

DISSERTATION

TECHNIQUES IN REACTIVE TO PROACTIVE OBSOLESCENCE
MANAGEMENT FOR C5ISR SYSTEMS

Submitted by

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In partial fulfillment of the requirements

For the Degree of Doctor of Philosophy

Colorado State University

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Spring 2023

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ABSTRACT

Obsolescence is a significant challenge for the Command, Control, Communications, Computers, Cyber, Intelligence, Surveillance and Reconnaissance (C5ISR) community. Obsolescence can negatively affect a C5ISR system's cost, schedule, performance, and readiness. This research examines the challenge of obsolescence for C5ISR systems by focusing on the U.S. Army at Aberdeen Proving Ground, Maryland and their industry partners. The objective of this research is to synthesize insights from the experiences of government and industry practitioners that mitigate diminishing manufacturing sources and material shortages (DMSMS) challenges into mitigation techniques. The obsolescence mitigation areas described in this research include proactive and reactive obsolescence mitigation, obsolescence mitigation methods, and the importance of DMSMS contracting language. This research also offers approaches grounded in practitioner experiences to mitigate obsolescence through a proactive obsolescence management model, risk mitigation framework, metrics, modeling & simulation, and systems thinking methods. The combination of the models, methods, and approaches discussed from this research have the potential to achieve greater system readiness, more availability, better maintainability, and lower costs for C5ISR systems.

PREFACE

Prior to this research journey, I had been searching for a deeper technical truth in my work, I knew I was missing something, but I was uncertain about how to go about filling in this gap. I have often been highly challenged in my work with complex challenges. I eventually realized that I needed to develop strong research skills to assist me with my desire to solve complex problems. In this research journey, I found the skills I needed to perform the original and novel research needed to combat complex problems. I furthered the knowledge in this field beyond the current literature. I based my research on the experiences of Command, Control, Communications, Computers, Cyber, Intelligence, Surveillance and Reconnaissance C5ISR practitioners as well as systems modeling techniques, data science, and statistical methods. This research contributed to the theory and the techniques to transform organizations and their teams to shift from reactive obsolescence management to risk based proactive obsolescence management. This research contributed to the field with a proactive obsolescence management model, a risk mitigation framework, metrics, and a visualization tool for evaluating the risk of obsolescence. The tool was developed and deployed using the R statistical software program. The visualization tool focuses on the areas of component design life, procurement lead time, cost growth, and the number of manufacturers producing the component. Furthermore, this research contributed to the field with the development and refinement of mental models to link the relationships of the interactions between the system of interest (DMSMS Management System), system context (Engineered Systems), and enabling systems (*i* Supply Chain, *ii* Configuration Management, *iii* Budget System). This led to a deep understanding that the mental model needs to change from reactive obsolescence management to risk based proactive obsolescence

management to greatly increase the probability of success for teams and organization to proactively mitigate the obsolescence challenge.

DEDICATION

I dedicate this research to my wife Allison and children Catie, Lily, and Jack who have sacrificed so much of their time with me so that I could pursue my research. I am deeply appreciative of their loving support and encouragement.

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FUNDING & SUPPORT

I am an award winner of the highly competitive Department of Defense Science Mathematics and Research for Transformation (SMART) scholarship to conduct product support research within the field of systems engineering. This award supports my research in the area of proactive obsolescence mitigation for C5ISR systems.

CHAPTER 1: INTRODUCTION

1.1. CHAPTER INTRODUCTION

Obsolescence is a major challenge that continues to challenge the readiness of systems within the Department of Defense. There are many long-lived systems, as the technology ages and advances, the obsolescence challenges intensify. Obsolescence erodes areas beyond system readiness such as supply chain health, poorer maintainability, longer schedules and higher costs. The focus of this research is on obsolescence mitigation for the Army's Command, Control, Communications, Computers, Cyber, Intelligence, Surveillance and Reconnaissance (C5ISR) systems. A proactive obsolescence management approach focusing on the planning and execution of the activities to support early obsolescence mitigation solutions is critical for the long-term affordability and availability of C5ISR systems. There are many benefits associated with achieving successful proactive obsolescence management, such as greater system readiness, more availability, better maintainability, reduced schedule delays and lower costs. Obsolescence is an area that has been and continues to be a major challenge for the practitioners that are responsible for the long-term support of C5ISR systems. Therefore, this subject deserves further research to provide new methods to mitigate obsolescence challenges.

1.2. PROBLEM STATEMENT

The U.S. Army and its industry partners are profoundly challenged by obsolescence in support of C5ISR systems. Often solutions are reactive to the challenge posed by obsolete components. This results in lower operational availability, longer production and repair schedules, and greater system costs. More robust proactive diminishing manufacturing sources and material shortages (DMSMS) mitigation methods are needed to proactively manage the

numerous obsolescence challenges. Proactive DMSMS mitigation methods support higher system readiness, greater supply availability, and reduces life cycle costs.

1.3. RESEARCH QUESTIONS

The primary research questions include:

1. How does the Army and industry proactively mitigate obsolescence of C5ISR systems?
2. How can obsolescence challenges be modeled, simulated, and visualized for C5ISR systems?
3. How can the complexity of obsolescence for C5ISR systems be better understood to support proactive mitigation methods?

1.4. RESEARCH SIGNIFICANCE

This research delivers new methods and techniques for obsolescence management. Areas further developed through research include reactive vs. proactive obsolescence management, obsolescence risk management, metrics, modeling and simulation, and risk risk-based obsolescence data visualizations. This research extends as well as fills gaps in the theory and practice of risk based proactive obsolescence management for C5ISR systems. A list of my novel research contributions follows:

- New Proactive Obsolescence Management Model
- New Proactive Obsolescence Risk Mitigation Framework
- New Proactive Obsolescence Mitigation Metrics
- New Obsolescence Modeling & Simulation Technique
 - Coded in R
 - Applied to 9 risk based simulations representative of 81 possible permutations

- Applied to 1 non-simulated example using a drone system
- New Obsolescence Risk Management Visualizations
- New Obsolescence Management Mental Model Evolution
- New Reactive Obsolescence Management Mental Model
 - Supporting reactive obsolescence management causal loop diagram
- New Risk Based Proactive Obsolescence Management Mental Model
 - Supporting risk based obsolescence management causal loop diagram

1.5. CHAPTER CONCLUSION

Again, obsolescence is an area that has been and continues to be a major challenge for the practitioners that are responsible for the long-term support of C5ISR systems. This subject deserves focused research to develop new methods and techniques to mitigate the obsolescence challenges. This dissertation fills in many gap areas to assist practitioners as well as researchers with methods and tools to mitigate the obsolescence challenges.

CHAPTER 2: LITERATURE REVIEW

2.1. CHAPTER INTRODUCTION

There are many examples in the literature emphasizing obsolescence management to assist practitioners. These areas include Department of Defense (DoD) policy and research in many areas highlighting the obsolescence challenges and the need to be proactive. Furthermore, obsolescence is a complex challenge and the literature provides a framework to provide practitioners with a higher probability of success when combined with the research in this dissertation.

2.2. DOD OBSOLESCENCE MANAGEMENT POLICY

The policy includes the Department of Defense's Instruction 4245.15 Diminishing Manufacturing Sources and Material Shortages provides instruction on managing and mitigating challenges associated with DMSMS (Department of Defense, 2020). A more detailed guideline is in the *SD-22 Diminishing Manufacturing Sources and Material Shortages A Guidebook of Best Practices for Implementing a Robust DMSMS Management Program* which includes details for many obsolescence management methods such as the DMSMS Management Teams, DMSMS Management Plans, DMSMS monitoring and surveillance, and many other DMSMS management considerations (Department of Defense, 2021). More information to assist with contracting can be found in *SD-26 DMSMS Contract Language Guide Book* (Department of Defense, 2019).

2.3. OBSOLESCENCE MANAGEMENT CHALLENGES

The Beyond Reactive Thinking – We Should be Developing Pro-Active Approaches to Obsolescence Management Too! highlights the sustainment advantages and cost benefits

associated with adopting a proactive approach in lieu of a reactive approach to obsolescence management (Sandborn, 2004). Similar emphasis supporting proactive obsolescence is also found in *Forecasting and Proactive Management of Obsolescence for Sustainment-Dominated Systems* (Sandborn & Terpenney, 2006). The importance of proactive obsolescence management is further supported with modeling in the *Strategic Proactive Obsolescence Management Model* (Meng, Thörnberg, & Olsson, 2014). Another modeling approach to support proactive obsolescence is provided for the interaction between components using a Weibull's distribution in the *FMECA-Based Risk Assessment Approach for Proactive Obsolescence Management* (Trabelsi, Zolghadri, Zeddini, Barkallah, & Haddar, 2020). *Software Obsolescence – Complicating the Part and Technology Obsolescence Management Problem* also notes the importance of proactive obsolescence management to mitigate software obsolescence; however, suggests that more is needed to assist with the mitigations (Sandborn, 2007).

Research has also been conducted in the area of power plants. The *Proactive Obsolescence Management* paper highlights the importance of planning in advance to mitigate obsolescence for a nuclear power plant (Clancey, 2018). There are many activities that support proactive obsolescence management, the modeling in the *A Model to Manage Electronic Component Obsolescence for Complex or Long Life Systems* includes many activities that drive both proactive and reactive obsolescence management (Meyer, Pretorius, & Pretorius, 2004). Lastly, the *Obsolescence Risk Assessment Process Best Practice* discusses the use of risk to mitigate several obsolescence challenges (Rojo, Roy, & Kelly, 2012).

Based on the policy and the prior research there is a significant gap in the area of how to get from reactive to proactive obsolescence management, as well as robust models, simulations, tools and techniques for small teams to large organizations to utilize to mitigate their

obsolescence challenges. Even more fundamentally, there is an appreciation of proactive obsolescence management in lieu of reactive obsolescence management; however, there is not a clear understanding of the activities that constitutes proactive obsolescence management vs. reactive obsolescence management.

2.4. SYSTEMS THINKING & ADDRESSING COMPLEXITY

The literature supports addressing complex problems with a systems thinking approach to increase the chances of determining a successful solution. Finding a successful solution to a complex problem can be very difficult because any changes are highly interconnected and it takes time to tell if the changes are an improvement, produced no noticeable change, or made the problem worse. The *Dilemmas in a General Theory of Planning* describes types of problems as tame problems, which are relatively simple to solve, and wicked problems or dilemmas, which are very complex and difficult to solve (Rittel and Webber, 1973). The wicked problems require a more robust toolset to solve; the challenges of the obsolescence that affect C5ISR systems is one such challenge.

The work of Donella (Dana) Meadows defines a system as elements, interconnections, and a function or purpose. She provides a sports example to illustrate thinking in systems to open one's mind to what a system truly is, and this example also shows its applicability to more than engineered systems. In football, for example, elements include the coach, players, ball, and field; interconnections include communications between the players, rules, and coach's strategy; and the purpose is to win. The higher leverage areas to change a system is in the purpose and the interconnections, change the purpose from winning to tying or losing and the entire game has significantly changed (Meadows, 2008). She also introduces a very important stock element for understanding systems and defines a stock as "the elements of the system that you can see, feel,

count, or measure at any given time” (Meadows, 2008). Illustrating similar points, the work of Russ Ackoff uses many examples in the areas of education, management, government, etc. focusing on systems thinking and emphasizing the interactions, feedback, and the system as a whole (Ackoff, 2010). These stocks are further used in the modeling work in David Stroh’s *Systems Thinking for Social Change* showing the construction of a causal loop diagram and explaining the relationships and terminology, where an “S” or “+” indicates more of the same in a positive direction, an “O” or “-” indicates a response in the opposite direction, and double lines indicate a delay in the process (Stroh, 2015). Systems thinking and systems dynamic approach to solve complex problems was popularized in *The Fifth Discipline* (Senge 2006). This book highlighted the techniques that increase an organization’s chance of solving complex problems that do not have a straightforward solution. The analysis in *Systems Engineering in the Fourth Industrial Revolution* discusses the tools to address complexity in the context of applied systems thinking, systems engineering, software cybernetics, and risk management (Kenett et al., 2020). In *Holistic Thinking* there are deep system thinking fundamentals supporting the value of thinking in a way where the whole is more than the parts (Kasser, 2015). *Systems Thinking Creative Holism for Managers* provides a comprehensive guide through the areas of systems thinking, some areas include: the systems language, applied system thinking, creativity and systems, hard systems, soft systems methodology, systems dynamics, organizational cybernetics, and complexity theory (Jackson, 2016). Similarly, from a business point of view, *Business Dynamics Systems Thinking and Modeling for a Complex World* is a comprehensive guide to systems thinking. Some of the areas include learning in about complex systems, system dynamics, modeling, structure and behavior of dynamic systems, and tools for systems thinking (Sterman, 2000). The work of Kasser (2015) discusses the advantages of using a holistic thinking

approach over the traditional technology readiness level (TRL) as a more useful conceptual tool to understand the technology lifecycle from concept to obsolescence. His work does discuss systems thinking but the application of the tools to address the complex change of obsolescence management was outside of the scope of his article.

