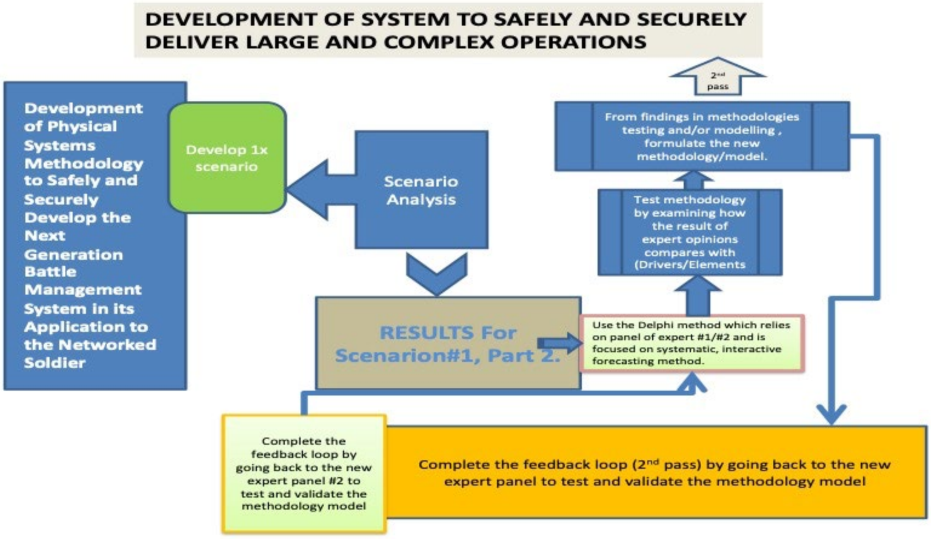

Diagram 2: Delphi analysis process, Pass 1 and 2

7. SoS emergent behavior background

Many authors (cf. Bonabeau et al., 1995; Emmeche et al., 2000; Fromm, 2005; Holland, 2007) agree that the notion of emergence involves the existence of levels in a system. Therefore, emergence can be summarized as a characteristic of a system. Properties appear at the system (macro) level that were not explicitly implemented and arise dynamically from the interactions between entities at the component (micro) level (Sing, 2017). Using Fromm's taxonomy to classify emergent behavior and the development of a suitable framework should provide a platform for simulating and analyzing behaviors in a multi-agent system (Mittal, 2017). To establish the theoretical framework for modeling and simulation, the taxonomy of emergent behaviors must first be established. The most cited works to date that have explored the classification of emergent behaviors are by Sing (2017), Johnson (2016), Holland (2007), Fromm (2005), and Bar-Yam (2004).

The emergence can be summarized as a characteristic of a system where properties appear at the system (macro) level that were not explicitly implemented but arise dynamically from the interactions between entities at component (micro) level. The Interactions that might result in emergent behaviour will manifest itself at the interfaces between systems, between systems and operators and or between systems and BMS software development elements. The BMS software in a battlefield environment allows the participants to successfully allow network data to be combined and analysed with more sophisticated algorithms and techniques in the operational environment. The emergent behaviour in BMS is not based on a priori knowledge, the knowledge is independent of experience, and it is difficult to clearly recognise, analyse and validate where the emergent behaviour exists. Using Fromm's taxonomy to classify emergent behaviours and the development of a suitable framework should provide a platform for simulating and analysing behaviours in multi-agent systems (Mittal 2017). The taxonomy of different types of emergent behaviours is based on the relationship between these macro and micro levels (O'Toole et al. 2014). The most cited works to date that have explored the classification of emergent behaviours are by Sing (2017), Johnson (2016), Holland (2007), Fromm (2005), and Bar-Yam (2004). Emergence was described by SEBoK (2015) as: "Emergent system behaviour can be viewed as a consequence of the interactions and relationships between system elements rather than the behaviour of individual elements."

8. Summary of supporting publication

The publication examines the emergence of SoS to understand the differences in SoS problems where there are multiple interdependent and interrelated SoSs in project management (Koskela and Howell, 2002; Najmanovich, 2002; Maier, 1998; Packendorff, 1995). The approach considered in this thesis is broader and examines a series of SoS methodologies, which are defined as systems with numerous stakeholders, nonlinearities, multiple interdependencies, and feedback systems. The supporting publications are:

- **Emergent behavior in the battle management system**

  Today, more than 30 countries use BMSs that enable commands to share situation awareness information; this study focuses on the distribution of information across a warfighting network. Similar to natural systems in which autonomous agents, such as ants and bees, follow a set of simple rules, a BMS is a network of bases and electronic warfighting platforms that have military assets as agents within the network, guided by the defense doctrine (e.g., rules, policies, procedures, and precedents). The rationale for the workability of such a system is based on each subsystem being reliable when multiple subsystems interact. However, the potential permutations and combinations of interactions can cause unpredictable negative or positive feedback loops, resulting in unpredictable and unwanted outcomes. The results of emergent behavior are unexpected and sometimes unwanted in areas such as intelligence, cybersecurity, weapons on target and wireless networks. Understanding emergent behavior is imperative in developing frameworks to deliver large and complex engineering projects safely and securely, produce new insights, and take practical steps towards improving the success of complex projects. (see: https://doi.org/10.1080/08839514.2022.2151183)

- **Cyber-physical systems and emergent behavior**

  This paper reviews existing cyber battle management systems (CyBMS) research. It highlights the need to develop complex structure thinking, cybernetics, wicked problem-solving, and emerging behaviour analysis by considering the relationship between complex and multi-structural systems. From a set of explicit perspectives, the systems-thinking approach solves complex problems by selectively identifying and understanding other associated systems, predicting systems' behaviour over time, and managing detailed changes that can obscure the underlying features of success. Furthermore, it explores the possibility of integrating cybernetics meta-methodology and the viable system model (VSM) with the application of metasystems reductionism to reduce the occurrence of negative emergent behaviour in complex systems. In this approach, the role of individual systems, systems of systems (SoSs), and metasystems is recognised. The fact that a single system is deterministic and VSM in a stochastic system in which the emergent behaviour is present is also elucidated. By integrating cybernetics in the form of VSM and meta-metasystems, the key parameters used to build an intelligent system are explored. Focus is also placed on understanding the challenges and opportunities in the design and development of future space vehicles, hybrid gas-electric cars, fully autonomous city driving, and prosthetic devices that allow the control of physical objects via brain signals. The literature suggests that meta-metasystems provide more excellent capabilities by providing a governing structure which coordinates and integrates multiple systems. In this manner, a novel review was conducted to improve understanding and knowledge of the application of cybernetics, VSM, and systems thinking in a meta-metasystems design such as CBMS and the environments. The results indicate that the meta-metasystem for CyBMS was developed for the design, execution, and evolution of SoS.

9. Cybernetics automated battle management system

A cybernetic automated BMS (CBMS) is based on an autonomic computing concept (Kopetz et al., 2016). The autonomic paradigm is inspired by the human autonomic nervous system, which handles complexity and uncertainties, and aims to realize computing systems (Johnson, 2016) and applications capable of managing themselves with minimum human intervention (Burbeck, 2007). Challenges are presented to ensure that cyberspace resources and services can effectively tolerate cyberattacks and automatically manage their resources and services (O’Connell, 2012). There are no effective commercial technologies for securing and protecting cyberspace resources and services. This is because they are labor intensive (e.g., patch updates), signature-based, and not sufficiently flexible to handle the complexity, dynamism, and rapid propagation of cyberattacks (O’Connell, 2012). Therefore, any changes in the environment and the operation will lead to a high level of false alarms. The high level of false alarms will make the normal intrusion detection systems ineffective. Most intrusion detection/protection systems that are commercially available today are signature-based and require intensive manual management (Song, Fink, and Jeschke, 2017). The primary reason for failure is that they are either signature-based or anomaly-based solutions that are very simple (e.g., threshold base) and require intensive fine tuning and adjustment. Changes in the environment and work lead to false alarms and make anomaly-based intrusion detection systems ineffective (Song, Fink, and Jeschke, 2017). The online use of smart or intelligent monitoring tools, such as the new smart algorithms, data mining, and statistical and correlation models, is to accurately characterize the normal behavior of cyberspace resources and services. The online smart monitoring tools can detect any anomaly events triggered by attacks, faults, or incidents.

The successful development of CBMS technology in command and battlefield layers will have profound impacts because it will present the following advantages:

- Stop/eliminate the effectiveness of cyberattacks (known or unknown);
- Deliver uninterrupted services and applications despite, attacks and failures; and
- Build ‘hassle-free’ computing environments that are self-aware, self-adapt, self-heal, and self-protect (Johnson, 2016; Sternberg and Frensch, 1991).

CBMS technology is extremely important for securing and protecting defense networks and services. In this study, we integrate BMS, process, computation, and networking and use embedded computers and networks to monitor and control the networked soldier’s behavior and to combat physiological monitoring systems with feedback loops in which the networked soldier’s behavior and actions can affect computation, and vice versa.

10. Justification of method used

During the Second World War, the mathematician Norbert Wiener (Wiener, 1973) and some respected professionals and colleagues (von Foerster et al., 1955) developed a new branch of applied science and named this science of information feedback systems *cybernetics*. Fourth-order cybernetics is called emergent cybernetics or meta cybernetics, which considers what happens when a system redefines itself. It implies that a system will "immerge" into its environment, of which it is a part. Particularly, the axioms or elements of systems theories are defined as the centrality, contextual, goal, operational, viability, design, and information. Using cybernetics management (Beer, 1959), this literature review is to examine emergent behavior through the theory of critical system thinking (D'Andreamatteo et al., 2015) and cybernetics methodology. The cybernetics methodology is called the "new paradigm" that has attracted numerous researchers and practitioners and introduced them to the discipline of systematic management. Meta cybernetics or fourth-order cybernetics acknowledges the emergent properties of complex systems.

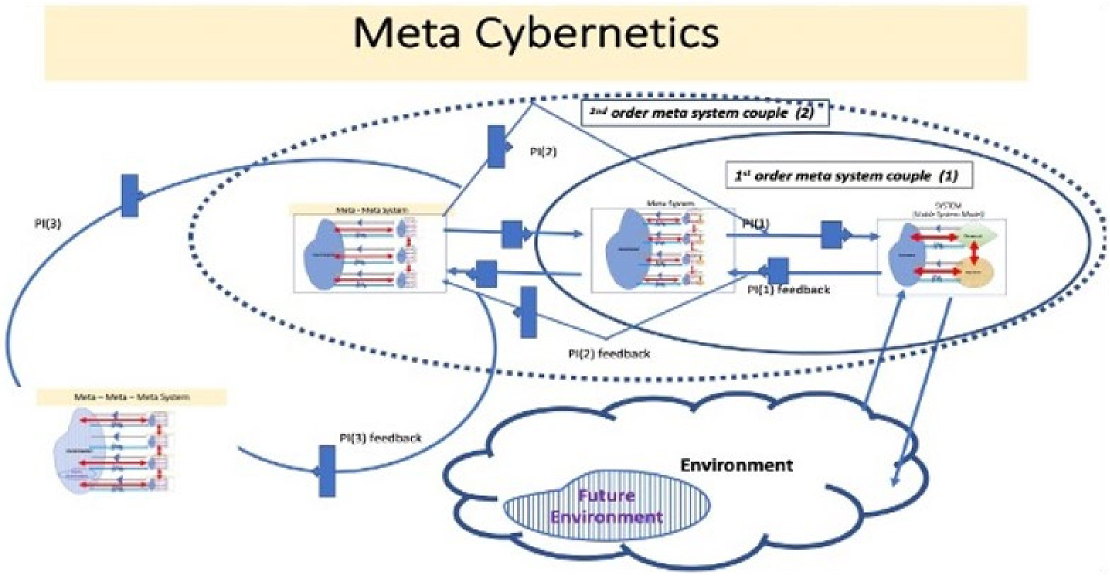

Diagram 3: 4th Order Metasystem (emergent cybernetics) Hierarchy for VSM.

Emergence entails a greater complexity that reduces knowability and predictability. Therefore, a system will immerge itself into the environment in which it exists. Immergence means "submergence" or "disappearance in, or as if in, a liquid." The distributed nature of fourth-order cybernetics is as follows:

- Who (or what) is capable of seeing a fourth-order system in its full complexity?
- At the fourth order, the discrete observer's boundaries become problematic.
- Who is sufficiently mercurial to notice all relevant changes as and when they occur?
- A single agent is unable to see enough, its standpoint is too fixed, partial, or out of date.
- Cyber-physical system (CPS) and cybernetics battle management system (CBMS)

11. Cyber-physical system (CPS) and cybernetics battle management system (CBMS)

Present-day CPSs integrate computational and physical processes to perform various mission-essential or safety-critical tasks (Nweke, Weldehawaryat, and Wolthusen, 2021). The ability to interact with and expand the capabilities of the physical world through computation, communication, control, and computers (C4) is a key enabler for future technological development. Opportunities and research challenges include the design and development of next-generation aeroplanes and space vehicles, electric vehicles, fully autonomous urban driving, and prostheses that allow brain signals to control physical objects. Increased efficiency of either information or data flow alone can change the entire organizational construct within which the system operates. CBMSs have traditionally combined elements of cybernetics, mechatronics, control theory, systems engineering, embedded systems, sensor networks, data, distributed control, and communications (Wiener, 2013). Properly engineered CPSs and CBMS rely on the seamless integration of digital and physical components, as well as the possibility of human interactions, which necessitates reliable C4I.

Increased information and data flow efficiency alters the entire organizational structure within which a system operates. CPSs and CBMS connect cyberspace to the physical world through a network of interconnected elements such as sensors, actuators, robots, and computational engines. These systems are highly automated, intelligent, and collaborative (Nweke, Weldehawaryat, and Wolthusen, 2021). Energy-neutral buildings, zero-fatality highways, and personalized medical devices are all examples of CPSs.

A direction for future research on CPSs is creating standardised abstractions and architectures that permit the modular design and development of CPSs; these are urgently needed. CPSs and cybernetics feedback techniques link cyberspace with the physical world through a network of interrelated elements such as sensors and actuators, robotics, and computational engines (Walsh, 2019). These systems are highly automated, intelligent, and collaborative. Examples of CPSs and cybernetics include energy-neutral buildings, zero-fatality highways, and personalized medical devices. CBMSs require detailed modeling of the dynamics of the environment and a clear understanding of the interactions between the dynamics of the embedded system and its environment (Walsh, 2019). It is important to consider the scenario in which an alert is issued because of a cyber or an electronic warfare attack that has spoofed the system. Therefore, headquarters (HQ) looks at an uncommon BMS program location for something that does not exist; however, another covert operation is being carried out elsewhere (Ward and Chapman, 2011).

Cybernetics began to question the ideas of systems in control and out of control in first and second order behaviors. The Law of Requisite Variety makes it clear that control has limits. When Ashby described first and second order effects, he was not thinking of autonomy or intelligent SoS, though he clearly understood the possibilities of emergent behavior (Ashby, 2011).

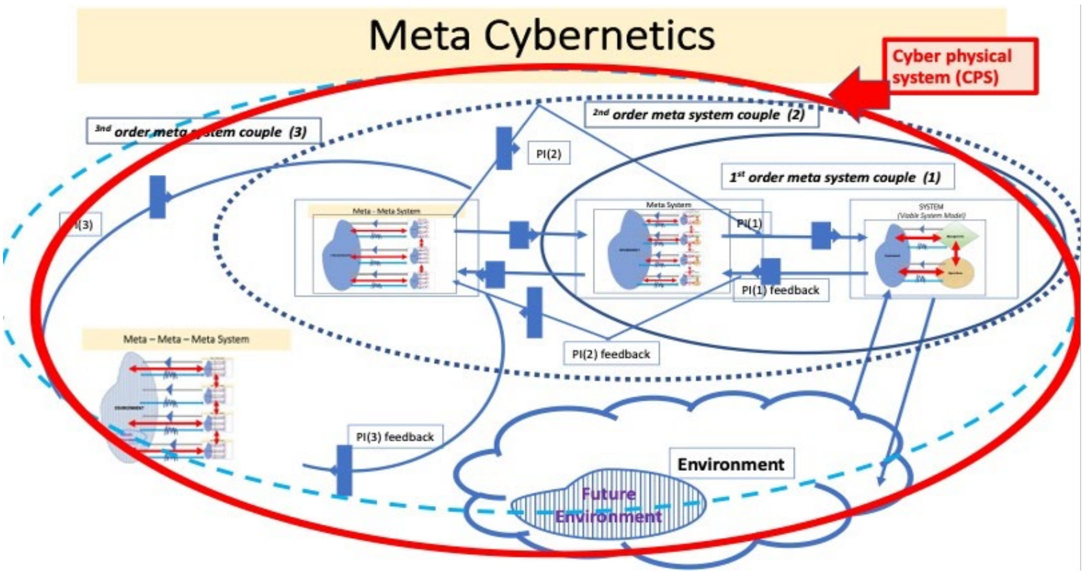

Diagram 4: Meta-Meta Cybernetics and CPS domain

Future effects of the CBMS and Cyber-Physical System (CPS) will have a considerable impact on our personal and professional lives (Song, Fink, and Jeschke, 2017). Autonomous machines and complicated data environments involve legal requirements such as responsibility, liability, data ownership, and privacy (Katz and Ruhl, 2015).

Systems and components of systems are configurations of tangible and intangible objects such as mechanical, electrical, electronic, software, knowledge, or natural objects (System Engineering Body of Knowledge (SEBoK) Editorial Board, 2021; Dyson, 1997). These objects perform functions and behaviors to meet a specified purpose, and they fit within the description of emergent behavior defined by Maier (2014). Although the objects provide a purpose in their own right, situations exist in which there are hidden states where such a system can be considered exosystemic. Thus, a machine SoS exists that must be designed, manufactured, and operated to deliver its purpose (Dyson, 1997). An example of this is a communication SoS (satellites, land stations, submarine cables, and facilities) that enables household and business transactions, manufacturing, the control of autonomous vehicles in mines, or the management of a battlespace. The components of this SoS are systems in their own right.

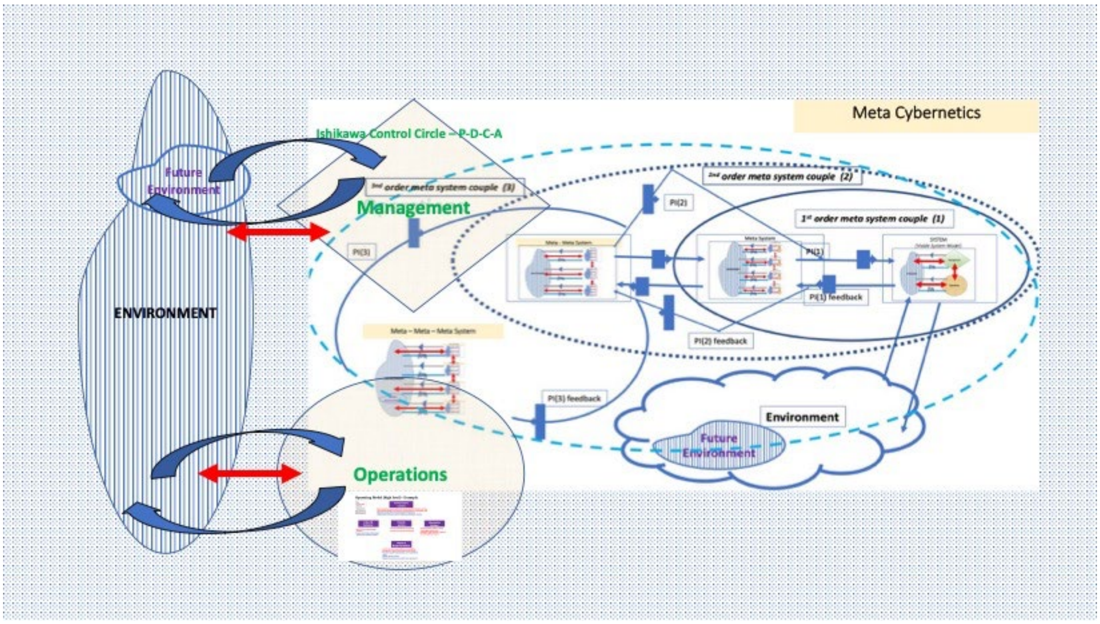

Diagram 5: Meta cybernetics (VSM) in SoS System

For the system to meet its purpose, another complex SoS must be in place (Bar-Yam, 2004): a system of maintenance and support (Dyson, 1997). This additional system has objects, such as human skills, machine learning, performance measures, tools, knowledge, and facilities (Dyson, 1997), and has two main subsystems: social and technical. A social subsystem describes the functions and behaviors that humans apply to a maintenance system (Dyson, 1997). A technical subsystem describes the technological functions and behaviors that deliver the required purpose.

In future conflicts, Australian land forces may have degradation or lack of communications capabilities essential for BMS coordination and situation awareness understanding.

Therefore, the introduction of the DBM solution, which is the disruptive new technology, may serve to develop suitable automated decision tools to integrate with BMS command and soldiers. The DBM solution is to develop new algorithms that are reliable and realistic for warfighting environments. The automated BMS will not be considered in this paper. The automated BMS is used to support the human decision-makers. The ABMS is developed to process large amounts of data to develop battlespace knowledge and awareness and identify and prioritize resources and actions.

12. BMS and networked soldier system

The networked soldier system is a system rather than an SoS; thus, it is important to identify the critical set of systems that affect the SoS's capability objectives and understand their interrelationships (Australian Soldier Systems Architecture (ASSA), 2013). The SoS can place demands on constituent systems that cannot be supported by said systems. The Land BMS Support System is defined as the sum of the existing support infrastructure (including that of the owner, the contractors, and subcontractors) and the additional support elements being generated to enable the Mission System to be effectively supported, so that it can meet its operational requirements. It is here we introduce the BMS C2 support system. This includes the following:

- All of the physical support deliverables being generated under the BMS support systems.
- Acquisition, design, development and production of any logistic resources associated with those physical deliverables (i.e. the logistic resources required for the support of support system elements).

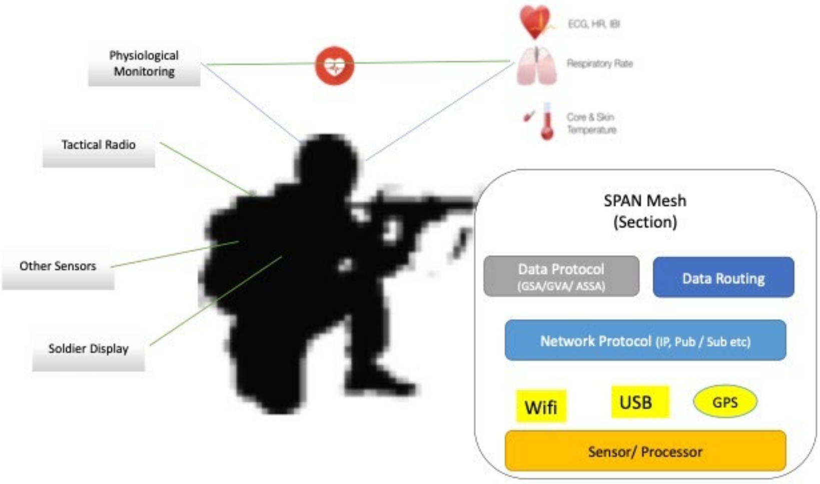

Diagram 6: Network soldier

Combinations of systems operating together and collaborating within the SoS contribute to the overall capabilities. Maier (2014 and 1998) defines managerial and operational independencies, which combine systems and lead to emergent behaviors more than is usual in single systems. These emergent behaviors, as with emergent behaviors of single systems, may either improve or degrade performance (Jackson, 2010). In addition to the ability of the systems to support the functionality and performance called for by the SoS, there can be differences in characteristics between the systems that contribute to the SoS's suitability (Menčík 2016) such as reliability, supportability, maintainability, assurance, and safety (Zio and Sansavini, 2011). The challenge of designing a system is to leverage the functional and performance capabilities of the constituent systems to achieve the desired SoS's capability, as well as its crosscutting characteristics, to ensure the fulfilment of broader user needs (Jackson, 2010).

13. Network soldier as a system

The technological advances that have enabled a new way of using wearable sensors for medical purposes (e.g., temperature, heart rate) can be used to identify whether a soldier is in medical distress. In the past, it was not possible to access this information remotely unless the soldier radioed in and offered the information. With medical information connected to a BMS and tactical network, the soldier's (known as a networked soldier) medical condition can be identified before the soldier may even be aware of it, and an alert may be raised. If an alert is raised on an entire company, the system will 'know' that a stressor of some kind is impacting the soldiers, and that some action is necessary (ASSA, 2013). Smartphone ad-hoc networking (SPAN) and mesh concept design interconnections between devices or nodes are provided. Data from a networked soldier can be used to simulate different scenarios for testing and analysis purposes (Osipov et al., 2018). Data can be used to identify areas where the safety and security of a soldier as a system or subsystem exist (ASSA, 2013).

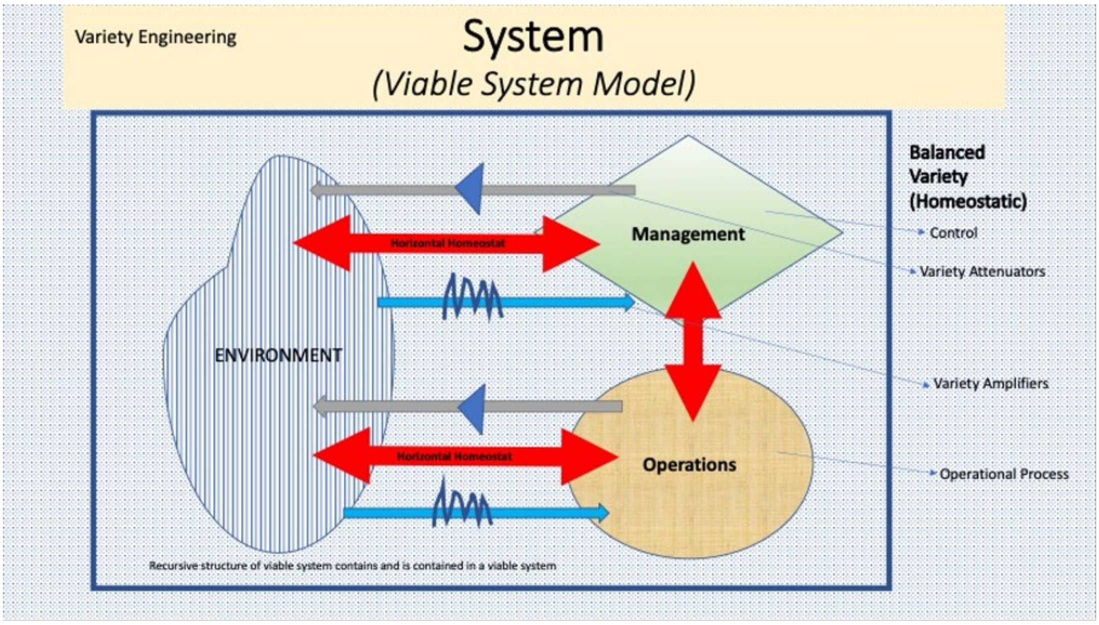

Diagram 7: Viable System Model (VSM) single system

The soldier is treated as a system, including everything from batteries to new concepts such as the digital water bottle. The balance between armour and mobility is the sharing potential of a fully integrated infantryman combat system, where commanders at tactical, operational, and strategic levels can continuously monitor the mission in real time. The soldier functions as a sensor and relays vital information directly to the command element from the battlefield (Generic Soldier Architecture (GSA), 2017). Below are some of the key high-level requirements of the network soldier system:

- Soldiers shall be able to input and update the relevant information into the system swiftly and only the essential information shall be shown,
- Information is to be distributed within the squad level network immediately and sometimes automatically,
- Speech and data communications shall be available simultaneously and in real time,
- The system shall have an integrated information security solution suited to the battlefield,
- The system shall have a modular and scalable architecture, and
- The system shall support visual and physical sensors to supply real-time information to the squad leaders.

a. Physiological monitoring

- The ability to remotely monitor the physical condition of each soldier in a dismounted unit is an essential component of the safety, efficiency, and effectiveness of the unit. The physiological monitoring system focuses on collecting, storing, and transmitting physiological data from soldiers to commanders. The system comprises a set of wearables (minimally invasive sensors) that collect data and monitor several parameters of the soldier's body, such as electrocardiogram (ECG), heart rate (HR), and core and skin temperature, and an algorithm to collect, correlate, and distribute the data efficiently (ASSA, 2013).

b. User–machine interface

- Significant progress has been made in ensuring that the C4I computer and BMS software meet the needs of dismounted soldiers. While the system has operational value for mission planning and situational awareness when on the halt, the current solution provides a limited means for situational awareness while on the move.

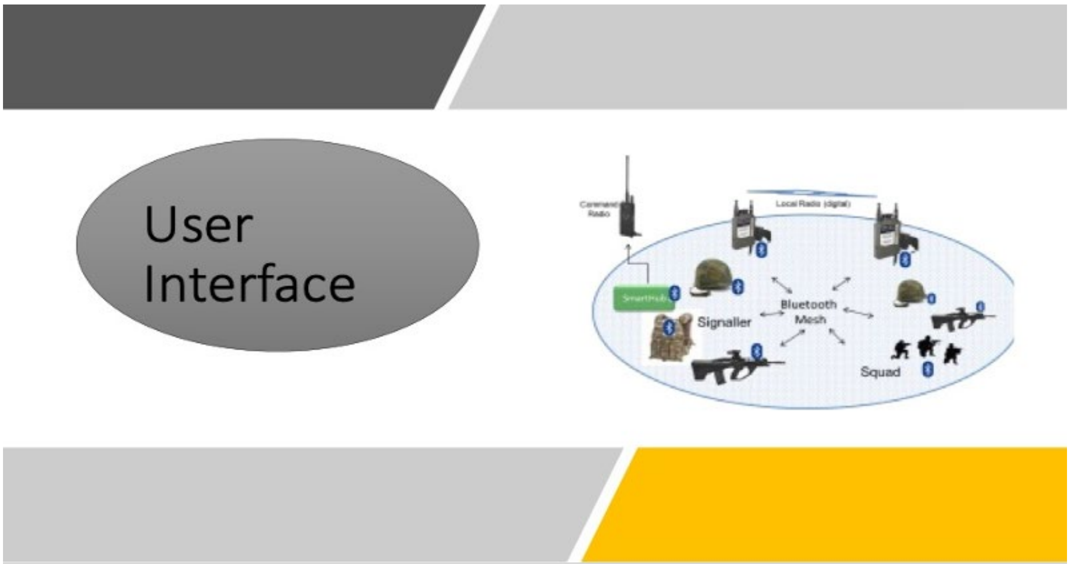

Diagram 8: Soldier User Interface (Elbit Systems Australia)

- Additional technologies and solutions, such as voice control, in-ear earphones, and see-through glasses, must be explored to provide a well-rounded solution that can be used during all phases of the dismounted soldier's mission. The soldier system must be sufficiently flexible so that any mix of sensors, processors, user interfaces, and communications can be combined on different fitment locations to create an operational outcome (ASSA, 2013).

14. BMS and network soldier modularity

A future soldier system is required to provide an optimized solution for several soldier roles in a variety of mission types. To achieve this, the system must be modular and configurable to support multiple configurations using the same set of building blocks. Its ability to link soldiers in a section and integrate them with the broader land force communication landscape is key to the delivery of SPAN mesh networks (nodes). Networks are now widely seen as the key element in combat, being fitted on a tank, ship, aircraft, or soldier. The network needs to allow for future support of an increasing range of sensors and broader field intelligence capabilities (ASSA, 2013). The SPAN solution is an innovative mesh network for sharing data between soldiers in a section, and between commands and sections. In this study, the mesh network is built on a standardized technology platform and supports a set of standard data exchanges based on generic vehicle (GVA) and generic soldier (GSA) architecture models (Generic Soldier Architecture (GSA), 2017). This allows the SPAN mesh to provide the network for all sensors.

The SPAN mesh at the soldier and section levels is based on leveraging a number of existing wireless technologies with new and evolving technology to create a low-power mesh network such as Bluetooth/Wi-Fi and/or ultra-wide band (UWB). Creating a data standard over a mesh network will allow any sensor, device, or computer to connect as a node and collect or share its data with other nodes in the network. The mesh network's routing capability enables data to flow through the entire section (Generic Soldier Architecture (GSA), 2017). Thus, a dispersed section can continue to share data through links between individual soldiers over a significant distance. Because of the small size, weight, and power (SWAP) of these network components, many sensors can be self-contained and do not require a large separate power supply.

Integrating SPAN with the broader army network is achieved by connecting the SPAN to an existing very high-frequency (VHF) network, broadband, and future waveforms. By combining some existing radio knowledge with the new SPAN mesh and local higher capacity network, a link is created with the land force backbone network. A section commander, signaler, or vehicle can carry the SPAN transceiver and tactical radio to allow this data exchange. With the creation of the SPAN mesh, multiple sensors can be fused to create higher-order information (ASSA, 2013). By connecting sensors via mesh networks to a BMS's processing capability, additional algorithms and techniques can be used to combine and analyze network data (Osipov et al., 2018). Sensors, such as shot and electronic warfare detection and range finders, can be combined to generate information that can be shared across sections and the wider BMS system. Images and videos from local support can be integrated with ranger finders, BMS, and UAV data to create situational awareness (Generic Soldier Architecture (GSA), 2017). The challenge for the modern digital army is the sharing of relevant situational awareness information in and between dismounted teams and outwards to other levels of command and flanking elements (ASSA, 2013).

15. Network soldier system

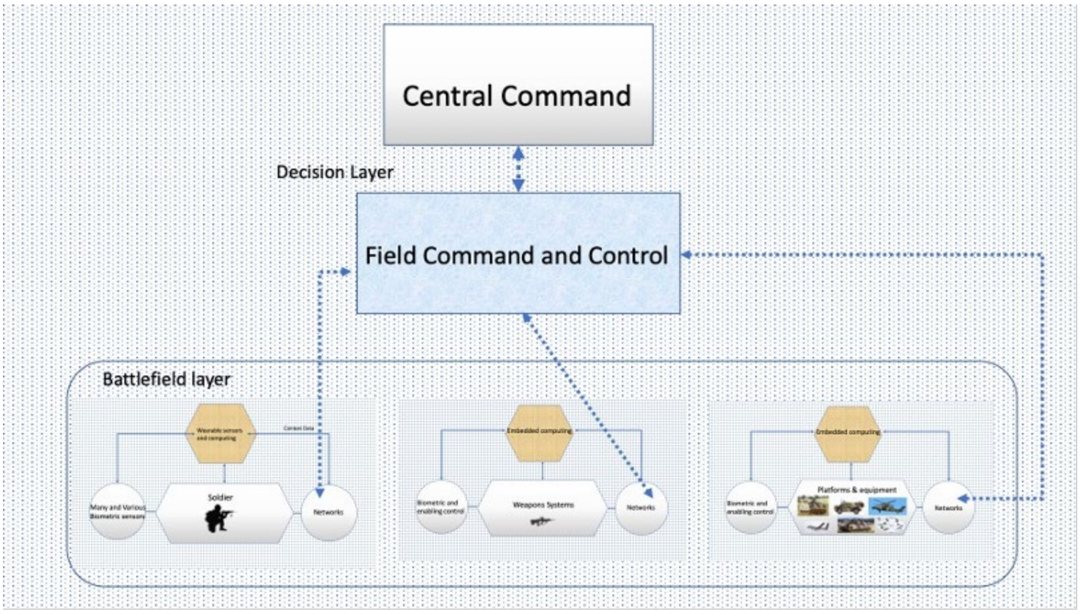

Diagram 9: Command, battlefield and computing architecture

During the scenario development, the following areas have been identified as limitations to solutions that are to be addressed in the future solider roadmap:

- Weight, bulk, and cabling of solution affect the manoeuvrability of the dismounted soldier,
- Limited duration of system operation because of energy constraints,
- Limited situational awareness capability when on the move and in active combat because of HMI constraints,
- Lack of Blue Fore Tracking where GPS signal is not available.
- Limited awareness of the physical state of the soldiers in the platoon, and

The network soldier system has evolved significantly over the past years and continues to evolve through an ongoing development plan driven by advances in technology together with lessons learned through operational use in the field. The Next-Generation Soldier System is a product of several cycles of evolution, each cycle bringing enhancements and improvements at the component level as well as additional components to address specific needs. The resulting solution, while functional and with distinct operational value, can be significantly enhanced in terms of functionality, performance, and usability though the employment of advanced technologies now available or to be available in the near future.

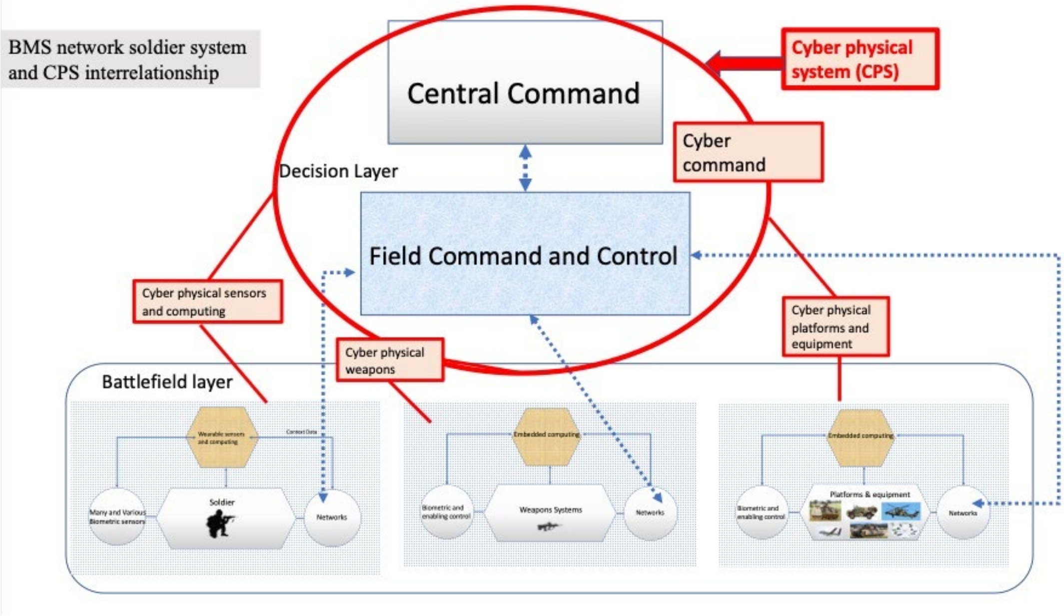

Diagram 10: BMS network soldier system and CPS interrelationship

Missions

The BMS-C2 will provide battlefield commanders with enhanced decision-making capability across the tactical, operational, joint and coalition environments. This is achievable in order to enable an increased operational tempo of deployed forces.

The BMS-C2 will be available for Platforms (tanks, etc.,) that will perform mission roles in the operational area. The mission of the BMS-Network soldier component is to provide dismounted combat teams (soldiers) the ability to conduct battle preparations and execute close combatant lethal and non-lethal effects at an operational tempo greater than that offered by the dismounted component (states and modes) of Land forces.

Example of required states and modes:

The BMS-C2 should have the following mutually exclusive states and nodes (not exclusive).

a. Storage
b. Transit
c. Installed
d. Node Initialisation
e. Administrator Maintenance
f. Node Voice
g. Operational
h. Levels Maintenance

Therefore, a Communication and Control (C2) General Support System Procedure (GSSR) is required.

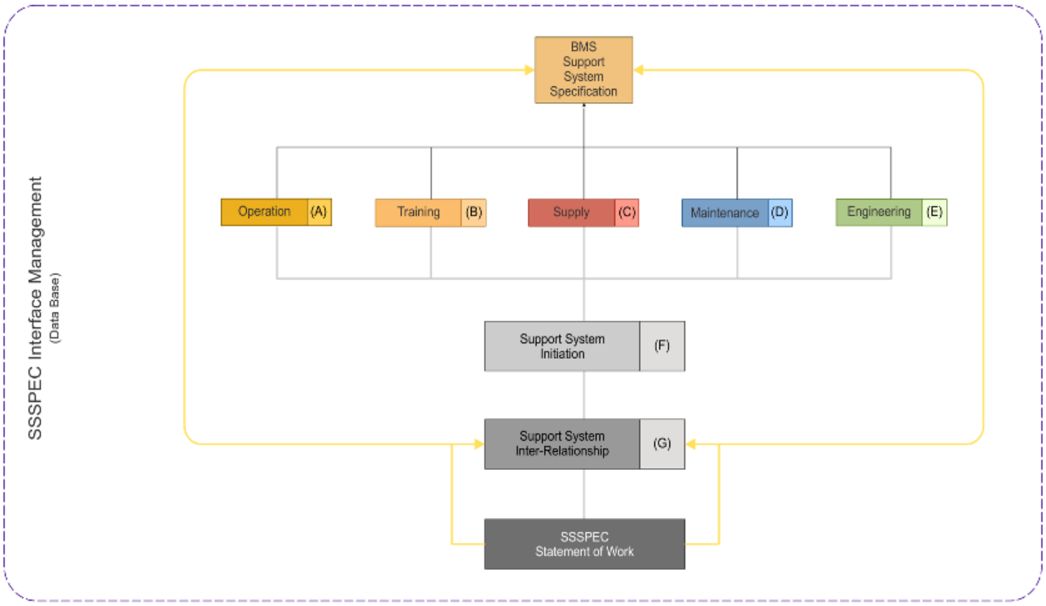

Diagram 11: C2 Support System Interface

Aim: This procedure is used to develop Communication and Control (C2) support system specifications that are lean, complete, ordered, and integrated. It has two aims:

- To act as a standalone procedure to develop a plan of work for support system design and development.
- To provide a procedure that enables other support related procedures or requirements to be a logical, efficient and effective specification where there are gaps, dysfunctions or other misalignments between them. The procedure will not be included in this article.

Method. The procedure is a framework and pathway to ensure that all of the issues that need to be considered and specified in a support system architecture are considered. Where it is used as a stand-alone procedure, it forms the basis of understanding to develop a system support plan. Where it is being used to supplement other procedures which may be subject to contract, it becomes a linking procedure to ensure that anything that is missed is identified and formally managed. The procedure may not be a part of the contract; but, its function could be to make the contract work.

In all cases, the procedure is tailored and adapted to the level required; at all times it should be the minimum necessary to specify the requirements. This does not mean optimisation, but rather a rational solution.

NOTE: Not everything has to be done all of the time. The Law of Parsimony applies all of the time.

Requirements
The procedure shall consist of the following requirements to specify a support system.

- Baseline Requirements. This requirement identifies baselines and their status against which a support system is to be developed.
- Through Life Cost and Economics Requirements. This requirement conducts any necessary cost and economics analysis as they apply to the development and implementation of through life support plans, irrespective of phase.
- Performance Requirements. This requirement states any performance requirement of the system support solution. It identifies the performance to be measured, what data is required, how it will be collected, how it will be analysed, and how it will be reported.
- Relationship and Interface Requirements. This requirement identifies and explains any relationship or interface requirements need to be specified.
- Logistics System Requirements. This requirement identifies those logistics systems, this will usually be policies and standards that are required or relevant to support system design and operations.
- Logistics Requirements Determination. This requirement is an assessment of the situation and determines what logistics elements are needed to form the support system design and operations. The assessment is based on economic and technical objectives. It also identifies constraints and obstacles. It is a tailored determination to suit the need. In some cases, it may only require a life cycle cost to support an existing specification.
- Logistics Work Plan Requirement. This requirement is a plan of work to identify tasks to be done, resources required (human, machine, financial, etc), schedule and so forth.

16. What is emergent behavior?

Emergent behavior in SoS performs functions and establishes purposes that do not reside in any component system. These behaviors are emergent properties of the entire SoS and cannot be localized to any component system. The principal purpose of the entire SoS is fulfilled by these behaviors. The SoS engineering applications that meet the definition of an SoS have also been outlined by Maier (2013). Mittal and Rainey developed and described the emergence complexity funnel used to classify simple to spooky emergence in deterministic and stochastic systems complexity. The total behavioral events of the combined systems working alone or collectively must be visible from the strategic requirement of system performance to the implementation of the system to sustain its purpose. The scope of all aspects of SoS involves an indeterminate number of possible emergent behavior events. These can occur at the purpose strategy level or at the purpose implementation level. Emerging behavior should be anticipated even if it cannot be identified in the first instance. Emergent behavior, positive or negative, is an element of systems engineering that should improve both capacity and capability (Dyson, 1997).

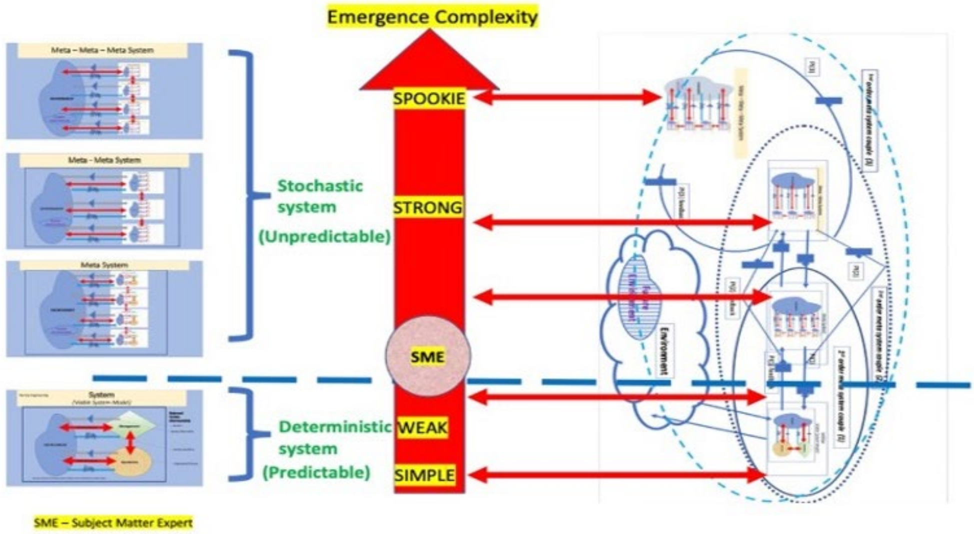

Diagram 12: The classification of emergence complexity type (Mittal et al., 2015 and Rainey et al., 2015)

17. Emergence behavior analysis

The method/means technique used for the analysis of emergence in a real-time hostile environment uses graph theory and cognitive science methodology and is applied early in the SoS (Osipov et al., 2018). At this stage, knowledge is independent of experience, and it is difficult to clearly recognise, analyse, and validate where emergent behavior exists; however, it is recommended to use agent-based modeling and simulation to identify the presence of emergent behavior in a BMS (Lee et al., 2018). The presence of emergent behavior in a given SoS application can be proven using agent-based modeling and simulations (Holland et al., 2007). Agent-based modeling is a robust tool for identifying emergent behaviors and clearly demonstrates that emergent behavior does exist in a BMS. Emergent behavior cannot be determined ‘through the literature’ but through the use of agent-based modeling and simulation, or some other applicable modeling and simulation (M&S) tool, applied to a given SoS engineering application (Lee et al., 2018; Maier, 2014; Maier, 1998; Wilensky, 1999 and Schwaninger, 2009). If the presence of emergent behavior is considered to have negative effects, one needs to identify what needs to be done to control it; if the presence of emergent behavior is considered to have positive effects, one aims to identify what needs to be done to capitalize on it.

The complex events used in the analysis of emergent behavior in a multi-agent system are composed of interrelated events, which can be defined at any level of spatio-temporal abstraction. The systems with a large number of components are complex, and their intricate interactions are pervasive (Chen et al., 2014). Examples include natural systems that range from animal flocks to socio-ecological systems and leading-edge engineering (artificial) systems such as the internet and social networks. These systems called complex adaptive systems (CAS) exhibit behaviors from non-linear spatio-temporal interactions among a large number of components and subsystems and are used in data analysis (Kaisler and Madey, 2009) where data is collected across both space and time. These interactions may lead to properties that are often called emergent ones and cannot be derived from those of individual components. Numerous attempts to define emergence have been documented (Holland, 2007). However, a generally agreed upon definition is still lacking. Many authors, such as

Singh et al. (2017), Johnson (2016), Holland (2007), Fromm (2021), and Bar-Yam (2004a), have agreed that the notion of emergence involves the existence of levels in the system. Therefore, emergence can be summarized as a characteristic of a system (Schwaninger, M. (2009). In this manuscript, we are addressing the issue of emergent behavior in SoS.

a. Scenario: BMS network soldier creation

The challenge for the modern digital army is the sharing of relevant situational awareness information in and between dismounted teams and outward to the other levels of command and flanking elements. The growth of new technology and miniaturization of sensors, such as laser range finders, UAVs, and night vision means that significant advantage can be gained by sharing the relevant acquired information via images or tagged data directly to command, section, or soldier.

Diagram 13: Example of BMS Communication Network (Elbit System Australia)

The kinetic mesh technology can be used in many applications where infrastructure devices are constantly moving in a rugged environment similar to defense land forces. The Internet of Military Things (IoMT) is a class of Internet of Things used in combat operations and warfare. The military domain is home to a network of interconnected entities, or “things”, that communicate constantly with each other to coordinate, learn, and interact with the physical environment so that a wide array of tasks can be accomplished more efficiently and effectively. Machine intelligence and cyber warfare will dominate future military battles in urban environments, so IoMT is essentially driven by the belief that future wars will take place in urban settings.

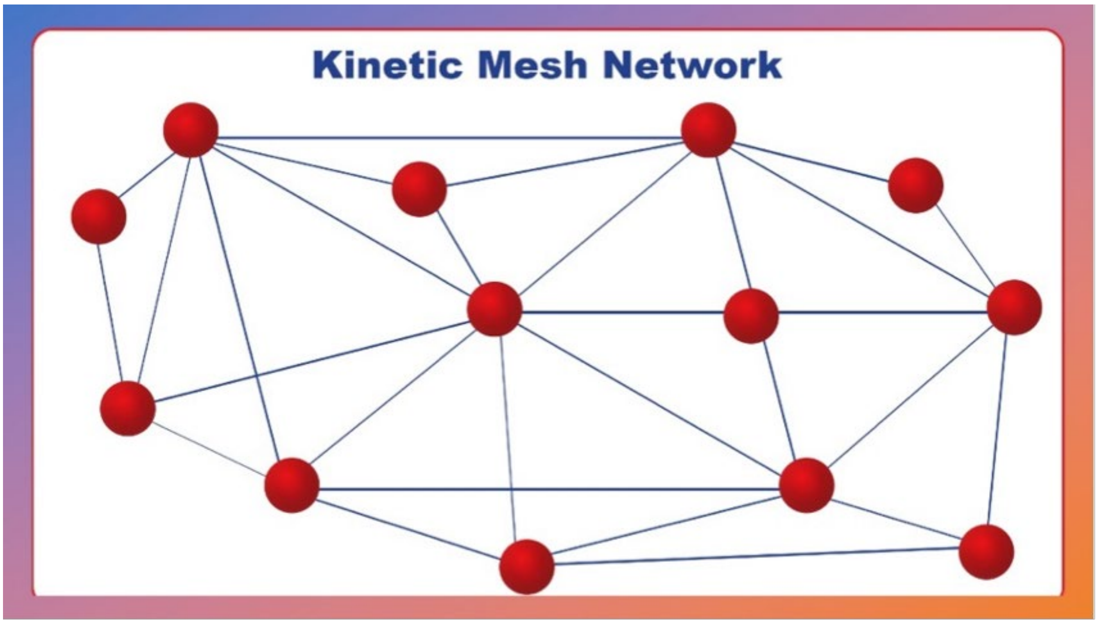

Diagram 14: Example Kinetic Mesh Network

By launching a miniature ecosystem of smart technology capable of distilling sensory information and managing multiple tasks autonomously, the IoMT conceptually relieves a significant amount of the physical and mental burden that warfighters face during combat. To explain the use of IoT technology for reconnaissance, surveillance, unmanned warfare, and other combat purposes, a number of different terms are introduced overtime. In addition to the Military Internet of Things (MIoT), we also now have the Internet of Battlefield Things (IoBT), which, will not be covered in this article.

18. Pilot test scenarios and test case

The Pilot test is captured as follows:

Purpose of Pilot

- The primary purpose of the Pilot was to verify that the cybernetics BMS network soldier scenario developed in this paper for model design, analysis and integration of BMS, process, computation, and communication networking is valid.
- The secondary purpose was to use the lessons learned from the Pilot to confirm that embedded computers and communication networks control the networked soldier behavior and combat the physiological monitoring system (feedback loops) in which the networked soldier's behavior and actions can affect computation and vice versa.

Scope of Pilot

- The Pilot tested the CBMS SoS emergent behavior related to the CBMS network soldier in the battlefield environment. The specific areas chosen for this Pilot test are only in the areas of the BMS platform and system integration, site configuration, unit data manager, and network management. The soldier is a 'system' and integrated within the BMS 'SoS'. The application of (cybernetics is deterministic 'system') viability is controlled through LRV. In SoS, the application of cybernetics is described as meta cybernetics. The summary of this modeling is based on validating this Pilot test, and the BMS emergent behavior theory is supported by literature.

19. BMS network soldier conceptual model observations

The challenge for the modern digital army is the sharing of relevant situational awareness information in and between dismounted teams and outward to the other levels of command and flanking elements. The growth of new technology and miniaturization of sensors, such as laser range finders, UAV's, and night vision means that a significant advantage can be gained by sharing the relevant acquired information via images or tagged data directly to command, section, or soldier. The networked soldier is a good scenario model for design and analysis because of the integration of BMS, process, computation, and networking, where embedded computers and networks can monitor and control the networked soldier behavior and combat the physiological monitoring system with feedback loops in which networked soldier behavior and actions can affect computation and vice versa.

a. How does the emergent behavior manifest itself?

The SoS, in this case, is a network of bases and electronic warfighting platforms (Lee et al., 2018), and has military assets as agents within the network that are guided by a defense doctrine (e.g., rules, policies, procedures, and best practice). Although each subsystem is reliable, when multiple subsystems interact, potential permutations and combinations of interactions can cause unpredictable negative or positive feedback loops, resulting in unpredictable or unwanted outcomes (Chen et al., 2011). A BMS function and performance specification (FPS) is developed by the defense for the contractor and is defined and validated by a set of requirements (ISO/IEC/IEEE International Standard 2011) for the BMS material systems (Syamil, Doll, and Apigian, 2004). 'The FPS can identify the start of emergent behavior manifesting in a system or SoS' (Lee et al., 2018).

b. What are the physical results of the presence of emergent behavior?

The physical results of the presence of emergent behavior in a BMS are goal-seeking elements that may exhibit probabilistic unanticipated behavior. This is because of a set of input conditions that were unanticipated by system software engineers or from the adaptation of a person or software agent to sets of input rules such as misapplication of the rules by a person (Lee and Miller, 2004). Emergent behavior occurs because of the complex web of interconnections within a BMS (Mittal et al., 2015 and Rainey et al., 2015).

c. What are the implication(s) for the existence of the presence of emergent behavior?

Emergent behavior results are unexpected and sometimes unwanted in areas of intelligence, cyber security, weapons on target, wireless networks, integrated power hubs, sensors, EUDs, tactical routers, and network-enabled technologies (O'Connell, 2012). Enabling technologies, such as networks and graphs, are collections of first-person shooter (FPS) elements (nodes, vertices) and their pairwise links (edges, connections) and are presented in the simple form of a connection matrix showing positive or negative unexpected emergent behavior. This can be analyzed from the perspective of graph theory and cognitive science methodology (Adams et al., 2014).

d. When does emergent behavior occur/arise?

The BMS software in a battlefield environment allows participants to successfully combine and analyze network data with more sophisticated algorithms and techniques than in an operational environment (Lee et al., 2018). Emergent behavior occurs in the communication system interface and in the configuration of the combat network in land dismounted wireless networking, sensors, systems which include human biosensors, targeting, shot detection, UAVs, small arm digital sights, range finders, and data (Singh et al., 2017).

20. Conclusion

A BMS focuses on distributing information across a warfighting network and is a network of bases and electronic warfighting platforms. In this paper, we outlined a framework to explore emergent behaviors in a multi-agent system (O'Toole, Nallur, and Clarke, 2014) and provided insight into the existence of emergence behavior in CBMS by applying the Delphi technique, simple modeling, and referring to the literature.

The objective was to demonstrate the existence of emergent behaviors in a system, for example, a complex (multi-agent) system exhibits emergence and can be represented formally using the developed framework (Singh et al., 2017). This would make it easy for a modeler to analyze and study the causal relationships between the micro and macro layers of a system (Bar-Yam, 2004). It is possible to use a case study to demonstrate how the BMS framework can be useful in implementing and classifying emergent behaviors using existing and known approaches in the literature (Singh et al., 2017). This can be done via system modeling, which includes the analysis, construction, and development of frames, rules, constraints, models, and theories applicable to predefined classes of problems. These methods are critical for effective risk management (Ward and Chapman, 2011). The CPS's involvement in an SoS's emergent behavior necessitates detailed modeling of the environment's dynamics as well as a clear understanding of the interactions between the dynamics of the embedded system and its environment. Maier (2009) defined an SoS's architecture as "communications among components."

The challenge in designing an SoS is leveraging the functional and performance capabilities of constituent systems to achieve the desired capability (Juli, 2011). To establish a theoretical framework for M&S, a taxonomy of emergent behaviors in a project, which is not always clear, must be first established (Mingers and Brocklesby, 1997).

The studies outlined in this paper examined emergent behavior in BMS and vis-à-vis cyber-physical systems (Singh et al., 2017) and make a significant contribution to the literature because they offer insights into a domain that has not been examined in as much depth or detail thus far; valuable additions to the literature can be useful in shaping future research and policymaking in the domain. Furthermore, these papers will be of interest because they present path-breaking and epoch-making contributions to the literature and have the potential to expand the scope of the extant literature on defense.

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22. Disclosure statement

The authors report that there are no competing interests to declare.

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Pilot Test Scenario and Test Case

Situation: *The physical results of the presence of emergent behaviour in a BMS are goal-seeking elements that may exhibit probabilistic unanticipated behaviours. This is because of a set of input conditions that were unanticipated by the defence doctrine, FPS, and other supporting policy and governance documents for the acquisition of assets, or from the adaptation of a person (agent) or software to sets of input rules such as misapplication of the rules by a document and person (agent).*

- *A future soldier system is required to provide an optimized solution for several soldier roles in a variety of mission types. Once this system is integrated into the whole network we are faced with the emergent behavior occurring.*

- *The network needs to allow for future support of an increasing range of sensors and broader field intelligence capabilities. The mesh network is built on a standardized technology platform and supports a set of standard data exchanges based on generic vehicle (GVA) and generic soldier (GSA) architecture models. This allows the SPAN mesh to provide the network for all sensors.*

- *The SPAN mesh at the soldier and section levels is based on leveraging several existing wireless technologies with new and evolving technology to create a low-power mesh network such as Bluetooth/Wi-Fi and/or UWB.*

Test Scenario 1: The CBMS communication system interface and the configuration of the combat network in land forces include wireless networking, sensors, human biosensors, targeting, shot detection, UAVs, small arm digital sights, range finders, and data to consider important issues where an alert/deficiency/loss/failure is experienced due to cyber or electronic warfare attack that has spoofed the BMS system.

- *In this instance, headquarters (HQ) looks at an uncommon BMS program location for something that does not exist; however, another covert operation is being carried out elsewhere.*

- *The ability to remotely monitor the physical condition of each soldier in a dismounted unit is an essential component for the safety, efficiency, and effectiveness of the unit. Why?*

- *A cyber or electronic warfare attack to BMS and network soldier communication network causes data exchange failure. As SPAM is mobile, the section commander, signaler, or vehicle can carry the SPAN transceiver and tactical radio to allow data exchange. Will this capability enhance the positive emergence in SoS?*

Context/Framing Information:

- *SPAN is integrated with the broader army network by connecting it to an existing VHF network, broadband, and future waveforms. By combining some existing radio knowledge with the new SPAN mesh and local higher capacity network, a link is created with the* *land force backbone network. Will this capability enhance the positive emergence in SoS or will it be destructive? Why?*

Test Cases 1: Australian land forces face limitations in communication capabilities essential for BMS coordination and situation awareness understanding.

- *CBMS rely on the seamless integration of digital and physical components, as well as the possibility of human interactions, which necessitates reliable C4I. Is this seamless integration of digital and physical components feasible? Why?*
- ***Not covered in this paper** - Automated BMS is used to support human decision-makers. The introduction of the DBM solution (which is the disruptive new technology) may serve to develop suitable automated decision tools to integrate with the BMS command and soldier. Is this technology a good idea and/or is it required?*

ANNEX A: PILOT TEST CASE RESPONSES AND ASSOCIATED CHANGES TO THE CBMS NETWORK SOLDIER DESIGN

Table 3
Pilot Test Case responses and associated with CBMS network soldier

Test Scenario	**Test Case**	**Response**	**Change to CBMS network soldier Design**
Test Scenario 1 – The CBMS communication system interface and in the configuration of the combat network in land forces where wireless networking, sensors, human biosensors, targeting, shot detection, UAVs, small arm digital sights, range finders, and data to consider important issue where an alert/ deficiency/loss/failure is experienced due to cyber or electronic warfare attack, that has spoofed the BMS system.	Test Case 1: Australian land forces may have degradation or lack of communications capabilities essential for BMS coordination and situation awareness understanding.	CBMS rely on the seamless integration of digital and physical components, as well as the possibility of human interactions, which necessitates reliable C4I.? Enabling technologies, such as collections of first-person shooters (FPS) elements (nodes, vertices) and their pairwise links (edges, connections) and are presented in the simple form of a connection matrix showing positive or negative unexpected emergent behavior in soldier SoS.	The automated BMS is used to support the human decision-makers. The introduction of the DBM solution (which is the disruptive new technology) may serve to develop suitable automated decision tools to integrate with BMS command and soldier. The SPAN solution is an innovative mesh network for sharing data between soldiers in a section, and between commands and sections.

- **Key Findings and Lessons Learned**
  - **Findings**

- Overall, the Pilot successfully tested the applicable elements of the CBMS and network soldier. With the creation of the SPAN mesh, multiple sensors can be fused to create higher-order information. By connecting sensors via mesh networks to a BMS's processing capability, additional algorithms and techniques can be used to combine and analyse network data.
- CBMSs have traditionally combined elements of cybernetics, mechatronics, control theory, systems engineering, embedded systems, sensor networks, data, distributed control, and communications.

  - **Lessons Learned**

Regarding the CBMS and network soldier, we shall consider the use of cybernetics VSM application in meta meta-systems named meta cybernetics to control variety.

  - **Conclusion**

The Pilot was successful in testing the CBMS network soldier against the professional and experienced personnel and confirmed against the current literature referenced in chapter 3 and 5 of this thesis.

  - **Recommendations**

As a result of the Pilot, there are key recommendations:

- Use meta cybernetics in BMS to control variety and reduce negative behaviors.
- Introduce new technology, automated systems that use new logarithms to detect cyberattacks and negative emergent behaviors.
- DBM solution (which is the disruptive new technology) may serve to develop suitable automated decision tools to integrate with the CBMS command and soldier.

6.3. Links between Paper 2 and Paper 3

The linking theme between Paper 2 and Paper 3 lies in their collective exploration of the impact of advanced technology on modern warfare and the role of complex systems thinking in understanding and managing the complexities of military operations.

The second paper, "Cybernetics Battle Management System and its Application to the Network Soldier," investigates emergent behaviour within Systems of Systems (SoS) and underscores the importance of understanding how these behaviours manifest in complex military networks. It introduces Yolles' meta-cybernetics framework and emphasises the roles of process intelligence (PI) and operative intelligence (OI) in controlling emergent behaviours. The paper recognises the natural adaptability of systems within their environmental contexts and the pivotal role of flexibility in managing these systems effectively.

The third paper, reviewing cyber battle management systems (CBMS) research, highlights the need for complex systems thinking, cybernetics, and analysis of emergent behaviour. It stresses the importance of considering the relationships between complex and multi-structural systems and employing a systems-thinking approach to solve complex problems. The paper explores the integration of cybernetics meta-methodology and the viable system model (VSM) to mitigate negative emergent behaviour in complex systems. It recognises the distinct nature of single deterministic systems and SoS as stochastic systems with emergent properties, leading to an exploration of key parameters for building intelligent systems.

These papers collectively delve into the intricacies of modern military operations in the digital age, where technology and complex systems thinking play vital roles. The second paper focuses on emergent behaviours within SoS, while the third paper delves into the use of cybernetics and meta-metasystems to address complex issues within military systems. Both themes underline the critical role of technology and systems thinking in the evolving landscape of modern warfare.

CHAPTER 7: PAPER 3. CYBER-PHYSICAL SYSTEMS, SYSTEMS OF SYSTEMS, AND EMERGENT BEHAVIOUR

7.1. Observations on Paper 3.

This paper investigates the challenges associated with information distribution in complex systems, with a specific focus on military Battle Management Systems (BMS) used worldwide. It introduces the concept of a cyber BMS (CBMS), which emerges from the interaction between BMS and cyber-physical systems (CPS) and aims to mitigate negative emergent behaviour in complex systems while improving system viability. The paper introduces the meta-metasystem, focusing on the environment, operation, and management unit, and addresses the Viable System Model (VSM) as part of this system. It advocates for systems thinking and meta-modelling to develop frameworks applicable to specific problem classes. The novelty lies in the application of cybernetics VSM and systems thinking in meta-metasystems, particularly in the context of cyber and BMS domains. The paper also explores complex adaptive systems (CAS) in both natural and artificial systems, where interactions among components can lead to emergent properties and unpredictable outcomes. This is particularly relevant in the context of BMS and the potential for unpredictable results from interactions between military assets in a networked BMS.

The research emphasises the interconnected nature of metasystems, highlighting that systems do not operate in isolation and are influenced by other connected systems. It underscores the importance of complex systems thinking, cybernetics, and the understanding of emergent behaviour in complex systems and multi-system relationships.

The study presents next-generation BMS for networked military applications as an example of integrated modular design, wherein embedded systems monitor and control networked soldiers. It explores the integration of meta-metasystems and cybernetics to achieve overarching mission goals beyond individual systems, providing a framework for coordinating and integrating multiple systems.

The study underlines the importance of a complex problem-solving meta-methodology in addressing cybersecurity threats in cyberspace, considering it a subset of complex problem-solving. Researchers have applied systems-thinking theory and cybernetics principles to develop meta-methodologies for this purpose.

7.2. Paper 3. Cyber Battle Management Systems (CBMS) are considered as systems of systems (SoS) and emergent behaviour is present, where viable system model (VSM) only controls system variety

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Cyber Battle Management Systems (CBMS) is Considered as Systems of Systems (SoS) and Emergent Behavior is Present, where Viable System Model (VSM) only Controls System Variety

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ABSTRACT

This manuscript critically examines existing research on cyber battle management systems (CBMS) and underscores the importance of advancing complex structure thinking, cybernetics, wicked problem-solving, and emerging behavior analysis. It advocates for a systems-thinking approach to solving complex problems by identifying and understanding associated systems, predicting their behavior, and managing changes. The manuscript explores the integration of cybernetics meta- methodology and the viable system model with metasystems reductionism to address negative emergent behavior in complex systems. The study highlights the roles of individual systems, systems of systems, and metasystems, emphasizing the deterministic nature of single systems and the stochastic characteristics of systems of systems. By integrating cybernetics, viable system models, and meta-metasystems, the manuscript explores key parameters for building intelligent systems, revealing that meta-metasystems offer superior capabilities for coordinating and integrating multiple systems. The research results demonstrate the successful development of a meta-metasystem tailored for CBMS, providing a strategic framework for the future of cyber battle management.

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Introduction

This manuscript makes a significant contribution by focusing on the distribution of information within complex systems, specifically military battle management systems (BMSs) used globally. Recognizing the threat posed by cyber-physical systems (CPS) to BMS, the study justifies its rationale through an exploration of metasystems reductionism and cybernetics. The overarching goal is to mitigate the occurrence of negative emergent behavior in complex systems and enhance system viability.

The novelty of the study lies in its examination of meta-metasystems and the integration of cybernetics, particularly the Viable System Model (VSM), to achieve overarching missions and functions beyond individual systems. By discussing the next-generation BMS for networked military applications, the manuscript exemplifies an integrated modular design based on computational, logistical, and networking analyses. This integration serves as a pioneering effort, providing insights into meta-metasystems' application in the cyber and BMS domains.

The manuscript focuses on the distribution of information across a complex system, such as military battle management systems (BMSs), used by over 30 countries worldwide. A cyber-physical system (CPS) is a serious threat to a BMS. A cyber BMS (CBMS) can be regarded as system behavior emergent from the relationship between a BMS and a CPS (Chong, Sandberg, and Teixeira 2019; Gupta et al. 2020; Nweke, Weldehawaryat, and Wolthusen 2021; O'Connell 2012; SBRI USA 2011; Stephenson 2017; Wiener 2013). The research rationale is justified by undertaking this study of metasystems reductionism and cybernetics to reduce the occurrence of negative emergent behavior in complex systems and control system viability (Ashby 2013; Bradley, Katina, and Keating 2016; Mittal and Rainey 2015; Nweke, Weldehawaryat, and Wolthusen 2021; Wiener 2013). The interactions between two metasystems pose a risk and are complex. Bradley, Katina, and Keating (2016) stated that systems are not expected to perform in isolation as they are connected and, therefore, subject to influences from other interconnected systems.

This review was conducted to demonstrate the need for introducing complex systems thinking, cybernetics (VSM) and emergence behavior in complex systems and multi-systems relationships (Ashby 2013; Becker and Wicked 2007; Bradley, Katina, and Keating 2016). The next-generation BMS for networked military applications is an example of an integrated modular design based on detailed computational, logistical, and networking analyses of BMSs, where embedded systems monitor and control the behaviors of networked soldiers (Hao et al. 2013). This study is novel in its examination of the meta-metasystems and integration of cybernetics VSM to achieve overarching missions and functions beyond those of the constituent systems. The VSM can be used for the analysis of an architecture for a command, control, communication and intelligence architecture (Ashby 2013; Mittal and Rainey 2015). Studies conducted by Ashby and Pierce (1957, 2013), Bar-Yam (2004b, 2004a), Beer (1989), Holland (2007), Jackson (2010), Maier (2009), Mingers and Brocklesby (1997), Pe´rez R´ıos (2008), Rainey and Tolk (2015), Thomann (1973), Wiener (1948), Yolles (2021) for meta-methodology, Kopetz et al. (2016), Nweke, Weldehawaryat, and Wolthusen (2021), O'Connell (2012), Schwaninger et al. (2005, 2008a, 2008b, 2009) and Syamil, Doll, and Apigian (2004), have indicated that meta-metasystems should provide superior capabilities by providing a governing structure that coordinates and integrates multiple systems (Bradley, Katina, and Keating 2016; Wiener 2013).

In simpler terms, the concept of "meta-metasystems" refers to a higher-level structure that oversees and integrates multiple systems. These systems could be anything from technological networks to organizational structures. The idea is that by having this overarching governing structure, it becomes possible to better coordinate and manage the interactions between different systems, leading to improved capabilities and performance.

These studies collectively contribute to a deeper understanding of the challenges and strategies involved in managing and securing complex systems like military battle management systems. The following work is summarized:

Chong, Sandberg, and Teixeira (2019): This study might explore the integration of cybernetics into physical systems, particularly focusing on how cyber-physical systems interact and the implications for various applications, including military systems.

Gupta et al. (2020): This research could be centered on cybersecurity issues, potentially analyzing the latest cyber threats and vulnerabilities affecting military systems and proposing strategies for Defense against cyber-attacks.

Nweke, Weldehawaryat, and Wolthusen (2021): This study likely investigates emergent behaviors within complex systems, examining how interactions between different components lead to unexpected outcomes and exploring methods to predict and control these emergent behaviors.

O'Connell (2012): This work may relate to cyber-physical systems or military technology, possibly discussing the integration of digital technologies into physical systems and the challenges and opportunities this presents.

SBRI USA (2011): This reference might point to a report from the Small Business Research Initiative in the USA, potentially discussing innovative solutions developed by small businesses to address challenges in military technology or cyber Defense.

Stephenson (2017): This study could focus on complex systems theory or cybernetics, exploring the principles governing the behavior of interconnected systems and their applications in various domains, including military operations.

Wiener (2013): This likely refers to the work of Norbert Wiener, a pioneering figure in cybernetics. The study may discuss cybernetic principles and their applications in understanding and controlling complex systems, including military systems.

Ashby (2013): This study may relate to the work of W. Ross Ashby, particularly his research on cybernetics and systems theory. It could discuss how systems adapt and self-regulate in response to environmental changes, with potential applications in military systems design.

Bradley, Katina, and Keating (2016): This research might explore the dynamics of complex systems and the interactions between different components, aiming to identify patterns and principles that govern system behavior and inform strategies for system design and management.

Mittal and Rainey (2015): This study could focus on emergent behaviors in complex systems, investigating how interactions between components lead to collective behaviors that are not apparent from the individual parts, with potential implications for military systems.

The studies cover various aspects related to complex systems, particularly focusing on military battle management systems and cybersecurity. For instance, Chong et al., Gupta et al., and O'Connell likely explore cyber threats and the integration of cybernetics into physical systems, such as military technologies. Stephenson, Wiener, and Ashby's works contribute to understanding complex systems and cybernetics, providing frameworks to analyze system behavior. Bradley et al. and Mittal and Rainey may offer insights into emergent behaviors within complex systems and strategies for control. Additionally, studies like Hao et al. and Bar-Yam likely delve into the design and analysis of networked military applications.

In this manuscript, the meta-meta system discussion consists of the environment, operation, and associated management unit, and we address VSM as a system (see Figure 1). The meta-metasystem introduces systems thinking, cybernetics, and emergent stochastic systems with emergence behavior into CBMS.

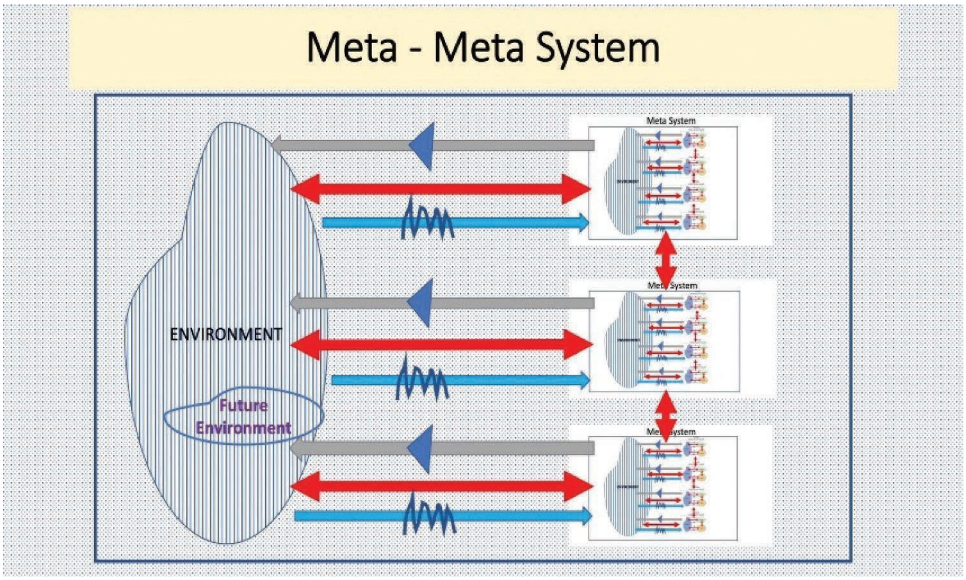

Figure 1. Meta-metasystem and cybernetics (only the variety is associated with VSM) coupling and feedback loops.

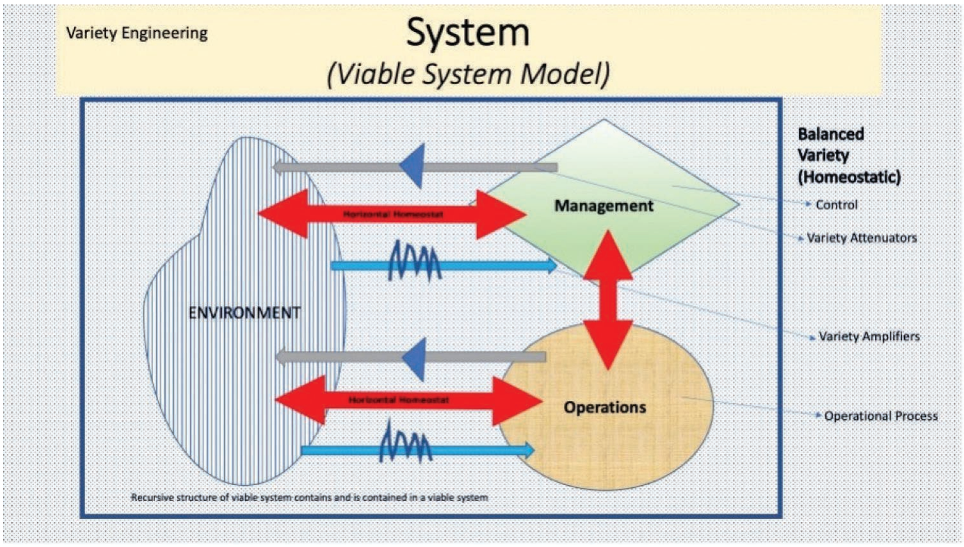

Figure 2. Deterministic system and VSM.

The systems-thinking approach (Ackoff and Wilson 2010) aims to organize and structure the problem- solving process from a set of explicit perspectives by selectively handling details that can obscure the underlying features of a situation.

Meta- modeling is the analysis, construction, and development of frameworks, rules, constraints, models, and theories applicable and valuable to predefined classes of problems (Chen et al. 2015; Zalewski, McKinna, and Morris 2020). A meta-methodology is a critical component of a systematic review (Thomann 1973; Zalewski, McKinna, and Morris 2020). The novelty of this review is that it provides insights into the application of cybernetics VSM, and systems thinking in meta- metasystems, such as in cyber and BMS domains and environments. The meta-metasystem for CBMS is developed for the design, execution, and evolution of systems of systems (SoSs) (Bradley, Katina, and Keating 2016; Stocchero et al. 2022). CBMS necessitates resilient defense techniques to evaluate systems for current threats and potential design weaknesses (La and Kim 2010). A CBM SoS is termed "mission-aware" if it shares information across a computer network to improve situational awareness and organizational effectiveness (Buchler et al. 2016; Ward and Chapman 2011). Therefore, a complex problem-solving meta- methodology is required to minimize the occurrence of disasters, accidents, and malicious acts in cyberspace (Sternberg and Frensch 1991). Several researchers have applied systems-thinking theory and cybernetics principles to complex problem solving via meta-methodologies (Von Foerster, Mead, and Teuber 1950). Rittel and Webber (1973) stated that cyber-security is a subset of complex problem solving and identified such problems.

Contributions and hypothesis

This review highlights the need for incorporating complex systems thinking, cybernetics (VSM), and emergence behavior into CBMS, paving the way for the integration of these principles in the design of next-generation BMS for military applications. The novelty of the study lies in its exploration of meta- metasystems and the integration of cybernetics VSM, providing insights into overarching missions and functions beyond individual systems. The developed meta-metasystem for CBMS focuses on the design, execution, and evolution of systems of systems (SoSs), requiring resilient defense techniques to evaluate current threats and potential weaknesses (Silva and Batista 2017; Stocchero et al. 2022). The hypothesis centers around the application of cybernetics VSM and systems thinking in meta-metasystems, particularly in the cyber and BMS domains. The study introduces the meta-

meta system, encompassing the environment, operation, and associated management unit, along with VSM as a system. The systems-thinking approach, meta-modeling, and meta-methodology are emphasized as tools for organizing problem-solving processes and conducting systematic reviews.

Natural systems ranging from animal flocks to socio-ecological systems, as well as sophisticated artificial systems such as the Internet and social networks, consist of several components and involve intricate interactions. These systems exhibit nonlinear spatiotemporal interactions among numerous components and subsystems and are commonly known as complex adaptive systems (CAS) (Bowers 2014). These interactions may produce emergent properties or emergencies, which cannot be derived from the characteristics of individual components. Although some researchers have attempted to define the meaning of emergence, a widely accepted definition remains elusive. Ants and bees are autonomous agents that follow the rules of natural systems. Similarly, a network of bases and electronic warfighting platforms has military assets as agents within a network guided by defense doctrines (such as rules, policies, procedures, and precedence). The rationale is that, despite each subsystem being reliable, when multiple subsystems interact, the potential permutations and combinations of interactions can cause unpredictable negative or positive feedback loops, resulting in unpredictable and unwanted outcomes.

To further expand on the comparison between the behaviors of ants and bees and the functioning of military battle management systems (CBMS), as well as how the concept of meta-metasystems applies in this context. Ants and bees operate within highly organized colonies where individual members exhibit simple behaviors, yet collectively they achieve remarkable feats. For example, in ant colonies, individual ants carry out tasks such as foraging, nest maintenance, and caring for the young. Each ant follows local rules based on simple interactions with its immediate environment and other ants, such as following pheromone trails laid by foragers. This decentralized decision- making allows ants to efficiently respond to changes in their environment and find optimal solutions to complex tasks like food collection and nest Defense.

Similarly, in bee colonies, individual bees perform specialized roles such as scouting for food, tending to the queen, or regulating hive temperature. Through intricate communication methods like the waggle dance, bees convey information about the location and quality of food sources to their nestmates. This collective decision-making process ensures the effective allocation of resources and the overall health and survival of the colony.

In the context of military battle management systems, these natural systems serve as powerful analogies. Military systems consist of various components, including bases, personnel, equipment, and communication networks, each performing specialized functions. Just as ants and bees work together to achieve common goals, military systems rely on the coordination and integration of these diverse components to accomplish missions effectively and adapt to changing circumstances on the battlefield.

Just like natural systems, military systems can face challenges due to the interactions between different subsystems. The interactions between bases, electronic warfighting platforms, and other military assets can lead to emergent behaviors, both positive and negative. For example, miscommunication between different units or delays in decision-making processes can result in inefficiencies or even mission failure.

To address these challenges, researchers propose the concept of meta- metasystems for CBMS. Meta-metasystems provide a governing structure that coordinates and integrates multiple subsystems within the military system, similar to how the organization within ant and bee colonies ensures collective success. By applying principles from systems thinking, cybernetics, and emergence behavior, researchers aim to develop meta-metasystems that can anticipate and mitigate the effects of complex interactions between various components within military systems. The ants and bees demonstrate how simple rules can lead to complex behaviors and efficient problem-solving in natural systems, the study of meta-metasystems aims to apply similar principles to military battle management systems, enhancing their effectiveness and resilience in complex and dynamic environments like the modern battlefield.

Cybernetics is a domain of deterministic systems where behavior is predictable and organized using communication, feedback, and control, leading to regulation and stability. The VSM is about managing variety as addressed by Ross Ashby and further elaborated upon by Beer (see Figure 2). In a deterministic system (predictable), variety is managed through the application and specification of constraints that determine the permissible output values or behaviors. When information is lacking, the variety or constraints will progress to emergence behavior that requires the generation of new information to handle both variety and constraints. When the information set is available and complete in the deterministic domain, the resulting complex behavior is classified as simple or weak.

A stochastic system is unpredictable and emergent behavior or plain emergence is present. When the stochastic nature of the complex system (Systems of Systems) results in variety and constraints that are available in the domain space but not yet used in regulation and control, we witness assertive emergent behavior (Stocchero et al. 2022).

In the transition or cross over area between deterministic to stochastics systems the subject matter experts can provide greatest value in providing valued information's and recommendations to solving complex problems and control variety. The information available through subject matter experts (SMEs) is the only hallmark of assertive emergence behavior that provides us with an opportunity to handle the apparent variety and application of constraints. Assertive emergence behavior, although undesirable in the real world, is a significant advantage in the computational world, as it provides an opportunity to engineer control mechanisms to bring a system back into the deterministic domain from the stochastic domain. From the knowledge-based perspective of solid emergence, which becomes causal only if knowledge exists to exploit the behavior (see Figure 3).

The categorization of solid emergence in the stochastic region in this article allows the manifestation of novel behavior, although understandable by SMEs. Two concepts have been drawn from Cybernetics by William R. Ashby. First is the Law of Requisite Variety: To control a system, the controller must have equal or more states (Ashby 1956) (i.e. variety as termed by Ashby) than the system being controlled. The second is the Conant – Ashby Theorem: Every good regulator of a system must be a model of the system itself (Ashby 1956; Ashby 2013; Ross 1958).