There is a gap in the literature in the area of using the tools of systems thinking to assist with mitigating the complex challenge of obsolescence. The literature does not address applying the tools of systems thinking to the complex problem of obsolescence management. This is a deceptively complex problem because at the surface it is difficult to identify the causes of the challenges and the interconnections of the challenges among the system of interest, the enabling systems, and the context systems. Furthermore, this research complements the other research by providing systems thinking models to guide teams and organization in their pursuit of transforming from a reactive obsolescence management to risk based proactive obsolescence management. Furthermore, the policy in the Department of Defense's *Instruction 4245.15 Diminishing Manufacturing Sources and Material Shortages*, the SD-22 *Diminishing Manufacturing Sources and Material Shortages A Guidebook of Best Practices for Implementing a Robust DMSMS Management Program*, and the SD-26 *DMSMS Contract Language Guide Book* could be complemented by the systems thinking approaches presented in this article.

2.5. CHAPTER CONCLUSION

DoD policy and the literature highlighting the obsolescence challenges that are applicable to C5ISR systems. This dissertation complements the existing policy and literature. The novel research contributions in this dissertation fills some of the gaps in the areas of modeling, methods, and techniques to aid with obsolescence mitigation.

CHAPTER 3: ARMY & INDUSTRY'S OBSOLESCENCE MANAGEMENT OF C5ISR SYSTEMS

3.1. CHAPTER INTRODUCTION

Obsolescence is a significant challenge for the Command, Control, Communications, Computers, Cyber, Intelligence, Surveillance and Reconnaissance (C5ISR) community. Obsolescence can negatively affect a C5ISR system's cost, schedule, performance, and readiness. This chapter examines the challenge of obsolescence for C5ISR systems by focusing on the U.S. Army at Aberdeen Proving Ground, Maryland, and their industry partners. Data were gathered by conducting interviews with 20 individuals who had experience with C5ISR systems: 10 government Army civilians and 10 industry partner employees. The objective of this chapter is to synthesize insights from the experiences of government and industry practitioners that mitigate diminishing manufacturing sources and material shortages (DMSMS) challenges. The obsolescence mitigation areas described in this chapter include proactive and reactive obsolescence mitigation, obsolescence mitigation methods, opportunities for alternative components and planned improvements, the importance of DMSMS contracting language, and obsolescence management practices to avoid. This chapter also offers approaches grounded in practitioner experiences to mitigate obsolescence through a proactive obsolescence management model, risk mitigation framework, and metrics. The combination of the obsolescence mitigation approaches discussed in this chapter has the potential to achieve greater system readiness, more availability, better maintainability, and lower costs for C5ISR systems.

Obsolescence is a major challenge which affects all Command, Control, Communications, Computers, Cyber, Intelligence, Surveillance and Reconnaissance (C5ISR) systems. A proactive obsolescence management approach focusing on the planning and

execution of activities to support early obsolescence mitigation solutions is critical for the long-term affordability and availability of C5ISR systems. Many benefits are associated with achieving successful proactive obsolescence management, such as greater system readiness, more availability, better maintainability, reduced schedules, and lower costs.

3.2. CHAPTER BACKGROUND

A well-known example in military aviation of a system that has experienced multiple obsolescence challenges in its history is the B-52 bomber (Newman, 2016).

The B-52 bomber was originally awarded in 1946 and is projected to be in service into the 2040s. While this instance may represent an extreme case for program lives, it is not uncommon for larger DoD programs to extend for several decades. As these systems age, the electronic and software systems within them will become obsolete over time and will eventually become unreliable, unmaintainable, unserviceable, underperforming, or nonfunctional, leaving the warfighter at risk of losing superiority on the battlefield.

The B-52 bomber is a very long-lived system example, which has some legacy communication systems on board; this magnifies the importance of managing obsolescence to save cost, schedule, and operational availability. In the case of long-lived systems, getting ahead of obsolescence challenges is critical because the outcomes will be realized many times over.

An example follows of how obsolescence challenges negatively impact systems. Imagine learning that one day the component needed to support a system is no longer available. This discrepancy is detected only after trying to place an order, and it comes as a complete surprise that a needed component is no longer available due to obsolescence. This leads to a scramble to find a replacement, to qualify an alternate component, or to find another source of supply. As a

part of the process to qualify the replacement component, engineering changes are made to this component and/or the receiving system. This results in a newly designed or redesigned component, and all the processes are accelerated to provide the replacement component as quickly as possible. This acceleration is important because it avoids the alternative of reducing the number of available systems. Reflection on this series of events results in the realization that failure to proactively manage obsolescence has resulted in delayed schedules, increased costs, and lower supportability. The research in this article will assist acquisition practitioners with mitigating obsolescence challenges prior to their unforeseen immersion in what becomes a reactionary situation.

This chapter examines the perspectives of government and industry practitioners who are routinely confronted with obsolescence challenges, with the focus on C5ISR systems managed by the U.S. Army at Aberdeen Proving Ground, Maryland. This research is applicable to C5ISR systems hardware and its embedded software. The government and industry participants were interviewed about their extensive experiences including successful obsolescence mitigation approaches, unsuccessful obsolescence mitigation approaches, and ways to improve obsolescence mitigation for C5ISR systems. This chapter synthesizes and builds upon these insights to offer a framework, model, and metrics to the community of acquisition practitioners and researchers to combat the obsolescence challenge. The insights of the practitioners that participated in this research significantly contributed to our collective knowledge of potential methods to achieve proactive obsolescence mitigation for C5ISR systems.

The inability to obtain replacement components for a system is commonly addressed within the context of diminishing manufacturing sources and material shortages (DMSMS). Significant advantages are associated with mitigating DMSMS challenges that can be leveraged

by putting into practice proactive initiatives in lieu of reacting to unforeseen issues requiring immediate attention.

3.3. CHAPTER PROBLEM STATEMENT

The U.S. Army and its industry partners are challenged by obsolescence in support of C5ISR systems. Often solutions are reactive to the challenge posed by obsolete components. This results in lower operational availability, longer production and repair schedules, and greater system costs. More robust proactive DMSMS mitigation methods are needed to proactively manage the numerous obsolescence challenges. Proactive DMSMS mitigation methods support higher system readiness, greater supply availability, and lower life-cycle costs. The primary three research questions set forth in this chapter include:

1. How does the Army proactively mitigate obsolescence of C5ISR systems?
2. How does the defense industry mitigate obsolescence for the Army's C5ISR systems?
3. Are there differences between how the Army and defense industry control obsolescence mitigation management for the Army's C5ISR systems?

3.4. CHAPTER METHODOLOGY

The research design for this study is qualitative and uses the phenomenological research methodology, which consists of interviewing participants about their experiences with mitigating obsolescence challenges for varied defense weapon systems. The participants included both government employees from the U.S. Army located at Aberdeen Proving Ground, Maryland, and their industry partners. All participants have experience supporting C5ISR systems in the operations and support phase of the system life cycle. The participants included 10 government Army civilian employees 10 industry partner employees (total of 20 government and industry

participants), nine engineers, six project managers, four logisticians, and one business manager. The 10 government Army civilian employees have an average of 23 years of experience. Similarly, the 10 industry partner employees have an average of 23.2 years of experience. The participants were all asked 13 open-ended questions in individual interviews (Table 1). The interviews lasted approximately 30–60 minutes. This study had Institutional Review Board approval from Colorado State University.

Table 1. Interview Questions for All 20 Participants

Interview Questions
1. Are you with the government (Army) or industry?
2. What is your area of expertise?
3. How many years of experience do you have?
4. What training have you received to mitigate obsolescence?
5. What tools do you use to mitigate obsolescence?
6. How do you identify obsolescence for your system(s)?
7. What role does risk management play in identifying obsolescence?
8. What role does risk management play in mitigating obsolescence?
9. How has contract language assisted or hindered your ability to mitigate obsolescence?
10. When do you normally discover an obsolescence problem for your system(s)?
11. What has worked well to mitigate obsolescence?
12. What has not worked well to mitigate obsolescence?
13. What is your organizations future initiatives to mitigate obsolescence beyond the current process/practice (next level)?

3.5. CHAPTER ANALYSIS & RESULTS

Participant responses were synthesized to identify current methods for proactive obsolescence mitigation, training for proactive obsolescence mitigation, opportunities for alternative components and planned improvements, the importance of DMSMS contracting language, and obsolescence management approaches to avoid. Overall themes from participant responses and the literature were then used to develop a proactive obsolescence management model, a proactive obsolescence risk mitigation framework, and preliminary metrics. The knowledge gained from this research is intended to strengthen the knowledge base and available methods for practicing proactive obsolescence mitigation best practices in support of C5ISR systems.

3.5.1. UNDERSTANDING PROACTIVE VS. REACTIVE OBSOLESCENCE MITIGATION

The participants in this study shared their obsolescence mitigation experiences; many had experiences using both proactive and reactive obsolescence mitigation methods. The preference was always to be proactive; however, some survey respondents reported that they had often been surprised by material shortages, which only left them the reactive obsolescence mitigation approach option. The mitigations focused on C5ISR system components, with the obvious exception of very low-risk parts, e.g., bolts, nuts, and screws. In some cases, identifying which mitigation approaches are proactive vs. reactive can be difficult. For example, Life-of-Type Buys solve an immediate challenge and may appear proactive for the long-term of the procured component. However, such buys are reactive because they act as an approximate buffer and do not account for the lack of long-term design stability of the components within the system. On one hand, some of the Life-of-Type Buy components likely will not be used. On the other hand,

one could err through buying too few components, further worsening the obsolescence challenge. Conversely, proactively redesigning an alternate component as well as several of the surrounding components 5 years before the need for a Life-of-Type Buy will mitigate the negative schedule, cost, and availability challenges of the DMSMS risk. Table 2 includes examples to assist in understanding “Proactive Obsolescence Mitigation Approaches” vs. “Reactive Obsolescence Mitigation Approaches.”

Table 2. Examples of Proactive vs. Reactive Obsolescence Mitigation Approaches

Proactive Obsolescence Mitigation Approaches	Reactive Obsolescence Mitigation Approaches
Analyze the system’s bill of materials with a predictive analysis tool to plan the appropriate development or selection of replacement components	Life-of-Type Buys – Order all the end-of-life components forecasted for the life cycle of the system (Trabelsi, Zolghadri, Zeddini, Barkallah, & Haddar, 2020)
Establish and maintain a DMSMS Management Team	Harvest components/parts from defielded systems
Establish and update a DMSMS Management Plan	Near-term redesign
Flow DMSMS contracting language through the supply chain to monitor the health of components and obtain recommended solutions	Near-term design modifications
Use Open System Architecture design solutions	Request manufacturer to continue producing the component(s)/part(s)
Early qualification of alternate manufacturing sources for a replacement that meets form, fit, and function criteria	Find an immediate substitute replacement that meets form, fit, and function criteria
Design by partitioning the system for logical component-level and cost-effective future design changes	Increase maintenance to extend the useable life of the system
Early development and use of metrics	Use the system less and lower the standard operating performance criteria to extend the useable life of the system; e.g. lower power usage reduces heat

3.5.2. METHODS FOR PROACTIVE OBSOLESCENCE MITIGATION

The research participants' methods of proactively mitigating the obsolescence of C5ISR systems for the Army at Aberdeen Proving Ground compared to methods of the defense industries that provide support for these systems are very similar. Both recognize the advantages of proactive obsolescence mitigation vs. the disadvantages of reactive obsolescence mitigation such as the schedule and cost impacts. Several methods stood out among the interviews that support proactive obsolescence mitigation. These methods include the following:

- Establish and maintain a DMSMS Management Team
- Establish and update a DMSMS Management Plan
- Analyze the system's bill of materials (BOM) with predictive analysis tools
- Flow DMSMS contracting language through the supply chain for monthly feedback on the health of components and recommended solutions

DMSMS Management Team. SD-22 Diminishing Manufacturing Sources and Material Shortages: A Guidebook of Best Practices for Implementing a Robust DMSMS Management Program states “all program offices should have a DMSMS management team (although it may be small under certain circumstances) that oversees the execution of a DMSMS management plan” (DoD, 2022). Further, several research participants highlighted that, in practice, establishing the DMSMS Management Team is the critical first step. This is the team that will do the majority of the activities required to achieve proactive obsolescence management for a system.

DMSMS Management Plan. These research participants emphasized the essential early assignment of the DMSMS Management Team is to create and receive approval of the DMSMS

Management Plan. The DMSMS Management Plan includes the strategy and the plan for the execution activities to achieve proactive obsolescence management for a system. Moreover, the SD-22 states “pursuant to Section 803 of Public Law 113-66, implement a risk-based and proactive DMSMS/Obsolescence Management Plan to monitor materials, technologies, and items throughout the program life cycle” (DoD, 2022).