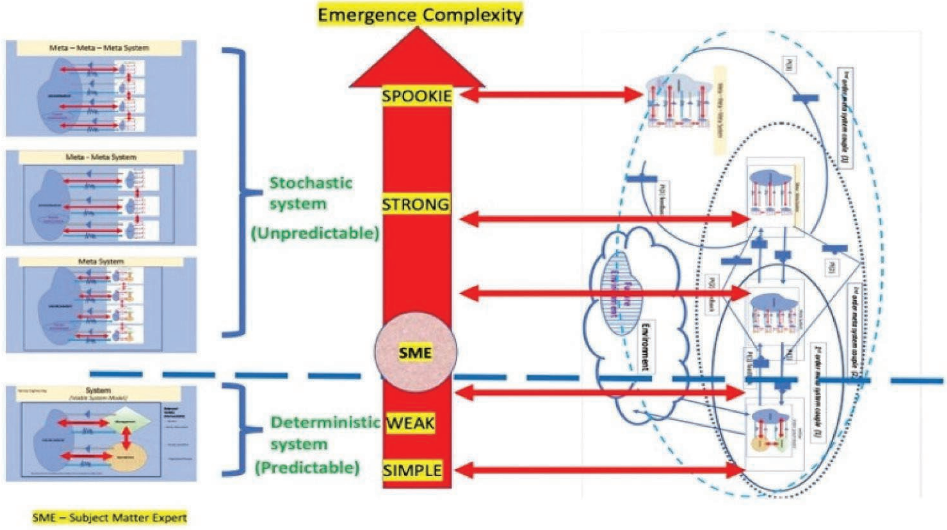

Figure 3. Categorisation of emergence in meta-metasystems design.

The research on aggregate systems, titled "Cybernetics and Battle Management System (CBMS)," places an even greater emphasis on the interface design of SoS and reliance on interface standards (Ross 1958). The SoS and taxonomic grouping focuses on distinctive classes within the system. The BMS network soldier assists stakeholders in breaking through communication barriers and exploring/showing how current and alternative development paths may affect the future. The ability to illuminate issues and break impasses makes finding sustainable solutions to the challenges extremely effective in opening new horizons, strengthening leadership, and enabling strategic decisions (Lewin and Regine, 2003). How data from a networked soldier can be used to simulate different scenarios for testing and analysis is open to discussion (Ko and Chung 2000). Areas where the safety and security of an army soldier exist as a system or subsystem need to be identified (Lewin and Regine, 2003; Ko and Chung 2000).

The study makes a substantial contribution by delving into the distribution of information within complex systems, focusing specifically on military battle management systems (BMSs) used globally. Acknowledging the threat posed by cyber-physical systems (CPS) to BMS, the paper grounds its rationale in metasystems reductionism and cybernetics, aiming to mitigate negative emergent behavior and enhance system viability.

The research landscape concerning complex systems, cybernetics, and emergent behavior has seen significant contributions. Notably, the work by Chong, Sandberg, and Teixeira (2019), Gupta et al. (2020), Nweke, Weldehawaryat, and Wolthusen (2021), and O’Connell (2012) establishes the foundation for understanding the relationship between BMS and CPS. These studies highlight the complexities arising from interconnected systems, emphasizing the need for comprehensive frameworks to address emergent behaviors.

Bradley, Katina, and Keating (2016) emphasize the interconnected nature of systems, challenging the expectation of isolated system performance. The manuscript builds upon this idea, advocating for a shift toward meta- metasystems and cybernetics integration. The incorporation of Viable System Model (VSM), particularly in the context of CPS and BMS, introduces a novel framework. This aligns with the findings of studies by Bar-Yam (2004b, 2004a), Yolles (2021), Pe ́rez R ́ıos (2008), and others, supporting the notion that meta-metasystems offer superior capabilities by coordinating and integrating multiple systems. The discussion extends to the next- generation BMS for networked military applications, emphasizing integrated modular design based on computational, logistical, and networking analyses. Studies by Hao et al. (2013) inform this approach, illustrating the significance of embedded systems in monitoring and controlling the behaviors of networked soldiers. The manuscript’s novel exploration of meta-metasystems contributes to the ongoing discourse on cybernetics, VSM, and systems thinking within the cyber and BMS domains.

The study aligns with the principles of systems-thinking theory (Ackoff and Wilson 2010), emphasizing the organization of problem-solving processes from various perspectives. Meta-modeling and meta-methodology, as discussed by Thomann (1973) and others, serve as critical tools for conducting systematic reviews and addressing emergent behavior in complex systems. The research highlights the application of cybernetics VSM and systems thinking in meta-metasystems, bringing valuable insights into cyber and BMS environments.

Comp cyber-physical systems (CPSs), cybernetics, cyber-security and complex problems

The complex problem framework can help clarify the nature of complex problems surrounding us (Becker and Wicked 2007; Miller and Lessard 2008; O'Connell 2012; Sheffield, Sankaran, and Haslett 2012; Snowden and Boone 2007). Cyber-security is a prime example of a complex problem requiring continuous and rigorous analysis and experimentation. Over many years, oversimplification of such problems has been a significant reason for their persistence in defying the best efforts of governments and societies.

W. Ross Ashby's law of Requisite Variety is so powerful that is known as the First Law of Cybernetics. Ashby's Law implies that the degree of control of a system is proportional to the amount of information available. This means you need an appropriate amount of information to control any system, whatever it is.

3 critical sys theories by: Bower's multy-paradigm framework; Jackson's critical sys practice; Minger's multi method.

From Minger's multi-methodology theory to represent the framework.

The methodology decomposition map is a holistic way of showing this relationship between the philosophy and methodology and methods.

The complex problem solving formalises sets of few highlights interrelated elements that are typically quantified (Halford, Wilson & Phillips (1998)) as complex systems.

Purposeful orientation of methodologies and methods.

(Operational excellence methodologies)

PO 1 - sense, understanding and simplicity;

PO 2 - eliciting, surfacing & engaging;

PO 3 - exploring & reconciliation, power and conflict.

Figure 4. Cyber-security incorporating critical systems thinking, cybernetics methodology, and complex problem-solving.

This is reflected in cyberspace by the subjective application of national or international laws and the varying motivations of governments and societies in addressing cyber-security problems (Miller and Lessard 2008; Murray, Webb, and Wheatley 2019; O'Connell 2012; Ruhl 2009; Sheffield, Sankaran, and Haslett 2012; Snowden and Boone 2007; Song, Fink, and Chapter 2017) (see Figure 4).

Determining the contributions of cyber-physical systems (CPSs) and their designs requires the detailed modeling of dynamic environments and a clear understanding of the interactions among embedded cyber-systems (CSS) (Chong, Sandberg, and Teixeira 2019; Gupta et al. 2020; Nweke, Weldehawaryat, and Wolthusen 2021; SBRI USA 2011). Complex systems or Systems of Systems (SoS) are characterized by unusual emergent behaviors, which appear to be fundamentally tractable through structured analyses (Miller and Lessard 2008; Stocchero et al. 2022). However, this is rarely possible in chaotic systems because cause-and-effect relationships tend to shift constantly, and no manageable patterns occur (Sheffield, Sankaran, and Haslett 2012; Snowden and Boone 2007) (see Figure 5).

In the world of social dynamics, chaos often manifests when a group of friends attempts to decide on a dinner destination. Each individual brings their own preferences, dietary needs, and restaurant suggestions to the table, sparking a lively yet chaotic discussion. One friend might passionately advocate for Italian cuisine, citing their love for pasta and pizza, while another insists on Asian fare, craving the tangy flavors of sushi or spicy noodles. Meanwhile, a third friend, committed to a vegan lifestyle, suggests a plant-based restaurant, emphasizing the importance of ethical dining choices. As the conversation progresses, more ideas are thrown into the mix, each with its own set of proponents and detractors, leading to a cacophony of opinions and conflicting desires.

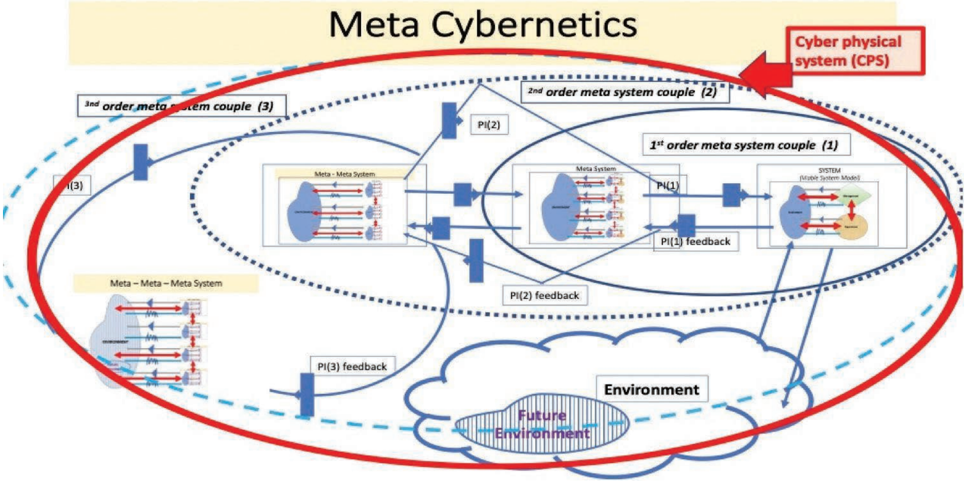

Figure 5. Cyber-physical system (CPS), meta cybernetics, and meta-methodology.

In a similar scenario, chaos lurks in distributed systems, such as cyber-physical systems (CPSs), where interconnected components interact dynamically to perform various functions. Consider a smart city's infrastructure – traffic lights, surveillance systems, transportation networks, and environmental sensors – all seamlessly integrated to enhance urban living.

However, this intricate web of interconnectedness also introduces vulnerabilities, as unforeseen events can disrupt the system's equilibrium. For instance, a sudden traffic accident or road closure can trigger a cascade of effects, causing traffic congestion, rerouting public transportation, and impacting overall city operations. Just as in the dinner discussion, where divergent preferences clash and compromise becomes elusive, the interactions among CPS components can lead to unpredictable outcomes, challenging traditional control mechanisms and predictive models.

In both scenarios, chaos emerges from the intricate interactions among diverse elements, challenging traditional methods of analysis and problem-solving. Structured approaches may offer some insights into emergent behaviors, but the dynamic nature of chaos necessitates a more adaptive and holistic perspective. Critical systems thinking, cybernetics methodology, and complex problem- solving become essential tools for navigating the complexities of social dynamics and distributed technological environments like CPSs. By embracing these approaches, stakeholders can better understand the underlying dynamics, anticipate potential disruptions, and devise resilient strategies to mitigate the impact of chaos on both human interactions and technological systems.

The meta-methodology of systems design (Thomann 1973) employs popular cybernetic methods such as Bowers' multi-paradigm system theory (Bowers 2014), Jackson's critical systems practice (Jackson 2010), and Mingers and Brocklesby's multi-methodology theory (Mingers and Brocklesby 1997). These provide a clear understanding of the SoS theory required to evaluate the emergent behavior phenomena in CPS metasystems (Rittel and Webber 1973). Understanding the various approaches for managing emergent behaviors in complex CPS metasystems necessitates investigating the nature of emergence processes, principles, operations, and outcomes from the perspective of modern warfare and SoS engineering (Chong, Sandberg, and Teixeira 2019; Gupta et al. 2020; La and Kim 2010; Nweke, Weldehawaryat, and Wolthusen 2021; SBRI USA 2011). Defense domains are highly flexible environments, vulnerable to computer and network attacks. The use of quantum computing to attack and destroy existing cryptosystems has motivated the development of a new discipline named "cyber-physical system protection" to handle post-quantum cryptography.

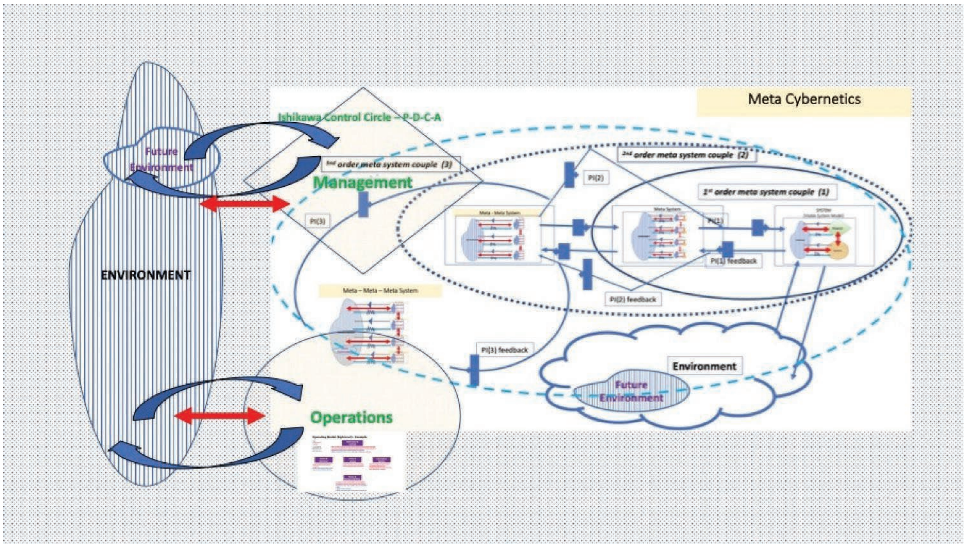

Figure 6. Cybernetics with Coupled SoSs and VSM feedback loop

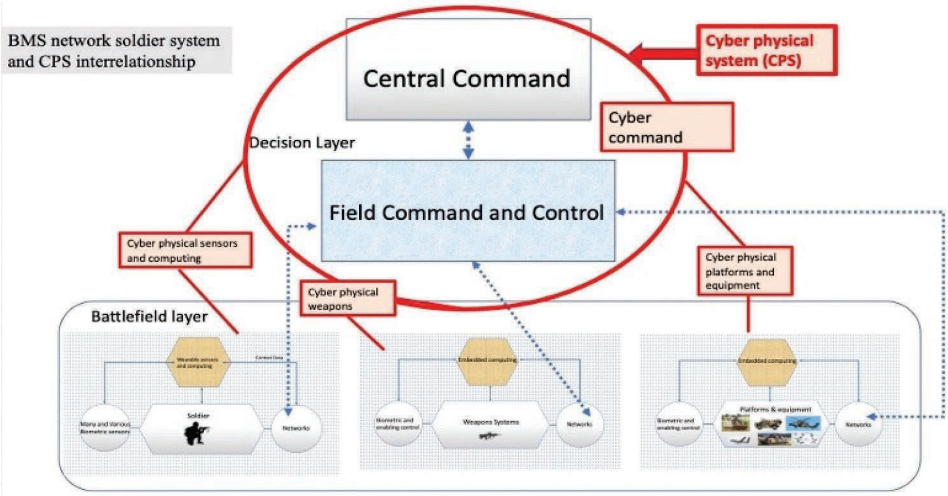

Figure 7. BMS network soldier system and CPS interrelationship.

Rainey and Loerch (2007) described the architectural modeling of complex systems within the CPS SoS construct, where emergent behaviors can be critically observed owing to the interactions among battlefield participants engaged in warfare gamification.

Rittel and Webber’s (1973) research on complex problem solving in the cyber-security domain has been instrumental in helping researchers and practitioners understand cyber-security breaches and their occurrences in various industries. It provides a clear understanding of the SoS theory required to evaluate the emergent behavior phenomenon in CPS metasystems (Rittel and Webber 1973) (see Figure 6).

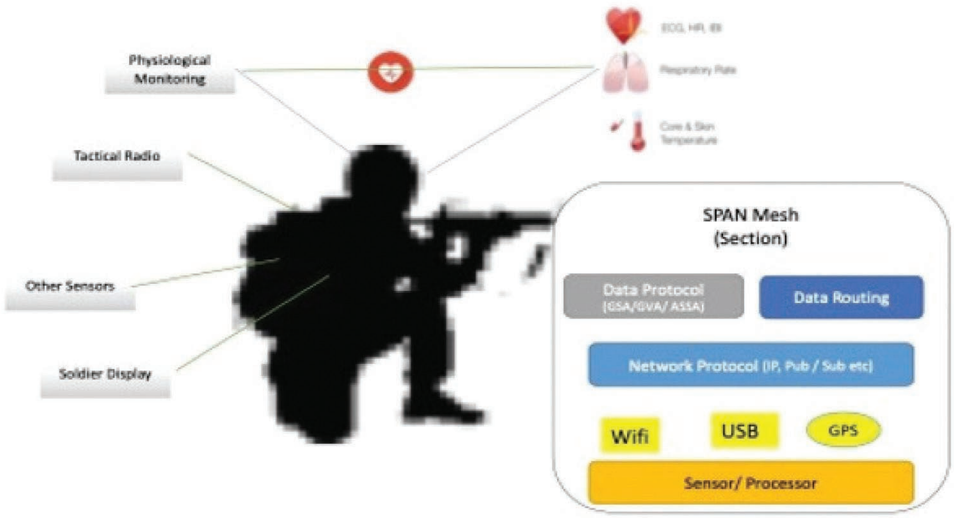

Figure 8. Illustration of network soldier basic technology.

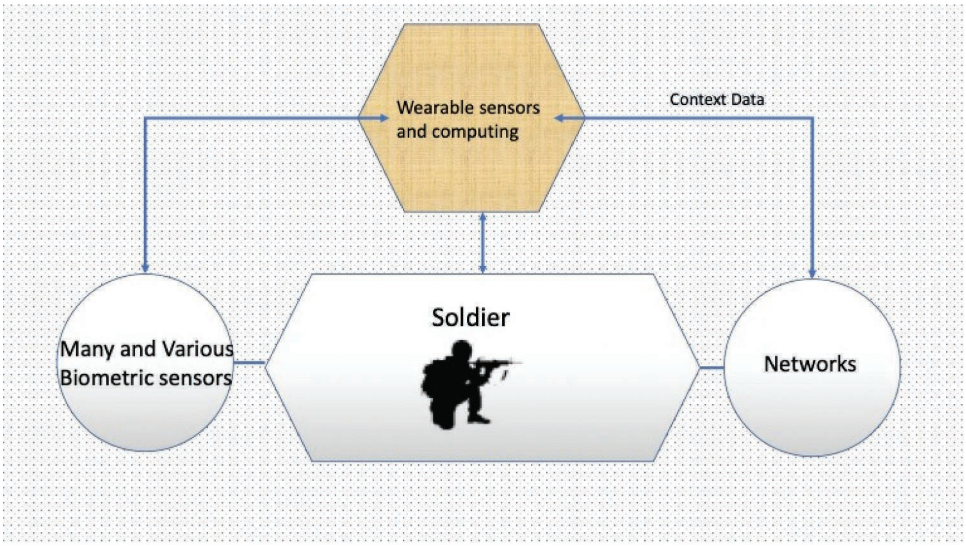

Figure 9. Network soldier wearable sensors.

Defense CPS security in physical and computing environments consists of optimal structures that allow sensors to observe and actuators to influence their environments. An SoS constitutes a collection of independent autonomous and technical constituent systems, such as CSS, providing valuable services (Kopetz et al. 2016). However, each proposed solution to a cyber- security problem has several layers and features that add complexity owing to terminological inconsistencies, immature or non-existent legal structures, and disparate business and social interests. The search for solutions inevitably results in the identification of numerous stakeholders eager to define the problem differently and propose contradictory solutions (Stacey 2007).

A potential limitation arises from the reliance on subject matter experts (SMEs) to manage assertive emergence behavior. While acknowledging their importance, this dependency introduces the risk of bias and subjective interpretations, potentially compromising the objectivity of emergent behavior management. The manuscript identifies the challenge of managing complexity during the transition from deterministic to stochastic systems. The practical implementation of control mechanisms within this transitional zone may face technical obstacles or demand substantial computational resources, posing a potential limitation to the feasibility of the proposed approach. Despite the manuscript's focus on understanding emergent behavior in cyber-physical systems (CPSs) and Systems of Systems (SoS), a limitation is evident in the lack of in-depth exploration into predictive modeling or forecasting of emergent phenomena (Stocchero et al. 2022). Incorporating predictive analytics could significantly enhance the proactive management of emergent behaviors, addressing a notable gap in the research.

The manuscript stands out for its comprehensive integration of cybernetics principles with emergent behavior analysis, particularly within the intricate realms of CPSs and SoS. This interdisciplinary approach not only enriches the theoretical foundations but also contributes to a deeper understanding of the dynamic complexities inherent in complex systems. The distinctive feature of the manuscript is the exploration of meta-metasystems, encapsulating systems thinking, cybernetics, and emergent stochastic systems. This innovative framework goes beyond traditional systems engineering paradigms, providing a holistic perspective on system design and management. The incorporation of meta-metasystems introduces a new dimension to the understanding of complex system dynamics.

Cyber-physical systems (CPSs), SoS and emergent behaviour

CPSs are at the core of digital innovations, transforming the world and redefining the interactions with intelligent machines in many industrial sectors and social contexts (see Figure 7). As mentioned, properly engineered CPSs rely on the seamless integration of digital and physical components and the possibility of human interaction (Becker and Wicked 2007; Miller and Lessard 2008; O'Connell 2012; Sheffield, Sankaran, and Haslett 2012; Snowden and Boone 2007). Therefore, CPS technologies are transforming how people interact with engineered systems in the physical world in the same way that the Internet has transformed how people interact with information (Ko and Cho 2000; Ruhl 2009). However, owing to the complexity of CPSs, developers are challenged by the lack of simulation tools and models for design and analysis ("European Defence Agency EDA advances work towards open architecture for soldier systems” 2017; Ackoff and Wilson 2010; Modul 2017; Murray, Webb, and Wheatley 2019; Ruhl 2009; Song, Fink, and Chapter 2017; Zalewski, McKinna, and Morris 2020). The extant literature provides several emergence detection techniques, ranging from statistical analyses to formal approaches (Chen, Nagl, and Clack 2007; Holland 2007; Maier 2009; Nweke, Weldehawaryat, and Wolthusen 2021; O’Toole, Nallur, and Clarke 2014; Stephenson 2017; Wiener 2013; Wincek 2011).

Although crisis literature (Loosemore, Raftery, and Reilly 2005) has demonstrated that emergencies occur for specific reasons, these reasons are frequently dismissed, hidden, or unrecognized. Such events have a low probability of occurrence, and their potentially significant consequences are seldom considered in contingency plans. Such conditions may be best addressed via an emerging strategy (Arndt 2011; Mintzberg, Ahlstrand, and Lampel 2020; Mittal and Rainey 2015). Miller and Lessard (2008) argued that successful projects were shaped rather than selected. US federal intelligence and defense agencies have examined several generic project failure examples and discovered that several early warning signs frequently occur (Maier 2014; Mittal and Rainey 2015). Therefore, emergence can be regarded as a system characteristic that cannot be predetermined. The taxonomy of different emergent behaviors is based on the interrelationship between the macro- and micro-levels (O’Toole, Nallur, and Clarke 2014). First, taxonomy must establish a theoretical framework for modeling and simulation (M&S).

The literature suggests that meta-metasystems provide superior capabilities by providing a governing structure that coordinates and integrates multiple systems. This thesis by publications reviews existing battle management systems (BMS) as systems of systems (SoS) research and highlights the need to develop complex structure thinking, cybernetics, depraved problem-solving and emerging behavior analysis considering the relationship between complex and multi- structural systems (Stocchero et al. 2022). The system-thinking approach aims to organize and structure the problem-solving process by selectively handling details that can obscure the underlying features of a situation from a set of explicit perspectives. The significance of the literature review lies in its contribution to the understanding of the foundational principles, hidden relationships, emergent behavior, and effective management strategies within metasystems and SoS (Stocchero et al. 2022). This understanding can spur future research, guide decision-making in system design and operation, and enhance the overall performance and safety of complex programs. The review also explores the foundations of operational capability and project control, which are critical for safe and efficient project management. By comprehending the underlying principles and factors that contribute to operational capability and project control, researchers and practitioners can develop strategies to enhance the performance and safety of complex systems (Silva and Batista 2017).

Networked soldier applications for the next-generation BMS software

The networked soldier is an excellent illustration of an integrated modular design based on thorough computational, logistical, and networking assessments of BMSs, with embedded systems monitoring and managing the behaviors of networked soldiers (Hao et al. 2013) (see Figure 8). In addition, stakeholders will benefit from more potent next-generation BMS networked troops to overcome communication obstacles and comprehend how potential future development routes may impact operations (Ko and Cho 2000).

Developing more powerful next-generation BMS networked soldiers will assist stakeholders in overcoming communication barriers and understanding how current and alternative development paths may affect future operations ("European Defence Agency EDA advances work towards open architecture for soldier systems 2017; Ko and Cho 2000; Modul 2017; Murray, Webb, and Wheatley 2019; Sinclair 2022). In the case of the networked soldier, wearable medical sensors (to measure vital signs such as temperature and heart rate) may be utilized to identify those showing symptoms of medical distress (Syamil, Doll, and Apigian 2004; Walker and Nogeste 2008). Historically, submitting such data to a central repository required voluntary, self- managed, and laborious transfer. These and other issues arise when a CPS connects to a BMS through a tactical network.

In the networked soldier example, wearable medical sensors may detect signs of medical hazards. Historically, such data had to be voluntarily and manually transferred to a central authority (see Figure 9). When a CPS is connected to a BMS via a tactical network, these and other conditions can be measured and assessed, even before the soldier is aware of a problem (Syamil, Doll, and Apigian 2004; Walker and Nogeste 2008). Theoretically, if several soldiers signal similar alerts simultaneously, the BMS could predict an attack (Ko and Cho 2000; Syamil, Doll, and Apigian 2004).

For a dismounted soldier unit to be safe, effective, and efficient, it must be possible to monitor the physical status of the soldiers remotely (Ko and Cho 2000, 24). A physiological monitoring system gathers, transmits, and saves data from soldiers to a central system ("European Defence Agency EDA advances work towards open architecture for soldier systems," 2017; Ko and Cho 2000; Modul 2017; Sinclair 2022). It consists of wearables and minimally intrusive sensors that gather information and track a range of biophysical characteristics (such as electrocardiographic data, heart rate, and core and skin temperatures). Then, using algorithms, the data are effectively gathered, correlated, and dispersed (”European Defence Agency EDA advances work towards open architecture for soldier systems,” 2017; Ko and Cho 2000; Modul 2017; Sinclair 2022).

In the world of networked soldiers, the advent of wearable medical sensors represents a significant advancement in ensuring troop health and operational readiness. These sensors possess the capability to detect early signs of medical hazards, such as fluctuations in vital signs or environmental conditions. Previously, the transmission of such critical data to central authorities required manual and voluntary efforts. However, with the integration of Cyber-Physical Systems (CPS) linked to Battle Management Systems (BMS) via tactical networks, these sensors now facilitate continuous monitoring and assessment of soldier health in real-time. This real-time monitoring provides invaluable insights into potential risks, even before soldiers themselves are aware of them. For instance, in the event that multiple soldiers within a unit simultaneously trigger similar alerts indicating physiological abnormalities, the BMS could swiftly identify patterns suggestive of an imminent attack. Such preemptive detection enables commanders to take proactive measures, potentially averting or mitigating threats before they escalate. This capability underscores the significance of leveraging technology to enhance operational safety and effectiveness.

In addition, to ensure the optimal functioning of dismounted soldier units, remote monitoring of soldiers’ physical status is indispensable. A comprehensive physiological monitoring system is meticulously crafted to gather, transmit, and store data from individual soldiers to a centralized system. This system comprises an array of wearable devices and minimally intrusive sensors meticulously designed to capture a diverse range of biophysical characteristics, including electrocardiographic data, heart rate, and core and skin temperatures. The sophisticated algorithms are deployed to efficiently process and correlate this vast trove of data, furnishing commanders with actionable insights into the health and readiness of their troops in real- time. Such timely and informed interventions not only bolster situational awareness but also serve to safeguard the well-being and operational effectiveness of dismounted soldier units across diverse operational landscapes. The seamless integration of wearable medical sensors and advanced monitoring systems exemplifies the transformative potential of technology in modern warfare. By harnessing these capabilities, military forces can navigate evolving threats with heightened vigilance and precision, ensuring the safety and success of missions in dynamic and challenging environments.

Future soldier system and SPAN mesh technology

In instances of soldiers not having access to Smartphone *Ad hoc* Networking (SPAN) mesh technology, the section-level command can combine several existing wireless technologies with new and evolving methods to create low-power mesh networks using Bluetooth, Wi-Fi, and ultra-wideband architectures. Developing a data standard for mesh networks will enable sensors, devices, and computers to connect as nodes and collect and share data cohesively and securely. The desired routing capability would enable dataflows throughout entire sections, allowing dispersed units to share critical real-time information through links provided by individual soldiers. Many sensors would be self-contained and, therefore, not require large power supplies owing to their small size, weight, and power requirements of the network components. SPAN could be integrated with broader army networks by connecting them to high- frequency networks, broadband trunks, and future waveforms. Links with the army backbone network would be established by combining existing radios with the SPAN mesh and local higher-capacity networks. A section commander, signaler, or vehicle may carry SPAN transceivers and tactical radios to facilitate such a data exchange ("European Defence Agency EDA advances work towards open architecture for soldier systems," 2017; Ko and Cho 2000; Modul 2017; Sinclair 2022).

Furthermore, multiple sensors can be combined to provide higher-order information. Connecting sensor data to BMS processors through these mesh networks would allow more sophisticated algorithms and techniques to be applied. For example, advanced technology such as shot detectors, electronic warfare devices, and range finders may be combined for tracking red forces to share a common operational picture. Imaging and video from local support units may also be integrated with BMSs and remote vehicles to improve situational awareness ("European Defence Agency EDA advances work towards open architecture for soldier systems," 2017; Ko and Cho 2000; Modul 2017; Sinclair 2022).

SPAN mesh technology unavailability

If SPAN mesh technology is unavailable to individual soldiers, the section-level command can combine several current wireless technologies with novel and developing techniques to build low-power mesh networks using Bluetooth, Wi-Fi, and ultra-wideband topologies. Creating a mesh network data standard would enable computers, devices, and sensors to join together as nodes and safely and cooperatively collect and share data (Syamil, Doll, and

Apigian 2004; Walker and Nogeste 2008). When data can flow throughout an entire section, as is the case with the required routing capabilities, dispersed units could communicate vital real-time information via linkages provided by individual troops. Owing to the modest size, weight, and power of such network components, many sensors would be self-contained and not need significant auxiliary power. SPAN would connect to a larger army by connecting through these sub-networks ("European Defence Agency EDA advances work towards open architecture for soldier systems," 2017; Ko and Cho 2000; Modul 2017; Sinclair 2022).

The manuscript's practical insights into applying emergent behavior analysis within military domains, particularly in the design of next-generation battle management systems, offer a tangible and real-world dimension to the research. This application-oriented approach enhances the relevance and significance of the proposed methodology, showcasing its potential impact in critical operational settings.

Cyber risk

There will always be a risk of false-positive alerts caused by cyber or electronic warfare attacks. Therefore, any mesh network solution must be battle-tested to eliminate as many "what-if" scenarios as possible. The future effects of CPSs will considerably impact personal and professional lives, and autonomous machines with complex data environments will involve numerous unforeseen legal aspects regarding responsibility, liability, ownership, and privacy (Ward and Chapman 2011). Human interactions with information systems are vulnerable and can be easily exploited to launch cyber-attacks. A better understanding of cyber-security elements will enable information managers to overcome any misguided sense of invincibility and close such security loopholes. Cybercrime and cyber- security threats can destroy businesses and their physical assets (Wincek 2011), which could also apply in the military domain.

Example: The Cyber Battle Management Systems (CBMS) communication system interface and the configuration of the combat network in land forces include wireless networking, sensors, human biosensors, targeting, shot detection, UAVs, small arm digital sights, range finders, and data to consider important issues where an alert/deficiency/loss/failure is experienced due to cyber or electronic warfare attack that has spoofed the BMS system. In this instance, headquarters (HQ) looks at an uncommon BMS program location for something that does not exist; however, another covert operation is being carried out elsewhere. Is this possible and what is the risk?

- The ability to remotely monitor the physical condition of each soldier in a dismounted unit is an essential component for the safety, efficiency, and effectiveness of the unit.
- A cyber or electronic warfare attack to BMS and network soldier communication network causes data exchange failure. As SPAM is mobile, the section commander, signaler, or vehicle can carry the SPAN transceiver and tactical radio to allow data exchange.

Monterey Phoenix (MP) analysis of emergent behaviours

The agent-based Monterey Phoenix (MP) M&S system demonstrates how emergent behaviors occur in SoSs. Rainey and Tolk (2015) applied agent-based modeling (ABM) and other tools to determine emergent behaviors in specific SoS engineering applications. The agent-based M&S can be used to detect emergent behavior in a SoS but cannot examine it or control it. Although MP can be used to delete negative emergence, it is the role of engineering to examine how to capitalize upon it, that is, facilitate modeling and simulation of SoS across many application domains and enable exposure and control of certain types of associated emergent behaviors.

The first task in designing a multi-agent system is to specify how each agent behaves in its environment and its role in behavior ontology (Burbeck 2015). Next, this description is transformed and expressed in the simulation engine's language and used as input for execution. The SoS is critical for meeting capability objectives and understanding interrelationships in the body of system engineering knowledge. However, defining an SoS' boundary is difficult, as its CSS typically has different owners supporting defense organizational structures; this is beyond the scope of SoS management.

The CPS requires detailed environmental dynamics modeling and a thorough understanding of the interactions among its embedded systems. For example, in any environment, the SoS software enables participants to successfully combine and analyze network data using sophisticated algorithms in the operational environment. Understanding emergent behaviors in SoSs with MP facilitates the M&S of SoSs across several application domains and enables the exposure and control of associated emergent behaviors (Rainey and Tolk 2015). In an SoS model, emergence can be detected using MP. This allows adverse emergence to be deleted and only positive emergence to be retained in the SoS. Therefore, it precludes potential negative influences and leads to potential force multipliers. This feature is critical, as negative emergent behaviors can significantly affect SoS missions. Dr. Kristin Giammarco of the US Naval Postgraduate School developed an MP modeling tool for planners and designers to detect emergence in an SoS model (Giammarco 2017).

Furthermore, ABM is gaining popularity among academics and practitioners as a robust methodology for complex adaptive system modeling. It demonstrates how simple behavioral rules and local agent interactions can produce complex patterns (Giammarco 2017).

Cyber physical system (CPS) and emergent behaviour

The key points regarding emergent behaviors found in CPSs are summarized as follows:

- Standardized abstractions and architectures that enable modular CPS design and development are urgently needed.
- CPS applications involve components that interact with one another through a complex coupled physical environment. Reliability and security pose unique challenges in this context, necessitating the development of new frameworks, algorithms, and tools.
- Future CPSs will require highly reliable and reconfigurable hardware and software components. In many applications, certifiability and trustworthiness must be extended to the system level.

Emergent behaviors can be defined as system characteristics that are invisible at the system (macro-) level but emerge unexpectedly owing to interactions between entities at the component (micro-) level. Emergent behaviors produce unexpected and sometimes undesirable outcomes in intelligence, cyber- security, weapons on target, and wireless networks (O'Connell (2012); Stephenson (2017). Interactions resulting in emergent behavior manifest at system interfaces, between systems and operators, and between systems and BMS software-development elements. The emergent behavior in a CBMS cannot be predetermined with existing knowledge, as the location of the emergent behavior in the system cannot be easily identified, analyzed, or validated.

Contributions to the field

High-risk industries are required to minimize the occurrence of disasters and accidents in the operation and delivery of engineering projects (7;47). This can be realized through systems modeling, which includes analyzing, constructing, and developing frames, rules, constraints, models, and theories applicable to predefined problem classes. These methods are critical for effective risk management (Syamil, Doll, and Apigian 2004; Ward and Chapman 2011; Zalewski, McKinna, and Morris 2020). The involvement of CPS in the emergent behavior of an SoS necessitates detailed modeling of the dynamics of the environment and a clear understanding of the interactions between the dynamics of the embedded system and its environment. Maier (2009) defined an SoS architecture in terms of communications among components.

Conclusion

Emergent behavior produces unexpected and, occasionally, unwanted outcomes in intelligence, cyber-security, weapons, wireless networks, integrated power hubs, sensors, end-user devices, tactical routers, and network-enabled technologies (O'Connell (2012); Stephenson (2017). Enabling technologies such as networks graphs are instantiations of Functional Performance Specification (FPS), elements (e.g. nodes and vertices), and their pairwise links (e.g. edges and connections) (Walker and Nogeste 2008)). Defense forces and other government institutions must understand the practical applications of the systems engineering process, as it maps to the development of FPSs. The objective is to understand and apply systems engineering processes and management behaviors to developing real-world FPSs. Capability roadmaps must describe the capability requirements within a defined capability area, the strategic context, specific capability goals, actions required to achieve the desired end-state, and the residual strategic or operational risks that must be mitigated or accepted (Walker and Nogeste 2008).

Emergence can manifest positively or negatively in various systems, from the simple to the highly complex. A mechanism that provides a structured approach for analyzing and controlling such behaviors is required, given that emergent behaviors and emergence are unexpected and mostly undesired. A CPS enables computer systems to monitor and interact with the physical world by merging computing and communications with physical processes. However, current computing and networking abstractions do not adequately reflect the attributes of the physical world. Networked embedded computers monitor and control physical processes, and CPSs share a *close hardware and* software relationship. They may operate on different spatial and temporal scales while exhibiting a variety of distinct behavioral modalities. Therefore, the behavior of a CPS may change in an operational or environmental context. This review significantly contributes to the extant literature, as it examines emergent behaviors in BMSs and CPSs. It also offers insights into a previously opaque domain. These valuable insights may help shape future research and policymaking in the defense industry.

A meta-methodology is a critical component of a systematic review (Thomann 1973). It is the novel research conducted in this work to improve understanding and knowledge in the application of cybernetics, VSM, and systems thinking in a meta-metasystems design like CBMS and the environments. The VSM may not be considered as a system of systems, and according to Dr. Mark Maier (Maier 1998, 2014), the true emergent behavior only occurs in his definition of a system of systems (Maier 1998). The Beer's VSM is about managing variety not emergent behavior, as this only occurs in a system of systems as addressed by Mark Maier. Dr. Maier's system of system is not a viable system model. The VSM is solely constructed upon managing variety as addressed by Ross Ashby and further elaborated upon by Beer. Beer's VSM is about managing variety not emergent behavior, as this only occurs in a system of systems as addressed by Mark Maier in his manuscript Architecting Principles for Systems-of- Systems (Maier 1998).

The meta-metasystem for CBMS is developed for the design, execution, and evolution of SoSs. The studies conducted by researchers such as Ashby (1956), Bar-Yam (2004b, 2004a), Beer (1989), Holland (2007), Jackson (2010), Maier (2009), Mingers and Brocklesby (1997), Mittal and Rainey (2015), Pe´rez R´ıos (2008), Thomann (1973), Wiener (1948), Yolles (2021) for meta-methodology, Kopetz et al. (2016), Nweke, Weldehawaryat, and Wolthusen (2021), O'Connell (2012), Schwaninger et al. (2005, 2008b, 2009), and Syamil, Doll, and Apigian (2004) suggest that meta- metasystems provide greater capability by providing a governing structure that coordinates and integrates multiple systems. This review helps elucidate the challenges and opportunities in meta-metasystems schema design for SoSs.

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Data availability statement

All data underlying the results are available as part of the article and no additional source data are required.

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Diagram captions

Diagram 1: Meta-metasystem and cybernetics, with viable system model (VSM) coupling and feedback loops.

Diagram 2: Deterministic system and VSM.

Diagram 3: Categorisation of emergence in meta-metasystems design.

Diagram 4: Cyber-security incorporating critical systems thinking, cybernetics methodology, and complex problem-solving.

Diagram 5: Cyber-physical system (CPS), meta cybernetics, and meta-methodology.

Diagram 6: Cybernetics with Coupled SoSs and VSM feedback loop.

Diagram 7: BMS network soldier system and CPS interrelationship.

Diagram 8: Illustration of network soldier basic technology.

Diagram 9: Network soldier wearable sensors.

7.3. In summary: The insights drawn from these papers

The insights drawn from these papers hold substantial relevance in the domain of project systems, particularly when dealing with complex projects involving modern warfare, military operations, or defence technology systems. Their collective focus on the impact of advanced technology within these contexts is an essential consideration for project stakeholders.

These papers provide valuable insights into the integration of cutting-edge technology in contemporary military strategies and the critical role it plays in the success of project systems. In the realm of modern warfare, these papers emphasise the importance of advanced systems, such as Battle Management Systems (BMS), in streamlining military operations. BMS has revolutionised how vital information is shared across military units, enhancing coordination and overall effectiveness. These papers also explore the shift from analogue to digital communication, a transformation particularly evident in conflicts like the situation in Ukraine. This transition not only accelerates the precision and speed of information dissemination but also empowers military decision-makers with the tools needed to make informed and timely decisions in the dynamic modern battlefield.

In addition, the focus on cybernetics and the mitigation of negative emergent behaviours in complex systems, as highlighted in the second paper, provides a valuable framework for addressing cybersecurity and managing project systems' complexities. The exploration of cyber battle management systems (CBMS) research in Paper 3 (above) holds direct relevance to project domains dealing with cybersecurity and defence technology systems. In the modern digital battlefield, safeguarding and managing information is of paramount importance in project systems, and these insights offer valuable guidance.

These three papers serve as a rich resource for project teams operating within the project systems domain, specifically those engaged in projects related to modern warfare, military technology, defence systems, and cybersecurity. They underscore the profound implications of advanced technology and the pivotal role played by complex systems thinking in addressing the multifaceted challenges and opportunities present in project systems. By recognising and applying these insights, project stakeholders can effectively navigate the evolving landscape of modern warfare, thereby enhancing the efficiency and efficacy of their endeavours in this project systems domain.