Bill of Materials. Analyzing the system’s bill of materials (BOM) with a predictive analysis tool emerged as a high-value proactive obsolescence mitigation activity among the research participants. This is an important method to support proactive obsolescence management. Using a predictive analysis tool to analyze the BOM is a foundation of proactive obsolescence management and will continually inform the DMSMS Management Team and the DMSMS Management Plan, as well as assist with monitoring the supply chain for DMSMS risks and issues. Additionally, this information supports the tailoring of the DMSMS contracting language. Examples of predictive analysis tools include Multifunctional Obsolescence Resolution Environment (MORE), Advanced Component Obsolescence Management (AVCOM), Electronic Resellers Association International (ERAI), and Information Handling Services (IHS) Haystack. These are examples intended to inform the defense acquisition community of some potential options as identified by the research participants, and is not an endorsement of any one tool in lieu of another. Further, the participants highlighted risk management as an essential aspect of proactive obsolescence mitigation. Unique components often change due to frequent technology advances and have one or few suppliers, are high risk, and require focused expertise. Less intensive proactive effort is still required to mitigate DMSMS risk for components that have a predictable useful life with planned replacements. The

components with the least DMSMS risk are those that rarely change, e.g., the system's frame, assembly hardware (nuts, bolts, etc.).

DMSMS Contracting Language. The research participants focused on the importance of flowing the DMSMS contracting language through the supply chain for feedback on the health of components, and recommended solutions were identified as very important for achieving proactive obsolescence management for a system. Some participants included their experiences with flowing down DMSMS contracting language to a subcontractor or vendor. However, no process was identified by the participants to verify the DMSMS language flowed through the supply chain to include all subcontractors, vendors, and material providers. It is important to verify the completion of the contract language flow down through the supply chain using the metric "DMSMS Contract Language Supply Chain Flow Down Verification," which is presented earlier in this chapter.

3.5.3. TRAINING FOR PROACTIVE OBSOLESCENCE MITIGATION

Many participants identified the importance of training to support an acquisition practitioner's efforts. In some cases where a participant had not received formal training, the survey reflected a comment indicating how helpful it would have been to receive prior training, especially when first addressing obsolescence challenges for DoD weapon system(s). As a result, gathered a list of training available from some of the participants in this study (Table 3). This is not a recommendation or endorsement of the listed training classes. Their mention in this chapter is to provide and promote awareness within the defense acquisition community.

Table 3. Participant Identified Obsolescence Mitigation Training

Training Source	Class/Seminar
Defense Acquisition University	<ul style="list-style-type: none"> - LOG 0630 - Parts Management Executive Overview - LOG 0640 - Diminishing Manufacturing Sources and Material Shortages - LOG 0650 - Diminishing Manufacturing Sources and Material Shortages Fundamentals - LOG 0660 - Diminishing Manufacturing Sources and Material Shortages Executive Overview - LOG 0670 - Diminishing Manufacturing Sources and Material Shortages Basic Component
International Institute of Obsolescence Management (IIOM)	<ul style="list-style-type: none"> - IIOM Certification 3-Day Course - IIOM Online Conference Seminars

3.5.4. OPPORTUNITIES FOR ALTERNATIVE COMPONENTS AND PLANNED IMPROVEMENTS

Several participants shared their experiences with harvesting components from decommissioned systems to address immediate shortages due to obsolescence. This is a highly reactive mitigation action to address obsolescence; however, an opportunity for much learning can emerge from this type of challenge. One lesson is to design or redesign these components several years ahead of a system repair. The alternate component should be designed for greater reliability, particularly if the component has a reliability challenge. Further, test data can be used to identify the medium- to high-risk components to select for an early alternate component design and improvements. On one hand, the redesign of an obsolete component is an opportunity to add or refresh capability and supportability. On the other hand, planning the phasing out of a component based on forecasting its end of life assists with promoting better replacement component planning. Further, the advance planning of schedules to integrate a replacement end

of life component or an increased capability component is an opportunity to save resources, e.g., lower DMSMS case resolution costs, lower modification costs, and shorter schedules.

One proactive obsolescence mitigation approach is to identify lower reliability components 5 years in advance of forecasted obsolescence, then select or design form-fit-function alternate components to improve the availability, reliability, and cost for the components that present higher risk. Reliability is one example; in some cases, changing the technology is necessary, e.g., the industry changes to only producing the component with a more durable material. Therefore, designing this improved alternate component as a form-fit-function replacement should begin with the identification of the new material. The key takeaway is to plan the redesigning of components to be available 5 years in advance of the forecasted current components end of life; this will lower risk, increase availability, and lower long-term supportability costs.

3.5.5. IMPORTANCE OF DMSMS CONTRACTING LANGUAGE

Both the Army and industry research participants stressed the importance of including language in the contract that addresses obsolescence/DMSMS monitoring, reporting, and mitigation. This language includes areas such as a forecast for when components and parts will become obsolete and prompts the industry partner to recommend one or several solutions for the Army's consideration. The inclusion of this language is an enabler for the Army to proactively mitigate obsolescence for C5ISR systems, as well as a mechanism for industry to proactively plan for mitigating obsolescence of the system. The absence of this type of contracting language communicates a lack of importance to industry and results in minimal to no proactive effort to mitigate obsolescence. This finding reinforces the importance of DMSMS contracting language because industry performs to the funded requirements in the contract. Lastly, no participants

identified using obsolescence metrics to assist with guiding and evaluating an organization's methods for proactively mitigating obsolescence. Therefore, a gap in our research exists, but an opportunity emerges for acquisition leaders to recognize their importance and implement metrics within these organizations, on the contract, and through the supply chain. Such early identification of obsolescence challenges and mitigation recommendations could achieve greater proactive obsolescence management for C5ISR systems.

3.6. OBSOLESCENCE MANAGEMENT APPROACHES TO AVOID

The obsolescence management approaches to avoid include: ignoring the obsolescence problem, reactive obsolescence management in lieu of proactive obsolescence management, and addressing obsolescence challenges as a one-time issue. Many participants explained the importance of actively managing obsolescence challenges and pointed out the significant drawbacks to ignoring obsolescence. Ignoring the obsolescence problem worsens the negative impacts to a system's readiness, availability, maintainability, and costs. Further, these aforementioned negative impacts are also experienced when the obsolescence management is reactive. Lastly, addressing obsolescence challenges as a recurrent issue and investing in the DMSMS Management Team, DMSMS Management Plan, and a predictive tool that leverages collective obsolescence mitigation knowledge is essential for basic proactive obsolescence management. The predictive tool could be provided by a third party or internally developed within the organization. The benefit of using a tool includes the synergy from the collective knowledge of many and supports a structured proactive approach to solving obsolescence challenges.

3.7. PROACTIVE OBSOLESCENCE MANAGEMENT MODEL

Based on government and industry insights for Army C5ISR systems, I developed a model (Figure 1) to assist defense acquisition organizations and defense industries with implementing and maintaining proactive obsolescence management practices.

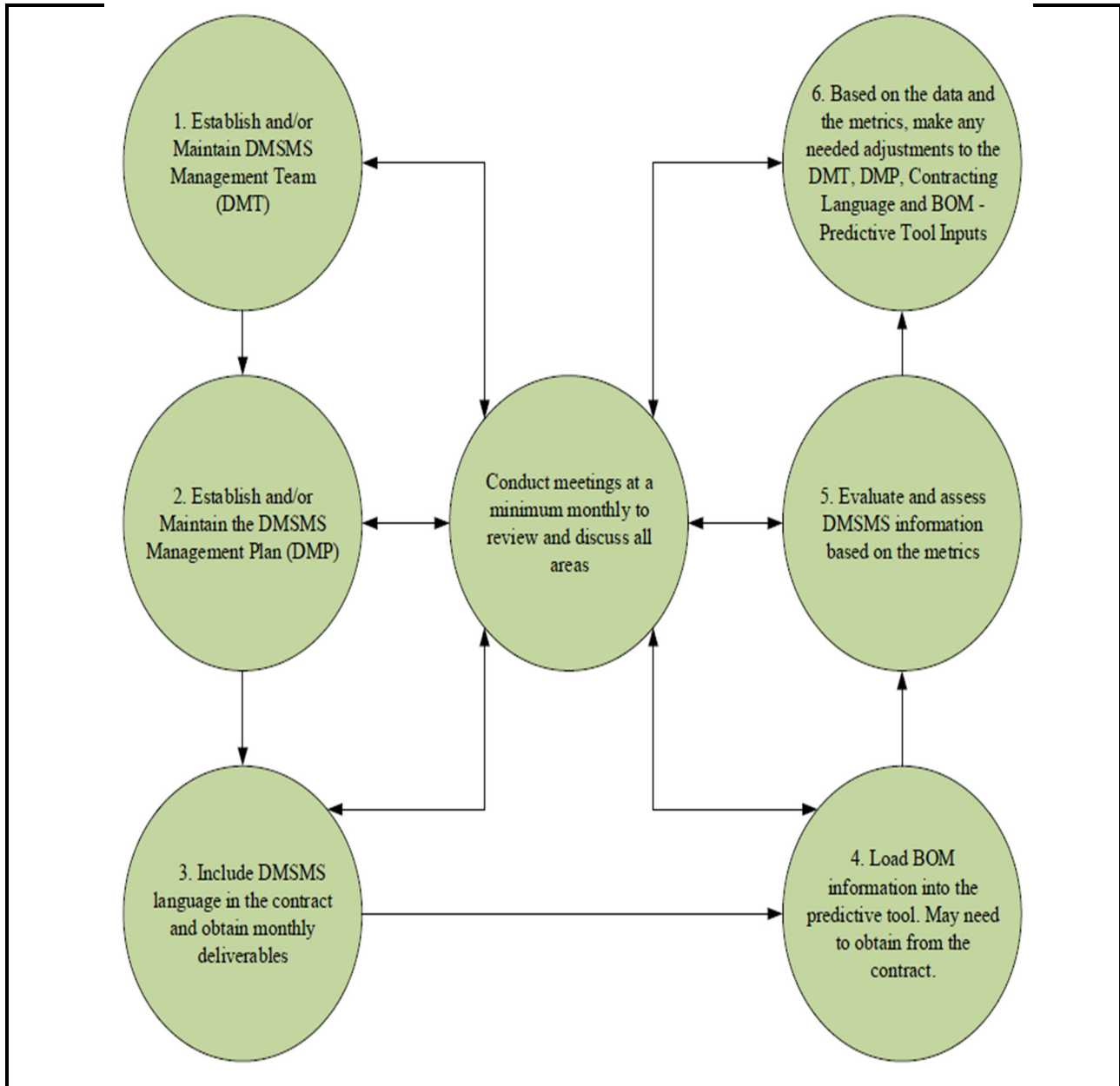


Figure 1. Proactive Obsolescence Management Model

The model first focuses on the DMSMS Management Team, which is essential because this team does the majority of the planning, coordination, and execution. The DMSMS Management Team then creates the DMSMS Management Plan, which includes all the key areas needed to proactively manage obsolescence. Next is the obsolescence management contracting language, which includes the key areas to report the DMSMS status for all the components. Additionally, this is the place to include the language that allows industry to produce mitigation plan(s) for all the high- and medium-risk components proactively. Subsequent selection and application of a predictive tool on the BOM information may help locate current and projected DMSMS challenges. This information will come from the contractor's reports and/or an inspection of the system's components by the engineering and/or logistics employees. The next step is evaluating the DMSMS data with the metrics to gain an understanding of the components that require short-term mitigation (less than 5 years) and the components that require long-term mitigation (more than 5 years and less than 12 years). Acquisition practitioners are advised not to invest effort in components and materials that rarely change, i.e., very long-term (more than 12 years). The metrics may also assist with improvements with processes, trade-off analysis, training etc. Lastly, decide which areas need to change, e.g., add team member(s) with different areas of expertise to the DMSMS Management Team, update DMSMS Management Plan, change the BOM to a redesigned component or a selected alternate component, change contract language, etc. Repeat the process, then review DMSMS information with the team on a monthly basis at a minimum to maintain a proactive obsolescence management approach.

3.8. OBSOLESCENCE RISK ANALYSIS MODELING

The participants recognized the importance of identifying and mitigating the risk of projected component obsolescence to assist with achieving proactive obsolescence management

for C5ISR systems. Typically, acquisition practitioners must evaluate many considerations regarding obsolescence management, such as frequency of design changes, reliability, ageing systems, cost, and component availability within the supply chain.

Based on the insights and concerns of the participants, constructed an obsolescence risk mitigation framework (Table 4), which categorizes the inputs and outputs to assist with mitigating obsolescence for C5ISR systems.

Table 4. Proactive Obsolescence Risk Mitigation Framework

Inputs	Outputs		
<i>Indicators</i>	<i>Low Risk</i>	<i>Medium Risk</i>	<i>High Risk</i>
Number of Manufactures	3 or more manufactures	2 or more manufactures	1 manufacturer
Cost of Component and/or Part	Cost growth is not more than 10% for the component/part	Cost growth is more than 10% but less than 25% for the component/part	Cost growth is more than 25% for the component/part
Schedule of Component/Part	Estimated delivery schedule is 6 months or less	Estimated delivery schedule is 6 - 12 months	Estimated delivery schedule is more than 12 months
Frequency of Design Changes	Estimated design changes are 12 years or greater	Estimated design changes are more than 5 years but less than 12 years	Estimated design changes are less than 5 years
Next Generation, Upgrade & Update Planning - Roadmaps for technology, systems, or products	Roadmaps indicate firm dates of the replacement component/part; e.g. month and year or quarter and year	Roadmaps indicate a date range; e.g. a span of several years for the replacement component/part	No roadmap or roadmaps do not indicate any dates

Component Replacement Planning	Planning component replacement early in the service life based on forecasted operational hours and cycles: One cycle is from powering a component on to powering the component off	Planning component replacement in the middle of the service life based on forecasted operational hours and cycles	No to minimal planning of component replacement
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Offering this proactive obsolescence risk mitigation framework to the acquisition community to assist with managing obsolescence risk. This framework provides criteria to perform analysis of a system’s DMSMS risk. Reactive obsolescence management is associated with the components that are assessed as medium- to high-risk. Proactive obsolescence management is associated with the components that are assessed as low-risk.

3.9. PROACTIVE OBSOLESCENCE MITIGATION METRICS

The importance of implementing metrics was also recognized by several of the research participants from the Army and their industry counterparts. However, a gap exists regarding what those metrics should be. Some organizations highlighted the importance of managing DMSMS with a system of cases to document the specifics of their obsolescence mitigations. Further, a challenge arises with identifying and gathering the data to inform obsolescence mitigations beyond reports that are based on known obsolescence issues rather than the required data to perform predictive analysis. Developed the following preliminary metrics for the community based on the themes in this research to assist with gathering more meaningful data and the assessment of these data.

$$\text{Mean Time to DMSMS Case Resolution} = \frac{\text{Sum Cases (Days from Case Opening to Closing)}}{\text{Total Number of Cases Resolved}} \quad (1)$$

$$\text{Cost of a DMSMS Case} = \text{Sum of Labor, Materials, and Travel Costs} \quad (2)$$

$$\text{DMSMS Cases Monthly Closure Rate} = \frac{\text{Total Number of Closed DMSMS Cases}}{\text{Total Number of Months}} \quad (3)$$

$$\text{Percent of BOM Loaded in a Predictive Tool} = \frac{\text{Total \# of BOM Components Loaded}}{\text{Total \# of BOM Components}} \quad (4)$$

$$\text{DMSMS Contract Language Supply Chain Flow Down Verification} = \frac{\text{Total Number of Verified Contracts with DMSMS Contract Language in the System's Supply Chain}}{\text{Total Number of Contracts for a System's Supply Chain}} \quad (5)$$

3.10. CHAPTER DISCUSSION

This research found that both the Army and industry use similar methods to mitigate DMSMS challenges with proactive obsolescence management. The findings for the first research question indicate that the Army proactively mitigates the obsolescence of C5ISR systems using a combination of focused teams, plans, training, predictive analysis tools for BOM analysis, and proactive contracting language. The findings for the second research question are similar; industry also uses a combination of focused teams, plans, training, predictive analysis tools for BOM analysis, and proactive contracting language. The findings for the third research question found the methods the Army and its industry counterparts for C5ISR systems use for proactive obsolescence mitigation are very similar.

These methods include a team approach, planning for DMSMS, predictive analysis tools, and contracting language. Note this is all predicated on adequately funding DMSMS activities. Otherwise, the monitoring and planning to mitigate obsolescence becomes dormant. This creates an environment of reactive obsolescence management, which is the most expensive and longest schedule impact approach. This research has also identified areas where additional methods have the potential to fill gap areas within the current methods and practices of proactive obsolescence. These proactive approaches to improve obsolescence mitigation effectiveness include a proactive obsolescence management model, proactive obsolescence risk mitigation framework, and proactive obsolescence mitigation metrics.

This chapter's findings has several limitations of note. The first is the relatively small sample size of participants. In addition, because our research was limited to participant experiences with managing obsolescence for C5ISR systems, approaches may differ for other types of systems. In areas where there is deep experience and profound expertise, there are also process gaps for obtaining data and defining criteria. This prompted the development of several new methods that are presented herein, i.e., the framework, model, and metrics. However, more research and data will be needed to refine these approaches. These approaches extend the participants' insights, provide the structure to refine the approaches for broader and deeper proactive obsolescence management methods, and assist with a way of capturing data to inform future refinement of methods that can empower acquisition practitioners to successfully implement proactive obsolescence mitigation methods.

Future research could replicate this study with a larger sample size, as well as repeat this study with one or more of the other military service branches. A future study could focus on broadening the scope of this research to systems that are not C5ISR systems. Additionally, a

future study could extend this research by implementing several or all of the top four proactive obsolescence management methods. Further, future research could focus on experimentation with physical or simulated data using the framework, model, and metrics.

3.11. CHAPTER CONCLUSION

Overall, this chapter provides a combination of proactive obsolescence mitigation, reactive obsolescence mitigation, proactive obsolescence mitigation methods, importance of DMSMS contracting language, obsolescence management practices to avoid, a proactive obsolescence management model, framework, and metrics. The combination of the obsolescence mitigation approaches in this chapter provides additional tools to contribute to achieving greater system readiness, more availability, better maintainability, and lower costs for C5ISR systems.

CHAPTER 4: OBSOLESCENCE VISUALIZATION TOOL FOR OBSOLESCENCE MANAGEMENT

4.1. CHAPTER INTRODUCTION

There are many important benefits associated with proactive obsolescence management for the Army's Command, Control, Communications, Computers, Cyber, Intelligence, Surveillance and Reconnaissance (C5ISR) systems. In regards to supply chain, a common theme among the literature is the acknowledgement that proactive obsolescence offers greater availability of system components, lower costs of components, shorter component schedules, and higher system readiness (DoD, 2022). Conversely, the opposite is true for reactive obsolescence management. The challenge of obsolete components in a system is complex and can lead to unknown, limited, and/or undesired availability of a needed component(s) at one or more levels within a system's supply chain. Moreover, the current methods of tracking the risk of components becoming obsolete rely on tables and spreadsheets, which make predicting the obsolescence risk of components and systems difficult and cognitively burdensome. The likelihood of a newly produced system shortly finding itself needing a reactive obsolescence mitigation solution is high; it is estimated that over 70% of electronic components are obsolete before the system is even installed (Sandborn, 2013). As a result, organizations often implement a more reactive obsolescence mitigation solution. In response to these current limitations, this chapter presents and validates a novel visualization tool for implementing reactive obsolescence risk for a system.

The increase of obsolete components in a system is inevitable over the life cycle as a system ages (Herald et al., 2009). The changing parameters based on advancing technology impacts long-lived systems in many areas, such as interfaces, weights, power needs, materials,

etc. There are several data points available during system component acquisition that are indicative of obsolescence risk across a variety of parameters. However, it is difficult to efficiently identify and understand the obsolescence risk of the components and integrate at the system level; particularly as obsolescence risk scales continuously from low to high. The visualization tool developed and presented in this chapter alleviates the cognitive burden of assessing and potentially misclassifying the obsolescence risk of a system, especially in the case of multiple systems.

This visualization tool was motivated to ease the cumbersome process practitioners use to identify and assess the risk of obsolescence in their systems. To aid the practitioner with mitigating the effects of Diminishing Manufacturing Sources and Material Shortages (DMSMS) on C5ISR systems and strengthening the practitioner's ability to understand the level of obsolescence risk. This led to hypothesizing that a practitioner's ability to assess obsolescence risk could be improved by developing a visualization method to assist with assessing risk. This chapter uses risk criteria to develop and validate a visualization tool. Visualization tools have been shown to decrease cognitive load (Anderson et al., 2011; Yelizarov and Gamayunov, 2014), which can be useful in managing obsolescence risk of complex systems.

There currently exists a gap in the literature of a detailed methodology in an open-source environment for visualizing the obsolescence risk of systems based on supply factors of components. Zheng and Terpenney (2013) discussed the ontology of obsolescence management, where they proposed a method for integrating obsolescence information using shared vocabulary, but their method did not present a visualization component. Specific to spacecraft obsolescence, Geng et al. (2016) introduced a framework to assist with obsolescence mitigations for payloads to help with the prioritization. Meyer et al. (2004) defined obsolescence drivers and developed a

simplified life-cycle cost model to aid in decision making. Dependency analysis and diagramming have also been used to identify key points of migrating software applications to prolong system life (McComb et al., 2002). Systems Modeling Language (SysML) has been used to aid obsolescence mitigation with models that build on current methods to deliver risk mitigations and strategies to assist system engineers and program managers with putting into practice Off-the-Shelf-Options in military systems (Constantine and Solak, 2009). Similarly, Zolghadri et al., (2018) presented a case study using system architecture modeling to predict the impact of DMSMS on a system by quantifying costs and delays. While these previous methods highlight the importance of considering obsolescence mitigation, they require the user to model system complexity in a way that this chapter aims to simplify.

The obsolescence risk management discussed in this chapter compliments current research in mapping of supply chains.). Furthermore, policy outlined in various Department of Defense publications on DMSMS, such as DoD (2019), DoD (2020), and DoD (2022), are complemented based on the research presented in this chapter showing improvements when using obsolescence management visualizations vs. traditional methods.

4.2. CHAPTER PROBLEM STATEMENT

The benefits of proactive obsolescence management are often not realized because a team cannot see its obsolescence risk early, as well as track the changing risk levels among the components over time. The ability to view the risk level associated with obsolete components within a system is not easily available. This lack of early visibility contributes to missing an opportunity to save schedule, reduce costs, and maintain systems readiness. Additionally, this lack of visibility slows the tracking of activities implemented to reduce the level of obsolescence risk within a system. The traditional tools such as tables and spreadsheets are cumbersome and is

a substantial time investment for both the preparer and consumer of the data used to assess a system's obsolescence risk. Furthermore, this complexity of this problem is challenging at the many levels within the supply chain. A missed assessment of one or more components anywhere in the supply chain will be realized when it is too late for proactive mitigation approaches.

4.3. CHAPTER RESEARCH QUESTIONS

There is a current gap in the research in visualizing the variables that contribute to obsolescence risk with C5ISR systems. Visualizing system obsolescence can provide further insights, such as by informing potential risk mitigations paths to reduce the risk of obsolescence. The objective of this chapter is to provide techniques to characterize the obsolescence of a system within the parameters of proactive and reactive obsolescence, through the development and use of a visualization tool. The outcome of this research can assist practitioners and researchers to develop a better understanding of how to interpret component level information that contributes to both successfully and unsuccessfully mitigating obsolescence risk. The following research questions are addressed in this chapter:

1. How can a data visualization tool facilitate proactive and mitigate reactive obsolescence risk management?
2. How can data visualization be used to understand component-level obsolescence risk for a system?
3. How does visualization improve human understanding of obsolescence risk in a system?

4.4. MATERIALS AND METHODS

Data simulation was used to generate various systems that ranged in values of obsolescence properties. Then, data visualization techniques were used to develop a visualization tool to provide visual comparisons and interpretation of system obsolescence risk. Lastly, the visualization tool was validated using a case study with a market available drone and through user testing with C5ISR subject matter experts.

4.4.1. OBSOLESCENCE PROPERTIES

There were four component properties included to model a system's obsolescence risk: design life, procurement lead time, cost growth, and number of manufacturers. These variables are based on results from Chellin and Miller (in press), who interviewed 20 experts on C5ISR obsolescence management and reported these four variables as critical in developing an obsolescence mitigation framework. Each of the four properties measure at the component level of a system, such that a system is comprised of a value for each property for every component in the system. For example, a system with 100 components would have 100 values for design life, 100 values for procurement lead time, 100 values for cost growth, and 100 values for number of manufacturers. Table 1 summarizes the risk level of obsolescence based on values for these properties described by Chellin and Miller (2022) and used in this chapter.