CHAPTER 8: DELPHI GROUP, DIGITAL TWIN AND AGENT BASE MODELLING (ABM) AND SIMULATION

8.1. Introduction

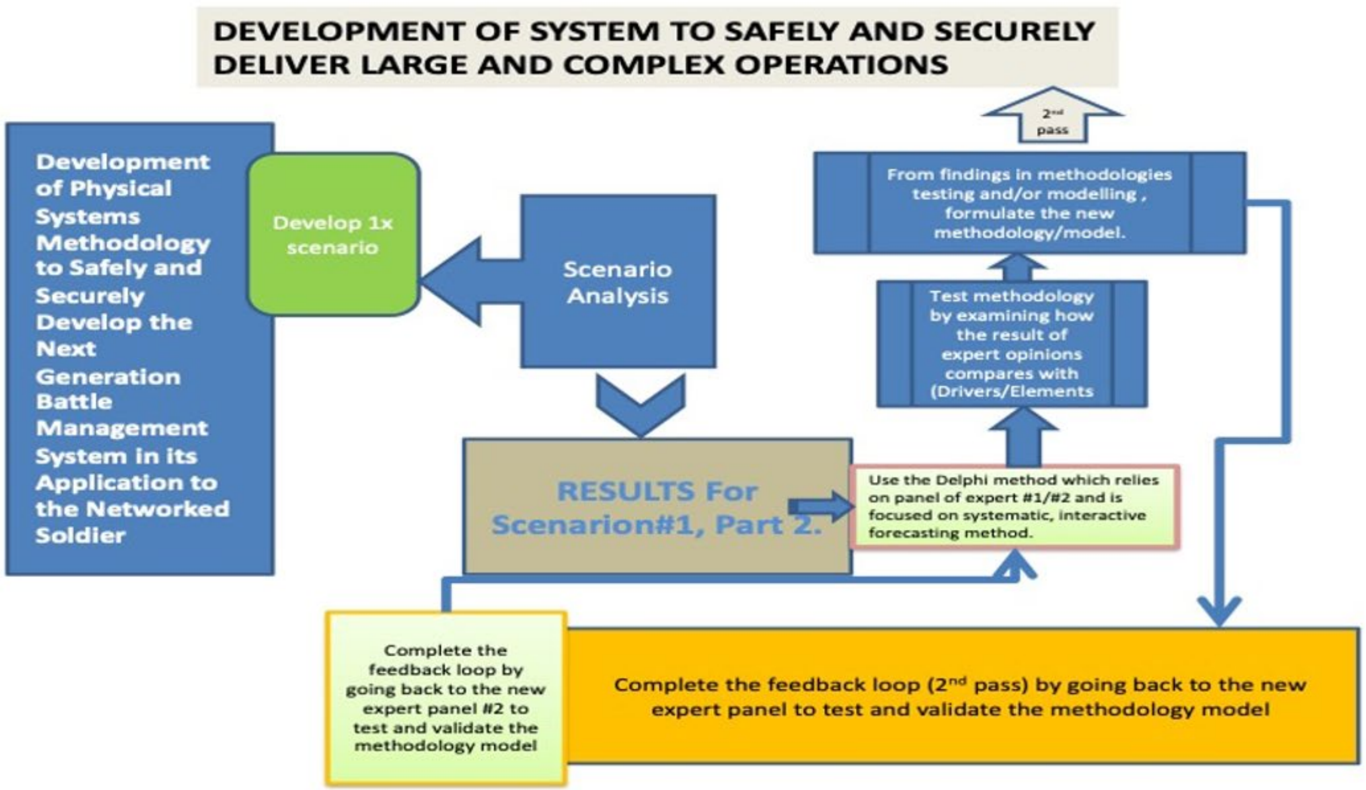
Chapter 8 offers a multifaceted exploration of vital topics within project systems. It begins with the Delphi technique, an established forecasting method that relies on the collective expertise of professionals, emphasising the importance of expert consensus in strategic forecasting. This approach recognises the value of collaborative expert insights in navigating the complexities of project systems and generating accurate forecasts. The chapter also delves into the 'Failure Mode Effects Criticality Analysis' (FMECA), a crucial process in reliability assurance technologies. FMECA meticulously evaluates each failure mode, determining appropriate dispositions to minimise downtime and meet operational objectives, making it a powerful tool for failure analysis and anticipation. The chapter highlights the utility of digital twin modelling and simulation, especially in complex deterministic systems. It details the approach to modelling and simulating emergent behaviour in Systems of Systems (SoS), involving explanations of individual system agents’ behaviour, the taxonomy of emergent behaviours, and the use of agent-based modelling and simulation techniques like 'AnyLogic' Agent-based Modelling (ABM). Complex projects often yield nonlinear outcomes, influenced by project attractors, causing variations in solutions and designs. The chapter recognises the significance of addressing changes during project execution and managing the transient nature of project organisations, which can introduce instability. Hidden states within SoS, situated outside the primary system, are explored, with their elucidation through metasystems, bridging higher-order cybernetics with lower orders. The chapter also explains the initial step in designing a Battle Management System (BMS) by detailing the behaviour of individual system agents within the environment, represented in the behaviour ontology, which is then translated into the simulation engine's language for execution.

The Delphi technique relies on a panel of experts and is a systematic, interactive method of forecasting. This method involves structured inquiries where participants share notable problems from their selected projects (Davidson, 2014). These narratives are recorded and then analysed to uncover the underlying drivers and components contributing to project failures. The Delphi technique typically involves multiple rounds in which experts answer questions and provide justifications, allowing for adjustments and revisions between rounds (as seen in Chapter 5). These iterative rounds continue until a predefined criterion for consensus is met, facilitating the experts in reaching a collective forecast on the topic under discussion (Okpi, 2004).

This chapter details the process of modelling and simulating emergent behaviour in Systems of Systems (SoS), covering individual system agents' behaviour, emergent behaviour taxonomy, and the application of agent-based modelling and simulation techniques. This exploration adds depth to the understanding of complex system dynamics and highlights the practicality of digital twin modelling and simulation, especially in complex deterministic systems.

It provides a comprehensive exploration of vital aspects of project systems and begins with an in-depth examination of the Delphi technique, a widely used forecasting method that taps into the collective expertise of professionals. Emphasising the significance of expert consensus in strategic forecasting, the chapter underscores the value of collaborative insights for navigating project complexities and generating accurate forecasts.

Figure 6
Delphi analysis process, 1st and 2nd pass diagram



8.2. Delphi Group participants and demographics are provided in the ethical approval form USQ Ethical approval (H22REA271) for Delphi analysis

> Network Soldier. Questions arise as to what the mechanism/process is generating emergent behaviour in the SoS and what types of emergences are experienced. Can cybernetics science provide much needed control of variance?

Pilot Test (Chapter 6, Annex A)

Article titled: ‘Cybernetics Battle Management System and its Application to the Network Soldier’

Situation: The physical results of the presence of emergent behaviour in a BMS are goal-seeking elements that may exhibit probabilistic unanticipated behaviours. This is due to a set of input conditions that were unanticipated by the defence doctrine, and other supporting policy and governance documents for the acquisition of assets, or from the adaptation of a person (agent) or software to sets of input rules such as misapplication of the rules by a document and person (agent).
Delphi Analysis is based on Chapters 6 and 7 published papers and extended to the thesis by the publication here in Chapter 8.

The following questions are considered:

- Title: ‘Cybernetics Battle Management System and its application to the future soldier system is required to provide an optimised solution for several soldier roles in a variety of mission types. Once this system is integrated into the whole network we are faced with the emergent behaviour occurring.
- The network needs to allow for future support of an increasing range of sensors and broader field intelligence capabilities. The mesh network is built on a standardised technology platform and supports a set of standard data exchanges based on generic vehicle (GVA) and generic soldier (GSA) architecture models. This allows the SPAN mesh to provide the network for all sensors.

- The SPAN mesh at the soldier and section levels is based on leveraging several existing wireless technologies with new and evolving technology to create a low-power mesh network such as Bluetooth/Wi-Fi and/or UWB.

Test Scenario 1: The CBMS communication system interface and the configuration of the combat network in land forces include wireless networking, sensors, human biosensors, targeting, shot detection, UAVs, small arm digital sights, range finders, and data to consider important issues where an alert/deficiency/loss/failure is experienced due to cyber or electronic warfare attack that has spoofed the BMS system.

- In this instance, headquarters (HQ) looks at an uncommon BMS program location for something that does not exist; however, another covert operation is being carried out elsewhere. Is this possible and what is the risk?
- The ability to remotely monitor the physical condition of each soldier in a dismounted unit is an essential component for the safety, efficiency, and effectiveness of the unit. Why?
- A cyber or electronic warfare attack to BMS and network soldier communication network causes data exchange failure. As SPAM is mobile, the section commander, signaller, or vehicle can carry the SPAN transceiver and tactical radio to allow data exchange. Will this capability enhance the positive emergence in SoS?
- Not covered in this pilot test and paper - Automated BMS is used to support human decision-makers. The introduction of the ABMS solution (which is the disruptive new technology) may serve to develop suitable automated decision tools to integrate with the BMS command and soldier. Is this technology a good idea and/or is it required?

The consideration is that there is “normally a relation between project complexity and project size”.

- Complexity comes from a multiplicity of parts interacting in ways such that the behaviour of the whole is difficult to deduce from understanding the individual parts.
- Behavioural complexity from the nature of human interactions?

- The complexity of the environment (rather than within the project) was seen by some as the most important?

What is the mechanism/process generating emergent behaviour in the SoS and what types of emergences are experienced?

- Does the paper contain new and significant information adequately?
- Does the paper demonstrate an adequate understanding of the relevant literature in the field?

The relationship diagram in Figure 7 shows the objectives achieved in Section 1.2.2. The research methods points are linked as first and second pass Delphi analysis. These relationships in Figure 7 are based on the pilot test scenario and test case, Delphi group in Chapter 6 and Chapter 8 and Section 9.3.

Figure 7 Delphi analysis process, 1st and 2nd pass and the relationship between research methods and objectives achieved

Relationship diagram between research methods (Delphi) and the objectives achieved from the source: published manuscript Chapters 5 and 6. (USQ Ethical approval (H22REA271) for Delphi analysis)).

8.3. The pilot test scenario and test case – Delphi group

In Chapter 6, the pilot test scenario and test case revolved around two main objectives. Firstly, the pilot test aimed to validate the effectiveness of the cybernetics BMS network soldier scenario proposed in this thesis. This scenario pertains to the design, analysis, and integration of BMS, encompassing processes, computations, and communication networking. Secondly, the pilot test sought to derive insights from the process to affirm that embedded computers and communication networks indeed influence the behaviour of the networked soldier and interact with the physiological monitoring system (feedback loops). This reciprocal relationship indicates that the soldier's behaviour can impact computations, and vice versa.

The pilot test was delimited to specific aspects, focusing on the BMS platform and system integration, site configuration, unit data management, and network management. The soldier is treated as a constituent of the larger 'system' and is integrated within the BMS 'Systems of Systems' (SoS) (Chapter 5). The application of deterministic 'system' cybernetics is regulated by the ‘Low-Risk Venture’. In the context of SoS, the application of cybernetics is referred to as meta cybernetics. This modelling is essentially aimed at validating the pilot test and supporting the BMS emergent behaviour theory, with the foundation of this theory grounded in existing literature.

8.3.1. The Delphi technique: Expert panel for systematic emerging themes

In this Chapter the Delphi technique is employed through a series of interview questions. These questions are rooted in concepts drawn from existing literature and are intentionally structured to be flexible in their sequencing. This approach enables the interviewer to adapt to the participant's narrative trajectory and delve into emerging themes. During the initial pass 1 of interviews the participants will be prompted to recount a notable problem they encountered within the context of the scenario outlined in Chapter 5 and the pilot test. The objective of this initial interview question is to pinpoint a chosen project and a key issue faced within that project, which will serve as the central focus for the subsequent interview discussions (Topper, 2006).

From Chapter 5 scenario findings, the system modelling is defined as the construction and development of the frames, rules, constraints, models and theories applicable to, modelling a predefined class of problems (Chang et al., 2014 and Weiner, 2013). It is important to understand during the questioning that although threats to research reliability and validity can never be eliminated, the researcher needed to strive to minimise this threat as much as possible (Wilson 2010) as the reliability refers to the extent to which the same answers can be obtained using the same instruments more than once. The issues in reliability are closely associated with the impact of an observer's subjectivity (Babbie, 2010). The subjectivity will have to be minimised at all times during this study by triangulation of data. The research results are valid, repeatable, and reliable.

8.3.2. Delphi methodology process

The questions were based on concepts from the pilot test scenario and backed by literature, designed to be asked in any order, allowing the researcher to follow the specific trajectory of the participant's answers and explore the emergent themes. In Chapter 6 the pilot study and Delphi methodology were applied to the scenario entitled *Cyber Battle Management Systems and its application to the network soldier*.

The questions were emailed to several professionals from organisations based in Australia. These professionals were from academia, the military, and the Defence industry and the assumption was that they would provide similarity in their responses (Chang et al., 2014). Test methodology was completed by examining how the result of expert opinions compared with driver's elements in Chapter 6. Completion of the feedback loop (pass 2) was by returning to the new expert panel to test and validate the model (Weiner, 2013).

8.4. Delphi Group result

Chapter 6 Manuscript - Cyber-Battle Management System (CBMS) and its Application to the Network Soldier.

Many countries use battle management systems (BMS), i.e., an SoS, that enable commands to share digital situational awareness information. The background of a BMS complex system is an SoS, and the research is focused on the distribution of information across the warfighting network (Chapter 3). The design or approach to the methodology for the CBMS and its application to the network soldier is evaluated, from system to multi/meta systems and including multi-ordered cybernetics application.

There is some understanding on how interactive planning, and the viable system model (VSM) can be combined to give a powerful methodology for studying and redesigning complex project systems. By using the VSM, we described how to define levels of recursion as well as identify and describe various systems. This theory explores the possibility of integrating cybernetics meta-methodology and VSM with the application of meta systems reductionism to reduce the occurrence of negative emergent behaviour in project complex systems (Chapters 2, 3, 5, 6, 7, 9 and 10). The integration of fourth-order emergent cybernetics model in meta - metasystems is of great value to the world of engineering (Chapter 2). By integrating cybernetics and meta-methodology we can manage and or control system viability.

Table 4
Delphi analysis Pass 1. Questions and comments (Demographics Australia, Military, Defence Industry/ PhD's)

Delphi questions	***On paper/ manuscript***	***On thesis by publications***	***About emergent behaviour***	***The research quality***	***Paper/ manuscript concept and knowledge***
Delphi Pass 1: Questions	*Does the paper demonstrate an adequate understanding of the relevant literature in the field?* *CBMS relies on the seamless integration of digital and physical components, as well as the possibility of human interactions, which necessitates reliable C4I and is this seamless integration of digital and physical*	*Does the thesis contain new and significant information adequately?*	*What is the mechanism/process generating emergent behaviour in the SoS and what types of emergences are experienced?*	*Has the research on which the paper is based been well designed and are the methods employed appropriate?*	*Does the paper clearly express its case, measured against the technical language of the fields and the expected knowledge?*
PARTICIPANT ONE	Yes. Academic understanding with regard to BMS is well understood from a research-based	Yes, especially around the Generic Architectures being developed by the	SoS frequently generate emergent behaviour when:	Yes. The research is, from my perspective, appropriate for an	Yes. As a technical expert (in the field of BMS, military engineering of SoS,

Delphi questions	*On paper/ manuscript*	*On thesis by publications*	*About emergent behaviour*	*The research quality*	*Paper/ manuscript concept and knowledge*
	viewpoint. The integration requirements are well discussed, draw from current, accepted research, and extend to the inclusion of cyber-physical systems. The ability to remotely monitor the physical condition of each soldier in a dismounted unit is an essential component for the safety, efficiency, and effectiveness of the unit.	Land Network Integration Centre.	• Systems are not designed to function together • Systems are compromised by electronic attack or cyber warfare • Systems are not correctly used by operators • Systems place junk information into the SoS • Systems cannot interpret the data provided through the SoS • SoS integrations are not adequately tested (including regression testing)	academic paper around a BMS. It lacks a practical employment perspective, however this is understandable. I have used a majority of the presented readings myself when working towards the building and delivery of an interim solution for Army.	and the generic architectures that the Australian Army developed) the paper uses accurate terminology, and where necessary correctly abstracts the technical detail to support its premise.
PARTICIPANT TWO	The examples of cyber-physical systems draw on civilian examples, rather than military. Military	While a number of papers reference 2017, the conclusions incorporate modern	Systems that are not designed to interact cleanly using an agreed information exchange	Yes, the architectures and diagrams included are appropriate, and workable for expansion	

Delphi questions	***On paper/ manuscript***	***On thesis by publications***	***About emergent behaviour***	***The research quality***	***Paper/ manuscript concept and knowledge***
	examples of cyber-physical systems that interact with BMS include: • deployed smart-grid generators • optionally manned vehicles • automated drones • automated remote sensors • remote deployed cameras	discussions and result in contemporary conclusions. The Emergence Behaviour Analysis (inclusive of the scenario) represents an excellent example.	mechanism will introduce emergent behaviours. This is a result of a lack of application programming interfaces or adherence to a formal messaging format such as those included in the ABCANZ Standards.	into the practical employment.	
PARTICIPANT THREE	These systems provide relevant information back into the BMS that allow for logistical planning, information gathering, automated geolocation tagging and so forth. This allows information-driven logistical and tactical operations to minimise	BMS network soldier conceptual model observations discussions are excellent and demonstrate forward thinking from not only an academic but from a practical perspective. I would	SoS compromise is typically a warfighting objective. This allows for intelligence operations, planning, and removes the fog of war. As such a breach needs to be assumed and planned for, with appropriate user/data restrictions and incident		The paper shows sufficient understanding of the field and I have confidence that the writer has the expected knowledge presented.

Delphi questions	*On paper/ manuscript*	*On thesis by publications*	*About emergent behaviour*	*The research quality*	*Paper/ manuscript concept and knowledge*
	waste and exposure to enemy actions.	highlight the emergent behaviours as being an aspect that most academics overlook.	management processes, personnel and technology employed to assure the integrity, availability and confidentiality of the SoS.		
PARTICIPANT FOUR	SPAN is integrated with the broader army network by connecting it to an existing VHF network, broadband, and future waveforms. By combining some existing radio knowledge with the new SPAN mesh and local higher capacity network, a link is created with the land force backbone network. Will this capability enhance the positive emergence in	Emergent behaviour is **continuous** and changes as the soldier or decision maker adjusts to a closed loop decision cycle (Observe Orient Decide Act loop) that is continuously changing, based on changes in information they receive from those items identified above.	System misuse is frequently overlooked cause of emergent behaviours. Military operators of BMS are usually well-trained, however fatigue is a constant in field operations, and incorrect manual entries and distribution will cause emergent behaviours.	Emergent effects manifest themselves **at a cognitive layer** by the soldier or decision maker as demonstrated by the command-and-control judgements • the information they receive via a BMS (comprising sensors and networks); • information from other battlefield agents, acting independently or as a SoS in their own right (e.g., unattended ground sensors, unmanned	

Delphi questions	***On paper/ manuscript***	***On thesis by publications***	***About emergent behaviour***	***The research quality***	***Paper/ manuscript concept and knowledge***
	SoS or will it be destructive? It will potentially provide real time and eyes on the ground reports – what the unit is seeing may be different to other sources of intelligence that are open to interpretation.			aerial vehicles, integrated air defence network that has its own sensors, networks, and command systems);	
PARTICIPANT FIVE	The discussion about spoofing, electronic attack and covert operations requires expansion. Large scale BMS can have thousands of elements and it is difficult to identify a rogue/unauthorised device manually. Suggest looking to *Fighting Artificial Intelligence Battles Operational*	A cyber or electronic warfare attack to BMS and network soldier communication network causes data exchange failure. As SPAN is mobile, the section commander, signaller, or vehicle can carry the SPAN transceiver and tactical radio to allow	Junk information is a constant threat in any SoS, but has real impact on BMS. Junk information can and will lead to planning and logistical errors as the BMS is treated as a point of truth. Once this information is distributed automated systems will work to it.		

Delphi questions	***On paper/ manuscript***	***On thesis by publications***	***About emergent behaviour***	***The research quality***	***Paper/ manuscript concept and knowledge***
	Concepts for Future AI-Enabled Wars by Peter Layton for more information.	data exchange. Will this capability enhance the positive emergence in SoS? Possibly but processes need to be considered for preventing SPAN being captured and used by enemy to disrupt.			
PARTICIPANT SIX	Standard phrases, flags as to urgency or messages may be required but also an ability to report in plain language with suitable encryption and urgency flags to draw attention to narrative. The latter is a rich source of data	To confirm continued on-ground readiness of individual, observe response to emerging and reactive situations. Is behaviour consistent with others in unit or as expected – differences could	Data interpretation can be a complex problem even in simple SoS, but with the multitude of separate discrete systems in a BMS it is an ever-constant problem. Simple updates to a component can have unforeseen issues across the ecosystem. Emergent	Emergent effects manifest themselves **at a cognitive layer** by the soldier or decision maker, as demonstrated by the command-and-control their own prior personal battlefield experiences (a priori information);	

Delphi questions	***On paper/ manuscript***	***On thesis by publications***	***About emergent behaviour***	***The research quality***	***Paper/ manuscript concept and knowledge***
		indicate kinetic or cyber interference to operation. Each soldier could be identified by a unique “fingerprint or DNA”, again providing a level of operation security?	behaviours will develop due to the way each discrete system receives, interprets and presents data to the user.	• attributes of their own inherent physiological profile and their inherent predisposition for different types of response mechanisms in their decision making (risk taker vs risk avoider); • prior training (both individual and collective training) that conditions the way in which they may respond to information. • the environment in which they are operating (physical environment as well the Fog of War); and • strategic direction and commanders’ intent.	

Do you think that cybernetics, and the viable system model (VSM) applied to Systems of Systems (SoS) can control variety and at the same time control negative emergence?

We understand that emergence is present in systems of systems only. Where, the Variety formula: V(C) >= V(S), where the variety of the Controller (C) must be equal or higher than the variety of the Situation (S, Environment).

DELPHI ANALYSIS PASS 2 QUESTIONS AND PARTICIPANTS' COMMENTS
(Demographics Australia, Military, Defence Industry/ PhD's)

Q1. I understand that there is an understanding of how interactive planning, and the viable system model (VSM) can be combined to create a powerful methodology for analysing and redesigning complex project systems. By using the VSM, we can define levels of recursion, identify and describe various systems, and explore the integration of cybernetics and VSM. This integration, along with the application of meta-systems reductionism, aims to reduce the occurrence of negative emergent behaviour in complex project systems.

A. When dealing with a stochastic system, we can anticipate the occurrence of strong and unpredictable emergent behaviour. What is your understanding of this phenomenon?

B. Can the field of cybernetics provide much-needed control over "variety" through the application of VSM in stochastic, systems of systems (SoS)?

Professional 1 – Comments

> I think your studies are interesting and worthwhile. Are you basing this work on examples and case studies as it is all too easy to theorise in this field.
>
> Predicting emergent behaviour is not trivial – are you distinguishing between anticipating the behaviour of complex systems of systems and anticipating the possible impacts that might occur from new emergent behaviour? I'm

reminded of Taleb's Black Swan theory and possibly bring in his ideas from 'Antfragile'. Can a VSM approach provide a framework that learns and improves a SOS responses?

Professional 2 – Comments

Alex - You might be interested in my recent publications that move beyond VSM under the heading meta cybernetics, which you may find will respond to your questions. In my paper with Frieden in 2021 it is explained how Von Foerster system stability in complex adaptive systems is important to the creation of coherent behaviour.

Professional 3 – Comments

The VSM is SOLELY constructed on managing variety as addressed by Ross Ashby and further elaborated upon by Beer's in his text *The Heart of Enterprise*. As was stated Beer's VSM is about managing variety NOT emergent behaviour as this ONLY occurs in a systems of systems as addressed by Mark Maier in his paper https://asymmetricleadership.com/wp-content/uploads/2020/04/architectingprinciplesofsystemofsystemsMAIER.pdf.

In your revision, you need to address that you are going to use Monterey Phoenix to model your systems of systems and to interrogate your SoS for the presence of emergent behaviour but, more so to delete the negative emergence and accentuate positive emergence.

Please send me a revised version of your Ph.D. program description addressing: (1) identification, i.e. reference to Maier's article (2) your description of your selected systems of systems to investigate and address how it fits Maier's criteria for an SoS and (3) what your impression/suspicion is of both positive and negative emergence. Once you have done this, I will forward to Dr. Kristin M Giammarco, Associate Professor, Naval Postgraduate School, USA. Please read Stafford Beer's Viable System Model (https://www.amazon.com/Heart-Enterprise-Classic-Beer/dp/0471275999/ref=sr_1_1?crid=38LPVTCTPVSEZ&keywords=The+Heart+of+Enterprise+by+Stafford+Beer&qid=1677033506&s=books&sprefix=the

+heart+of+enterprise+by+stafford+beer%2Cstripbooks%2C120&sr=1-1). It is ONLY Dr. Mark Maier who has defined emergent behaviour in only the context of the systems of systems (https://asymmetricleadership.com/wp-content/uploads/2020/04/architectingprinciplesofsystemofsystemsMAIER.pdf). Beer's Viable System Model is NOT a systems of systems as defined by Dr. Maier. Conversely, Dr. Maier's system of system is NOT a viable system model. I personally know Mark Maier and he would attest to the same.

Professional 4 – Comments

Thanks for reaching out, Alex! It's much appreciated. Control is an illusion. What the VSM facilitates is navigating the complexity of all kinds of emergent systems. However, discussing with Stafford Beer himself whom I had the privilege to meet during my studies with Raul Espejo in 1990/91, we also need to grasp the meaning of viability beyond survival. System 5 is not as trivial as purpose or consensus. It addresses the raison d'etre, the ultimate reason for existence. It addresses the existentiality of love. Systems sciences and cybernetics in there current form limit themselves by dutifully referencing themselves as sciences, as disciplines of focus and exclusion. However, they bear the capacity to transcend themselves, to grow out of themselves, from themselves, into themselves. Let's be co-facilitators of this process. With gratitude and kind regards, Louis.

8.5. Failure modes and effects criticality analysis (FMECA)

A ‘Failure Mode Effects Criticality Analysis’ (FMECA) is an important process in the range of reliability assurance technologies. FMECA considers each failure mode of a function or hardware and then proceeds through a logical analysis of each one to arrive at its most appropriate disposition. This could include options such as how to make a design change, provide alternate support, or it may have no effect. Nevertheless, the FMECA process will provide a robust and repeatable analysis of the failures in the function or actual hardware. Another way of considering FMECA is its usefulness to define the anticipation of faults and failures. Although FMECA is actually a simple process, it is a very powerful tool to analyse failures. The FMECA covers not only the FMECA techniques, but also the framework in which FMECA is used. There is no analytical method that works in a stand-alone environment, and it must have a reason for being.

By its very nature, FMECA is an analytically intensive technique, and it is designed to keep the down time of the assets (due to failure) to the absolute minimum and managed to meet operational objectives or missions. FMECAs are performed to support assets, and it is necessary to have a basic understanding of this framework. This is not a detailed discussion on this area, but it will give a broad insight into this very complex topic. The broad issues addressed in this framework set the environment in which an FMECA is to be performed. Firstly undertake the FMECA process and secondly, move on to digital twin modelling and simulation.

8.6. The concept of the digital twin

Digital twin analysis is best used in complex deterministic systems, as explained in Chapter 8.

The approach to modelling and simulating emergent behaviour in Systems of Systems (SoS) involves several key steps: explaining the behaviour of individual system agents, establishing a taxonomy of emergent behaviours, utilising agent-based modelling and simulation techniques, and addressing both negative and positive instances of emergence through the early research and simulation tools described elsewhere in Chapter 8.

In complex projects, nonlinear outcomes frequently arise. Even minor variations among stakeholders, termed project attractors, can lead to significantly different solutions or project designs. Changes during project execution are common, and deviations from plans can occur. The transient nature of project organisations can introduce instability. Hidden states within an SoS, situated outside the primary system, can be regarded as exosystemic. These hidden states and relationships can be elucidated using a metasystem, where the higher order of cybernetics can be explained in relation to lower orders.

The initial step in designing a multi BMS involves explaining how each system agent exists and operates within the environment, represented in the behaviour ontology (Chapter 5). This description is then translated into the simulation engine's language for execution. Notably, there is no evidence to suggest that the emergent behaviour observed in constituent systems aids in system design. Combinations of systems within the SoS contribute to overall capability, and the emergent behaviours stemming from these combinations can enhance or diminish performance and impact costs.

Defining the boundaries of an SoS can be challenging, especially when constituent systems have different owners and support structures beyond SoS management. Understanding variable relationships and cause-and-effect connections within an SoS is essential for complex projects. Analysing these variables and relationships enables the application of findings on the emergence of complex systems in published papers to complex SoS project frameworks.

The utilisation of data from a networked soldier to simulate various scenarios for testing and analysis is a topic open to discussion (Ko et al., 2000). Identifying areas where the safety and security of soldiers exist as a system or subsystem is a common approach. Systems subjected to repeated cyclic use operate in deterministic cycles of work and pause. Maintenance occurs during pause periods. However, for future networked soldiers, a new category of systems with complex operating modes is proposed. This complexity involves waiting for a system usage request and executing the request randomly upon arrival.

To address the reliability of deterministic systems with complex operating modes, an analytical model has been formulated in Chapter 8. This model presents a ratio for the non-stationary total coefficient of operational readiness. It delineates system functioning during waiting and usage intervals, where these durations are random variables. The model considers three options for defining functions that govern waiting and execution time distributions. By leveraging this developed model, reliability and maintainability requirements for systems with complex operating modes can be effectively established. The model enables quantification and evaluation of reliability indicators, providing insights into system performance under various waiting and execution time distributions. This information guides decision-making and sets appropriate reliability and maintainability standards for these systems. Through modelling, the interdependencies between operational reliability indicators and waiting/execution time distribution parameters can be examined. This analysis yields valuable insights into the impact of different distribution functions on system reliability performance. Based on these insights, recommendations can be formulated to substantiate reliability and maintainability requirements for systems with complex operating modes.

8.7. Simulation – reliability digital twin

Yes, it is possible to simulate reliability failures in SoS using digital twin technology. A digital twin represents a virtual replica of a physical object, process, or system, capturing real-time data for analysis, simulation, and optimisation. It finds applications in diverse industries such as manufacturing, healthcare, transportation, and energy (**Appendices F** & **G).**

ASSETSTUDIO SOFTWARE Data Driven Decisions (Reliability and Operation Simulation).

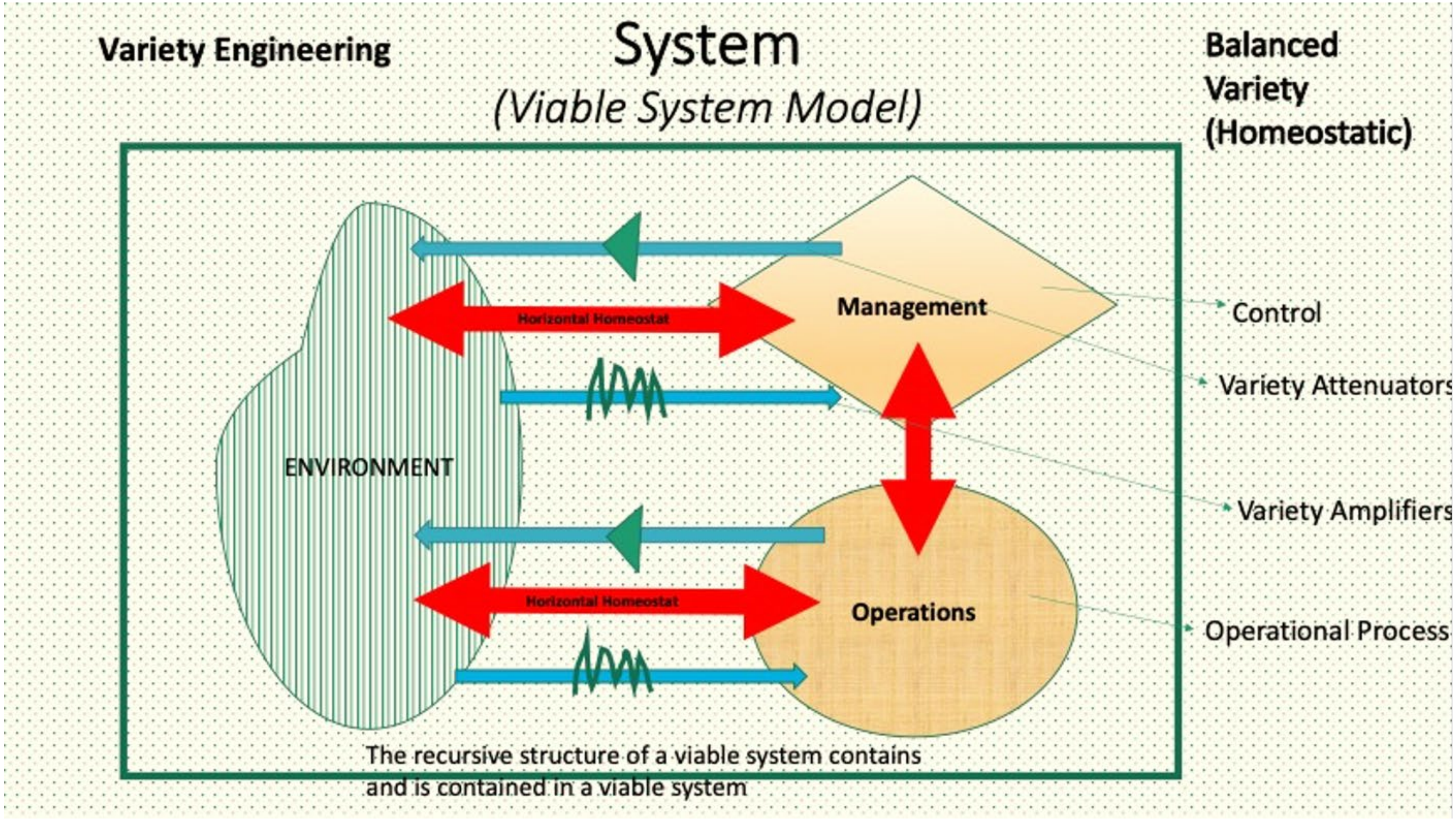
‘Reliability and Operation Simulation’ provides a mathematical approach to convert historical data into useful information to achieve the desired product performance resulting in the optimum financial health of a production asset.

USE NON-REPAIRABLE SYSTEM ANALYSIS

Reliability Digital Twin (Reliability Modelling) and Simulations

- Basic constructs for reliability digital twin
- Reliability metric: Availability and efficiency
- Equipment production loss contribution and Improvement Allocations
- Standby system
- Spare inventory optimisation

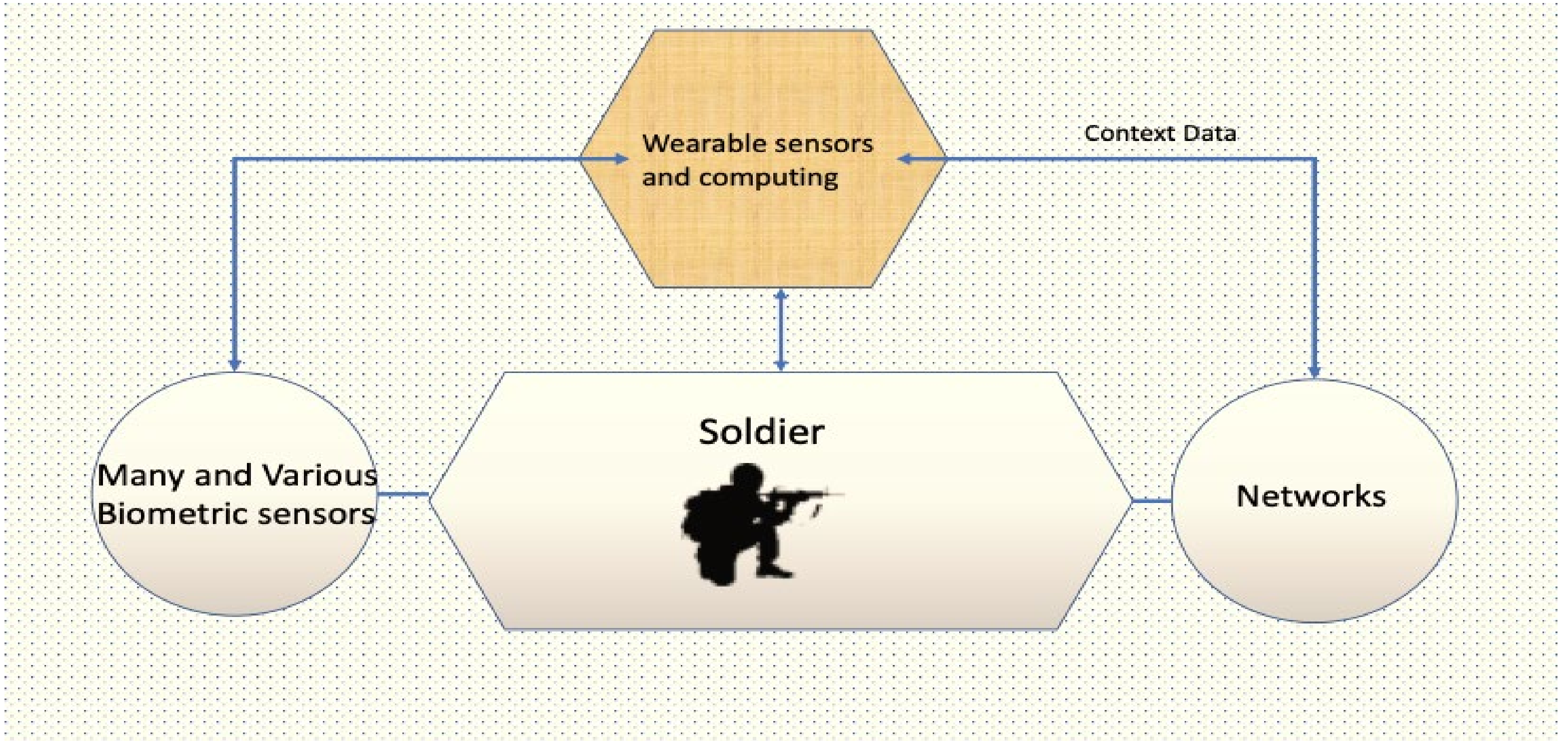
Figure 7
Viable System Model (VSM) Variety Engineering



Variety and value engineering in SoS and digital twin involves optimising complex interconnected systems and their virtual counterparts. Variety engineering in SoS and digital twin focuses on creating a diverse range of system configurations and variations to address different stakeholder needs. It involves managing subsystems, interfaces, and components to enable flexibility and customisation within the interconnected systems.

8.8. BMS network soldier article – modelling and simulation (example)

Figure 8
Soldier sensors and communication

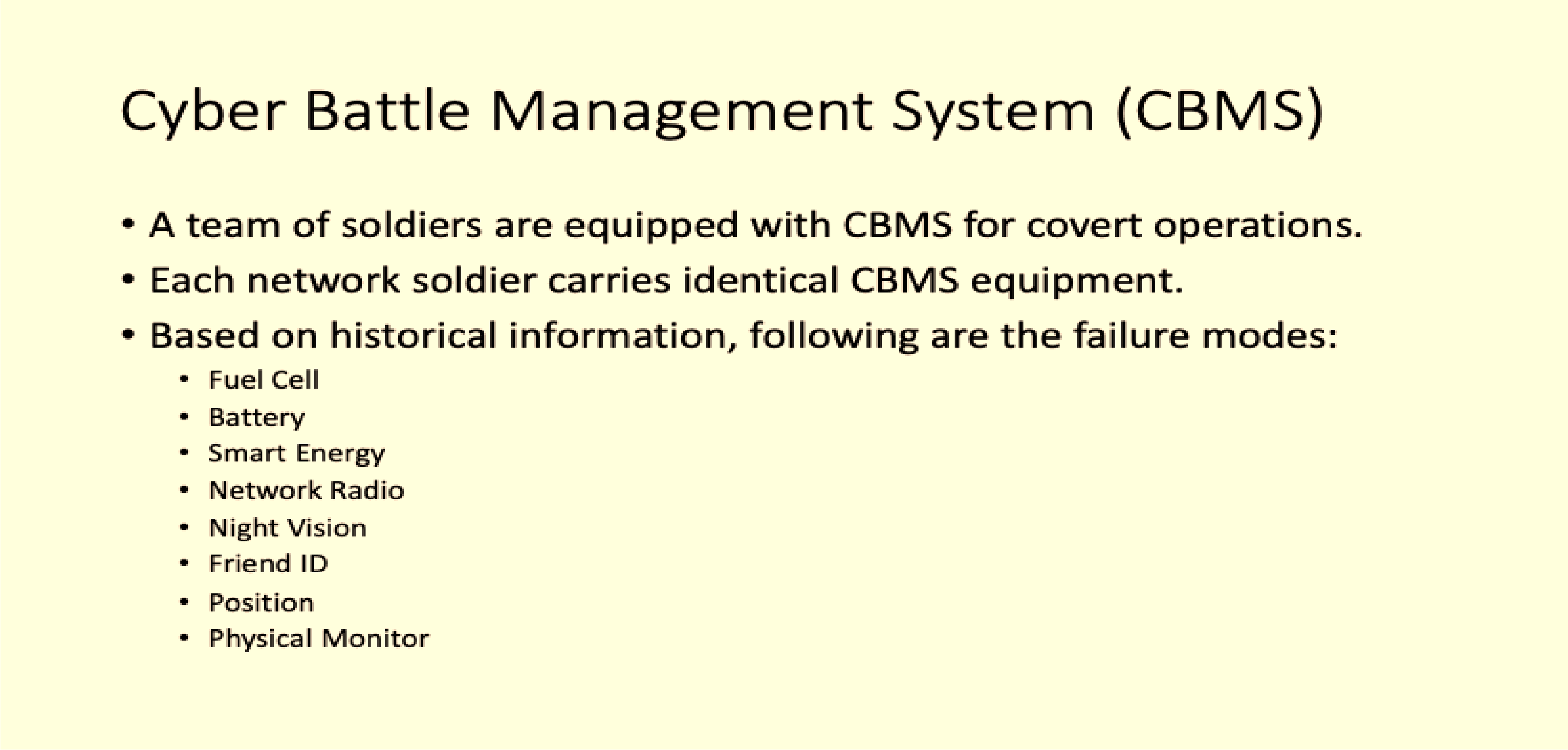


Figures 8 and 9 can be linked in the explanation and represent a small sample of battle management systems in the battlefield layer and are modelled and simulated in this chapter, Figure 7, Viable System Model (VSM) Variety Engineering. For digital twin simulation example, only soldier sensors and communication are used in the simulation. The soldier system elements are in Figure 10, CBMS failure effects.

AeROS™ is the simulation software program that creates a digital twin of a production system for predictive analysis using statistical methods. This digital twin predicts future outcomes, especially focusing on production uncertainties and how asset performance and maintenance affect production. Key features include analysing production impacts, identifying improvement opportunities, optimising resources and inventory, and supporting various analyses like Cost-Benefit and Queueing. AeROS™ is unique for supporting repairable and non-repairable life models, offering redundancy management, and storage functions, and providing comprehensive visualisations for better analysis. It stands out for its ability to optimise reliability and allocation for enhanced system performance.

The following slides present the process in reliability digital twin analysis based on the scenario in Chapter 6.

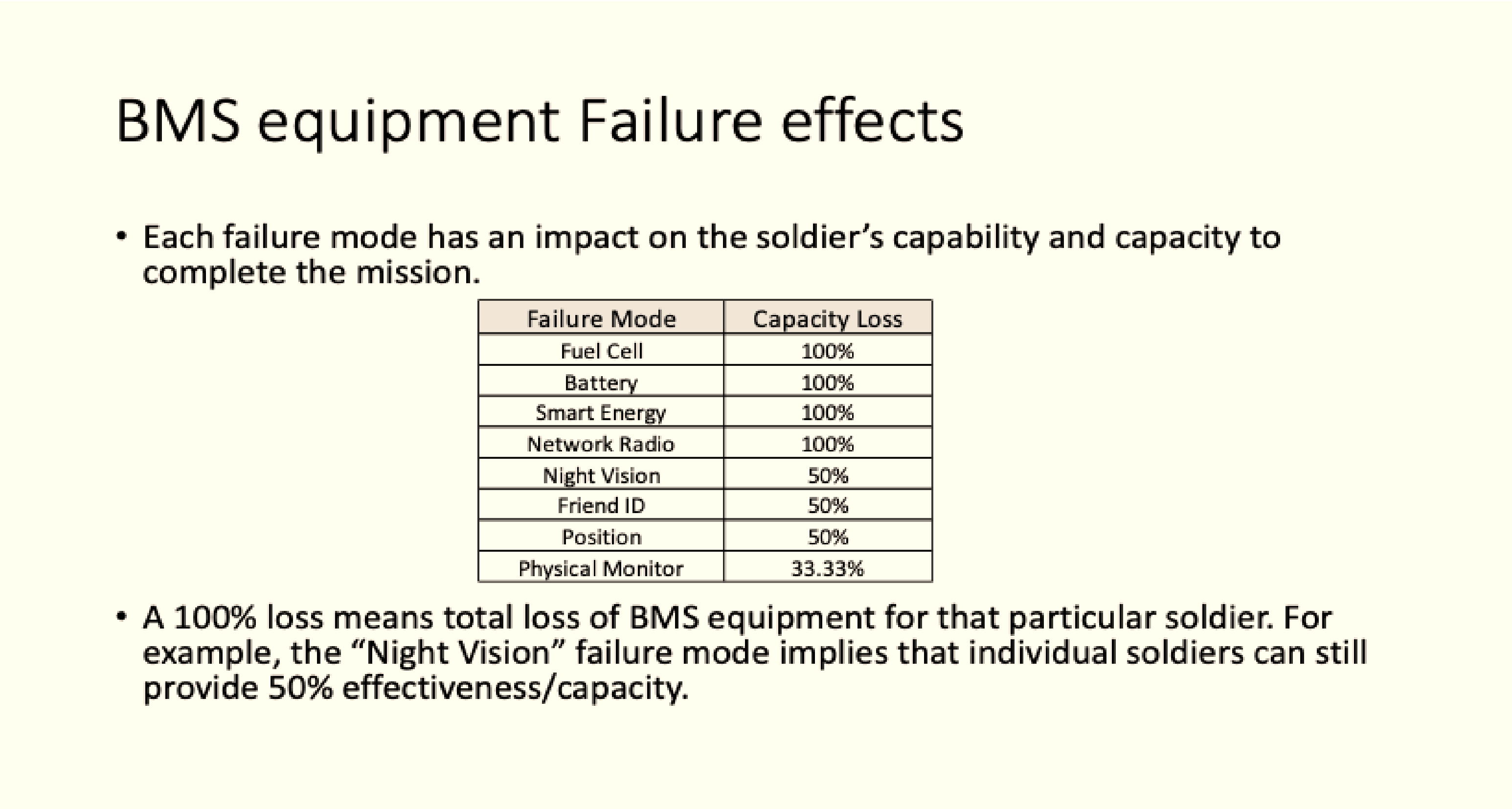
Figure 9
Network soldier equipment and sensors



Cyber Battle Management System (CBMS)

- A team of soldiers are equipped with CBMS for covert operations.
- Each network soldier carries identical CBMS equipment.
- Based on historical information, following are the failure modes:
  - Fuel Cell
  - Battery
  - Smart Energy
  - Network Radio
  - Night Vision
  - Friend ID
  - Position
  - Physical Monitor

Figure 10
BMS failure effects



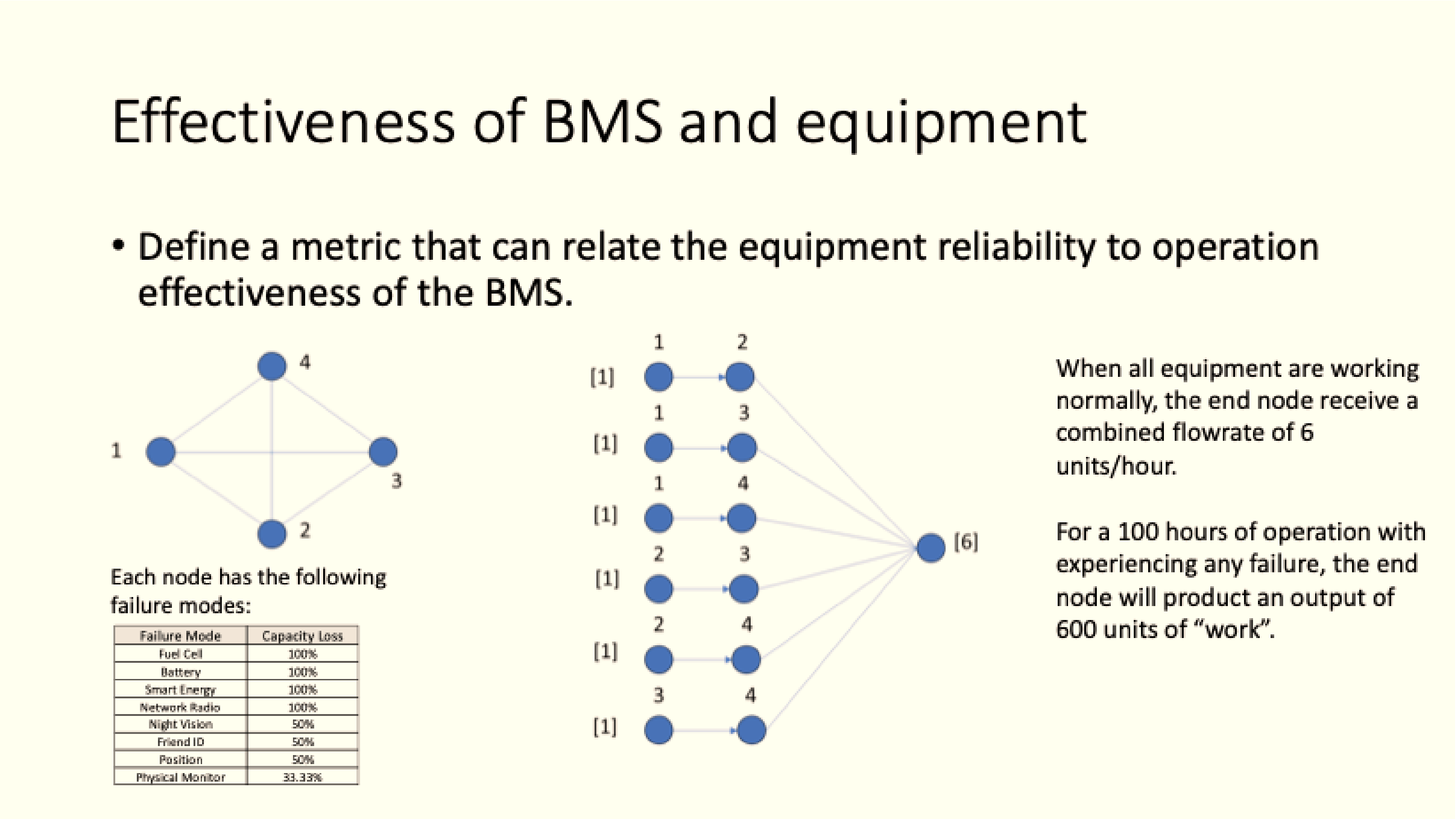
BMS equipment Failure effects

- Each failure mode has an impact on the soldier's capability and capacity to complete the mission.

Failure Mode	Capacity Loss
Fuel Cell	100%
Battery	100%
Smart Energy	100%
Network Radio	100%
Night Vision	50%
Friend ID	50%
Position	50%
Physical Monitor	33.33%

- A 100% loss means total loss of BMS equipment for that particular soldier. For example, the "Night Vision" failure mode implies that individual soldiers can still provide 50% effectiveness/capacity.

Figure 11
Network soldiers (4) descriptive model



Effectiveness of BMS and equipment

- Define a metric that can relate the equipment reliability to operation effectiveness of the BMS.

Each node has the following failure modes:

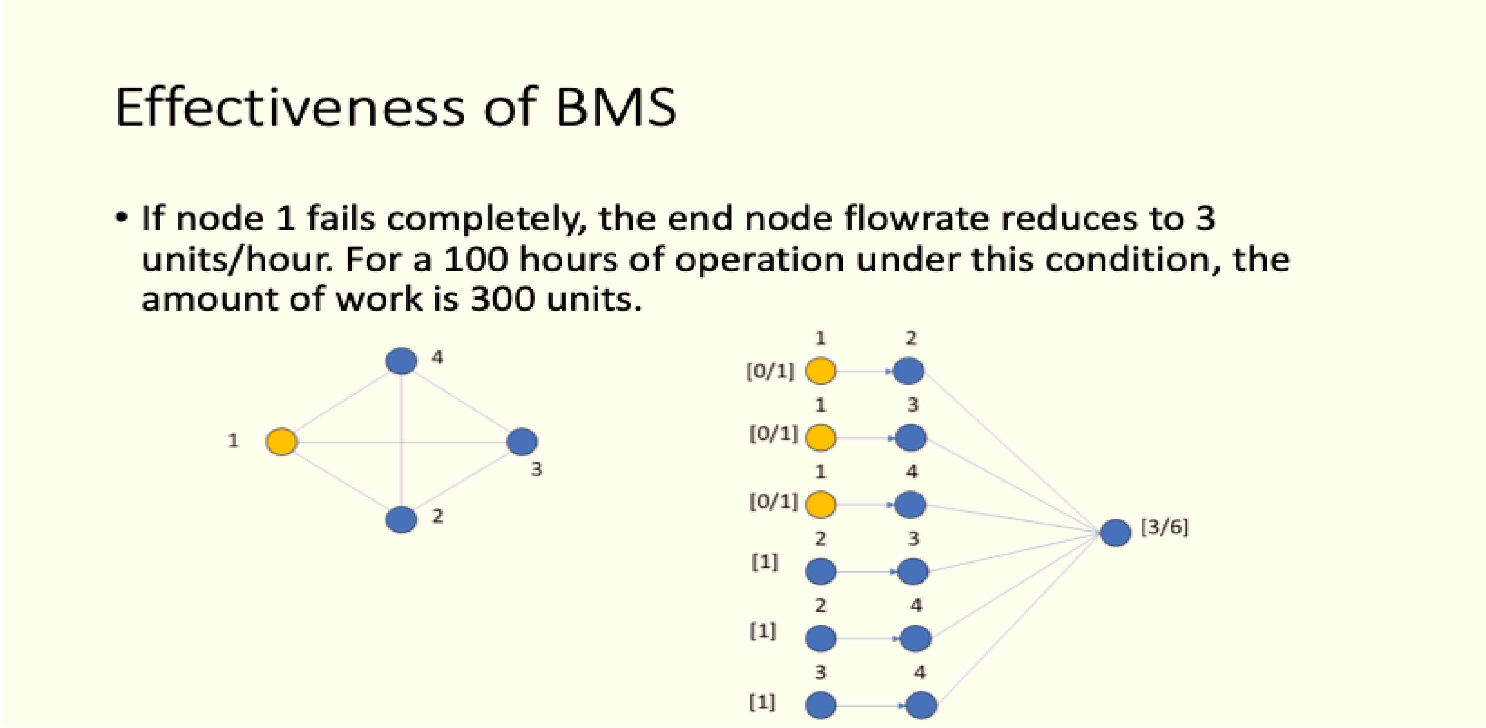
Failure Mode	Capacity Loss
Fuel Cell	100%
Battery	100%
Smart Energy	100%
Network Radio	100%
Night Vision	50%
Friend ID	50%
Position	50%
Physical Monitor	33.33%

When all equipment are working normally, the end node receive a combined flowrate of 6 units/hour.

For a 100 hours of operation with experiencing any failure, the end node will product an output of 600 units of "work".

In Figure 12 below, left side four soldiers are represented, one node is yellow and three nodes are blue and are connected, and **yellow node is not operational** where remaining **three are 100% operational**. The right side diagram represents the relationships.

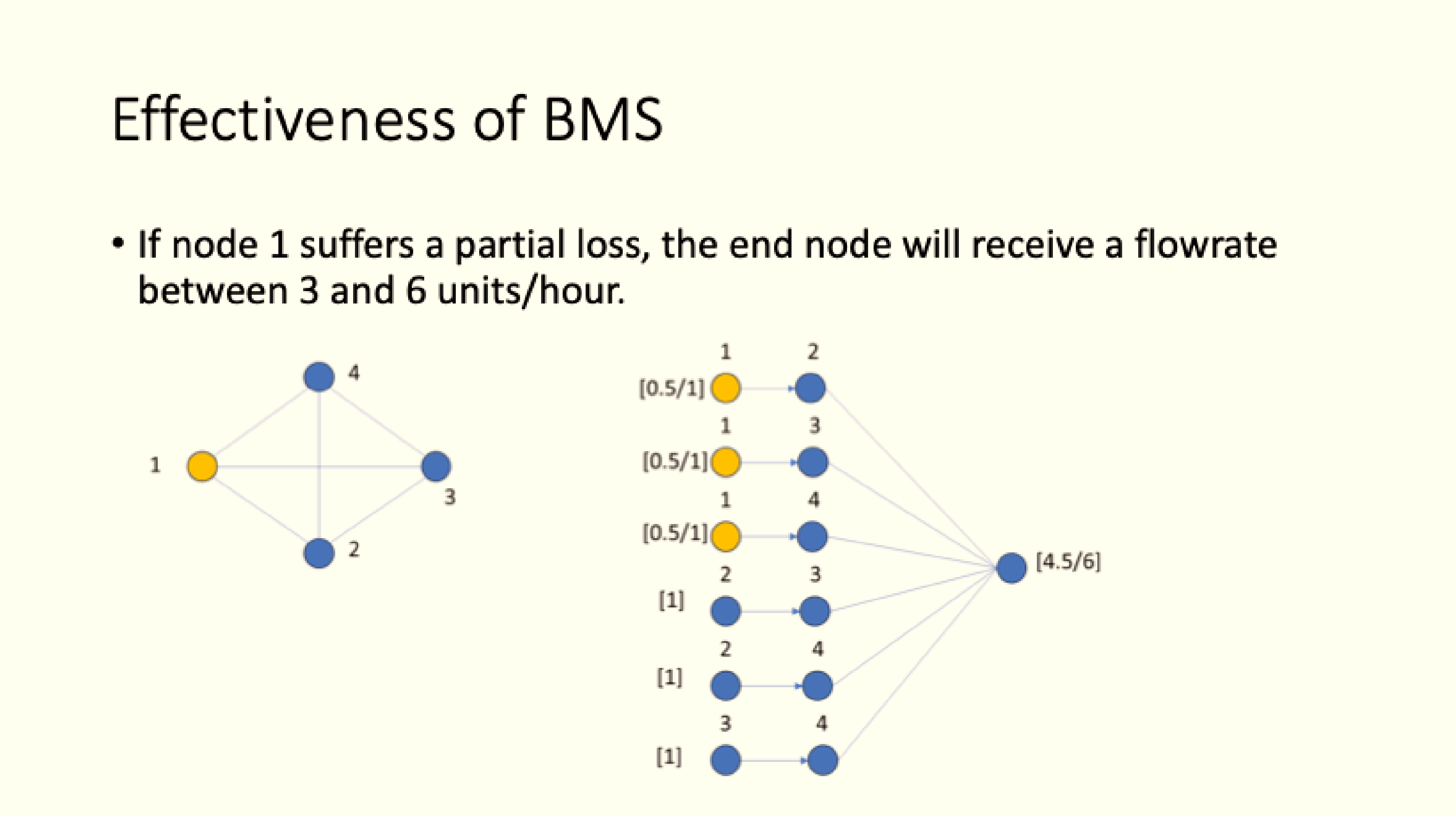
Figure 12
Effectiveness BMS network soldiers (4) model operational network



Effectiveness of BMS

- If node 1 fails completely, the end node flowrate reduces to 3 units/hour. For a 100 hours of operation under this condition, the amount of work is 300 units.

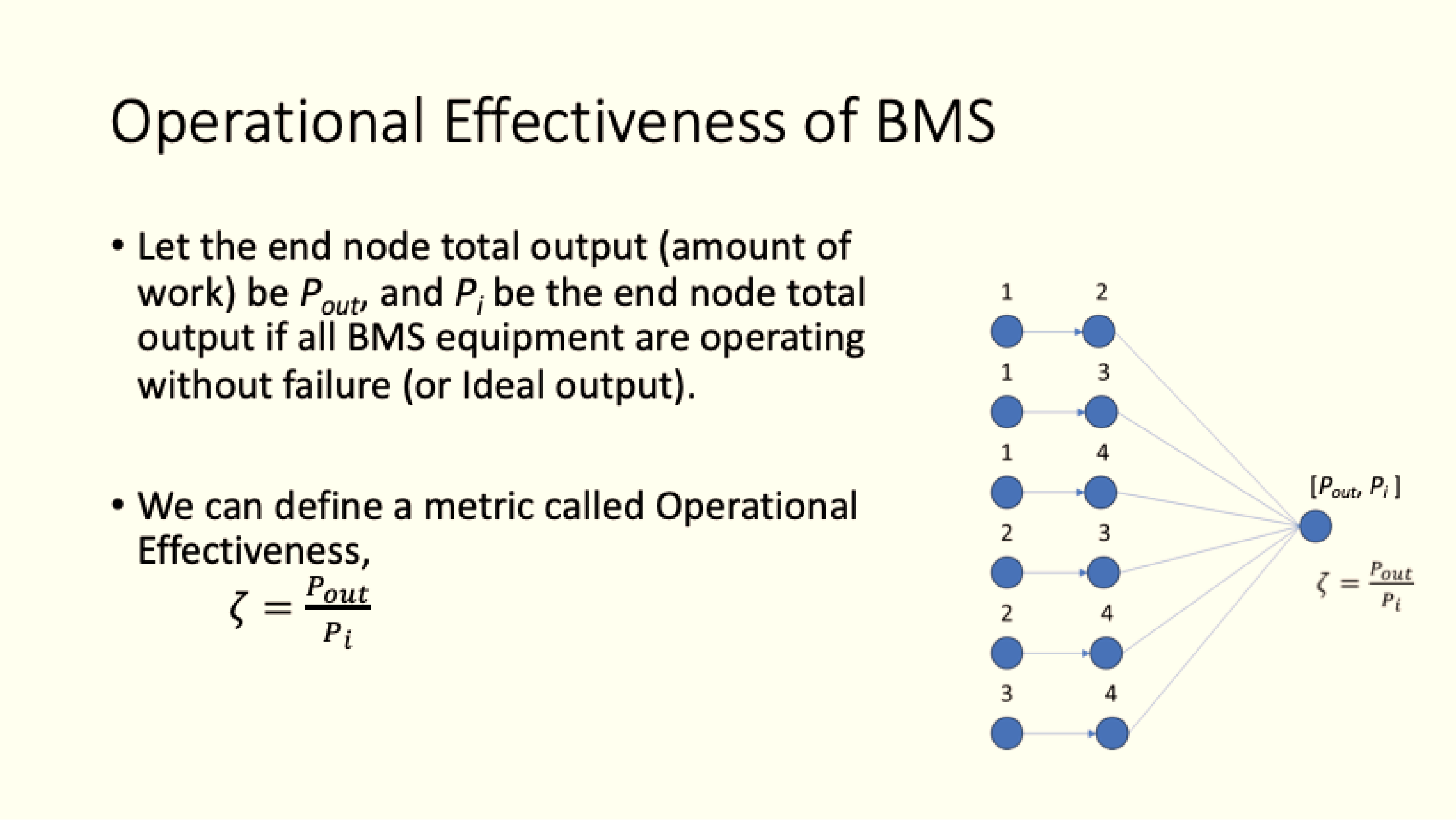
Figure 13
Effectiveness of BMS, four soldiers' network, one soldier not operational and relationships.



Effectiveness of BMS

- If node 1 suffers a partial loss, the end node will receive a flowrate between 3 and 6 units/hour.

Figure 14
BMS network soldier operational effectiveness



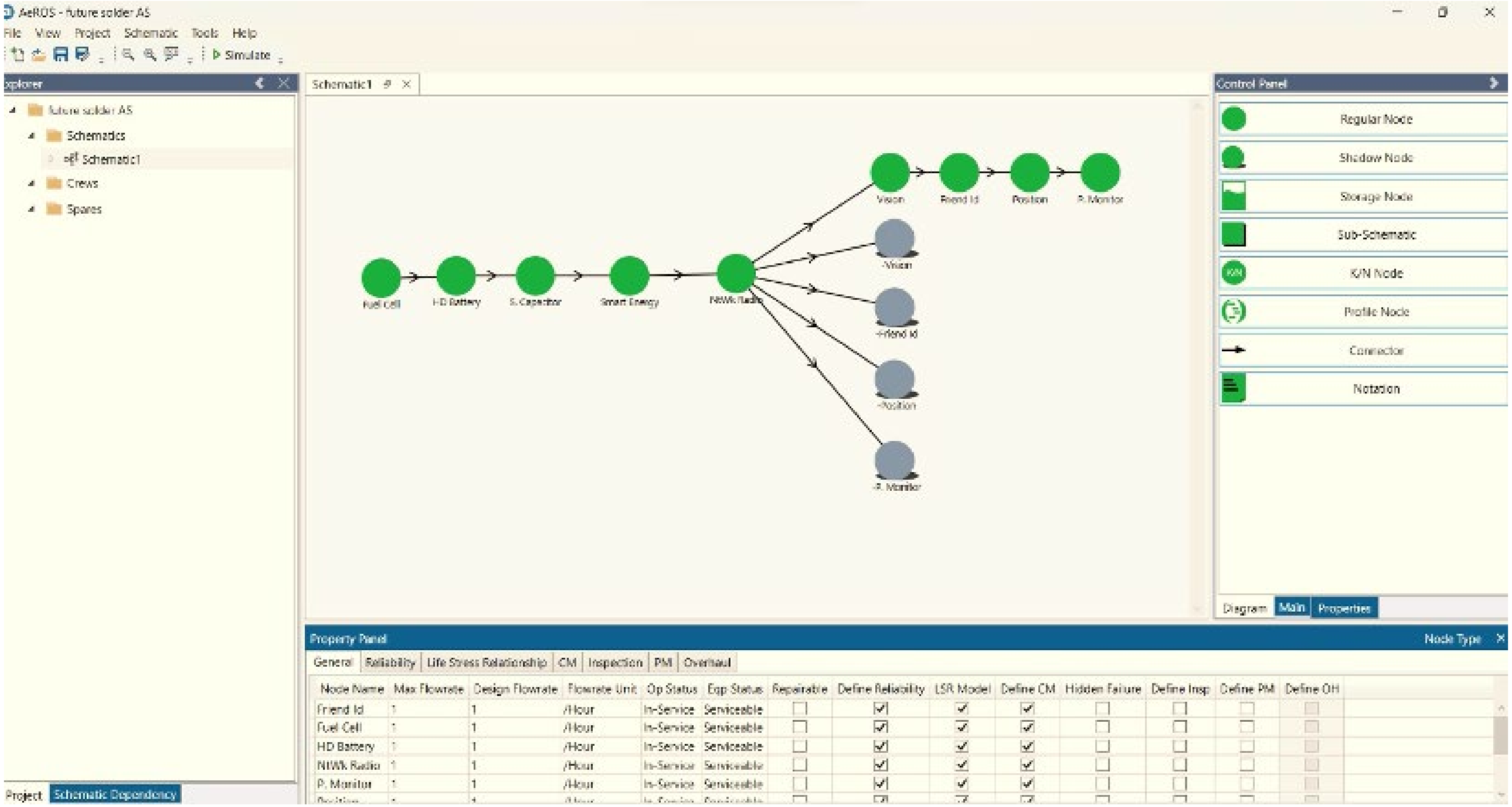
Operational Effectiveness of BMS

- Let the end node total output (amount of work) be P_{out}, and P_i be the end node total output if all BMS equipment are operating without failure (or Ideal output).

- We can define a metric called Operational Effectiveness,

$$\zeta = \frac{P_{out}}{P_i}$$

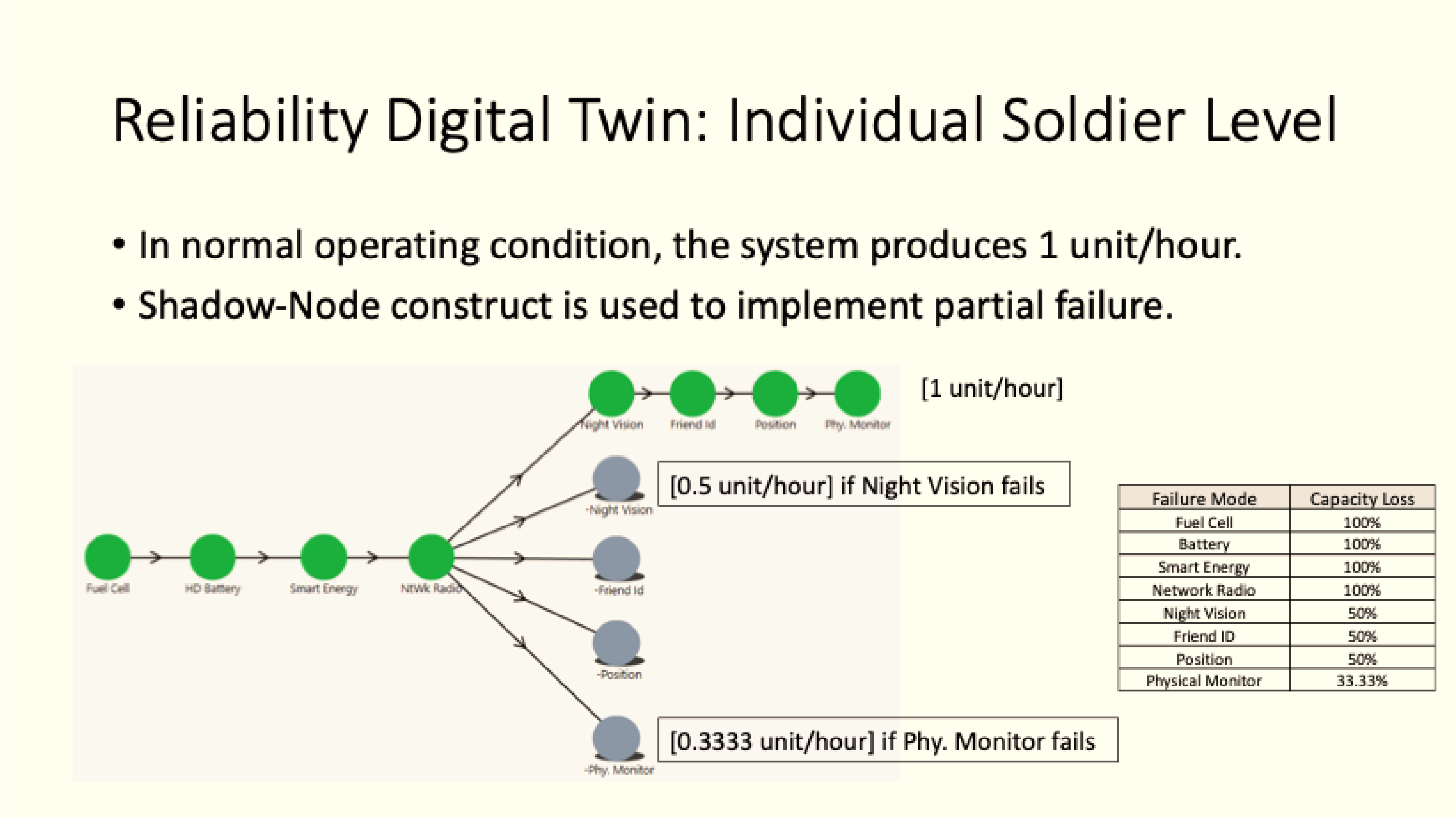
Figure 15
Digital twin simulation (system)



Node Name	Max Flowrate	Design Flowrate	Flowrate Unit	Op Status	Eqp Status	Repairable	Define Reliability	LSR Model	Define CM	Hidden Failure	Define Insp	Define PM	Define OH
Friend Id	1	1	/Hour	In-Service	Serviceable	☐	☑	✓	☑	☐	☐	☐	☐
Fuel Cell	1	1	/Hour	In-Service	Serviceable	☐	☑	✓	☑	☐	☐	☐	☐
HD Battery	1	1	/Hour	In-Service	Serviceable	☐	☑	✓	☑	☐	☐	☐	☐
NtWk Radio	1	1	/Hour	In-Service	Serviceable	☐	☑	✓	☑	☐	☐	☐	☐
P. Monitor	1	1	/Hour	In-Service	Serviceable	☐	☑	✓	☑	☐	☐	☐	☐

In the context of the digital twin, variety engineering involves designing virtual models that accurately represent the variations and configurations of the physical systems. Value engineering in SoS and digital twin aims to maximise the value and benefits derived from the interconnected systems. It involves analysing functions, performance, costs, and risks to optimise resource allocation, minimise redundancies, and enhance the overall value proposition. In the digital twin context, value engineering focuses on using virtual models to simulate and optimise the performance, reliability, scalability, and sustainability of physical systems.

Figure 16
Soldier system digital twin simulation



Reliability Digital Twin: Individual Soldier Level

- In normal operating condition, the system produces 1 unit/hour.
- Shadow-Node construct is used to implement partial failure.

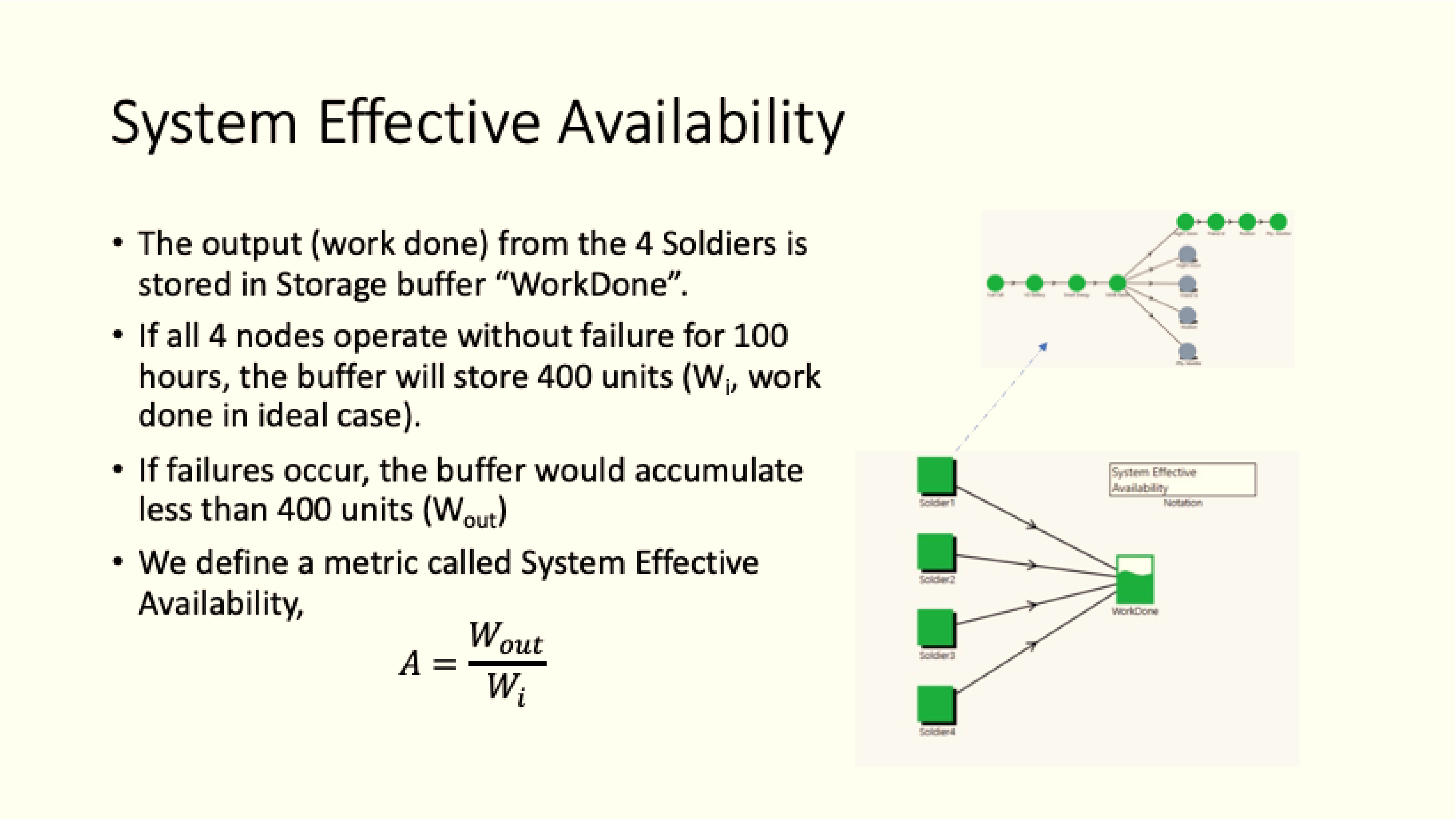
[1 unit/hour]

[0.5 unit/hour] if Night Vision fails

[0.3333 unit/hour] if Phy. Monitor fails

Failure Mode	Capacity Loss
Fuel Cell	100%
Battery	100%
Smart Energy	100%
Network Radio	100%
Night Vision	50%
Friend ID	50%
Position	50%
Physical Monitor	33.33%

Figure 17
Soldier system effective reliability



System Effective Availability

- The output (work done) from the 4 Soldiers is stored in Storage buffer “WorkDone”.
- If all 4 nodes operate without failure for 100 hours, the buffer will store 400 units (W_i, work done in ideal case).
- If failures occur, the buffer would accumulate less than 400 units (W_{out})
- We define a metric called System Effective Availability,

$$A = \frac{W_{out}}{W_i}$$

8.9. Next layer of digital twin systems called digital twin meta system

Figure 18
Meta System Diagram relates to behaviour system analysis (Cybernetics (VSM) referred to as value engineering) and controlling variety by applying amplifiers and attenuators)

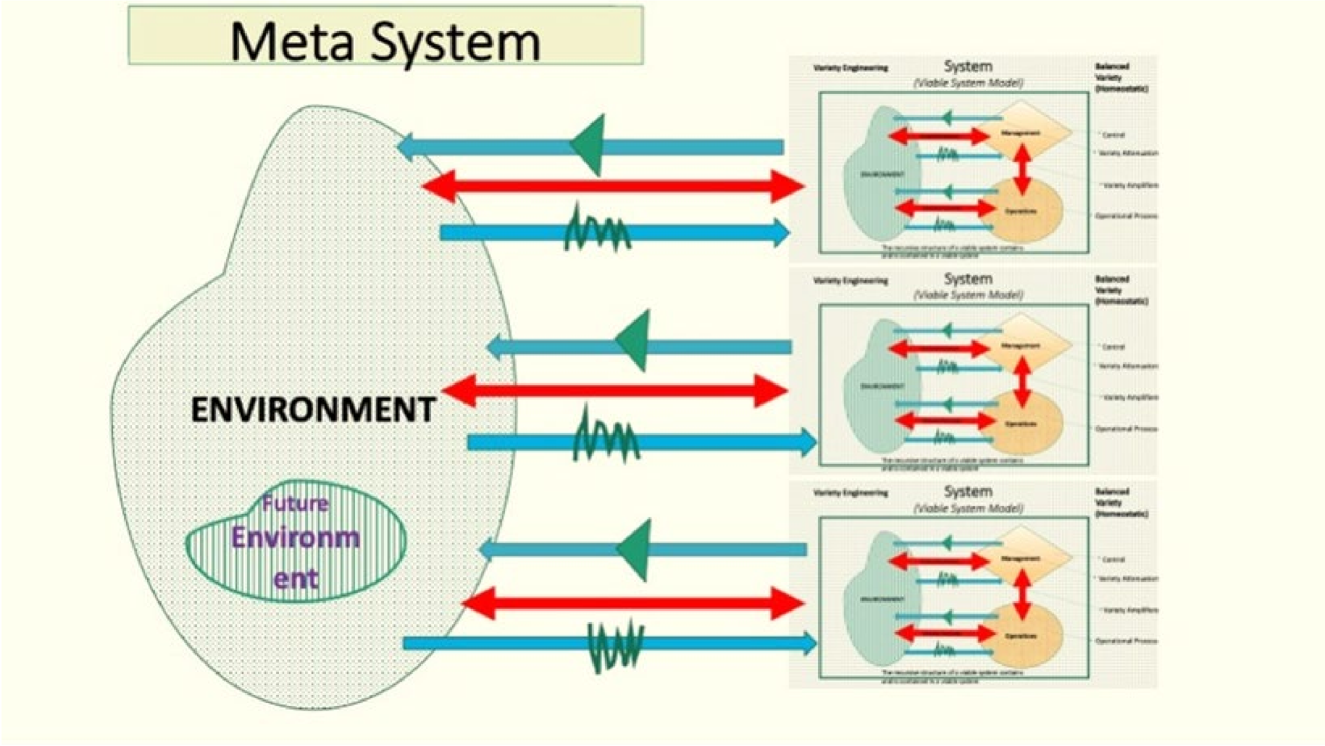
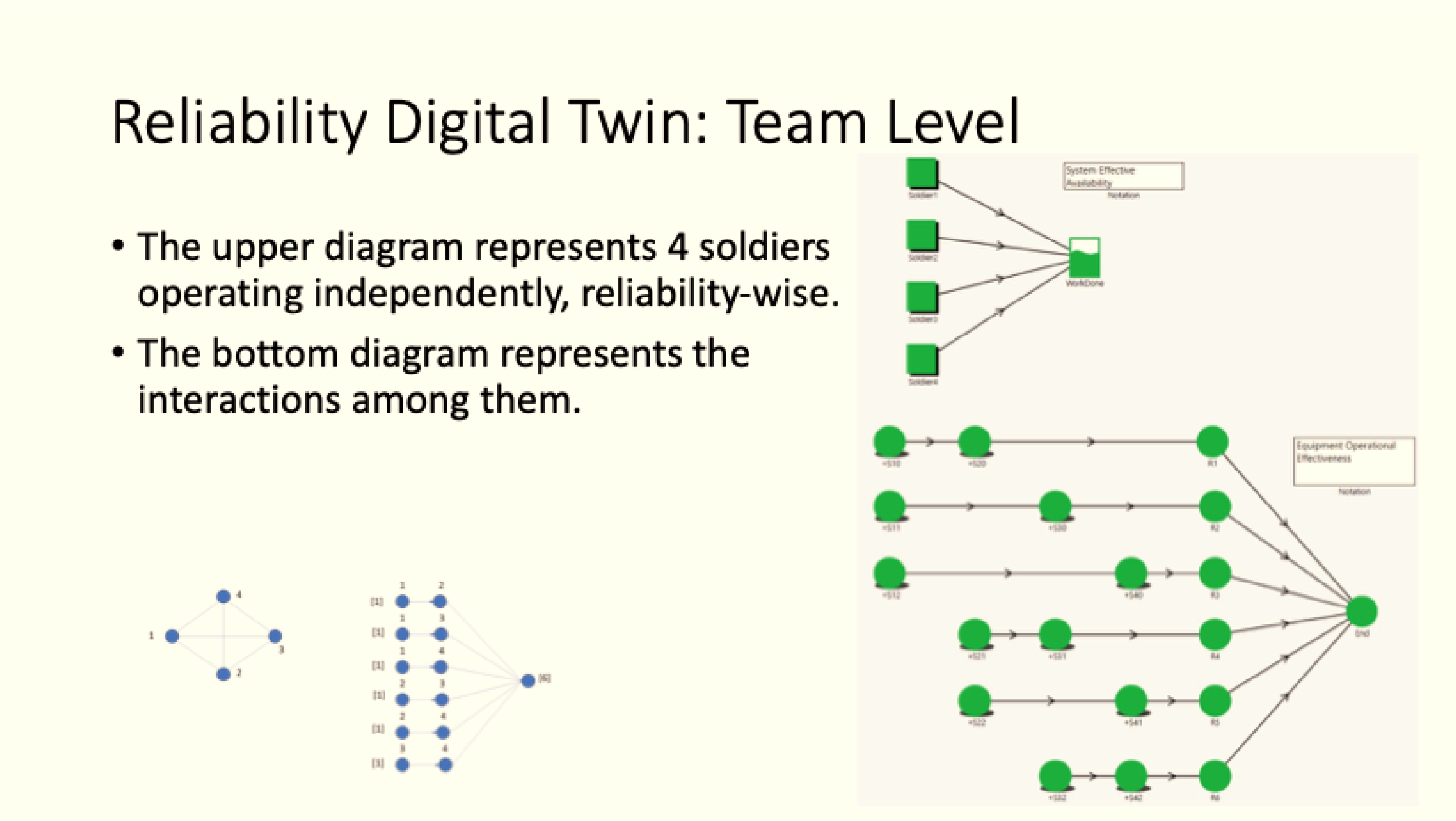


Figure 19
Digital twin meta system simulation

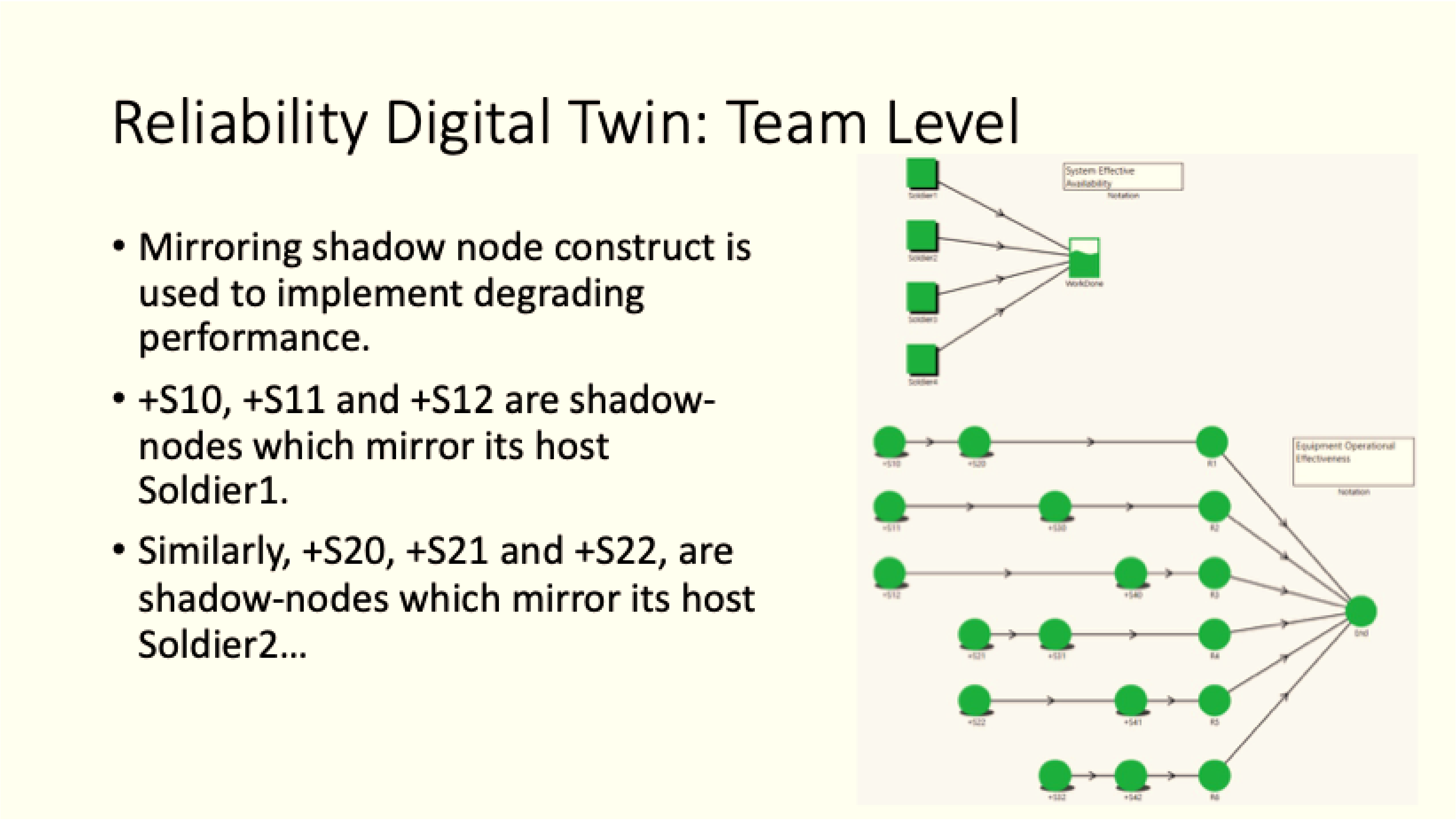


Reliability Digital Twin: Team Level

- The upper diagram represents 4 soldiers operating independently, reliability-wise.
- The bottom diagram represents the interactions among them.