Table 5. Obsolescence Risk Level by Component Properties

Risk Level	System Component Property			
	<i>Design Life (years)</i>	<i>Procurement Lead Time, PLT (months)</i>	<i>Cost Growth (%)</i>	<i>Manufacturers (N)</i>
Low	12.01 - 15	1 - 5.99	1 - 9.99	3 - 5
Medium	5 - 12	6 - 12	10 - 25	2
High	1 - 4.99	12.01 - 18	25.01 - 33.25	0 - 1

4.4.2. SIMULATED SYSTEM DATA

Since there were four properties of obsolescence and each property had three levels of risk, there were 81 possible unique permutations that a system could be classified. The risk level of each possible permutation follows:

Table 6. 81 Risk Permutations for the Obsolescence Properties

Possible Permutations (n)	Design Life	Procurement Lead Time	Cost Growth	Number of Manufactures
1	Low Risk	Low Risk	Low Risk	Low Risk
2	Low Risk	Low Risk	Low Risk	Medium Risk
3	Low Risk	Low Risk	Medium Risk	Low Risk
4	Low Risk	Medium Risk	Low Risk	Low Risk
5	Medium Risk	Low Risk	Low Risk	Low Risk
6	Low Risk	Low Risk	Low Risk	High Risk
7	Low Risk	Low Risk	High Risk	Low Risk
8	Low Risk	High Risk	Low Risk	Low Risk
9	High Risk	Low Risk	Low Risk	Low Risk
10	Low Risk	Low Risk	Medium Risk	Medium Risk
11	Low Risk	Medium Risk	Low Risk	Medium Risk
12	Low Risk	Medium Risk	Medium Risk	Low Risk
13	Medium Risk	Low Risk	Low Risk	Medium Risk
14	Medium Risk	Low Risk	Medium Risk	Low Risk
15	Medium Risk	Medium Risk	Low Risk	Low Risk
16	Low Risk	Low Risk	Medium Risk	High Risk
17	Low Risk	Low Risk	High Risk	Medium Risk
18	Low Risk	Medium Risk	Low Risk	High Risk
19	Low Risk	Medium Risk	High Risk	Low Risk
20	Low Risk	High Risk	Low Risk	Medium Risk
21	Low Risk	High Risk	Medium Risk	Low Risk
22	Medium Risk	Low Risk	Low Risk	High Risk
23	Medium Risk	Low Risk	High Risk	Low Risk
24	Medium Risk	High Risk	Low Risk	Low Risk
25	High Risk	Low Risk	Low Risk	Medium Risk
26	High Risk	Low Risk	Medium Risk	Low Risk
27	High Risk	Medium Risk	Low Risk	Low Risk
28	Low Risk	Low Risk	High Risk	High Risk
29	Low Risk	High Risk	Low Risk	High Risk
30	Low Risk	High Risk	High Risk	Low Risk
31	High Risk	Low Risk	Low Risk	High Risk

32	High Risk	Low Risk	High Risk	Low Risk
33	High Risk	High Risk	Low Risk	Low Risk
34	Low Risk	Medium Risk	Medium Risk	Medium Risk
35	Medium Risk	Low Risk	Medium Risk	Medium Risk
36	Medium Risk	Medium Risk	Low Risk	Medium Risk
37	Medium Risk	Medium Risk	Medium Risk	Low Risk
38	Low Risk	Medium Risk	Medium Risk	High Risk
39	Low Risk	Medium Risk	High Risk	Medium Risk
40	Low Risk	High Risk	Medium Risk	Medium Risk
41	Medium Risk	Low Risk	Medium Risk	High Risk
42	Medium Risk	Low Risk	High Risk	Medium Risk
43	Medium Risk	Medium Risk	Low Risk	High Risk
44	Medium Risk	Medium Risk	High Risk	Low Risk
45	Medium Risk	High Risk	Low Risk	Medium Risk
46	Medium Risk	High Risk	Medium Risk	Low Risk
47	High Risk	Low Risk	Medium Risk	Medium Risk
48	High Risk	Medium Risk	Low Risk	Medium Risk
49	High Risk	Medium Risk	Medium Risk	Low Risk
50	Low Risk	Medium Risk	High Risk	High Risk
51	Low Risk	High Risk	Medium Risk	High Risk
52	Low Risk	High Risk	High Risk	Medium Risk
53	Medium Risk	Low Risk	High Risk	High Risk
54	Medium Risk	High Risk	Low Risk	High Risk
55	Medium Risk	High Risk	High Risk	Low Risk
56	High Risk	Low Risk	Medium Risk	High Risk
57	High Risk	Low Risk	High Risk	Medium Risk
58	High Risk	Medium Risk	Low Risk	High Risk
59	High Risk	Medium Risk	High Risk	Low Risk
60	High Risk	High Risk	Low Risk	Medium Risk
61	High Risk	High Risk	Medium Risk	Low Risk
62	Low Risk	High Risk	High Risk	High Risk
63	High Risk	Low Risk	High Risk	High Risk
64	High Risk	High Risk	Low Risk	High Risk
65	High Risk	High Risk	High Risk	Low Risk
66	Medium Risk	Medium Risk	Medium Risk	Medium Risk
67	Medium Risk	Medium Risk	Medium Risk	High Risk
68	Medium Risk	Medium Risk	High Risk	Medium Risk
69	Medium Risk	High Risk	Medium Risk	Medium Risk
70	High Risk	Medium Risk	Medium Risk	Medium Risk
71	Medium Risk	Medium Risk	High Risk	High Risk
72	Medium Risk	High Risk	Medium Risk	High Risk
73	Medium Risk	High Risk	High Risk	Medium Risk
74	High Risk	Medium Risk	Medium Risk	High Risk
75	High Risk	Medium Risk	High Risk	Medium Risk
76	High Risk	High Risk	Medium Risk	Medium Risk

77	Medium Risk	High Risk	High Risk	High Risk
78	High Risk	Medium Risk	High Risk	High Risk
79	High Risk	High Risk	Medium Risk	High Risk
80	High Risk	High Risk	High Risk	Medium Risk
81	High Risk	High Risk	High Risk	High Risk

Note the above table is intended to show all the permutations of the obsolescence properties, these are not the values that are used in the simulations. The above table was calculated using the online omnicalculator (Szyk & Czernia, 2022). In the simulation, multiples of 9 were used to obtain 10 representative systems of the possible 81 unique permutations of obsolescence risk within a system; however, the values are generated based on assigned risk allocations. Hence, there were 10 different systems simulated, ranging from the lowest to the highest obsolescence risk based on the criteria in Table 5. Table 7 shows the 10 systems selected and the risk allocation assigned to each system for the simulations. The system with the lowest obsolescence risk (i.e., low risk across all four properties) is the most proactive a system can be and the simulated system with the highest obsolescence risk (i.e., high risk across all four properties) is the most reactive a system can be. The remaining systems (i.e., systems 9, 18, 27, 36, 45, 54, 63, 72) are a combination of variable parameters for low, medium, and high obsolescence risk.

Table 7. Overview of Systems Simulated based on Obsolescence Risk Criteria

System ID	Design Life	PLT	Cost Growth	Manufacturers
1 (Proactive)	Low	Low	Low	Low
9	Low	Low	Medium	Medium
18	Low	Medium	High	Low
27	Low	Low	High	High
36	Medium	Medium	Medium	Low
45	Medium	High	Medium	Low
54	Medium	High	High	Low
63	High	High	Low	High
72	Medium	High	High	Medium
81 (Reactive)	High	High	High	High

Data for these systems was simulated using the R statistical software program (version 4.1.0). Data was simulated at the component level for each system, where for each of the 10 systems, each system comprised of 1,000 simulated components. Hence, for each system, there were 1,000 observations simulated for design life, 1000 for procurement lead time, 1000 for cost growth, and 1000 for number of manufacturers. A uniform distribution was used to randomly select values for each component within the possible range of values for each risk level, as defined in Table 5. For example, system ID 1 [proactive] was assigned low risk across each of the four obsolescence properties. Thus, its simulated values for design life for each component were randomly and uniformly selected from 12.01 to 15; from 1 to 5.99 for procurement lead time; from 1 to 9.99 for cost growth; and 3 to 5 for number of manufacturers. The obsolescence risk visualizations for systems 9 – 72 from the data in Table 7 follows: System 9’s obsolescence risk visualization depicts low design life risk, low procurement lead time risk, medium cost growth risk, and medium manufacturing sources risk.

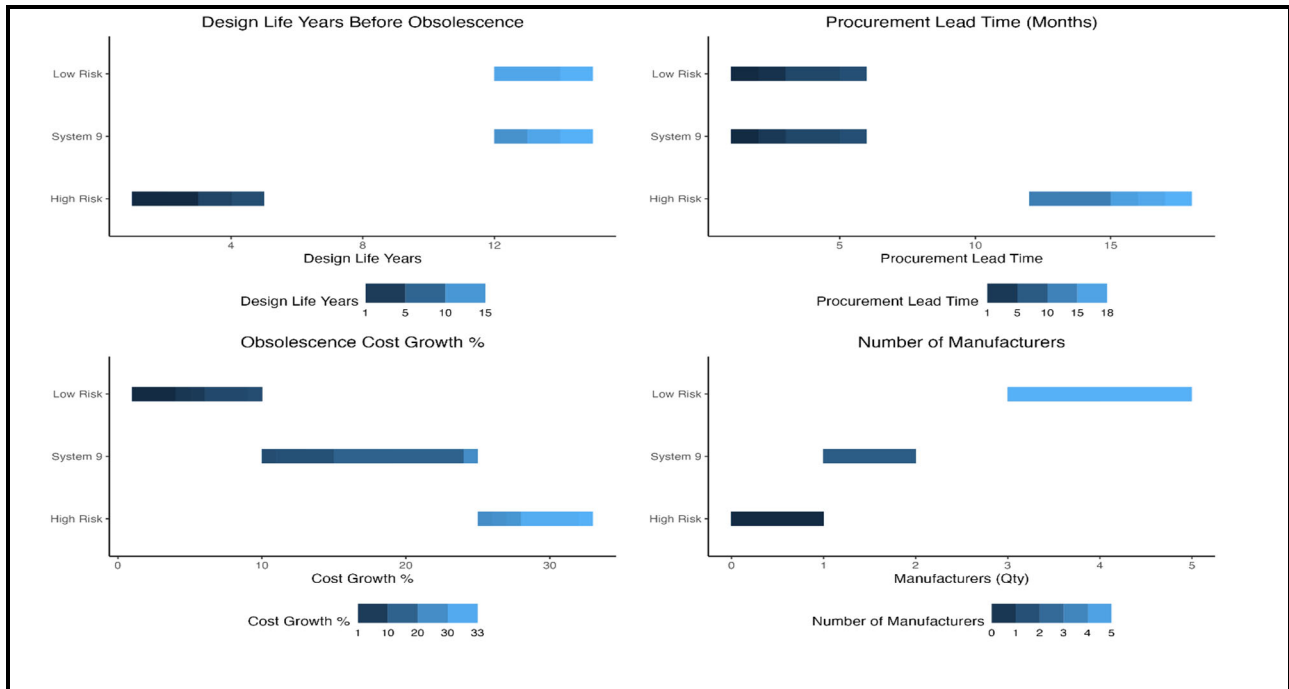


Figure 2. System 9’s Obsolescence Risk Visualization

System 18's obsolescence risk visualization shows low design life risk, medium procurement lead time risk, high cost growth risk, and low manufacturing sources risk.

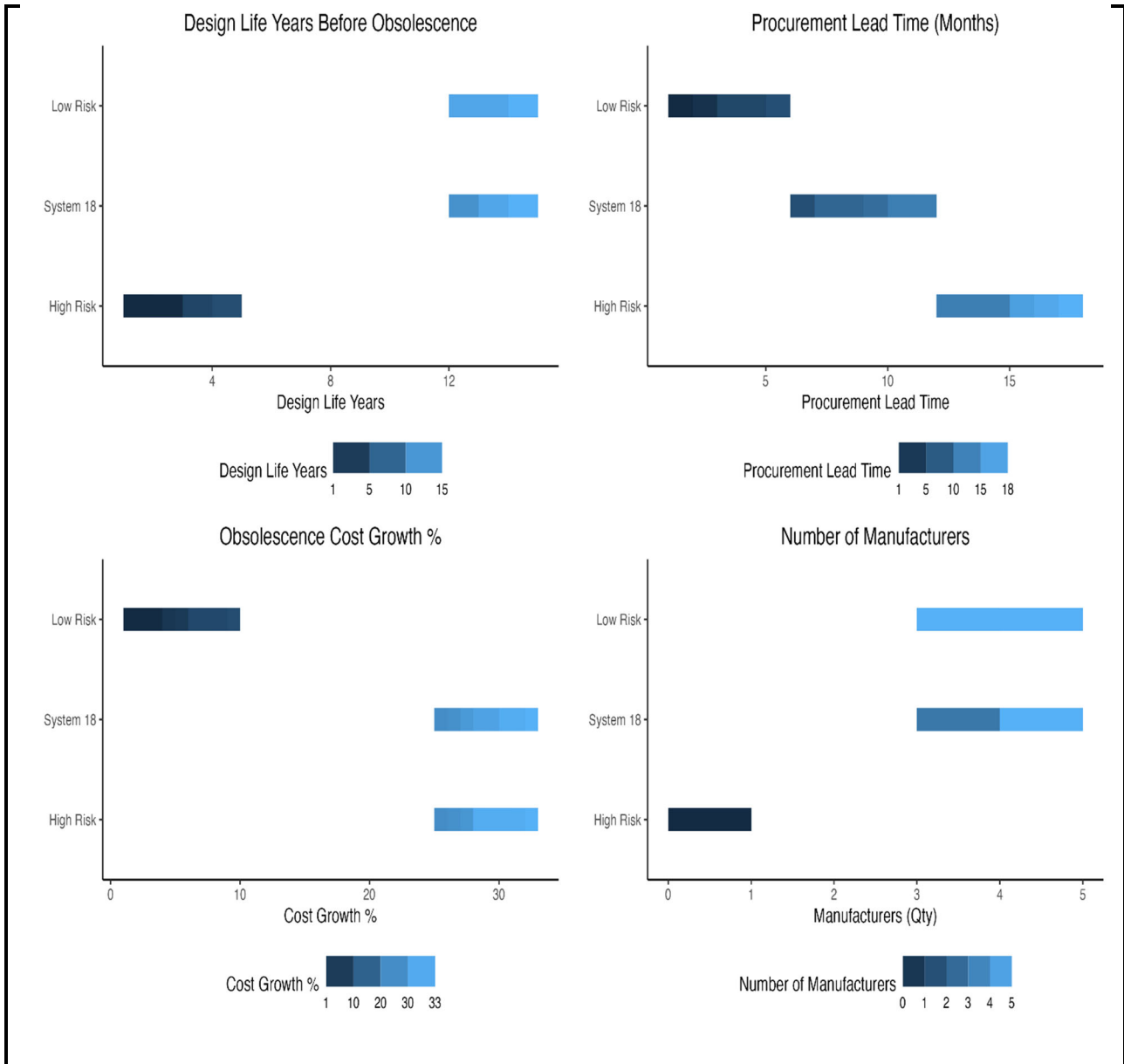


Figure 3. System 18's Obsolescence Risk Visualization

System 27's obsolescence risk visualization depicts low design life risk, low procurement lead time risk, high cost growth risk, and high manufacturing sources risk.

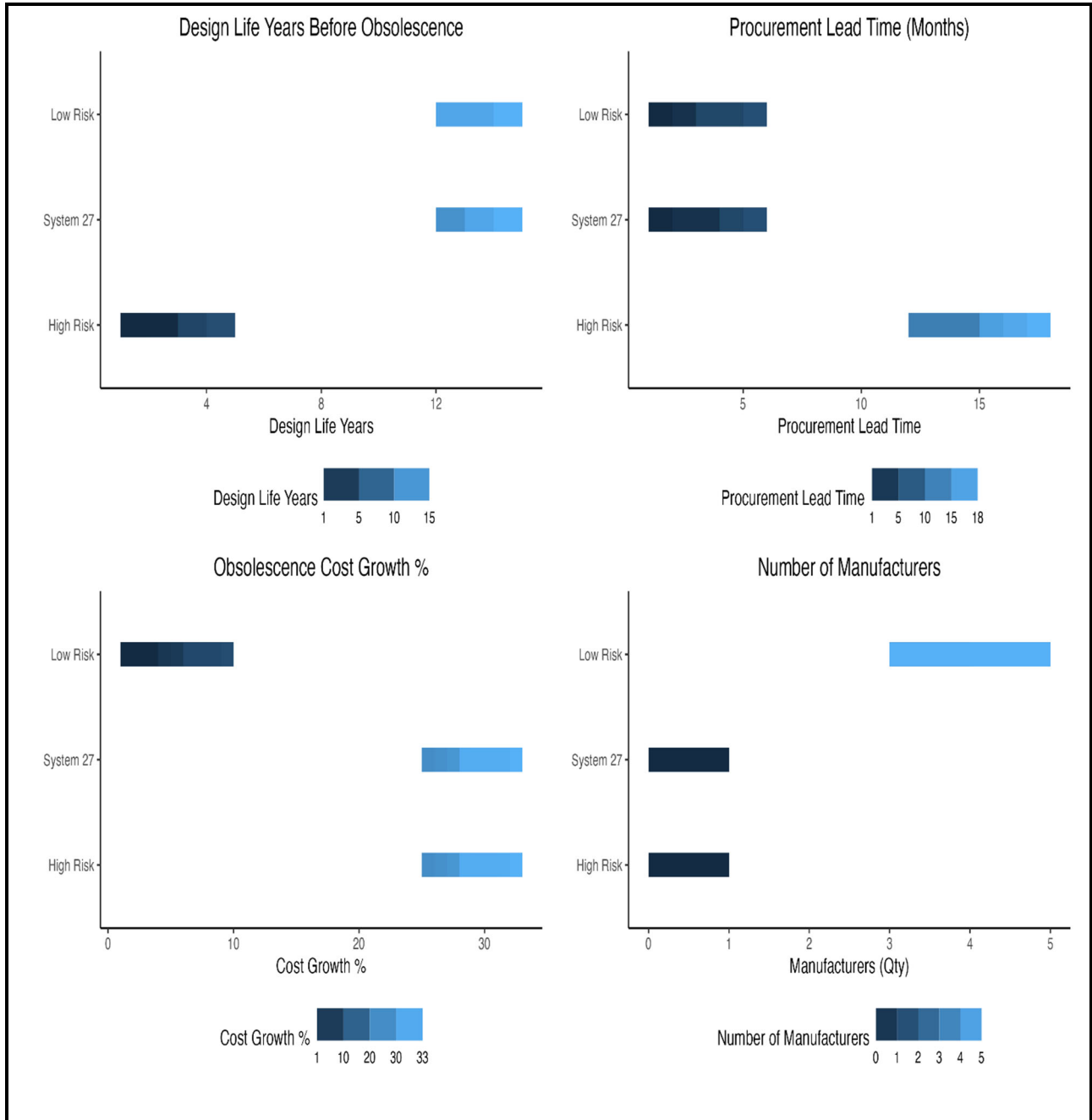


Figure 4. System 27's Obsolescence Risk Visualization

System 36's obsolescence risk visualization portrays a medium design life risk, a medium procurement lead time risk, medium cost growth risk, and low manufacturing sources risk.

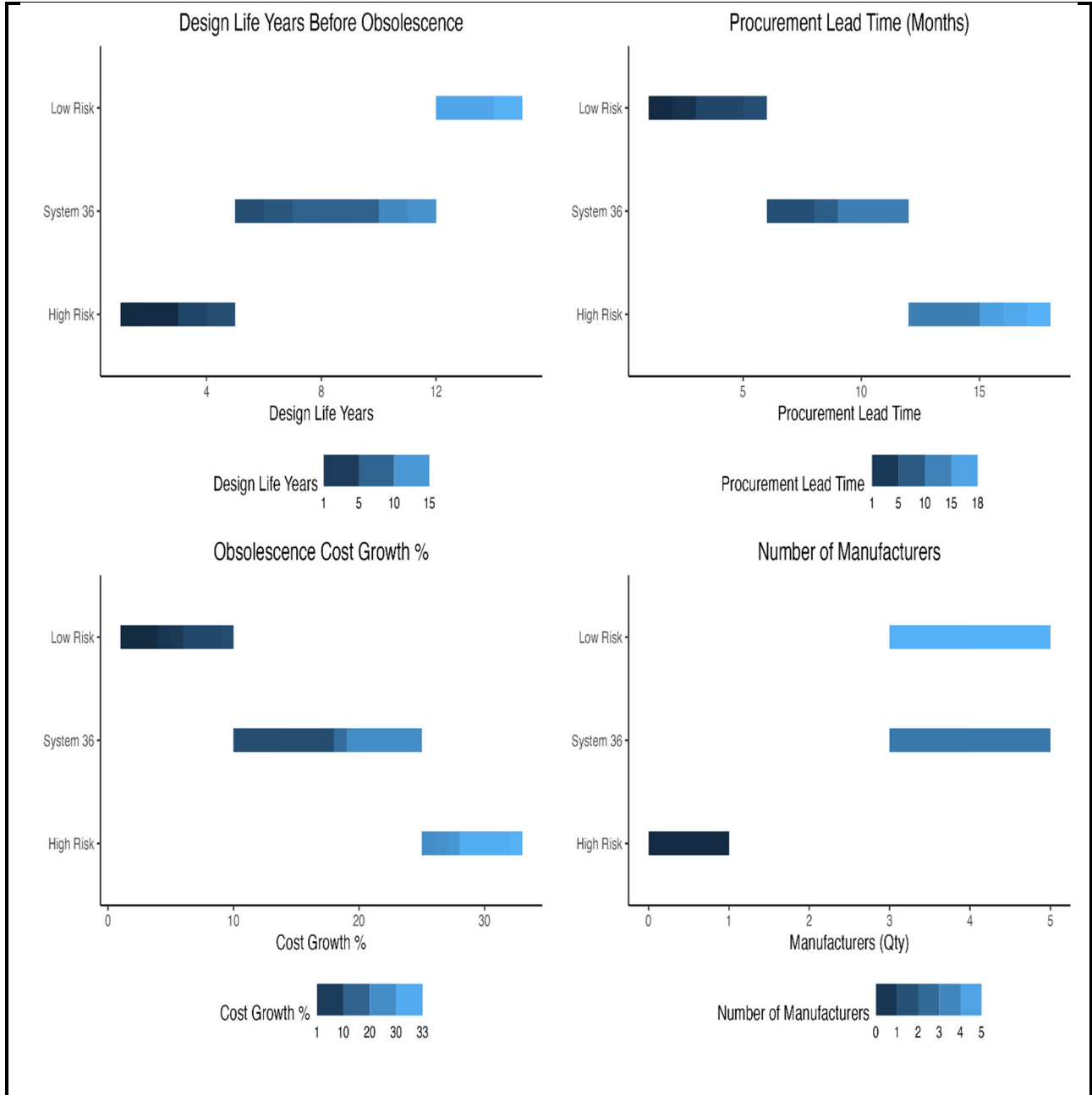


Figure 5. System 36's Obsolescence Risk Visualization

System 45's obsolescence risk visualization illustrates medium design life risk, high procurement lead time risk, medium cost growth risk, and low manufacturing sources risk.

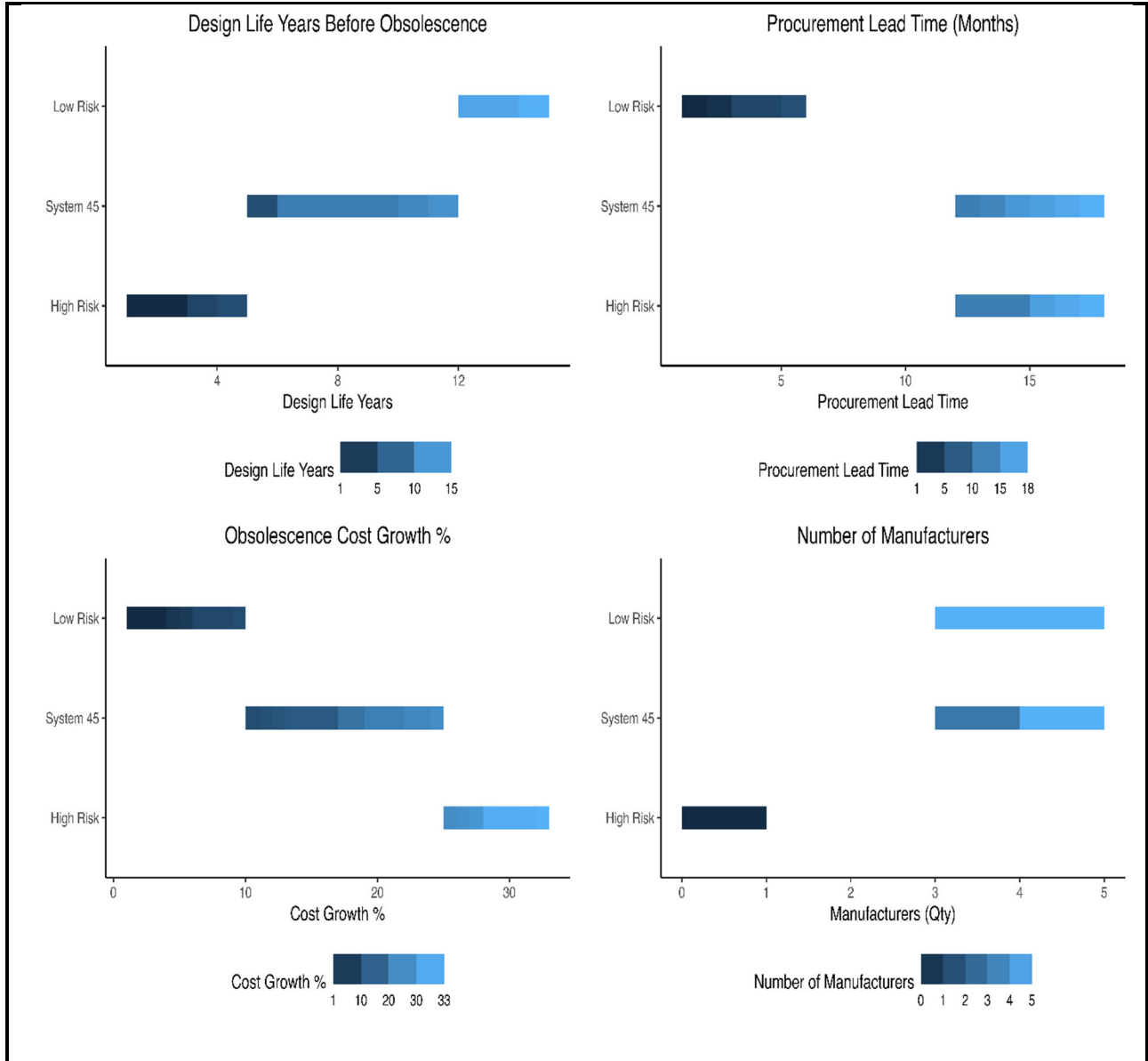


Figure 6. System 45's Obsolescence Risk Visualization

System 54's obsolescence risk visualization depicts medium design life risk, high procurement lead time risk, high cost growth risk, and low manufacturing sources risk.