Figure 20

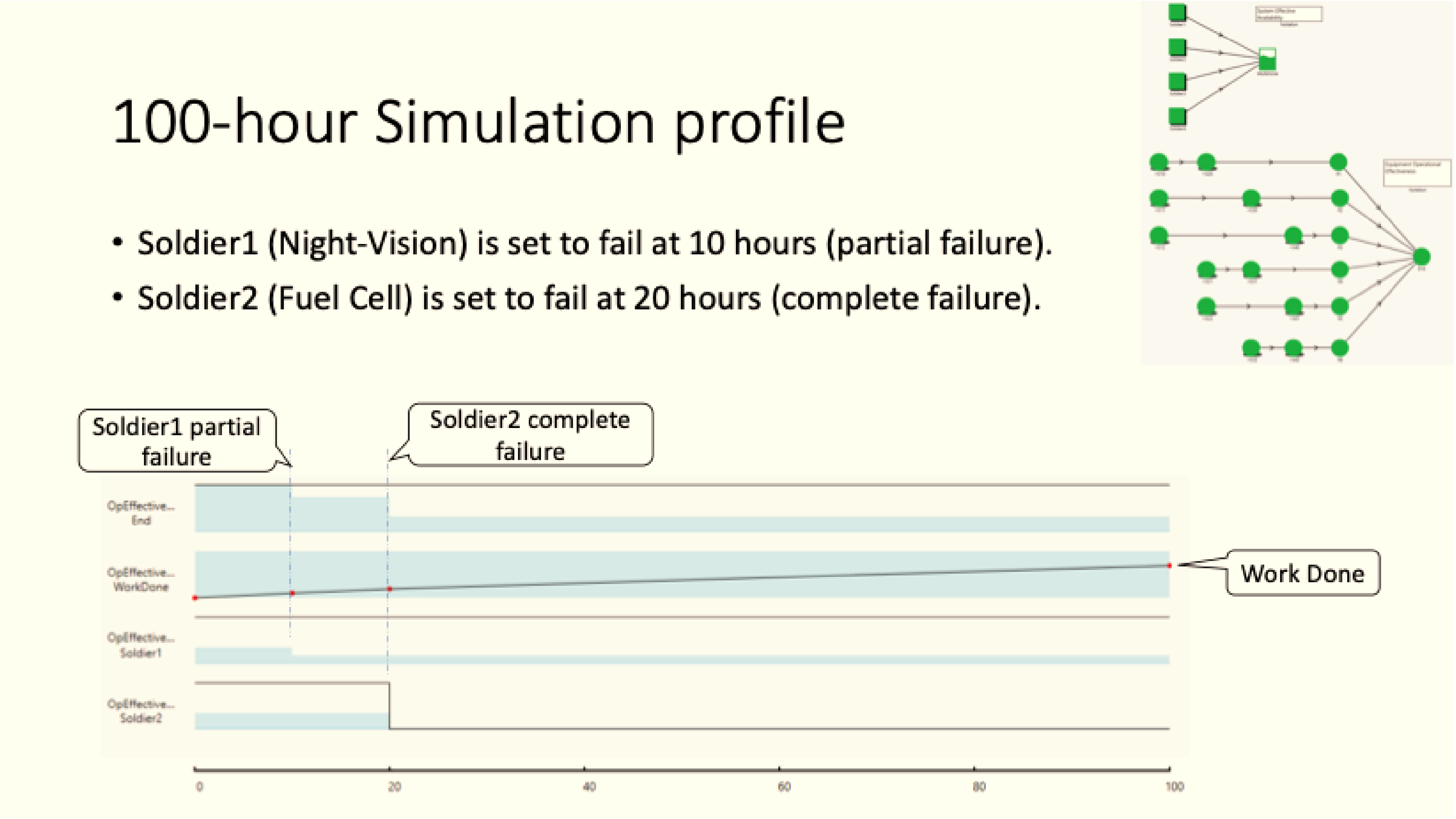
Viable System Model (System) reliability analysis construction



Reliability Digital Twin: Team Level

- Mirroring shadow node construct is used to implement degrading performance.
- +S10, +S11 and +S12 are shadow-nodes which mirror its host Soldier1.
- Similarly, +S20, +S21 and +S22, are shadow-nodes which mirror its host Soldier2…

Figure 21
Viable System Model (System) reliability plotting over time



100-hour Simulation profile

- Soldier1 (Night-Vision) is set to fail at 10 hours (partial failure).
- Soldier2 (Fuel Cell) is set to fail at 20 hours (complete failure).

Soldier1 partial failure

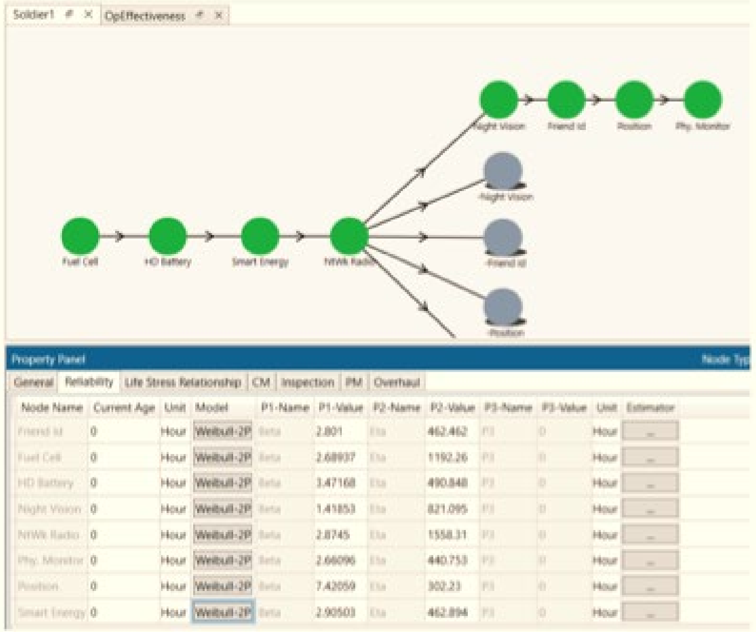
Soldier2 complete failure

Work Done

The digital twin technology enhances systems analysis by providing a virtual replica of the physical system. It captures real-time data, enables analysis and simulation, and deepens system behaviour and performance understanding. By integrating behaviour system analysis techniques, the digital twin facilitates the modelling and analysis of system components' dynamic relationships. This integration improves decision-making, optimises system performance, and identifies improvement opportunities (Sridhar 2018, Liu et al 2019).

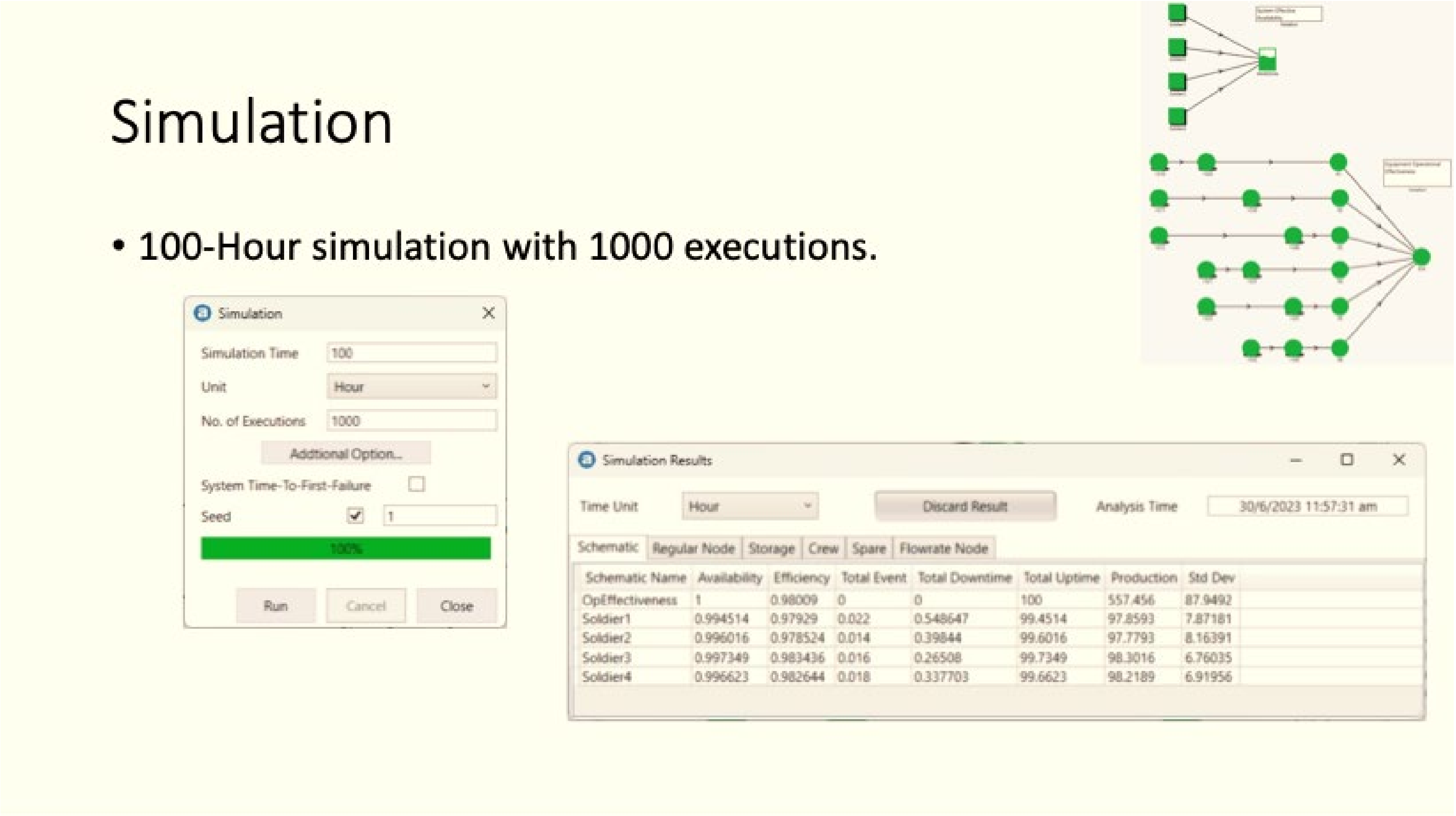
Figure 22
Reliability block diagram, Soldier 1 data analysis

Import Reliability Data from Data Analysis



Node Name	Current Age	Unit	Model	P1-Name	P1-Value	P2-Name	P2-Value	P3-Name	P3-Value	Unit	Estimator
Friend Id	0	Hour	Weibull-2P	Beta	2.801	Eta	462.462	P3	0	Hour	...
Fuel Cell	0	Hour	Weibull-2P	Beta	2.68937	Eta	1192.26	P3	0	Hour	...
HD Battery	0	Hour	Weibull-2P	Beta	3.47168	Eta	490.848	P3	0	Hour	...
Night Vision	0	Hour	Weibull-2P	Beta	1.41853	Eta	821.095	P3	0	Hour	...
NtWk Radio	0	Hour	Weibull-2P	Beta	2.8745	Eta	1558.31	P3	0	Hour	...
Phy. Monitor	0	Hour	Weibull-2P	Beta	2.66096	Eta	440.753	P3	0	Hour	...
Position	0	Hour	Weibull-2P	Beta	7.42059	Eta	302.23	P3	0	Hour	...
Smart Energy	0	Hour	Weibull-2P	Beta	2.90503	Eta	462.894	P3	0	Hour	...

Figure 23
Simulation



Simulation

- 100-Hour simulation with 1000 executions.

Simulation

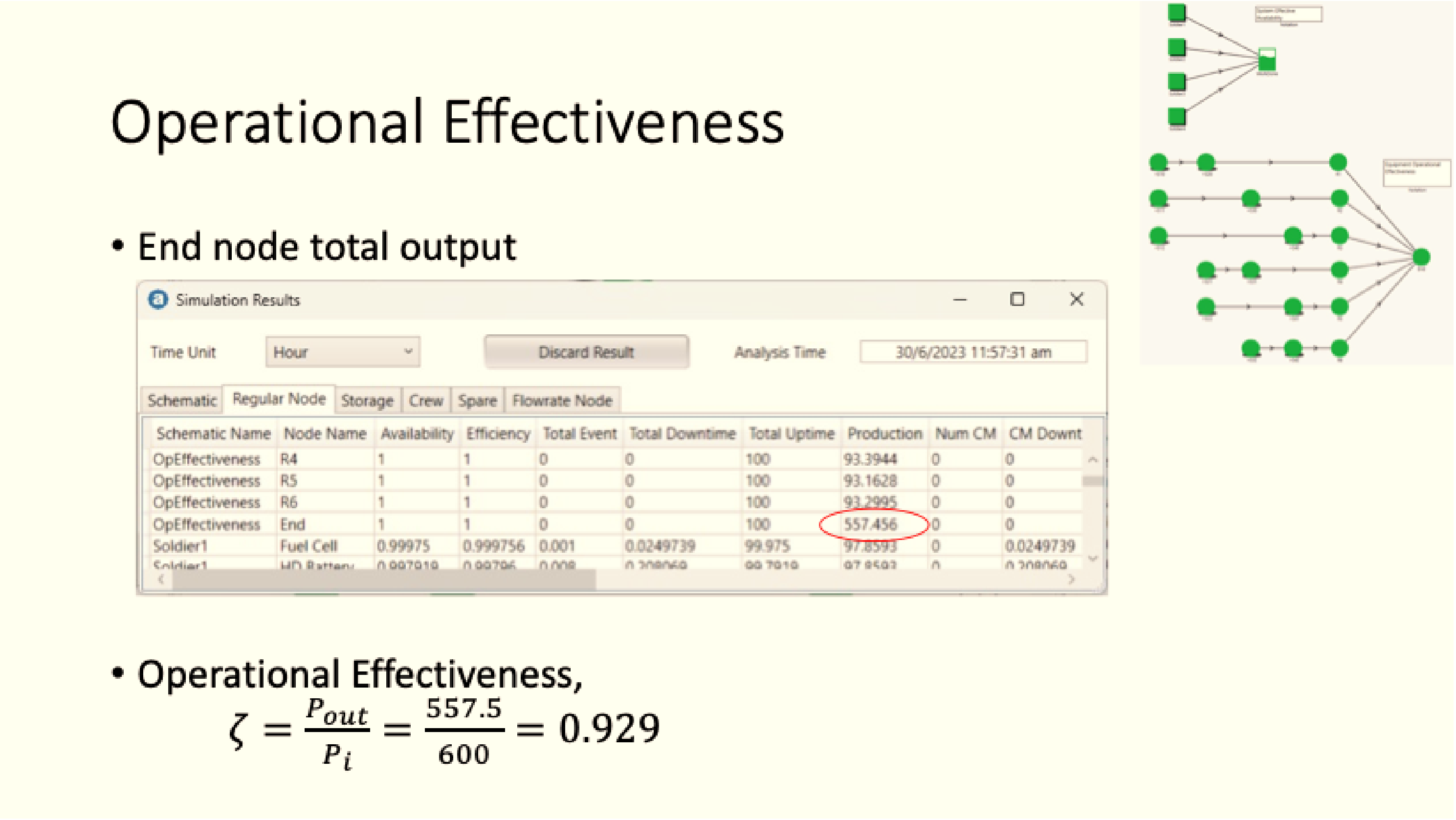
Simulation Time: 100
Unit: Hour
No. of Executions: 1000
System Time-To-First-Failure ☐
Seed ☑ 1
100%

Simulation Results

Time Unit: Hour
Analysis Time: 30/6/2023 11:57:31 am

Schematic Name	Availability	Efficiency	Total Event	Total Downtime	Total Uptime	Production	Std Dev
OpEffectiveness	1	0.98009	0	0	100	557.456	87.9492
Soldier1	0.994514	0.97929	0.022	0.548647	99.4514	97.8593	7.87181
Soldier2	0.996016	0.978524	0.014	0.39844	99.6016	97.7793	8.16391
Soldier3	0.997349	0.983436	0.016	0.26508	99.7349	98.3016	6.76035
Soldier4	0.996623	0.982644	0.018	0.337703	99.6623	98.2189	6.91956

Figure 24
Meta system operational effectiveness



Operational Effectiveness

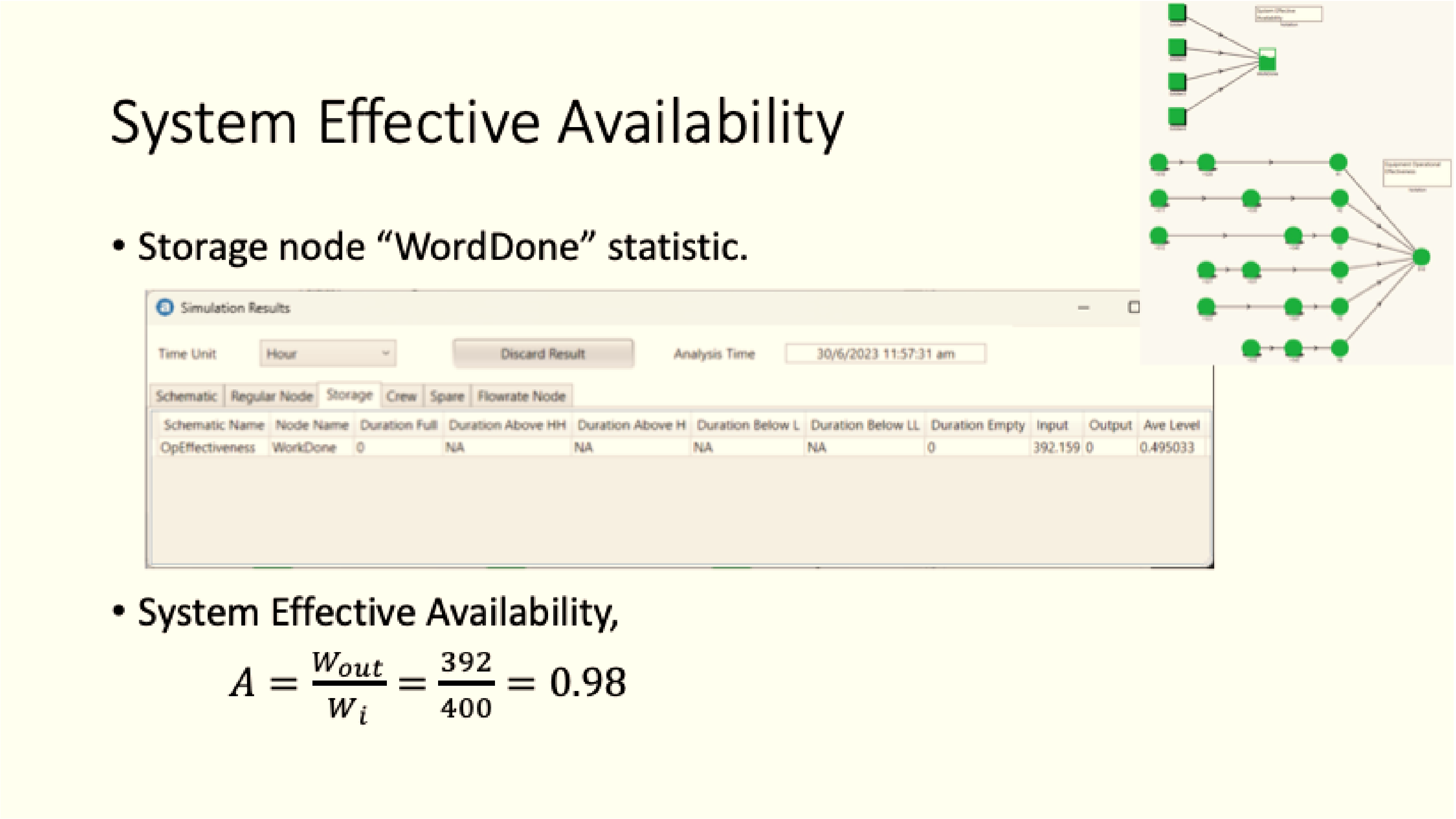
- End node total output

Schematic Name	Node Name	Availability	Efficiency	Total Event	Total Downtime	Total Uptime	Production	Num CM	CM Downt
OpEffectiveness	R4	1	1	0	0	100	93.3944	0	0
OpEffectiveness	R5	1	1	0	0	100	93.1628	0	0
OpEffectiveness	R6	1	1	0	0	100	93.2995	0	0
OpEffectiveness	End	1	1	0	0	100	557.456	0	0
Soldier1	Fuel Cell	0.99975	0.999756	0.001	0.0249739	99.975	97.8593	0	0.0249739
Soldier1	HD Battery	0.997919	0.99796	0.008	0.208069	99.7919	97.8593	0	0.208069

- Operational Effectiveness,

$$\zeta = \frac{P_{out}}{P_i} = \frac{557.5}{600} = 0.929$$

Figure 25
System effective availability



System Effective Availability

- Storage node “WordDone” statistic.

Time Unit: Hour

Analysis Time: 30/6/2023 11:57:31 am

Schematic Name	Node Name	Duration Full	Duration Above HH	Duration Above H	Duration Below L	Duration Below LL	Duration Empty	Input	Output	Ave Level
OpEffectiveness	WorkDone	0	NA	NA	NA	NA	0	392.159	0	0.495033

- System Effective Availability,

$$A = \frac{W_{out}}{W_i} = \frac{392}{400} = 0.98$$

8.9.1. Conclusions

The use of reliability digital twin technology enhances the analysis of systems by creating a virtual replica of the physical system's reliability. The digital twin takes the failure rate behaviour of crucial failure modes/items as input and conducts realistic simulations. These simulations yield a more profound comprehension of the system's behaviour and performance.

Through the integration of behaviour system analysis techniques, the digital twin enables the modelling and analysis of dynamic relationships among system components. This integration enhances decision-making, optimises system performance and identifies opportunities for improvement.

8.10. Simulation – Agent Base Modelling (ABM)

AnyLogic - Agent Base Simulation (ABM and simulation) based on scenario and publication in Chapter 6 and emergent behaviour analysis.

The integration of a digital twin and ABM (emergent behavioural system analysis) offers a powerful approach to comprehensively understanding the intricate interactions and dependencies among interconnected systems within a larger system. By combining the capabilities of a digital twin, which provides a virtual representation of the physical system, with the principles of behavioural system analysis, which focuses on understanding the behaviour of interconnected systems, this integration enables a holistic understanding of complex systems. The interplay between the behaviour of one system and its impact on other interconnected systems can be analysed, leading to enhanced insights into system dynamics and improved decision-making for optimising system performance. The agent-based model is based on Network Centric Warfare (NCW) in this example.

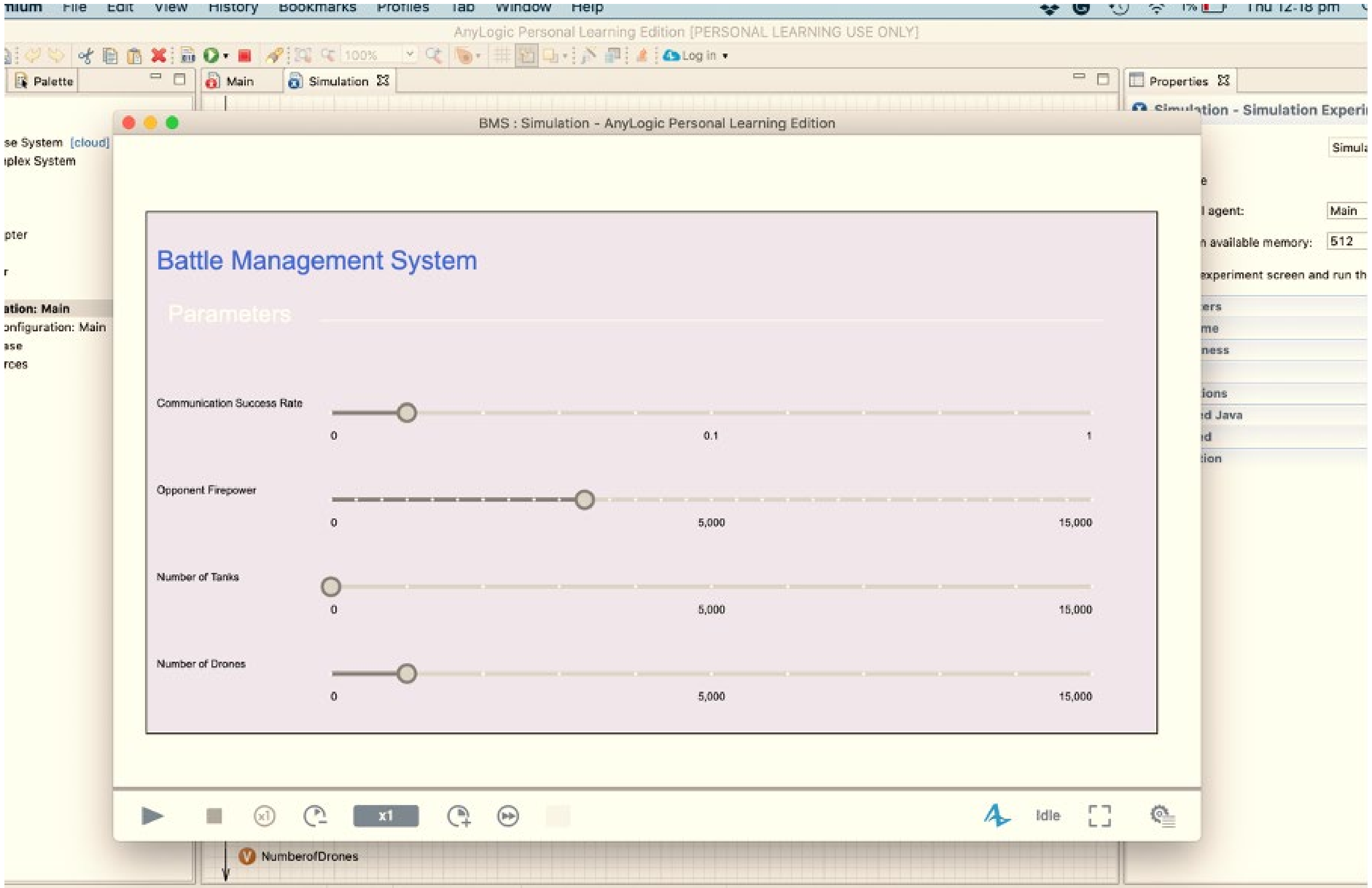
A simulation built on NCW is a virtual or computer-based environment that models and simulates the principles and concepts of NCW. NCW is a military doctrine that leverages advanced information and communication technologies to enable enhanced situational awareness, rapid decision-making, and synchronised actions across networked forces.

In a simulation based on NCW, various aspects of network-centric operations are replicated and tested. This includes modelling communication networks, information sharing and fusion, command and control systems, sensors, and various types of military platforms such as aircraft, ships, and ground vehicles. The simulation aims to recreate realistic scenarios and allows military personnel to train, plan, and evaluate strategies and tactics in a simulated networked environment.

The simulation may involve multiple participants, each representing different elements of a military force, such as commanders, operators, and intelligence personnel. These participants can interact with one another through the simulation, sharing information, issuing orders, and responding to changing situations. The use of the agent-based model has yielded invaluable insights. It has revealed intricate patterns of communication, decision-making bottlenecks, vulnerabilities in network nodes, and unexpected emergent behaviours within the network. For instance, the model may have unveiled that certain communication nodes are critical for maintaining network resilience, or it may have identified strategies for optimising decision-making in decentralised operations. These insights go beyond what traditional modelling approaches can provide.

By using an NCW simulation, military organisations can assess the effectiveness of their networked capabilities, test new technologies, develop tactics and procedures, and improve overall decision-making and operational effectiveness. The simulation allows for the exploration of various ‘what-if’ scenarios, enabling the evaluation of different courses of action and their potential outcomes in a controlled environment. The NCW simulation provides a valuable tool for training, experimentation, and analysis, helping military forces adapt to the challenges of modern warfare and optimise their networked capabilities.

Figure 26
Example - BMS model in AnyLogic agent based simulation



Therefore, a NCW simulation, enhanced by reliability digital twin technology, creates a powerful virtual environment for military organisations. This virtual realm not only models the principles of NCW but also delves into the reliability aspects of crucial system components. By combining these two elements, military entities gain a multifaceted tool that serves several vital purposes.

Relating to NCW, the results and insights from the agent-based model are highly pertinent. They directly contribute to enhancing the understanding of how networked military systems function in practice. For instance, by identifying vulnerabilities or recommending more efficient communication strategies, the model aids in improving the effectiveness, efficiency, and resilience of network-centric military operations. It also sheds light on how to adapt and optimise strategies for NCW scenarios. The utilisation of AnyLogic agent-based modelling in this simulation has significantly advanced our comprehension of NCW dynamics. It surpasses traditional modelling approaches by capturing the nuanced interactions and emergent behaviours of individual agents within the network. This not only enhances our theoretical understanding but also provides practical recommendations for military decision-makers, ultimately contributing to the improvement of complex military operations in a networked environment.

The agent-based model constructed for this study represents a diverse set of agents within the NCW framework. These agents include soldiers, sensors, command centres, and various nodes. Each agent is endowed with specific attributes and operates under defined rules and behaviours. For example, soldiers exhibit decision-making behaviours based on their training and situational awareness, while sensors may autonomously detect and report information. These agents interact in a simulated networked environment, mirroring the real-world dynamics of NCW. The agent-based M&S can be used to detect emergent behaviour in a SoS but cannot examine it or control it. Delphi analysis supports the SoS which frequently generates emergent behaviour when:

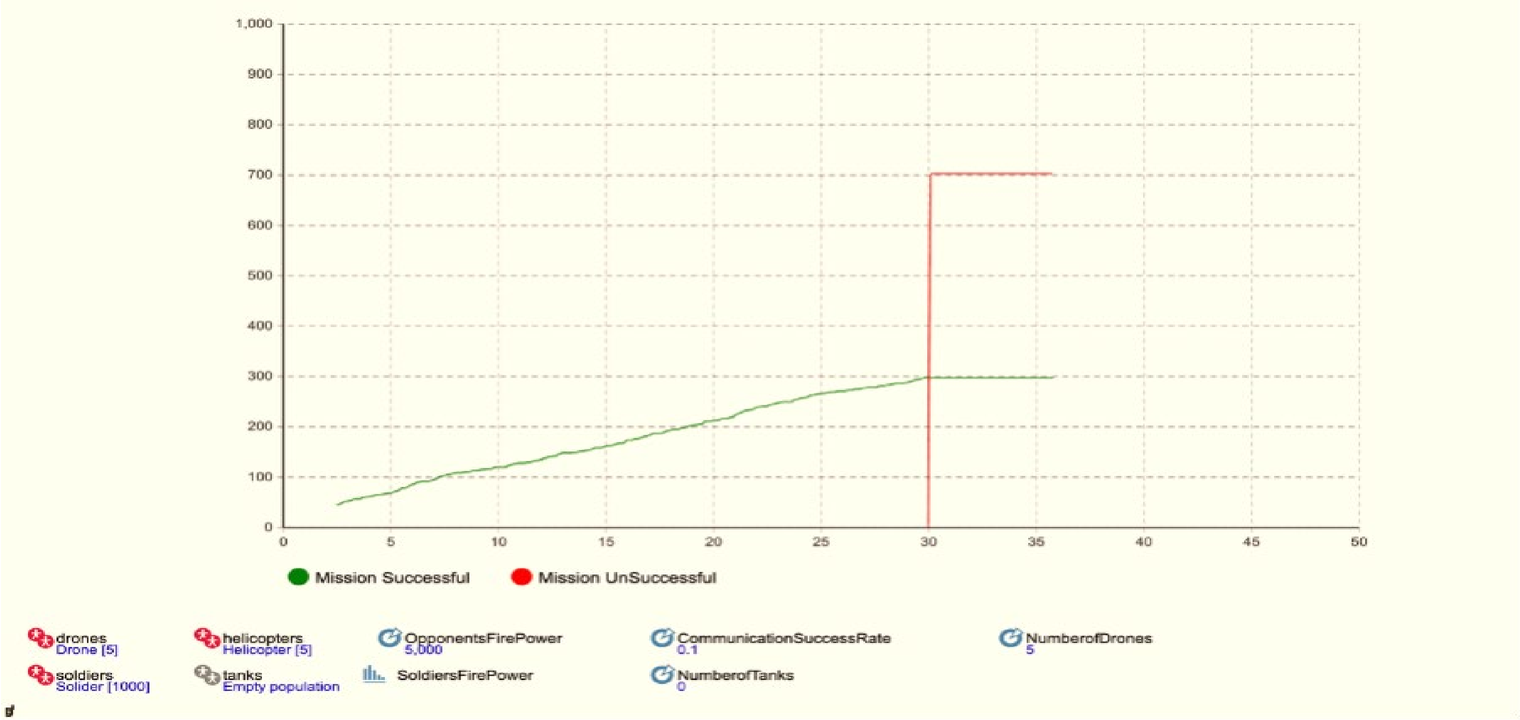
- systems are not designed to function together,
- systems are compromised by electronic attack or cyber warfare,
- systems are not correctly used by operators,
- systems place junk information into the SoS,

- systems cannot interpret the data provide through the SoS, or
- SoS integrations are not adequately tested (including regression testing).

Systems that are not designed to interact cleanly using an agreed information exchange mechanism will introduce emergent behaviours. This is a result of a lack of application programming Interfaces or adherence to a formal messaging format such as those included in the ABCANZ Standards, (formally, the **American, British, Canadian, Australian, and New Zealand Armies' Program)**, which are not covered in this research.

Figure 27

AnyLogic ABM, Axis X is the model time unit and Axis Y is the number of agents, the red line presents the time when emergence behaviour is generated



drones
Drone [5]

helicopters
Helicopter [5]

OpponentsFirePower
5,000

CommunicationSuccessRate
0.1

NumberofDrones
5

soldiers
Solider [1000]

tanks
Empty population

SoldiersFirePower

NumberofTanks
0

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A digital twin can be built in AnyLogic, which is versatile simulation software that supports agent-based modelling along with other modelling paradigms. AnyLogic provides a flexible and customisable environment for creating digital twins by incorporating agent-based simulation.

In this combined approach, the NCW simulation remains a cornerstone for assessing networked capabilities, testing emerging technologies, refining tactical strategies, and enhancing overall decision-making and operational effectiveness. It offers a controlled arena for exploring diverse 'what-if' scenarios, enabling a thorough evaluation of various courses of action and their potential outcomes. As a result, it enables military forces to adapt to the ever-evolving challenges of modern warfare and optimise their networked capabilities. The integration of reliability digital twin technology elevates system analysis by creating a virtual replica of the physical system's reliability. This digital twin utilises data on failure rates for critical system components, conducting realistic simulations to deepen understanding of system behaviour and performance. Through the incorporation of behaviour system analysis techniques, the digital twin also facilitates the modelling and analysis of dynamic relationships among these components. This integration not only enhances decision-making but also fine-tunes system performance while identifying opportunities for improvement. Together, these integrated tools provide military organisations with a comprehensive solution for navigating the complexities of modern warfare.

8.11. The future research in the behaviour system analysis (agent-based modelling and digital twin)

The integration of digital twin and behaviour system analysis allows for a deeper understanding of how changes in one system affect the behaviour of other interconnected systems (Zhao et al., 2023). By combining real-time data from the digital twin with analytical models and algorithms used in behaviour system analysis, it becomes possible to simulate and analyse the behaviour of the entire system holistically (Grieves, 2019). One capability of this integration is the ability to model and simulate different scenarios to understand how changes in one component or subsystem affect the overall performance of the larger system (Lv et al., 2023). For example, in manufacturing, a digital twin can be used to simulate changes in production processes or equipment configurations, while behaviour system analysis can analyse how these changes impact productivity, quality, or energy consumption (Chen et al 2022).

Another capability is the ability to identify potential bottlenecks or vulnerabilities within the system. By analysing the behaviour of interconnected systems using behaviour system analysis techniques, it becomes possible to identify critical points where failures or disruptions may occur (Xu et al 2021). This information can then be used to optimise the design or operation of the system to improve reliability and resilience (Hu et al. 2023). Furthermore, this integration allows for predictive analytics by leveraging historical data from the digital twin and behaviour system analysis models (Shrouf et al., 2022).

By analysing past behaviour patterns and performance data, it becomes possible to predict future outcomes and make informed decisions to optimize system performance (Tao et al., 2021). The integration between digital twin and behaviour system analysis also enables real-time monitoring and control of the interconnected systems (Vollmer, 2018). By continuously collecting data from the digital twin and analysing it using behaviour system analysis techniques, it becomes possible to detect anomalies, deviations, or potential issues in real time (Zeng et al., 2023). This information can then be used to trigger alerts, notifications, or automated actions to prevent or mitigate problems (Zhang et al., 2023).

CHAPTER 9: DISCUSSION

This research is about the understanding of how and why complex projects fail, and this study is about determining if a project framework system can be modelled to minimise the occurrence of failure through control and reduction of negative emergence. The publications which are included in this thesis are:

Emergent behaviour in the battle management system (Chapter 5)

- In the thesis research paper, Emergent Behaviour in the Battle Management Systems we examined the emergence of battle management systems to understand the difference between SoS multiple interdependent Battle Management Systems problems.

Cybernetics and battle management systems (BMS) and its application to network soldiers (Chapter 6).

- Examines the cyber-physical systems, systems of systems, and emergent behaviour. Cybernetics battle management systems (CBMS) is considered as a systems of systems (SoS) and the emergent behaviour is presented.

Cyber–physical systems, systems of systems, and emergent behaviour. Cyber battle management systems (CBMS) are considered as systems of systems (SoS) and their emergent behaviour is presented, wherein the viable system model (Chapter 7).

- The publications focus was on the crucial role of integrating methodologies in the context of managing large and intricate engineering systems of systems.

9.1. Projects complex systems involve numerous interconnected systems and subsystems

The integration of methodologies facilitates interdisciplinary teamwork, streamlined project management, risk mitigation, modular design, continuous testing, process standardisation, cybersecurity, and performance monitoring. Furthermore, the exploration of the methodologies extended to the significance of embracing complex systems thinking to comprehend the interactions and emergent behaviours of interconnected engineering project systems. By adopting a holistic perspective and incorporating cybernetic principles, project teams can proactively anticipate and manage potential risks, enhancing the adaptability and resilience of their systems (Esposito et al., 2023; Engwall, 2003).

The discussions in Esposito et al., (2023) and Engwall, (2003) introduced a novel research approach that integrates methodologies like digital twin technology, agent-based modelling, cybernetics (specifically viable system theory (VSM)), and the study of emergent behaviour in SoS. This research aims to overcome existing limitations and provide fresh insights into the management of complex engineering projects. The researcher emphasised the significance of the VSM in managing projects with diverse subsystems, particularly within the realm of systems of systems. The VSM's emphasis on organisational autonomy, self-regulation, and effective communication aligns well with the challenges of coordinating multiple interconnected subsystems in complex projects. These discussions encompassed various aspects of engineering systems management methodologies, complex systems thinking, and the VSM, highlighting the importance of robust and adaptive strategies for effectively and securely handling large and complex engineering projects.

Complexity is caused by interdependencies and uncertainties (Williams, 1999); it is also caused by human-oriented social aspects (Stacey, 2007) or behavioural complexity. In addition to internal complexities such as technology and interfaces of existing systems, external complexities such as stakeholder relationships (Pryke & Smyth, 2006) can lead to difficulties in understanding, in addition to assessing, project behaviour. Remington and Pollack (2007) discussed several types of complexities and tools to address the various elements in complex systems (Williams et al., 1995). Several researchers have argued for the incorporation of complexity into the framework of project management (Fortune & White, 2006). The nebulous nature of complexity has attracted discourses that are often abstract and far removed from the real world of project management. Concerns about the inadequacy of existing theories in project management and the concerted research efforts directed at alternate paradigms based on complexity theory are a more recent phenomenon (Koskela & Howell, 2002). Such research suggests that there is no universal theory for projects and one can explore multiple conceptualisations to explain or predict the behaviour of projects (Koskela & Howell, 2002; Soderlund, 2004; Turner, 2006).

Emergence appears in different forms (positive/negative) and shapes (types) in a variety of systems from simple to complex. Thus, there is a need for a mechanism that provides a structured approach for the analysis and control of such behaviours. This issue is addressed by proposing a framework for the exploration of emergent behaviours in multi-agent systems. The aim is to show that if any 'Emergent Behaviour Systems' , i.e., a complex (multi-agent) system exhibiting emergence, is represented formally using the framework, it would be easy for a modeller of the system to analyse and study the causal relationships between micro and macro layers. We have demonstrated with a case study in Chapter 6 and simulation in Chapter 8 how the BMS framework can be useful for implementing and classifying emergent behaviours using existing and known approaches in the literature. The challenge of design in an SoS is to leverage the functional and performance capabilities of the constituent systems to achieve the desired SoS capability. The BMS and warfare are inherently chaotic. Although these models claim to be detailed, it became theoretically clear when one tried to analyse the value of factors such as human behaviour and knowledge-based warfare, that these become quite limited.