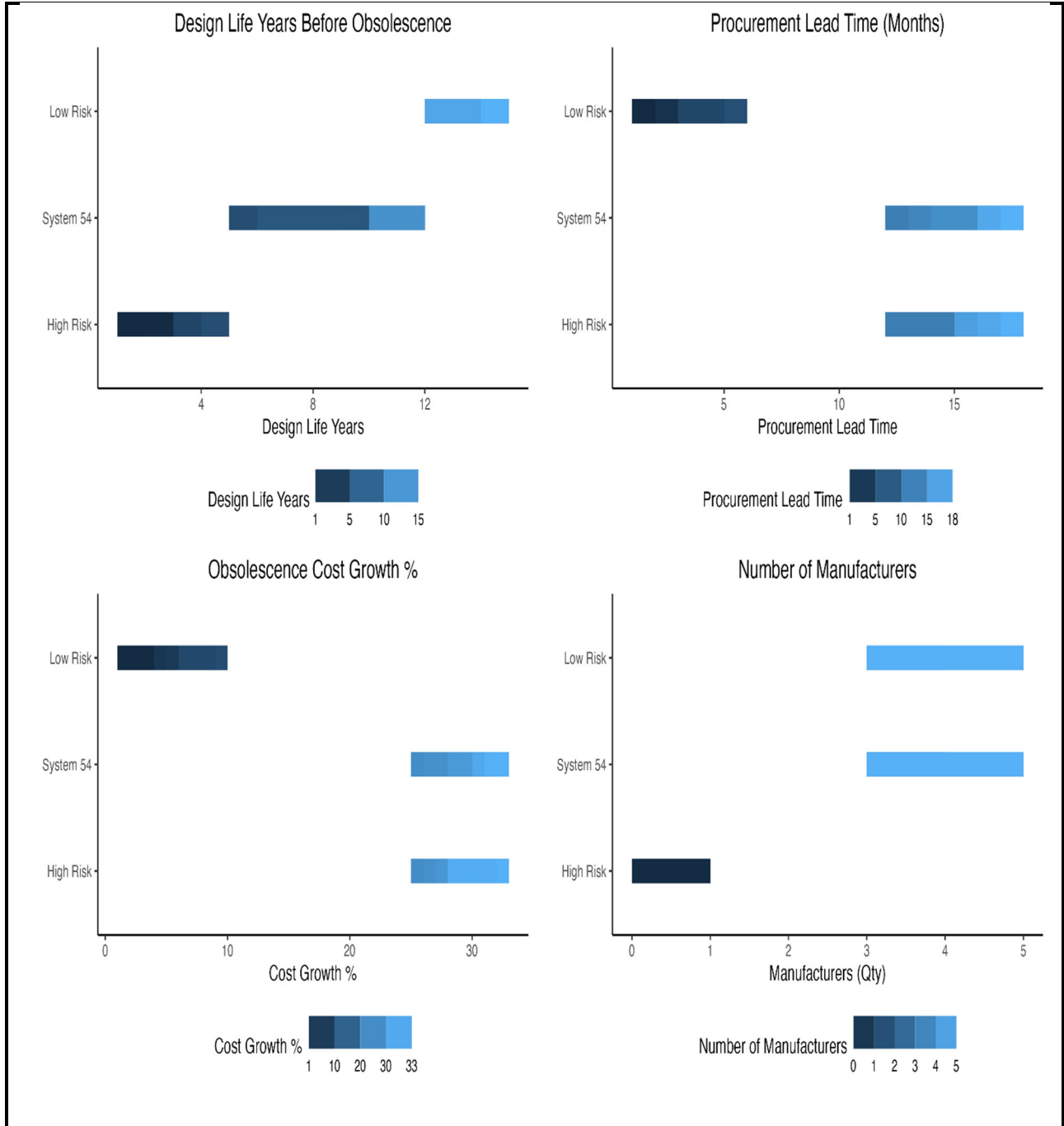


Figure 7. System 54's Obsolescence Risk Visualization

System 63's obsolescence risk visualization shows high design life risk, low procurement lead time risk, low cost growth risk, and high manufacturing sources risk.

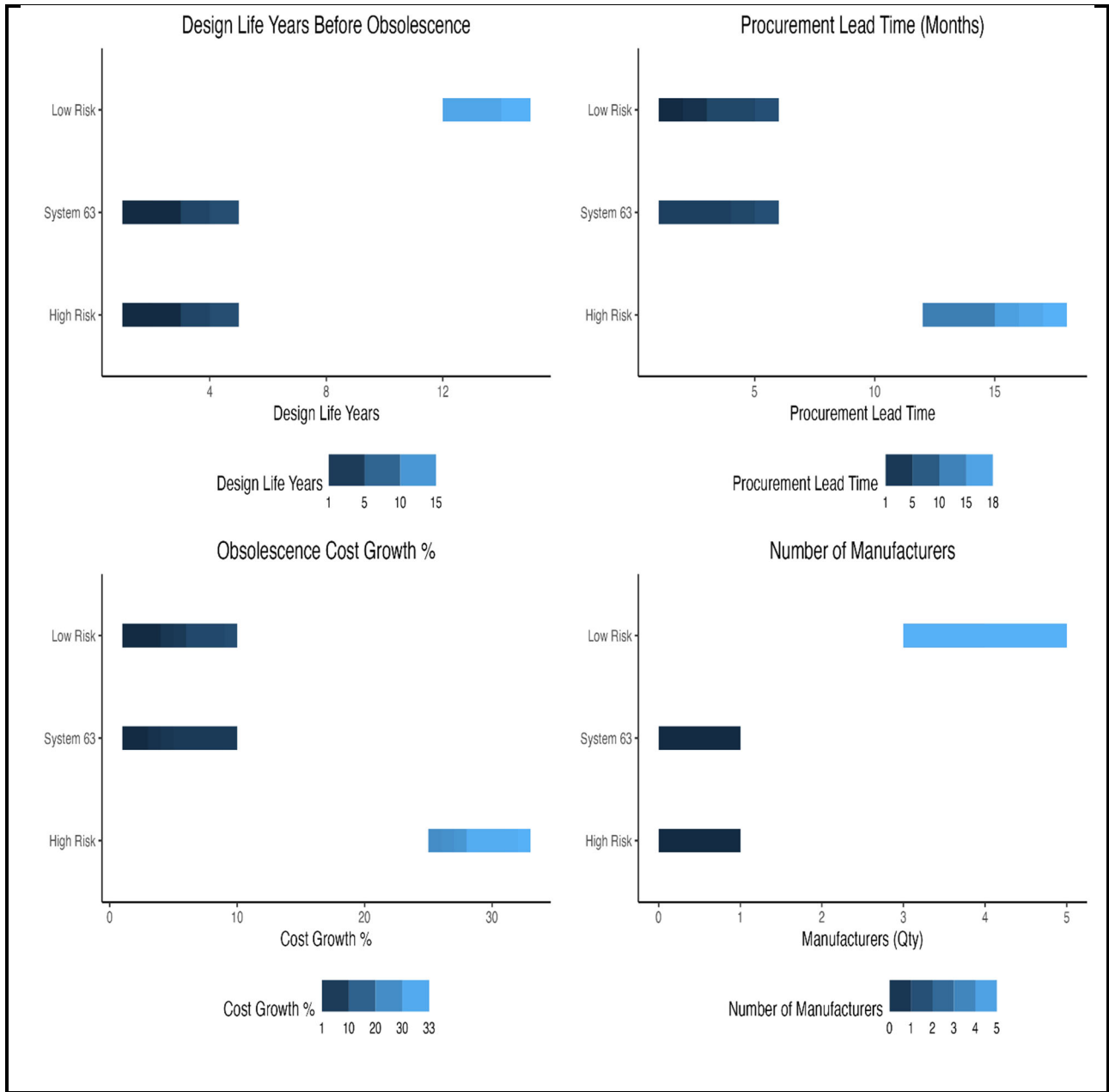


Figure 8. System 63's Obsolescence Risk Visualization

System 72's obsolescence risk visualization illustrates medium design life risk, high procurement lead time risk, high cost growth risk, and medium manufacturing sources risk.

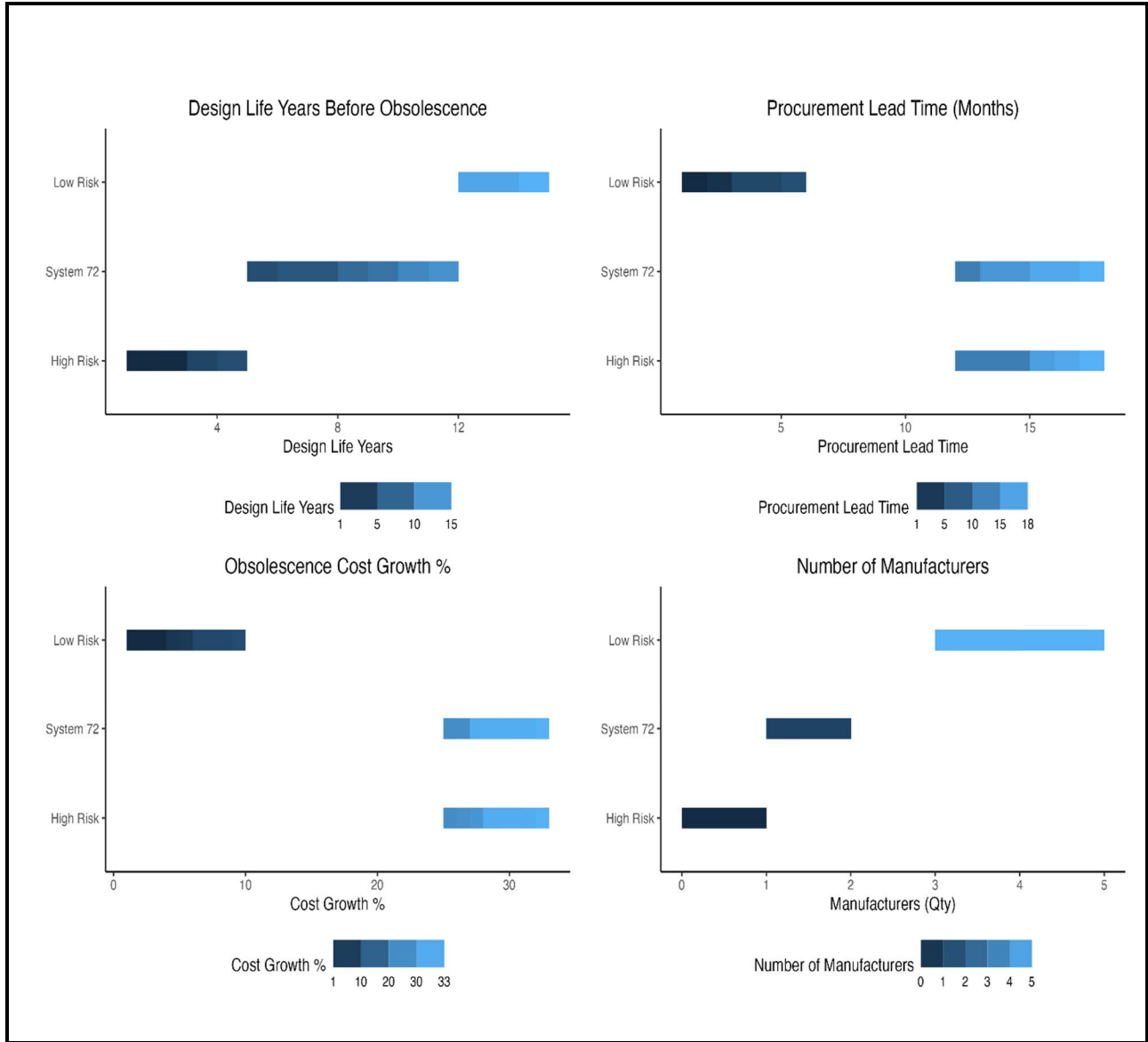


Figure 9. System 72's Obsolescence Risk Visualization

4.4.3. PHYSICAL DRONE SYSTEM

In addition to the 10 simulated systems used to develop and demonstrate the visualization tool, also evaluated the tool using an actual drone system to explore the usability and value of the

tool with a real, physical system. This provided a validation of the tool, while also providing a concrete example to utilize the visualization tool. The drone used in this study was selected specifically because all component information was publicly available and commercially available. The specific drone system itself is not crucial, but rather representative of an exercise in using the visualization tool.