9.2. Enhancing project control and management through multi-methodological approaches and cybernetic principles

In the realm of project management, Lee and Miller (2004) introduced a multi-methodological approach that merges system dynamics with critical project management, specifically focusing on interactions among projects. This approach caters to those involved in designing, developing, managing, operating, and maintaining systems, including SoS. SoS denotes a collective of task-oriented systems that synergise resources to create a new, more intricate system offering enhanced functionality and performance beyond the cumulative capabilities of its constituents. The adapted VSM played a pivotal role in capturing and interpreting project management structures, with Piney's (2008) modified VSM framework serving as the foundation for project management structure analysis. Effective project control involves identifying deviations from plans or baselines and taking corrective measures to realign with the intended trajectory. To uphold cybernetic control of a project, certain key elements must be present, including a project baseline, project measures, variance identification, and variance correction. Recognised as a form of mini-general management, project management entails broader responsibilities for engineering managers in large projects. The project manager oversees operational and material resources, encompassing equipment, materials, supplies, and finances, while also leading a diverse team including accountants, technical specialists, engineers, technicians, and tradespersons (Turner, 2006; Samson, 2009). This comprehensive approach integrates multi-methodology and cybernetic principles, contributing to a more effective and efficient management of complex SoS.

9.3. Synergising digital twins and system analysis for enhanced system understanding and optimisation

A digital twin serves as a virtual representation of a physical object, process, or system. It captures real-time data from sensors, devices, and other sources to create a digital replica that can be used for analysis, simulation, and optimisation. By integrating digital twin and behaviour system analysis, it becomes possible to combine the virtual representation of a physical object or system with the study of interconnected systems' behaviour. This integration enables the analysis, simulation, and optimisation of the overall system by capturing real-time data from sensors and devices. For example, in manufacturing, a digital twin can simulate changes in production processes and analyse their effects on productivity or energy consumption. It also helps identify potential bottlenecks or vulnerabilities within the system by analysing interconnected systems' behaviour. This information can be used to optimise the system's design or operation to improve reliability and resilience.

In Chapter 8, statistical modelling and simulations are employed to study complex systems and SoS. Researchers use statistical methods to analyse quantitative data collected through experiments, surveys, or other means. Simulations, on the other hand, involve creating computational models to simulate the behaviour of complex systems. These models can provide insights into the system's dynamics and help test different scenarios or interventions.

Qualitative data and Delphi group analysis (as discussed in Chapter 8), present information gathered through various means, such as interviews and discussions, which can provide valuable insights into human behavioural patterns, decision-making processes, and perceptions within complex systems. The researcher conducted Delphi group discussions with experts, stakeholders, or individuals with experience in the system under study to gather qualitative data. Conversely, the Delphi group is a structured qualitative technique that can uncovers diverse perspectives and opinions through group discussions and interactions among experts in a specific field.

9.4. Unlocking system insights: Leveraging predictive analytics for enhanced integration of digital twin and system analysis

Predictive analytics play a crucial role in the integration of digital twin and behaviour system analysis. By leveraging historical data from the digital twin and system analysis models, predictive analytics enables the forecasting of future outcomes and facilitates informed decision-making to optimise system performance. One important application of predictive analytics is predictive maintenance. By analysing historical data, patterns, and trends related to equipment failures or maintenance requirements can be identified. This information allows for the prediction of when equipment is likely to fail or require maintenance, enabling proactive scheduling of maintenance activities to minimise downtime and maximise operational efficiency. Predictive analytics can also be utilised for performance optimisation. By analysing historical performance data and understanding the relationships between different system components, predictive models can be developed to optimise settings, configurations, or resource allocations, thereby improving overall system performance. Energy efficiency is another area where predictive analytics can make a significant impact. By leveraging historical energy consumption data from the digital twin and behaviour system analysis models, predictive analytics can identify patterns and trends related to energy usage. This information enables the development of predictive models that optimise energy consumption and identify opportunities for energy savings, such as adjusting production schedules or equipment settings. Predictive analytics also play a crucial role in demand forecasting. By analysing historical data on demand patterns and external factors, predictive models can be developed to forecast future demand. This information assists in planning production schedules, inventory management, and resource allocation to meet anticipated demand, reducing the risk of overstocking or stockouts. Additionally, predictive analytics can help in predicting failures or disruptions within the system. By analysing historical data on system behaviour and performance, patterns or indicators that precede failures can be identified. Early detection of potential issues allows for preventive measures to be implemented, minimising the impact of failures and ensuring system reliability and uptime. Therefore, the integration of digital twin and system analysis, along with predictive analytics, offers several advantages for managing complex systems. It enables proactive maintenance, performance optimisation, energy efficiency improvements, demand forecasting, and early detection of failures or disruptions.

9.5. Problem solving for the reliability of complex technical systems

The ability to illuminate issues and to break impasses makes finding sustainable solutions to the challenges extremely effective in opening new horizons, strengthening leadership, and enabling strategic decisions (Regine & Lewin, 2000).

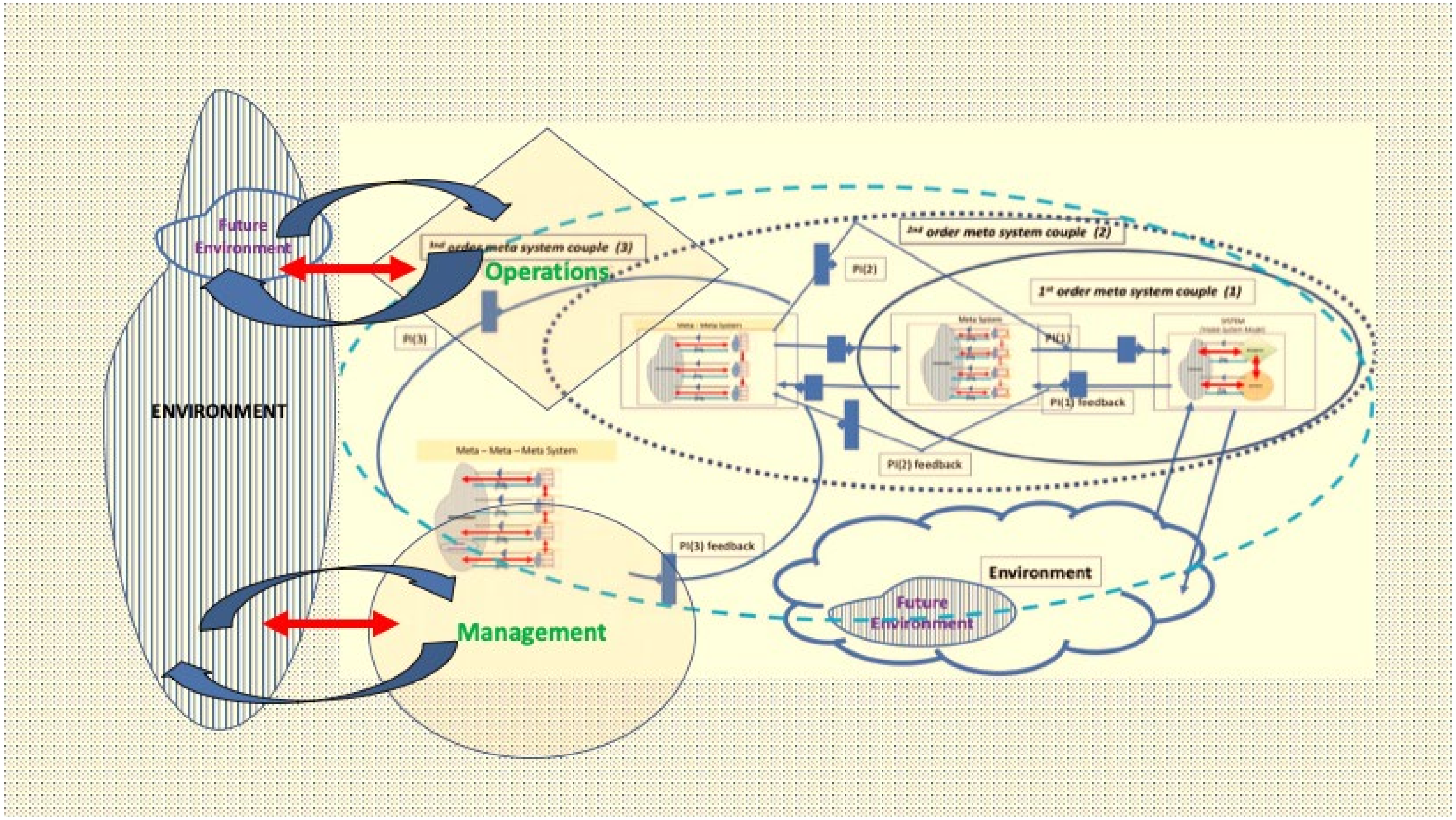
The classification and analysis of complex technical systems based on their purpose and modes of use provide a foundation for addressing reliability requirements. The development of an analytical model for systems with a complex operating mode allows for the assessment and establishment of reliability and maintainability requirements. By modelling the system's performance under different distribution functions, recommendations can be formulated to support the specification of reliable and maintainable systems for their intended purposes.

9.6. The integration of modelling and simulation (Chapter 8)

This integration enables the modelling and simulation of different scenarios to understand how changes in one component or subsystem impact the overall system performance. It also facilitates the identification of potential bottlenecks or vulnerabilities within the system, allowing for optimisation to improve reliability and resilience. The integration further enables predictive analytics by leveraging historical data from the digital twin and behaviour system analysis models. By analysing past behaviour patterns and performance data, it becomes possible to predict future outcomes and make informed decisions to optimise system performance. Additionally, the integration enables real-time monitoring and control of interconnected systems. By continuously collecting data from the digital twin and analysing it using behaviour system analysis techniques, anomalies, deviations, or potential issues can be detected in real-time. This information can be used to trigger alerts, notifications, or automated actions to prevent or mitigate problems.

The components of an SoS include tangible and intangible objects that perform functions and behaviours. Tangible objects are physical entities such as equipment, infrastructure, and hardware, while intangible objects encompass information, knowledge, processes, and organisational structures. Both tangible and intangible components are essential for the functioning and success of an SoS. Tangible objects provide physical capabilities, while intangible objects enable communication, coordination, and decision-making within the system. Managing and integrating both types of components are crucial for the overall performance of the SoS. The cybernetic approach can be applied to manage complex project systems, considering the nonlinear nature and emergent properties of such systems.

Figure 28
Meta meta methodology in systems of systems incorporating Rios and Yolles' concepts in project and organisation methodology



9.7. Cybernetic control – project control techniques

A Viable System Model (VSM) could be adapted for analysis of the project management structure and provides a well-established framework to aid the design and diagnosis of organisations to survive and thrive in complex operating environments (Lowe et al., 2020). Being manageable from a VSM perspective implies vertical unfolding complexity will ensure fundamental aspects with respect to viability and each level of recursion is considered to be a viable system. The level of recursion defines within the system in focus – what it does and the why (purpose). The operating entities define the how (system – how it interacts with its product and services to its relevant environment).

Therefore, the concept of higher-order cybernetics, expands the understanding of cybernetics through horizontal recursion and exploring orders beyond the traditional scope. The higher orders encompass various concepts related to cognition, epistemology, rationality, and socio-cybernetics. In the context of SoS, tangible and intangible components are crucial for the functioning and success of the system. Tangible objects provide physical capabilities, while intangible objects enable communication, coordination, and decision-making. Managing and integrating both types of components is vital for overall SoS performance. The cybernetic approach, considering the nonlinear nature and emergent properties of complex project systems, can be applied to project control techniques. The VSM is a useful framework for analysing project management structures, ensuring viability and manageability at each level of recursion within the system. The level of recursion determines the system's purpose while operating entities define how it interacts with products, services, and the environment.

CHAPTER 10: CONCLUSION

10.1. Complex systems in project management

Complex systems in project management refer to projects that involve numerous interconnected systems and subsystems. These systems must collaborate seamlessly to achieve the overall project objectives. Managing such projects requires a holistic approach that considers the intricate relationships among various components. This involves identifying dependencies, optimising resource allocation, and ensuring effective communication among stakeholders. Utilising tools like systems thinking and network analysis can help project managers navigate the complexities of these systems.

In this chapter the research concludes by emphasising the pivotal role of integrated methodologies in engineering projects. It outlines the achieved objectives, discusses limitations, proposes recommendations, and highlights the original contributions of the research. The research contributes insights into integrated methodologies, creating a transformative framework for collaboration, problem-solving, and project security. Objectives were successfully met through a comprehensive exploration of collaboration, risk management, modular design, continuous integration, standardisation, and performance monitoring. Acknowledging contextual and scope limitations, this study paves the way for nuanced investigations. Specific recommendations focus on tailored methodologies and interdisciplinary training, while general recommendations advocate for broader industry adoption. Future directions include longitudinal studies, comparative analyses, and exploration of emerging technologies within integrated methodologies. The research guides future research and industry practices, showcasing the transformative impact of integrated methodologies on engineering projects.

10.2. Enhancing project control and management through multi-methodological approaches and cybernetic principles in systems of systems

This topic delves into the application of cybernetic principles and multi-methodological approaches in managing systems of systems within a project. Cybernetics, the study of control and communication in systems, offers valuable insights into how to maintain control over interconnected components. By integrating various methodologies and drawing from cybernetic principles, project managers can better monitor, adapt, and optimise their projects, ensuring that they stay on track and meet their goals.

10.3. Unlocking system insights: Leveraging predictive analytics for enhanced integration of digital twin and system analysis

The integration of digital twins and predictive analytics in project management can significantly enhance decision-making and project control. Digital twins are virtual representations of physical systems or processes, while predictive analytics uses data and algorithms to forecast future outcomes. Combining these technologies allows project managers to simulate scenarios, predict potential issues, and make proactive decisions. This topic explores how organisations can harness these tools to improve project outcomes and reduce risks.

10.4. Problem-solving for the reliability of complex technical systems

Complex technical systems, such as aerospace or industrial manufacturing systems, often require rigorous problem-solving to ensure their reliability. This involves identifying potential failure points, conducting root cause analyses, and implementing effective solutions. Reliability engineering techniques, such as Failure Mode and Effects Analysis (FMEA) and Reliability-Centered Maintenance, play a crucial role in addressing reliability issues and maintaining the functionality of complex systems.

10.5. The integration of modelling and simulation

Modelling and simulation play a vital role in understanding and managing complex systems. This involves creating mathematical or computational models that mimic the behaviour of the actual systems. Simulation helps project managers test different scenarios, optimise resource allocation, and evaluate the impact of various decisions on project outcomes. It's particularly valuable for risk assessment and decision support.

10.6. Cybernetic control – project control techniques

Cybernetic control principles are applied to project management to maintain control over complex systems. This includes the use of feedback loops, real-time monitoring, and adaptive control mechanisms to adjust project parameters as necessary. By employing cybernetic control techniques, project managers can respond quickly to changes, mitigate risks, and optimise project performance.

Managing complex systems in the project domain requires a multidisciplinary approach that combines principles from cybernetics, predictive analytics, modelling and simulation, and reliability engineering. By leveraging these approaches, project managers can enhance control, make informed decisions, and ultimately improve the success rate of complex projects.

10.7. The research thesis by publications

These research papers address several questions related to complex systems and SoS emergent behaviour. They explore the physical manifestations and implications of emergent behaviour, identify where and when it occurs, and examine how it is manifested. To determine whether a multi-system framework like meta-methodology can be built and what factors positively influence such an endeavour, the definition of project complexity is influenced by the researcher's ontological stance.

The distinct perspectives of project complexity are examined by the **systems theory perspective** and the **difficulty perspective**. The systems theory perspective operationalises complexity in terms of differentiation and interdependency, while the difficulty perspective emphasises structural complexity. The thesis delves into and addresses questions about the manifestations, implications, occurrence, and manifestation of emergent behaviour. The thesis also examines different perspectives of project complexity, highlighting the importance of understanding complexity factors in project management.

Research on the ‘theory of projects’ is seen to span the entire spectrum of perspectives (Soderlund, 2004). On one end, the view is that the theory of projects is well defined and understood, while on the other end researchers are debating the existence of any theory of projects (Soderlund, 2004; Koskela & Howell, 2002). Between these dichotomous positions, many researchers find that the existing theory is nascent and needs further research to render it mature and adequate for practical purposes (Koskela & Howell, 2002; Turner, 2006).

10.8. Integrating meta cybernetics and the viable system model offers a solution for redesigning complex project systems and managing emergent behaviour

To explore how the integration of meta cybernetics and the viable system model can be applied to reshape complex project systems and manage emergent behaviour, we established the following thesis statement as the cornerstone.

10.8.1. Thesis statement

The integration of diverse methodologies presents a robust approach that capitalises on a wide array of techniques, effectively tackles emergent behaviours, and establishes dependable communication and control mechanisms across the project's entire lifespan. The adoption of this integrated system empowers organisations to elevate their project management capabilities, thus enhancing the probability of attaining successful project outcomes.

10.8.2. Detailed explanation

The systemic improvement methodology finds widespread application among professionals striving to enhance specific elements or components within intricate system frameworks, reaping the benefits of improvement. Consequently, it becomes crucial to embrace a multi-dimensional process for system improvement that places priority on key components, thus supporting the realisation of operational methodology objectives.

The complexities and inherent unpredictability entailed in project management find better expression in non-linear systems. These non-linear systems are optimally managed through adaptive, self-organised distributed systems that incorporate positive feedback (Yolles, 2021). Cybernetic systems are grounded in higher-order tensions among interlinked processes (Astrom, 2011). An important development in the domain of complex systems is neocybernetics, introduced by Heikki Hy¨otyniemi (1994) (Chapter 5). Neocybernetics departs from the traditional practice of studying physical first-principle models, instead focusing on the direct examination of emergent models.

10.8.3. Future research opportunities

Anticipating ongoing and forthcoming research, there are exciting prospects in the realm of stochastic systems of systems and the analysis of emergent behaviour, which can be governed by cybernetics principles, as discussed in Chapters 6 and 8.

Cybernetics principles pivot on the concepts of feedback, control, and communication within a system, all directed toward achieving specific objectives. When combined with behavioural systems analysis, digital twin technology, and predictive analytics, a robust framework emerges for comprehending and steering complex interconnected systems.

10.8.4. Integration benefits

Through the incorporation of these principles alongside behavioural systems analysis, digital twin technology, and predictive analytics, the system can be continuously monitored, meticulously analysed, and precisely controlled in real-time to optimise its performance.

Behavioural systems analysis contributes to a deeper understanding of system behaviour and interactions, aiding in the recognition of system-level patterns and dependencies. This knowledge serves as the foundation for the development of analytical models and algorithms that seamlessly integrate into the digital twin. The digital twin, in turn, captures real-time data from the physical system and offers a dynamic platform for simulating and evaluating various scenarios.

Predictive analytics leverages historical data derived from the digital twin and behavioural system analysis models to anticipate future outcomes and fine-tune system performance (Khademi et al., 2021).

This integration empowers proactive decision-making by identifying and addressing potential issues and their potential impact on interconnected systems before they materialise. It also facilitates the optimisation of system performance by assessing the repercussions of different control strategies and configurations on the overall system behaviour.

10.9. The outcome of ongoing and on future research

Future research opportunities are eagerly anticipated in the realm of stochastic SoS and the analysis of emergent behaviour, which can be governed by cybernetics principles at the deterministic level as discussed in Chapters 6 and 8.

Cybernetics principles are centred on the concepts of feedback, control, and communication within a system, all aimed at achieving specific goals. When combined with behavioural systems analysis, digital twin technology, and predictive analytics, a robust framework emerges for comprehending and steering complex interconnected systems.

By incorporating these principles alongside behavioural systems analysis, digital twin technology, and predictive analytics, the system can be continuously monitored, meticulously analysed, and precisely controlled in real-time to optimise its performance.

Behavioural systems analysis contributes to a deeper comprehension of system behaviour and interactions, aiding in the recognition of system-level patterns and dependencies. This knowledge serves as the foundation for the development of analytical models and algorithms that can seamlessly integrate into the digital twin. The digital twin, in turn, captures real-time data from the physical system and offers a dynamic platform for simulating and evaluating various scenarios.

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This integration empowers proactive decision-making by identifying and addressing potential issues and their potential impact on interconnected systems before they materialise. It also facilitates the optimisation of system performance by assessing the repercussions of different control strategies and configurations on the overall system behaviour.

10.10. Complex problem-solving capabilities in engineering projects

In the domain of complex problem-solving, it is crucial to consider the systemic properties inherent in any given issue, as these properties reveal the true nature of the problem (Ackoff, 2010). The fields of cybernetics and system thinking introduce a novel approach to problem-solving, one that is not yet fully defined but holds promise in the assessment of operations and projects within engineering operations (Ackoff, 2010).

Therefore, while solving problems in complex projects, all the systemic properties are investigated, and that is when the nature of the problem is revealed (Wiener, 2013; Ackoff, 2010). There is limited understanding of complex engineering projects and the occurrence of operational disasters through the application of meta-methodology in project system design (Sage, 1977). There is no evidence of the emergent behaviour observed in constituent systems that support systems in project design. Combinations of systems operating together within the SoS contribute to the overall capabilities. Combining project systems can lead to emergent behaviours, which may either improve or degrade performance as well as decrease or increase project costs.

Complex projects are characterised by unforeseen behaviour that is fundamentally still traceable by structured analysis (Zeigler, 2016). Chaotic projects are those in which the relationships between cause and effect are impossible to determine (Sheffield et al., 2012; Snowden et al., 2007). The cybernetics of Norbert Wiener are associated with self-regulation and equilibrium stabilisation and around project goals through negative feedback loops and are an attractive proposition for project management. Therefore, it would bring together cybernetics and project management by applying Beer’s viable system model (VSM) to complex project alliances (Henneveld, 2006; Love et al., 2010; Langfield-Smith, 2008; Burgess & Wake, 2012; Mills et al., 2019). The VSM is proposed as a governing framework that can be applied where the number of subsystems represent the project parties (client, integrator, and suppliers) (Hildbrand & Bodhanya, 2015; Yolles, 2021). For any project, the issues of quality, time, costs, and delivery dates are critically significant and must be associated with the management of individuals and groups on the project (Samson, 2009). Projects are usually subject to risks and uncertainties (Chapman & Ward, 1997) and several factors contribute to the risk and uncertainty in investment decisions in project management. Managerial and operational independence work together and represent a collaborative approach to strengthening systems (Langfield-Smith, 2008).

The application of VSM can also be used as a platform to enhance the integration and cooperation of project entities as it will set the communication channels among them (Burgess & Wake, 2012; Hildbrand & Bodhanya, 2015), by enhancing project performance (cost, time, and quality) and realising value for money. The complexity and chaos of projects are better reflected by non-linear systems, which in turn are better manageable in adaptive and self-organized distributed systems with positive feedback (Yolles, 2021). In complex problem solving, we can assume that all systemic properties will be investigated; however, this is where the nature of the problem is revealed. The focus can be on digital twin, behavioural systems analysis, and predictive analytics which equip organisations with an exhaustive understanding of intricate systems. This empowerment enables them to optimise system performance, bolster reliability, and enhance resilience through proactive maintenance, performance enhancement, energy efficiency enhancements, demand forecasting, and the early detection of failures or disruptions (Chapter 8). By drawing upon historical data and real-time information, organisations can make informed decisions and elevate the overall management of complex systems (Zeng et al., 2023).

In the context of complex problem-solving solving as outlined in Chapters 6 and 8, the process involves a thorough examination of all systemic properties (Liu, 2019). This comprehensive investigation is essential as it leads to a deeper understanding of the core issues, as discussed in Chapters 5, 6 and 7. To facilitate this intricate problem-solving process, the introduction of systemic thinking and cybernetics, as discussed in Chapters 5, 6 and 7 plays a pivotal role. These chapters provide the foundational elements and methodologies necessary to create a meta-methodological model. Currently, this model lacks clarity and accessibility.

The publications in question introduce an innovative research approach that integrates various methodologies, including digital twin technology, agent-based modelling, cybernetics (specifically VSM), and the exploration of emergent behaviour within SoS. This research endeavour aims to overcome existing limitations and deliver fresh insights into the effective management of complex engineering projects.

One notable emphasis within these discussions is the significance of the VSM in handling projects that involve diverse subsystems, particularly in the context of SoS (Vollmer, 2018). The VSM places a strong emphasis on principles like organisational autonomy, self-regulation, and effective communication. These principles align seamlessly with the challenges associated with coordinating numerous interconnected subsystems in complex projects (D’Andreamatteo et al., 2019).

These discussions cover a broad range of topics, including engineering systems management, various methodologies, complex systems thinking, and the practical applications of the VSM. They underscore the critical importance of developing robust and adaptive strategies for efficiently and securely managing extensive and intricate engineering projects drawn as a conclusion.

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APPENDIX A: SYSTEMS OF SYSTEMS AND DIGITAL TWIN

Describes some basic concepts of theory related to the digital twin model for reliability. An experimental model is proposed to study the reliability in the intercommunication network, considering the deterministic system as well as the probabilistic, dynamic, aspects of the network.

Digital twins can be extended to encompass the interconnected nature of systems of systems and provide a simulated environment to assess their reliability and failure modes.

1. Model Development: A digital twin model is created to represent the interconnected systems. This model includes the individual components, their interactions, and the overall behaviour of the system. The model should capture the key aspects that influence reliability, such as component failure rates, dependencies, and feedback loops.

2. Failure Modes and Effects Analysis (FMEA): FMEA is performed on the digital twin model to identify potential failure modes and their effects on the system. This involves analysing the vulnerabilities, failure mechanisms, and their impact on system performance. The FMEA results provide insights into the critical areas that need to be addressed for improving reliability.

3. Probability and Risk Assessment: Using probabilistic techniques, such as Monte Carlo simulations, the digital twin model can be subjected to random variations and uncertainties. This allows for the assessment of the system's reliability under different operating conditions and potential failure scenarios. By simulating a large number of random events and their consequences, the probability of system failures can be estimated.

4. Failure Propagation Analysis: The digital twin model enables the analysis of how failures propagate and impact the interconnected systems within the system of systems. By simulating the cascading effects of failures, it becomes possible to assess the vulnerabilities and risks associated with the interconnected components and their dependencies.

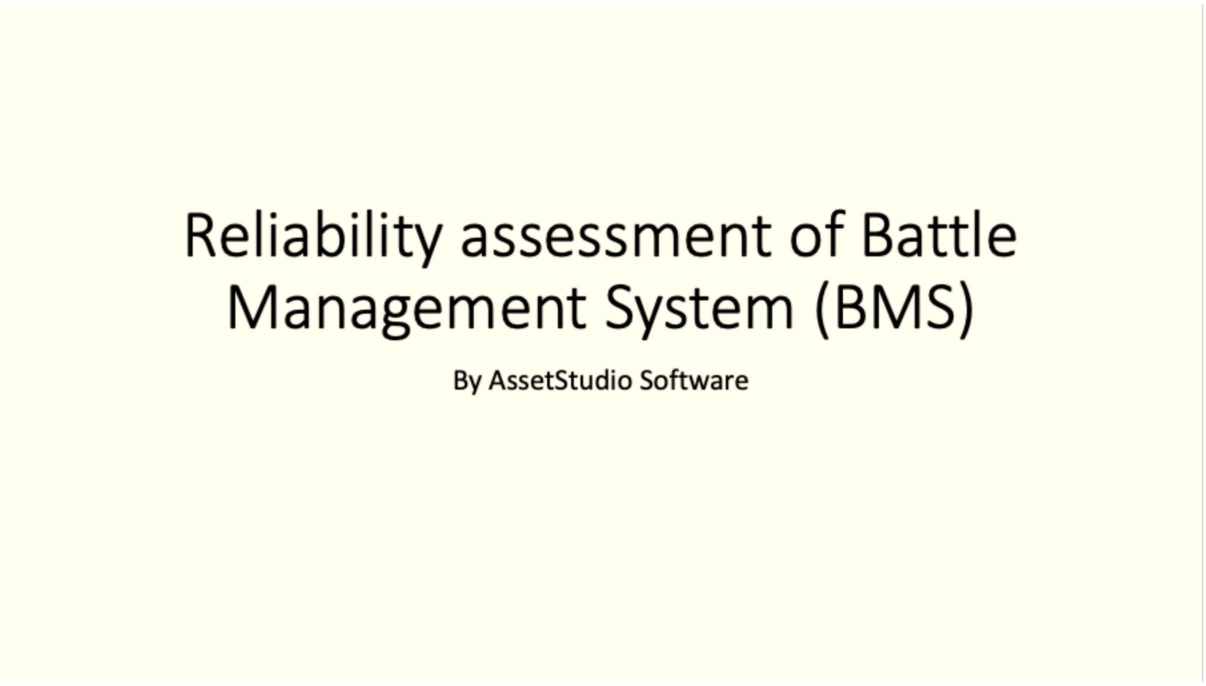
5. Sensitivity Analysis and Optimisation: The digital twin model can be used to conduct sensitivity analysis to identify the most critical factors influencing system reliability. This analysis helps in prioritizing mitigation strategies and optimizing the system's design or maintenance approaches to enhance reliability.

6. Predictive Maintenance and Decision Support: By integrating real-time data from the actual systems and their digital twin counterparts, predictive maintenance strategies can be developed. The digital twin can provide insights into the expected future reliability, enabling proactive decision-making and optimizing maintenance schedules to prevent failures and minimize downtime.

By simulating reliability failures in systems of systems using digital twin technology, organizations can gain valuable insights into potential risks, vulnerabilities, and failure modes. This allows for proactive decision-making, optimization of maintenance strategies, and continuous improvement of system reliability and performance.

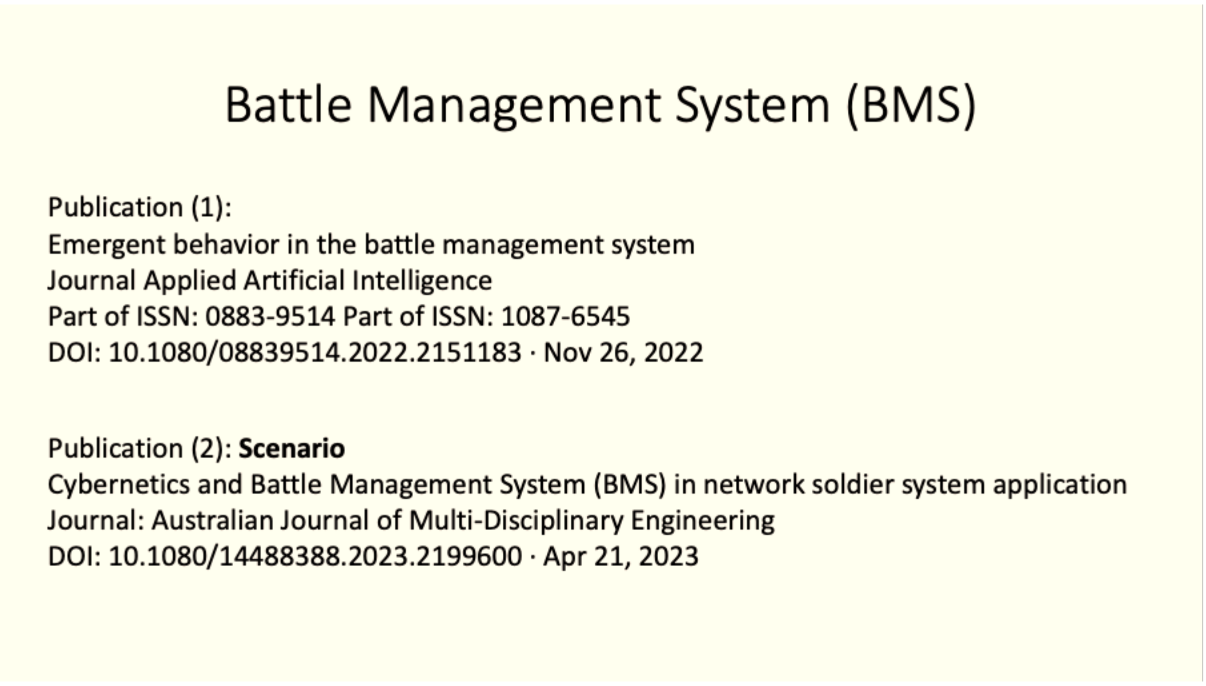
APPENDIX B: DIGITAL TWIN RELIABILITY MODEL

Presents computer implementation details of the reliability model and implementation of a model for reliability analysis of network soldier systems.



Reliability assessment of Battle Management System (BMS)

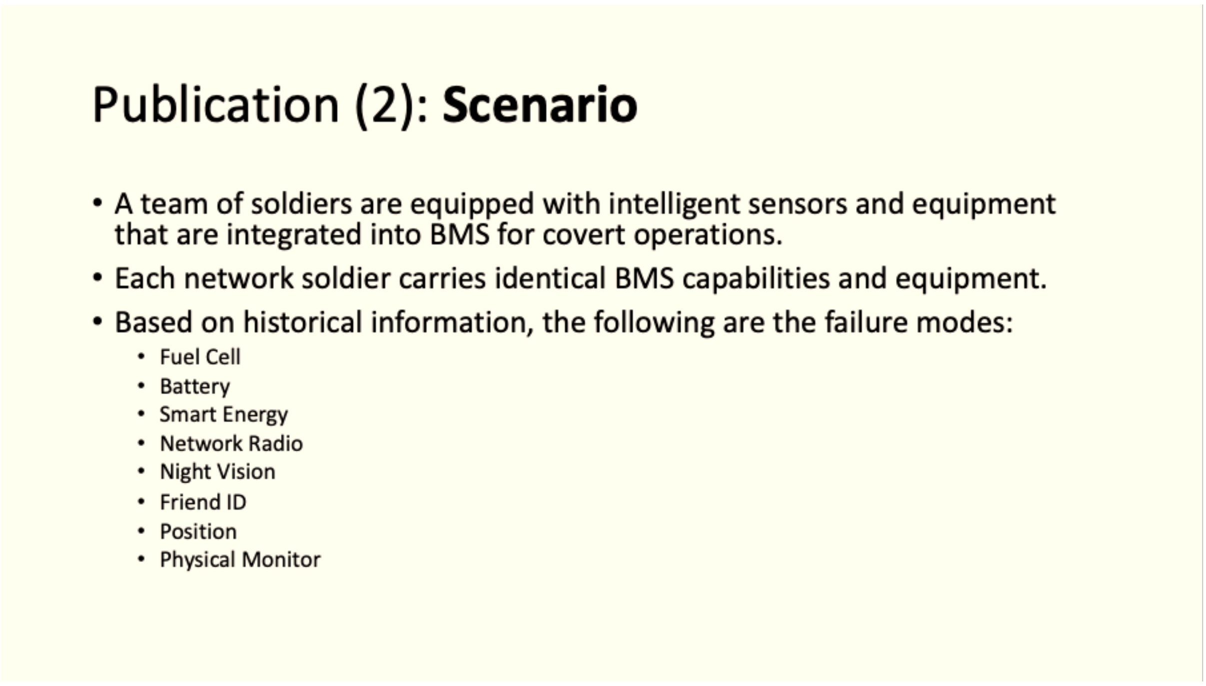
By AssetStudio Software



Battle Management System (BMS)

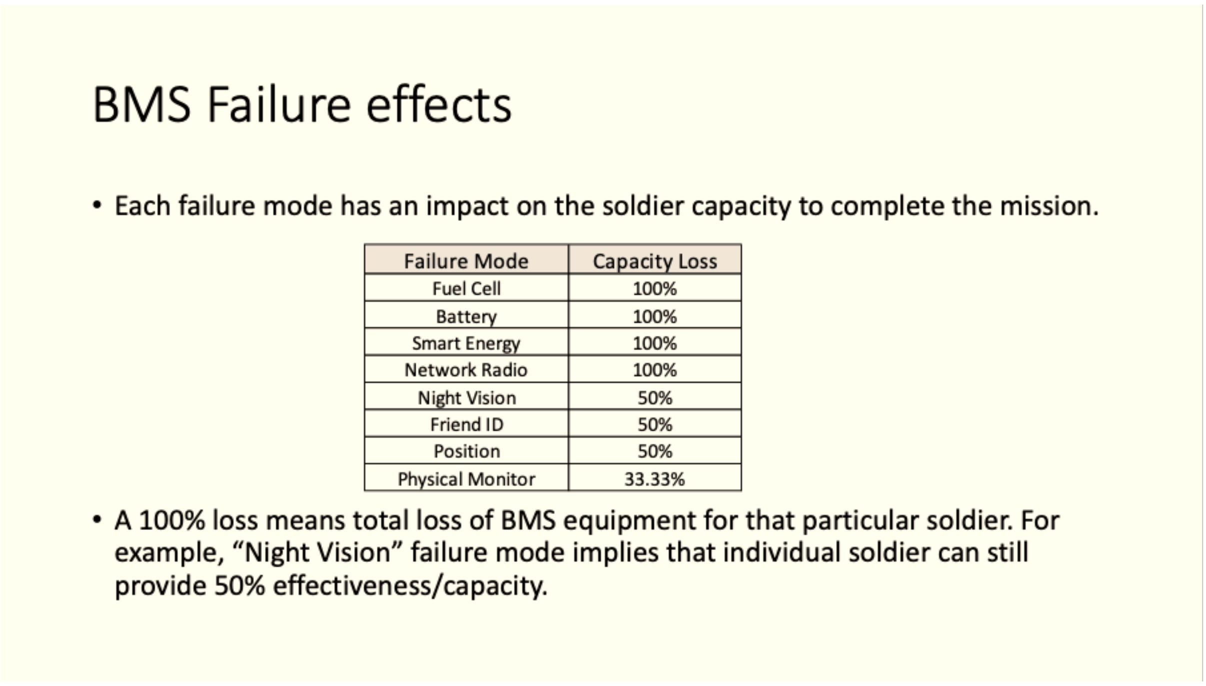
Publication (1):
Emergent behavior in the battle management system
Journal Applied Artificial Intelligence
Part of ISSN: 0883-9514 Part of ISSN: 1087-6545
DOI: 10.1080/08839514.2022.2151183 · Nov 26, 2022

Publication (2): **Scenario**
Cybernetics and Battle Management System (BMS) in network soldier system application
Journal: Australian Journal of Multi-Disciplinary Engineering
DOI: 10.1080/14488388.2023.2199600 · Apr 21, 2023



Publication (2): **Scenario**

- A team of soldiers are equipped with intelligent sensors and equipment that are integrated into BMS for covert operations.
- Each network soldier carries identical BMS capabilities and equipment.
- Based on historical information, the following are the failure modes:
  - Fuel Cell
  - Battery
  - Smart Energy
  - Network Radio
  - Night Vision
  - Friend ID
  - Position
  - Physical Monitor



BMS Failure effects

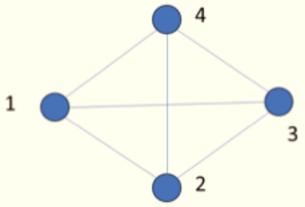
- Each failure mode has an impact on the soldier capacity to complete the mission.

Failure Mode	Capacity Loss
Fuel Cell	100%
Battery	100%
Smart Energy	100%
Network Radio	100%
Night Vision	50%
Friend ID	50%
Position	50%
Physical Monitor	33.33%

- A 100% loss means total loss of BMS equipment for that particular soldier. For example, “Night Vision” failure mode implies that individual soldier can still provide 50% effectiveness/capacity.

Effectiveness of BMS

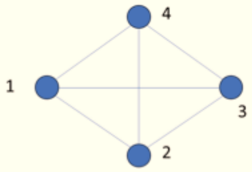
- The diagram represents a team of 4 soldiers equipped with BMS.



- BMS maintains the communication links among the soldier.

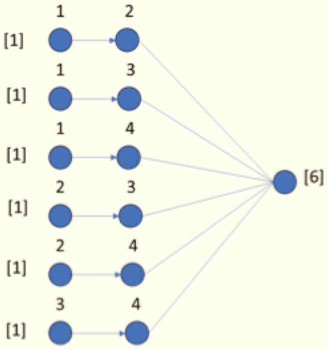
Effectiveness of BMS

- Define a metric that can relate the equipment reliability to operation effectiveness of the BMS.



Each node has the following failure modes:

Failure Mode	Capacity Loss
Fuel Cell	100%
Battery	100%
Smart Energy	100%
Network Radio	100%
Night Vision	50%
Friend ID	50%
Position	50%
Physical Monitor	33.33%

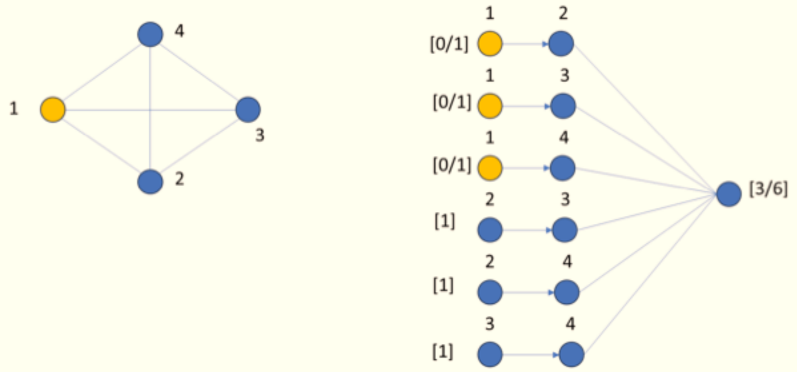


When all equipment are working normally, the end node receive a combined flowrate of 6 units/hour.

For a 100 hours of operation with experiencing any failure, the end node will product an output of 600 units of "amount of work".

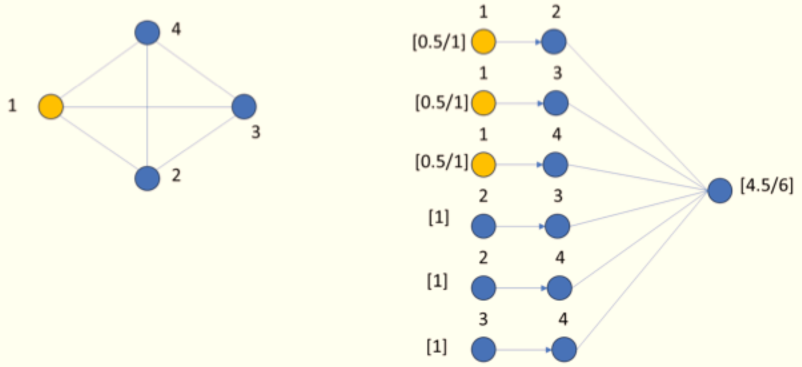
Effectiveness of BMS

- If node 1 fails completely, the end node flowrate reduces to 3 units/hour. For a 100 hours of operation under this condition, the amount of work is 300 units.



Effectiveness of BMS

- If node 1 suffers a partial loss, the end node will receive a flowrate between 3 and 6 units/hour.

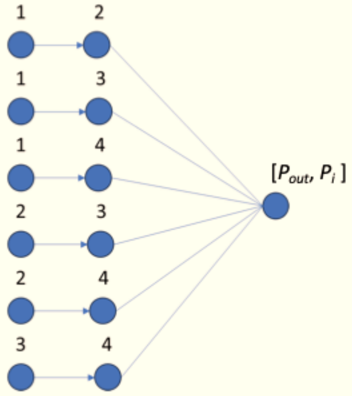


Operational Effectiveness of BMS

- Let the end node total output (amount of work) be P_{out}, and P_i be the end node total output if all BMS equipment are operating without failure (or Ideal output).

- We can define a metric called Operational Effectiveness,

$$\zeta = \frac{P_{out}}{P_i}$$



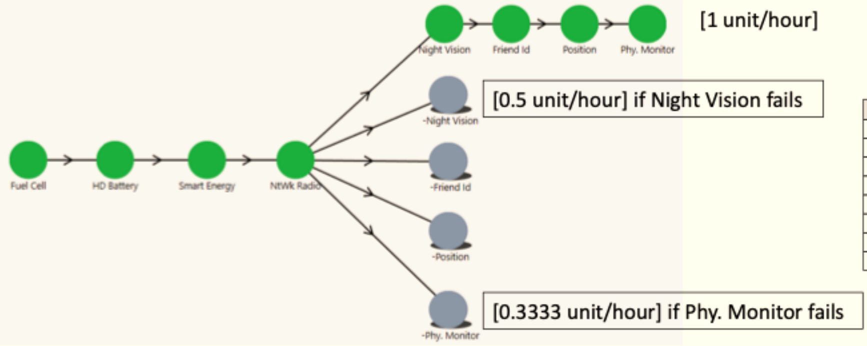
Reliability Digital Twin

- A Reliability Digital Twin is created to determine the Equipment Operational Effectiveness, ζ.

- The digital twin consists of schematics that represent the reliability relationships and throughput performance:
  - Failure modes of individual soldier equipment.
  - Interactions among the 4 soldiers.

Reliability Digital Twin: Individual Soldier Level

- In normal operating condition, the system produces 1 unit/hour.
- Shadow-Node construct is used to implement partial failure.



[1 unit/hour]

[0.5 unit/hour] if Night Vision fails

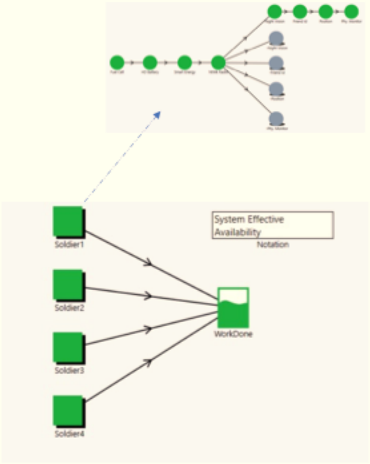
[0.3333 unit/hour] if Phy. Monitor fails

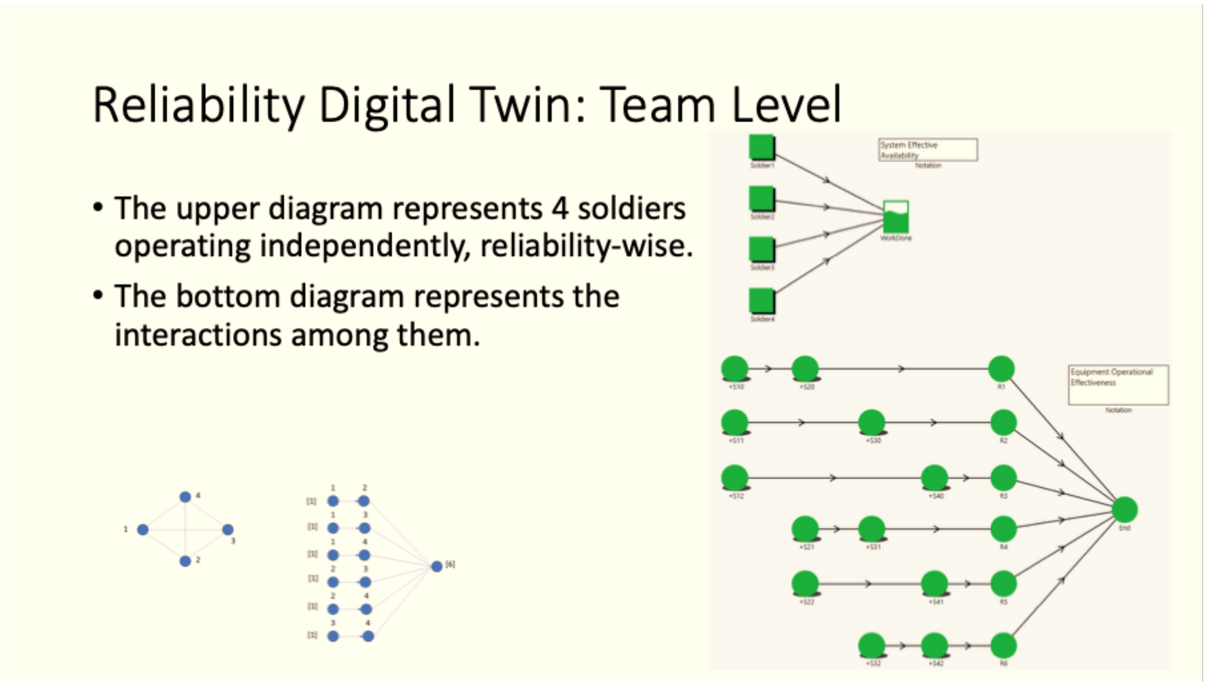
Failure Mode	Capacity Loss
Fuel Cell	100%
Battery	100%
Smart Energy	100%
Network Radio	100%
Night Vision	50%
Friend ID	50%
Position	50%
Physical Monitor	33.33%

System Effective Availability

- The output (work done) from the 4 Soldiers is stored in Storage buffer “WorkDone”.
- If all 4 nodes operate without failure for 100 hours, the buffer will store 400 units (W_i, work done in ideal case).
- If failures occur, the buffer would accumulate less than 400 units (W_{out})
- We define a metric called System Effective Availability,

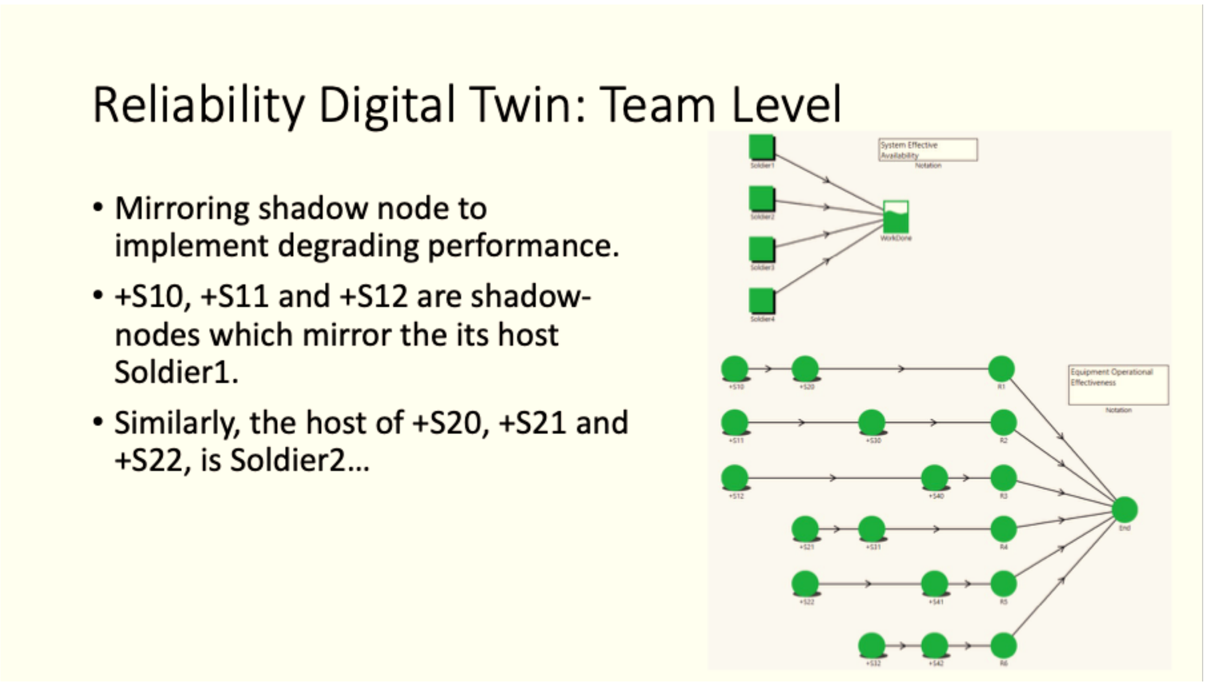
$$A = \frac{W_{out}}{W_i}$$





Reliability Digital Twin: Team Level

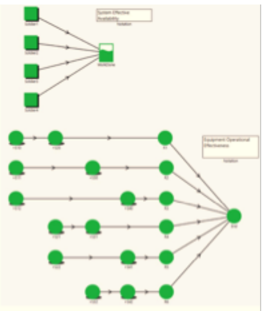
- The upper diagram represents 4 soldiers operating independently, reliability-wise.
- The bottom diagram represents the interactions among them.



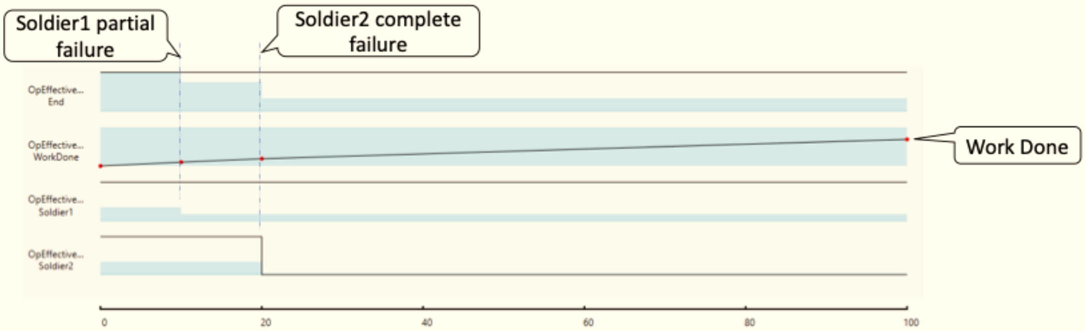
Reliability Digital Twin: Team Level

- Mirroring shadow node to implement degrading performance.
- +S10, +S11 and +S12 are shadow-nodes which mirror the its host Soldier1.
- Similarly, the host of +S20, +S21 and +S22, is Soldier2…

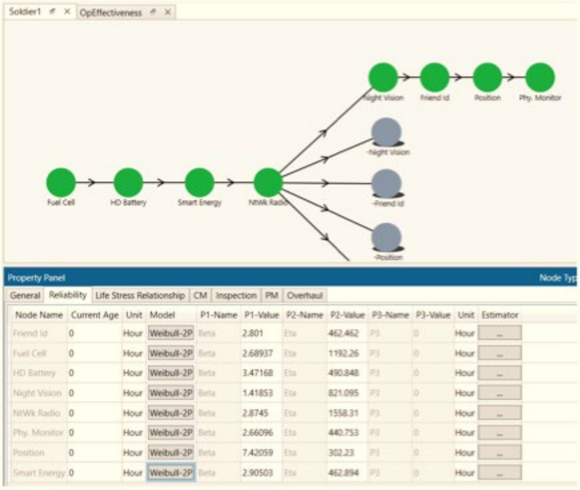
100-hour Simulation profile



- Soldier1 (Night-Vision) is set to fail at 10 hours (partial failure).
- Soldier2 (Fuel Cell) is set to fail at 20 hours (complete failure).

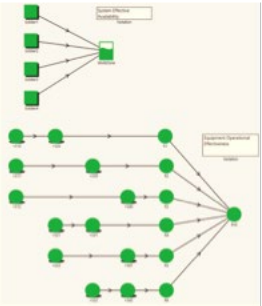


Import Reliability Data from Data Analysis

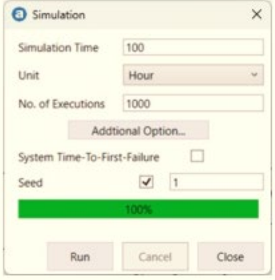


Node Name	Current Age	Unit	Model	P1-Name	P1-Value	P2-Name	P2-Value	P3-Name	P3-Value	Unit	Estimator
Friend Id	0	Hour	Weibull-2P	Beta	2.801	Eta	462.462	P3	0	Hour	...
Fuel Cell	0	Hour	Weibull-2P	Beta	2.68937	Eta	1192.26	P3	0	Hour	...
HD Battery	0	Hour	Weibull-2P	Beta	3.47168	Eta	490.848	P3	0	Hour	...
Night Vision	0	Hour	Weibull-2P	Beta	1.41853	Eta	821.095	P3	0	Hour	...
NtWk Radio	0	Hour	Weibull-2P	Beta	2.8745	Eta	1558.31	P3	0	Hour	...
Phy. Monitor	0	Hour	Weibull-2P	Beta	2.66096	Eta	440.753	P3	0	Hour	...
Position	0	Hour	Weibull-2P	Beta	7.42059	Eta	302.23	P3	0	Hour	...
Smart Energy	0	Hour	Weibull-2P	Beta	2.90503	Eta	462.894	P3	0	Hour	...

Simulation



- 100-Hour simulation with 1000 executions.



Simulation

Simulation Time: 100

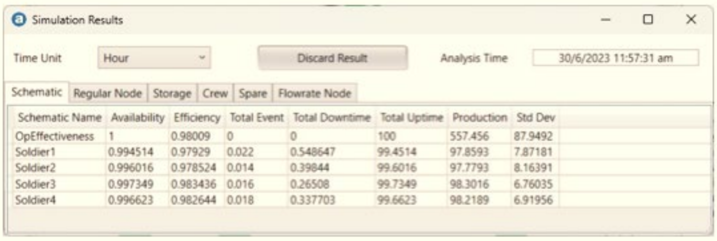
Unit: Hour

No. of Executions: 1000

System Time-To-First-Failure ☐

Seed ☑ 1

100%



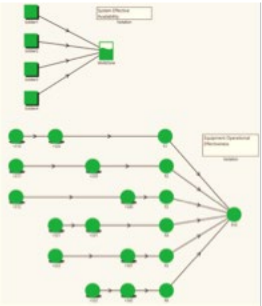
Simulation Results

Time Unit: Hour

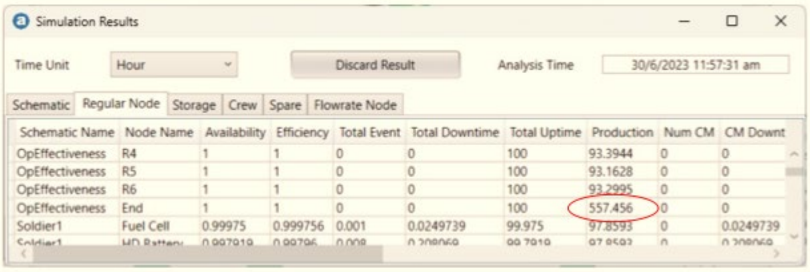
Analysis Time: 30/6/2023 11:57:31 am

Schematic Name	Availability	Efficiency	Total Event	Total Downtime	Total Uptime	Production	Std Dev
OpEffectiveness	1	0.98009	0	0	100	557.456	87.9492
Soldier1	0.994514	0.97929	0.022	0.548647	99.4514	97.8593	7.87181
Soldier2	0.996016	0.978524	0.014	0.39844	99.6016	97.7793	8.16391
Soldier3	0.997349	0.983436	0.016	0.26508	99.7349	98.3016	6.76035
Soldier4	0.996623	0.982644	0.018	0.337703	99.6623	98.2189	6.91956

Operational Effectiveness



- End node total output



Simulation Results

Time Unit: Hour

Analysis Time: 30/6/2023 11:57:31 am

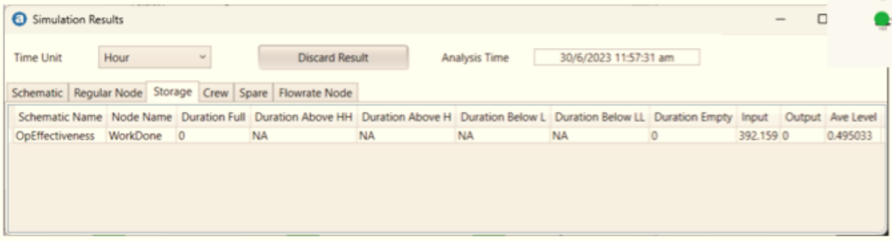
Schematic Name	Node Name	Availability	Efficiency	Total Event	Total Downtime	Total Uptime	Production	Num CM	CM Downt
OpEffectiveness	R4	1	1	0	0	100	93.3944	0	0
OpEffectiveness	R5	1	1	0	0	100	93.1628	0	0
OpEffectiveness	R6	1	1	0	0	100	93.2995	0	0
OpEffectiveness	End	1	1	0	0	100	557.456	0	0
Soldier1	Fuel Cell	0.99975	0.999756	0.001	0.0249739	99.975	97.8593	0	0.0249739

- Operational Effectiveness,

$$\zeta = \frac{P_{out}}{P_i} = \frac{557.5}{600} = 0.929$$

System Effective Availability

- Storage node “WordDone” statistic.



Time Unit: Hour

Analysis Time: 30/6/2023 11:57:31 am

Schematic Name	Node Name	Duration Full	Duration Above HH	Duration Above H	Duration Below L	Duration Below LL	Duration Empty	Input	Output	Ave Level
OpEffectiveness	WorkDone	0	NA	NA	NA	NA	0	392.159	0	0.495033

- System Effective Availability,

$$A = \frac{W_{out}}{W_i} = \frac{392}{400} = 0.98$$

Conclusions

- The use of Reliability Digital twin technology enhances the analysis of systems by creating a virtual replica of the physical system's reliability. The digital twin takes the failure rate behavior of crucial failure modes/items as input and conducts realistic simulations. These simulations yield a more profound comprehension of the system's behavior and performance.

- Through the integration of behavior system analysis techniques, the digital twin enables the modeling and analysis of dynamic relationships among system components. This integration enhances decision-making, optimizes system performance, and identifies opportunities for improvement.

APPENDIX C: ICCPM WEBINAR

-FEEDBACK-

ICCPM
INTERNATIONAL
CENTRE FOR
COMPLEX
PROJECT
MANAGEMENT

WEBINAR

COMPLEX PROJECT
SYSTEMS OF SYSTEMS
EMERGENT BEHAVIOUR PHENOMENON

by ALEKSANDAR SEIZOVIC

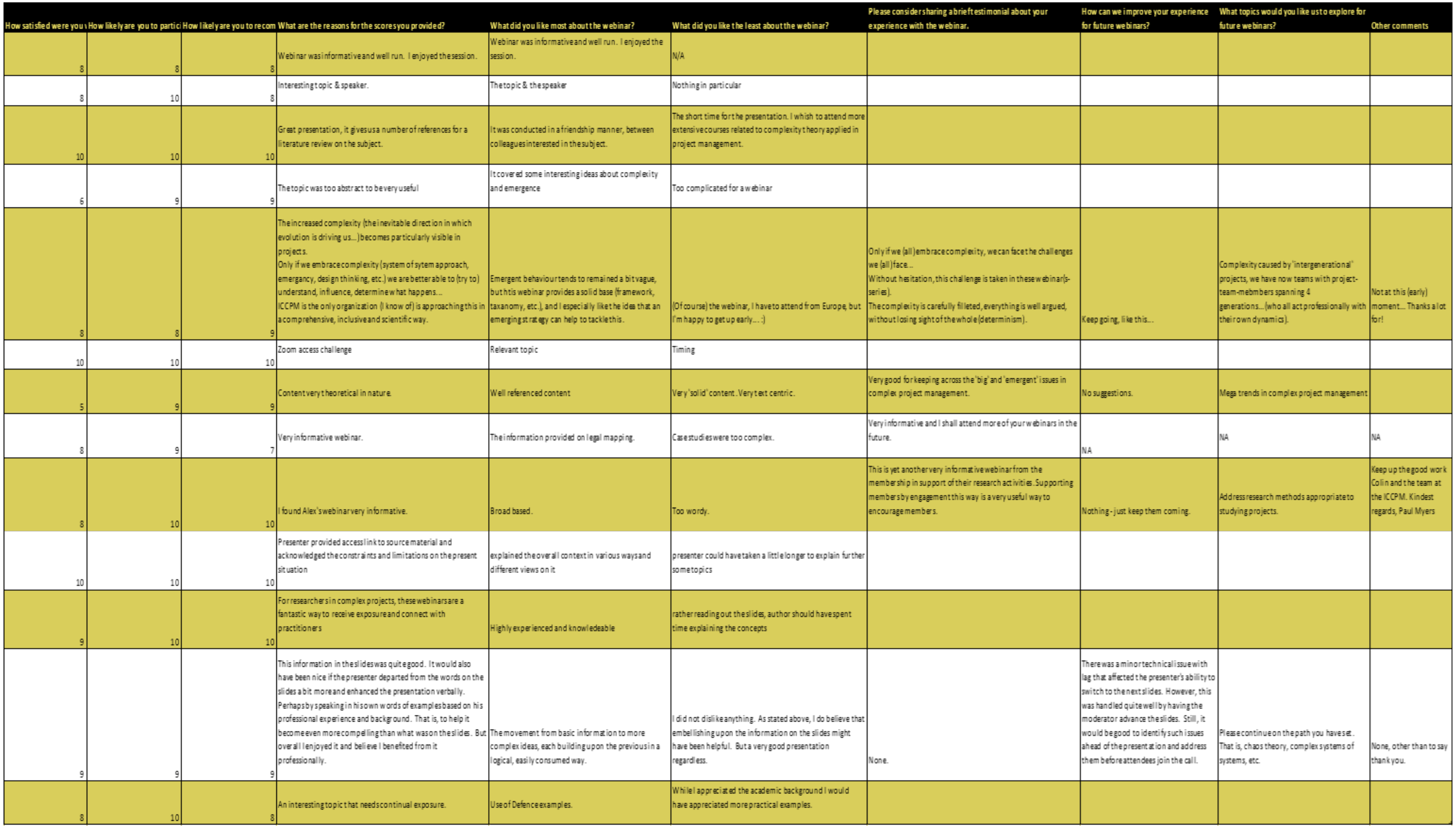
30 NOVEMBER 2021
12:00PM-1:00PM AEDT
Fee: **FREE**

DELIVERED ONLINE
INTERACTIVE Q&A SESSION
PARTICIPATE IN CURRENT RESEARCH

This webinar will investigate various theories and elements that are and can be relevant to system emergent behaviour in complex systems of systems (SoS).

WWW.ICCPM.COM/WEBINAR-SYSTEMS-OF-SYSTEMS

Project SoS - Webinar Feedback-A-Seizovic-30-11-2021



How satisfied were you	How likely are you to partici	How likely are you to recom	What are the reasons for the scores you provided?	What did you like most about the webinar?	What did you like the least about the webinar?	Please consider sharing a brief testimonial about your experience with the webinar.	How can we improve your experience for future webinars?	What topics would you like us to explore for future webinars?	Other comments
8	8	8	Webinar was informative and well run. I enjoyed the session.	Webinar was informative and well run. I enjoyed the session.	N/A				
8	10	8	Interesting topic & speaker.	The topic & the speaker	Nothing in particular				
10	10	10	Great presentation, it gives us a number of references for a literature review on the subject.	It was conducted in a friendship manner, between colleagues interested in the subject.	The short time for the presentation. I whish to attend more extensive courses related to complexity theory applied in project management.				
6	9	9	The topic was too abstract to be very useful	It covered some interesting ideas about complexity and emergence	Too complicated for a webinar				
8	8	9	The increased complexity (the inevitable direction in which evolution is driving us...) becomes particularly visible in projects. Only if we embrace complexity (system of sytem approach, emergancy, design thinking, etc.) we are better able to (try to) understand, influence, determine what happens... ICCPM is the only organization (I know of) is approaching this in a comprehensive, inclusive and scientific way.	Emergent behaviour tends to remained a bit vague, but htis webinar provides a solid base (framework, taxanomy, etc.), and I especially like the idea that an emerging strategy can help to tackle this.	(Of course) the webinar, I have to attend from Europe, but I'm happy to get up early.... :)	Only if we (all) embrace complexity, we can face the challenges we (all) face... Without hesitation, this challenge is taken in these webinar(s-series). The complexity is carefully filleted, everything is well argued, without losing sight of the whole (determinism).	Keep going, like this...	Complexity caused by 'intergenerational' projects, we have now teams with project-team-mebmbers spanning 4 generations... (who all act professionally with their own dynamics).	Not at this (early) moment... Thanks a lot for!
10	10	10	Zoom access challenge	Relevant topic	Timing				
5	9	9	Content very theoretical in nature.	Well referenced content	Very 'solid' content. Very text centric.	Very good for keeping across the 'big' and 'emergent' issues in complex project management.	No suggestions.	Mega trends in complex project management	
8	9	7	Very informative webinar.	The information provided on legal mapping.	Case studies were too complex.	Very informative and I shall attend more of your webinars in the future.	NA	NA	NA
8	10	10	I found Alex's webinar very informative.	Broad based.	Too wordy.	This is yet another very informative webinar from the membership in support of their research activities. Supporting members by engagement this way is a very useful way to encourage members.	Nothing - just keep them coming.	Address research methods appropriate to studying projects.	Keep up the good work Colin and the team at the ICCPM. Kindest regards, Paul Myers
10	10	10	Presenter provided access link to source material and acknowledged the constraints and limitations on the present situation	explained the overall context in various ways and different views on it	presenter could have taken a little longer to explain further some topics				
9	10	10	For researchers in complex projects, these webinars are a fantastic way to receive exposure and connect with practitioners	Highly experienced and knowledeable	rather reading out the slides, author should have spent time explaining the concepts				
9	9	9	This information in the slides was quite good. It would also have been nice if the presenter departed from the words on the slides a bit more and enhanced the presentation verbally. Perhaps by speaking in his own words of examples based on his professional experience and background. That is, to help it become even more compelling than what was on the slides. But overall I enjoyed it and believe I benefited from it professionally.	The movement from basic information to more complex ideas, each building upon the previous in a logical, easily consumed way.	I did not dislike anything. As stated above, I do believe that embellishing upon the information on the slides might have been helpful. But a very good presentation regardless.	None.	There was a minor technical issue with lag that affected the presenter's ability to switch to the next slides. However, this was handled quite well by having the moderator advance the slides. Still, it would be good to identify such issues ahead of the presentation and address them before attendees join the call.	Please continue on the path you have set. That is, chaos theory, complex systems of systems, etc.	None, other than to say thank you.
8	10	8	An interesting topic that needs continual exposure.	Use of Defence examples.	While I appreciated the academic background I would have appreciated more practical examples.				

APPENDIX D: ENGINEERS AUSTRALIA, INTEGRATED PROJECT ENGINEERING CONGRESS (IPEC)

-FEEDBACK-

The inaugural Integrated Project Engineering Congress (IPEC), developed in response to market demand, promises to be one of industry's most influential, transdisciplinary events, covering topics of Leadership and Management, whilst bringing together representatives from within the fields of Risk, Systems Engineering, Cost Engineering, Project Controls and Asset Management.

IPEC
INTEGRATED PROJECT ENGINEERING CONGRESS
27 - 28 May 2021
Virtual Congress

Creating the Future Together

PRESENTED BY

Certificate of Attendance

This is to certify that

Aleksandar Seizovic

has attended the event

Integrated Project Engineering Congress (IPEC) 2021 held virtually

on
Thursday 27 May 2021 – 7 CPD
Friday 28 May 2021 – 7 CPD

All presentations will be delivered virtually to participants, providing the opportunity to network and watch the presentations anywhere in the world.

APPENDIX E: A RESEARCH LITERATURE SUMMARY

1. Ashby, Ross W. 1965, 2011. Introduction to Cybernetics. London: Chapman & Hall, Ltd. This reference is a book that provides an introduction to the field of cybernetics, exploring concepts and principles related to the study of control and communication in systems.
2. Australian Soldier Systems Architecture (ASSA) for Land 125 Phase 4. 2013. This document discusses the development of the Australian Soldier Systems Architecture (ASSA) for the Land 125 Phase 4 project, which focuses on soldier systems.
3. Bar-Yam, Yaneer. 2004. “Multiscale Variety in Complex Systems.” This article explores the concept of multiscale variety in complex systems, highlighting the importance of diversity and adaptability in addressing complex problems.
4. Bar-Yam, Yaneer. 2004. Making Things Work: Solving Complex Problems in a Complex World. This book by Yaneer Bar-Yam discusses strategies and approaches for solving complex problems in a complex world, providing insights into system behavior and dynamics.
5. Beer, Stafford. 1984. “The Viable System Model: Its Provenance, Development, Methodology and Pathology.” This article focuses on Stafford Beer's Viable System Model (VSM), which is a framework for understanding the structure and behavior of complex systems.
6. Dyson, George. (1997) Darwin Among the Machines. "Dyson Among the Machines" is a book by George Dyson that explores the historical development of computer technology and its implications for society.
7. Elbit Systems Australia Pty Ltd 2020, Copyright approval Generic Soldier Architecture (GSA) – MODUK – DEF STAN 23–012. 2017. This reference is a copyright approval document related to the Generic Soldier Architecture (GSA) for the Ministry of Defense United Kingdom (MODUK).
8. Henshaw, Mike. 2015. “Good Practice in Systems of Systems Engineering (SoSE).” This paper discusses good practices in Systems of Systems Engineering (SoSE), providing insights and recommendations for effectively managing complex systems.

9. Holland, Orgal T. 2007. “Taxonomy for the Modeling and Simulation of Emergent Behavior Systems.” This article proposes a taxonomy for modeling and simulating emergent behavior in complex systems, providing a framework for understanding and studying such systems.
10. Hyötyniemi, H. (2006): Neocybernetics in Biological Systems. This document focuses on neocybernetics in biological systems, exploring the application of cybernetics principles in the study of biological phenomena.
11. IEEE/ISO/IEC 29148-2011 – ISO/IEC/IEEE International Standard – Systems and Software Engineering – Life Cycle Processes—Requirement’s Engineering. This reference is an international standard for requirement engineering in systems and software engineering, providing guidelines and best practices for managing requirements throughout the development life cycle.
12. Kopetz, Hermann, Andrea Bondavalli, Francesco Brancati, Bernhard Frömel, Oliver Höftberger, and Sorin Iacob. 2016. “Emergence in Cyber-Physical Systems-of-Systems (CPSoSs).” This paper discusses the concept of emergence in Cyber-Physical Systems-of-Systems (CPSoSs), highlighting the challenges and opportunities in managing complex, interconnected systems.
13. Lee, Bengee, and James Miller. 2004. “Multi-project Software Engineering Analysis Using Systems Thinking.” This article explores the use of systems thinking in analyzing and managing multi-project software engineering initiatives, emphasizing the importance of a holistic perspective.
14. Maier, Mark W. 2013. “Architecting. Maier, Mark W. 2013. “Architecting Principles for Systems-of-Systems.” This paper explores the principles of architecting systems-of-systems (SoS), discussing the challenges and considerations involved in designing and managing complex interconnected systems.
15. Maier, Mark W. 2014. Chap. 2. “The Role of Modeling and Simulation in System of Systems Development.” This chapter focuses on the role of modeling and simulation in the development of system-of-systems, highlighting their importance in understanding system behavior, performance, and interactions.
16. Mancilla, R. G. (2013). Introduction to sociocybernetics (part 3): fourth order cybernetics. This article introduces the concept of fourth-order cybernetics, exploring the application of cybernetics principles to social systems and

emphasizing the importance of reflexivity and self-awareness in understanding complex social phenomena.

17. McCulloch, Warren S. 1995. “‘Summary of the points of agreement reached in the previous nine conferences on cybernetics.’" This summary provides an overview of the points of agreement reached in nine conferences on cybernetics, discussing various aspects of cybernetics and its applications in biological and social systems.
18. Morris, P. W. G. (2012). Cleland and King: Project management and the systems approach. This paper examines the systems approach to project management as discussed in Cleland and King's book, highlighting the integration of various components and stakeholders in successful project implementation.
19. Menčík, Jaroslav. 2016. “Reliability of Systems.” This chapter discusses the reliability of systems, exploring concepts, models, and methodologies for assessing and improving the reliability of complex systems.
20. Miller, Roger, and Donald R. Lessard. 2008 Chap. 8. “Evolving Strategy: Risk Management and the Shaping of Mega-projects.” This chapter focuses on risk management and its role in shaping and evolving strategies for mega-projects, highlighting the importance of considering and mitigating risks throughout the project lifecycle.
21. Mingers, John., and John Brocklesby. 1997. “Multimethodology: Towards a Framework for Mixing Methodologies.” This article presents a framework for mixing methodologies, emphasizing the benefits of combining different research methods to enhance understanding and analysis in complex domains.
22. Mittal, Saurabh and Larry Rainey. 2015. “Harnessing Emergence: The Control and Design and Emergent Behavior in System of Systems Engineering.” This paper explores the control and design of emergent behavior in system-of-systems engineering, discussing approaches for understanding and managing emergent properties and behaviors in complex systems.
23. Nweke, Livinus O., Goitom K. Weldehawaryat, and Stephen D. Wolthusen. 2021. “Threat Modelling of Cyber–Physical Systems Using an Applied π-Calculus.” This article discusses the use of an applied π-calculus for threat modeling in cyber-

physical systems, highlighting the importance of formal methods in analyzing system vulnerabilities and potential threats.

24. Nweke, Livinus O., Goitom K. Weldehawaryat, and Stephen D. Wolthusen. 2021. “Threat Modelling of Cyber–Physical Systems Using an Applied π-Calculus.” International Journal of Critical Infrastructure Protection 35: 100466. doi:10.1016/j.ijcip.2021.100466.
25. O’Connell, Mary E. 2012. “Cyber Security without Cyber War.” Journal of Conflict and Security Law 17 (2): 187–209. doi:10.1093/jcsl/krs017.
26. Osipov, Yu S., and V. I. Maksimov. 2018. “Tracking the Solution to a Nonlinear Distributed Differential Equation by Feedback Laws.” Numerical Analysis and Applications 11, 158–169. doi:10.1134/S1995423918020064.
27. O’Toole Eamonn, Vivek Nallur, and Siobhan Clarke. 2014. “Towards Decentralised Detection of Emergence in Complex Adaptive Systems.” Vol. 2014 IEEE Eighth International Conference on Self-Adaptive and Self-Organizing Systems, 60–69. doi:10.1109/SASO.2014.18.
28. Polanyi, Michael, and Rainer Tod Allen. 1997. “Society, Economics and Philosophy” In New Brunswick NJ: Transaction Publishers, edited by Larry B. Rainey, and Andreas Tolk 2015. Modeling and Simulation Support for System of Systems Engineering Applications. Hoboken: John Wiley & Sons, Inc.
29. Rainey, Larry B., and Mo. Jamshidi. eds. 2019. Engineering Emergence: A Modeling and Simulation Approach. Boca Raton: CRC Press.
30. Rainey, Larry B and Andrew G. Loerch. eds. 2007. “Methods for Conducting Military Operational Analysis.” Military Operations Research Society and LMI Research Institute.
31. Rainey, Larry B., and Andreas Tolk. eds. 2015. Modeling and Simulation Support for System of Systems Engineering Applications. Hoboken: John Wiley & Sons, Inc.
32. R´ıos, J. Pe´rez (2008d), “Supporting organizational cybernetics by communication and information technologies (VSModw)”, International Journal of Applied Systemic Studies, Vol. 2 Nos 1/2 (special issue: organizational cybernetics in focus. Perez Rios, J. and Schwaninger, M. (Guest editors)).

33. Sage, Andrew. P. 2016. “Cybernetics and Complex Adaptive Systems.” In Encyclopedia of Operations Research and Management Science, edited by Saul I. Gass, and Michael C. Fu. Boston, MA: Springer. doi:10.1007/978-1-4419-1153-7_205.

34. Silva, E. Cavalcante, and T. Batista. 2017. Refining Missions to Architectures in Software-Intensive Systems-of-Systems. In Proceedings of the Joint 5th IEEE/ACM Joint International Workshop on Software Engineering for Systems-of-Systems and 11th Workshop on Distributed Software Development, Software Ecosystems and Systems-of-Systems. IEEE, USA, 2--8. https://doi.org/10.1109/JSOS.2017.12

35. Schwartz, Shalmon. H. 2012. “An Overview of the Schwartz Theory of Basic Values.” Online Readings in Psychology and Culture 2 (1). doi:10.9707/2307-0919.1116.

36. Schwaninger, M. (2009), Intelligent Organizations. Powerful Models for Systemic Management, 2nd ed., Springer, Berlin.

37. Singh, Shweta, Shan Lu, Mieczyslav M. Kokar, Paul A. Kogut, and Martin L, 2017. “Detection and Classification of Emergent Behaviors Using Multi-agent Simulation Framework.” Proceedings of the Symposium on Modeling and Simulation of Complexity in Intelligent, Adaptive and Autonomous Systems. Accessed Apr 23–26. https://dl.acm.org/doi/abs/10.5555/3108414.3108417 Paper presented at MSCIAAS’17. Virginia Beach, VA.

38. Song, Houbing, Glenn, A. Fink, and Sabina Jeschke. 2017. “Legal Considerations of Cyber-Physical Systems and the Internet of Things” In Security and Privacy in Cyber-Physical Systems: Foundations, Principles and Applications: 93–115. doi:10.1002/9781119226079.ch5.

39. Stephenson, Peter R. 2017. “Defining a Cyber Jurisprudence.” Paper presented at the Annual ADFSL Conference on Digital Forensics, Security and Law, Florida, May 15 and 16.

40. Sternberg, Robert J., and Peter A. Frensch, eds. 1991. Complex Problem Solving: Principles and Mechanisms. Hillsdale, NJ: Lawrence Erlbaum.

41. Stocchero, J.M Silva C.A, L. d. S. Silva, M. A. Lawisch, J. C. S. d. Anjos and E. P. d. Freitas, 2022, "Secure Command and Control for Internet of Battle Things Using Novel Network Paradigms," in IEEE Communications Magazine, doi: 10.1109/MCOM.001.2101072.
42. Syamil, Ahmad, William J. Doll, and Charles H. Apigian. 2004. “System Performance in Product Development: Measures and Impacts.” European Journal of Innovation Management 7 (3): 205–217. doi:10.1108/14601060410549892.
43. Thomann, James, 1973. “Meta-methodology: An Overview of What It Is and How It Was Developed.” Paper presented at the 58th American Educational Research Association Annual Meeting, New Orleans, Louisiana, February 26 – March 1.
44. Walsh, Melany 2019. “How to Best Protect Military Industrial Control Systems from Cyberattacks.” https://www.fifthdomain.com/opinion/2019/08/01/how-to-best-protect-military-industrial-control-systems-from-cyberattacks/.
45. Ward Stephen and Chris Chapman. 2011. How to Manage Project Opportunity and Risk: Why Uncertainty Management Can Be a Much Better Approach than Risk Management. John Wiley & Sons.
46. Wilensky, U. (1999). NetLogo. http://ccl.northwestern.edu/netlogo/.
47. Yolles, Maurice. 2021. “Metacybernetics: Towards a General Theory of Higher Order Cybernetics.” Systems 9 (2): 34. doi:10.3390/systems9020034.
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APPENDIX F: RELEVANT AUTHORS

Ashby, Ross W. 1965, 2011

Bar-Yam, Yaneer. 2004 - 2023

Beer, Stafford. 1984

Chris Chapman. 2011

Dyson, George. (1997)

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Martin L, 2017.

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Silva C.A, 2022

Silva, L. d. S, 2022

M. A. Lawisch, 2022

J. C. S. d. Anjos 2022

E. P. d. Freitas, 2022

Thomann, James, 1973

Walsh, Melany 2019

Ward Stephen, 2011

Wilensky, U. (1999).

Zio, Enrico, 2011

APPENDIX G: RELEVANT DATABASES USED IN THIS RESEARCH

The relevant databases and sources for your thesis on the emergence of systems of systems (SoS) and complex projects, you can consider the following:

Academic databases:

- USQ Library
- ANU Library
- New England Complex Systems Institute Library
- EEE Xplore
- ACM Digital Library
- ScienceDirect
- SpringerLink
- Taylor & Francis Online
- JSTOR
- Engineers Australia (EA)
- International Centre Complex Project Management (ICCPM)
- Google Scholar (for broader search)
- Academia
- Medium

Research journals:

- Systems Engineering
- Journal of Systems Science and Systems Engineering

- Systems
- IEEE Systems Journal
- Journal of Complex Systems
- International Journal of System of Systems Engineering
- Journal of Project Management

Conference proceedings:

- IEEE International Conference on Systems, Man, and Cybernetics (SMC)
- International Conference on Complex Systems (ICCS)
- International Symposium on System Engineering (ISSE)
- International Conference on Systems Engineering (ICSEng)
- International Council on Systems Engineering (INCOSE) conferences
- Engineers Australia (EA)
- International Centre Complex Project Management (ICCPM)

Books and book chapters:

- "System of Systems Engineering: Innovations for the Twenty-First Century" by Mo Jamshidi
- "Systems Thinking: Managing Chaos and Complexity" by Jamshid Gharajedaghi
- "Complexity and Systems Thinking" by David C. Lane and David Pumfrey
- "Managing Complex Projects: A New Model" by Kathleen B. Hass

- "Managing the Complex: A Critique of the Analysis of Scale and Application in Science" by William R. L. Anderegg.

  And see ANNEX D – Relevant authors

Government and industry reports:

- Defense Advanced Research Projects Agency (DARPA) reports
- National Aeronautics and Space Administration (NASA) reports
- National Institute of Standards and Technology (NIST) reports
- Institute for Defense Analyses (IDA) reports
- Aerospace industry reports (e.g., Boeing, Lockheed Martin)
- Department of Defence Australia, various reports

Theses and dissertations:

- ProQuest Dissertations and Theses Global
- Networked Digital Library of Theses and Dissertations (NDLTD)
- Naval Postgraduate School, USA Thesis

Industry:

- Airbus Australia
- Air Force Institute of Technology in the Department of Aeronautics and Astronautics
- Asset Studio Software. - AeROS (Asset Reliability and Operation Simulation).
- AnyLogic Software
- BAE

- Boeing
- KBR
- Leidos Australia
- Lockheed Martin
- PWC
- Raytheon Technologies
- L3 Harris
- Nova Systems
- Elbit Systems Australia
- Thales