An online tutorial website for a fully opensource multicopter drone was used to get a list of drone system components (i.e., bill of materials) (Chamorro, 2017). Then searched for these individual parts to build the drone in Amazon to estimate procurement lead time, cost growth, and number of manufacturers. Procurement lead time was estimated based on Amazon delivery time for that component, which represents a component that is already sitting on the shelf ready to ship. The cost growth was estimated using the percentage change from the searched component compared to its recommended replacement or alternative component. The number of manufacturers was based on how many different sellers on Amazon sold that part. Lastly, design life was estimated at the drone level due to limitations in component level information. This was calculated by looking at DJI's product history timeline of drone generations, which includes details about popular commercial drone brands (DJZ Photography, 2018). Then calculated the difference in time between first-generation to second-generation releases for identical drone models, for which information was found on four drones: Phantom, Ronin, Inspire 1, and Mavic Air. The mean design life for these four drones was 1.896 years (SD = 0.786). Then assigned mean + SD (i.e., 2.68) to half of the components and mean – SD (i.e., 1.11) to the other half of the components. The component level data used in the visualization for this drone is summarized in Table 8.

Table 8. Drone Component Obsolescence Data

Component	Description	Design Life (yrs)	PLT (mos)	Cost Growth (%)	Manuf. (N)
Frame	F450 Drone Frame Kit 4-Axis Airframe 450mm Quadcopter Frame Kit with Landing Skid Gear	1.11	0.83	22.23	3
Transmitter	Turnigy TGY-i6 AFHDS Transmitter and 6CH Receiver (Mode 2)	1.11	0.27	-12.22	1
Charger	Turnigy E3 Compact 2S/3S Lipo Charger 100-240v	1.11	0.39	30.45	4
Propellers	9450 White Propeller	1.11	0.27	0.0215	3
Flight Controller	AfroFlight Naze32 Rev5 Acro FunFly Controller	2.68	0.27	267.75	1
Battery	ZIPPY Flightmax 2800mAh 3S1P 30C	2.68	0.45	69.81	3
Motors	MultiStar Size 2212 With CW/CCW	2.68	0.27	57.66	3
ESC	Afro ESC 30Amp (SimonK Firmware)	2.68	0.29	17.74	3

4.4.4. VISUALIZATION TOOL

The visualization tool was developed and deployed using RStudio (R version 4.1.0). The tool is comprised of a .csv file and a .R script file. The .csv file allows the user to input their component level data, similar to Table 8 above. The .R script file only requires the user to change their file path to where the .csv file is saved and the file path to where they want the visualization output [.png] file. The .R script file also allows the user to modify the ranges for the obsolescence risk levels if they desire, otherwise the default ranges match those presented above in Table 7.

4.5. USER EVALUATION

User testing of the visualization tool was conducted with 21 participants, all of whom had experience with mitigating the challenges of C5ISR obsolescence. The purpose of the user

evaluation was to compare a user’s ability to recognize a system’s obsolescence risk using conventional tables with using our visualization tool.

The Qualtrics online survey platform was used to conduct the user evaluation. Each participant was sent a link to the Qualtrics survey. Participants were not provided with any training prior to using the visualization tool; it was their first time seeing the visualization tool. Participants were asked to identify the obsolescence risk of 10 different systems based on one of the four obsolescence properties. Five of the systems required the user to use the traditional table method to assess obsolescence risk and five of the systems required the user to use the visualization tool. The number of components within the system increased from 10, to 25, to 50, to 75, to 100. Table 9 further details the combination of parameters presented to the users.

Table 9. Combination of System Conditions Presented to Users

Tool	Number of Components	Obsolescence Property	Obsolescence Level
Table	10	Design Life	Low Risk
Visualization	10	Cost Growth	High Risk
Table	25	PLT	Medium Risk
Visualization	25	Num Manuf.	Medium Risk
Table	50	Design Life	Low Risk
Visualization	50	PLT	High Risk
Table	75	Num Manuf.	Low Risk
Visualization	75	Design Life	Medium Risk
Table	100	Cost Growth	Medium Risk
Visualization	100	PLT	High Risk

An example is shown in Figure 10 of how the tools were presented to each participant in the Qualtrics survey, which provides the visualization tool (left) and table tool (right) for a system with 10 components.

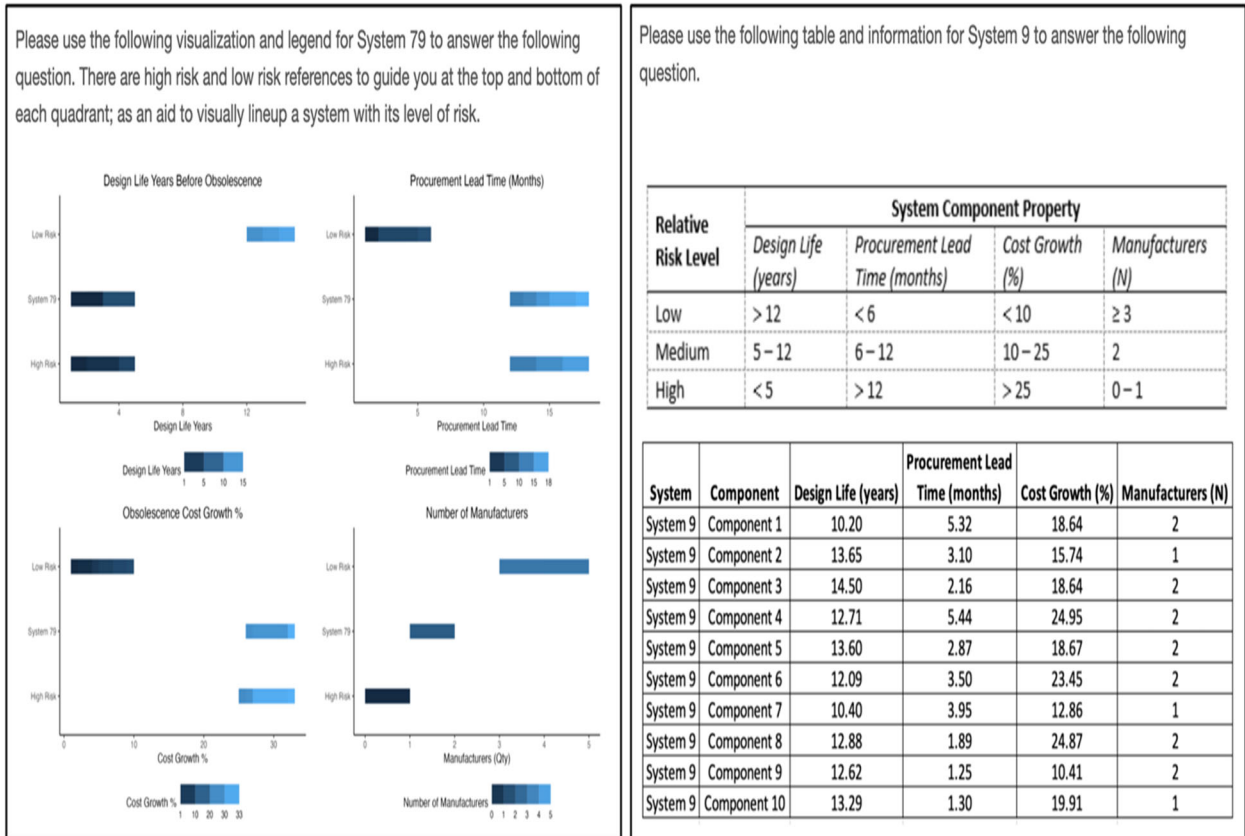


Figure 10. Example of visualization (left) and table (right) tool presented to user in the survey

There were three dependent variables collected to assess performance from the participant for each of the 10 systems they were presented. (1) Participants were asked to identify if the system was low, medium, or high risk. There was only one correct response, thus their accuracy was scored as correct or incorrect. (2) Participants were not aware, but their response time for the previous question was recorded by Qualtrics. Hence, the time it took for them to review the tool and select low, medium, or high risk was evaluated. (3) Participants were also asked how confident they were in their assessment of low, medium, or high risk. Their confidence was measured on a 5-point Likert scale (extremely unconfident to extremely confident). The data was analyzed using Wilcoxon signed-rank tests with $\alpha = .05$.

4.6. CHAPTER RESULTS

4.6.1. VISUALIZATION TOOL OVERVIEW WITH SIMULATED DATA

The output of the visualization tool yields a single figure comprising of four plots, representing the risk of a system across the four obsolescence properties: design life, procurement time, cost growth, and number of manufacturers. Each system is plotted as one bar within each plot, where the content of the bar is generated based on the individual components in a system. In each of the four plots, the proactive (low risk) and reactive (high risk) systems are included to provide a reference to how risky the user's system is. These references provide a quick and straightforward assessment of a system's risk.

The following visualization (Figure 11) demonstrates the output of the visualization tool for the simulated data, where every 9th system of the possible 81 risk permutations of low, medium, and high were simulated. Each quad displays one of the four obsolescence properties with a legend below each respective plot. This demonstrates the scenario where a user would be interested in visualizing the obsolescence risk of eight systems compared to the reference low and high risk systems. The visualization tool would generate a bar for as many systems as the user inputs data for into the .csv file.

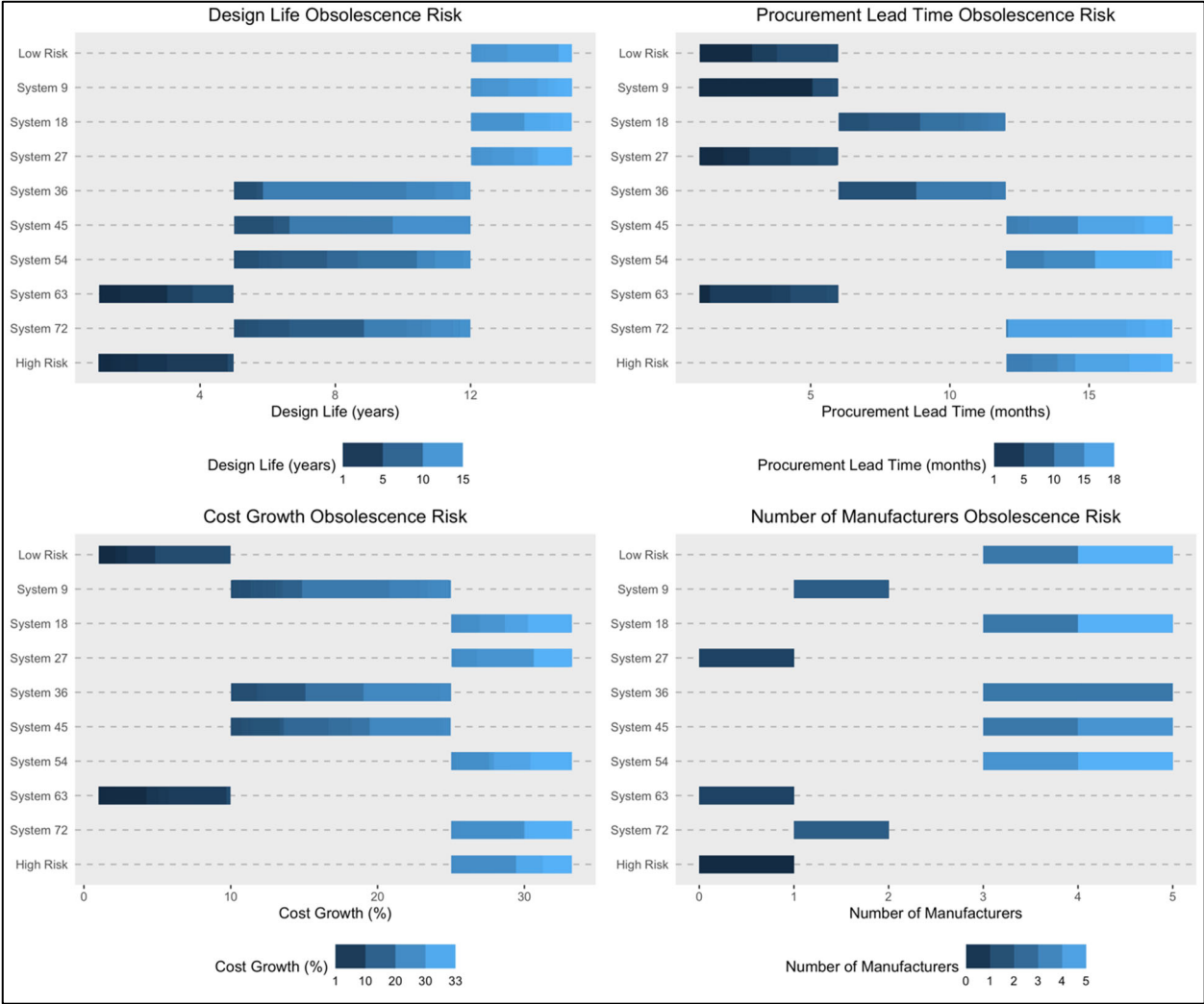


Figure 11. Every 9th system’s obsolescence risk visualization with proactive (low) and reactive (high) reference systems

Similarly, a user might be interested in only visualizing one system relative to the low and high risk reference systems. Figure 12 demonstrates this for a single system, where simulated system 45 was selected. For reference, system 45 was simulated such that its components were medium risk for design life, high risk for procurement lead time, medium risk for cost growth, and low risk for number of manufacturers.

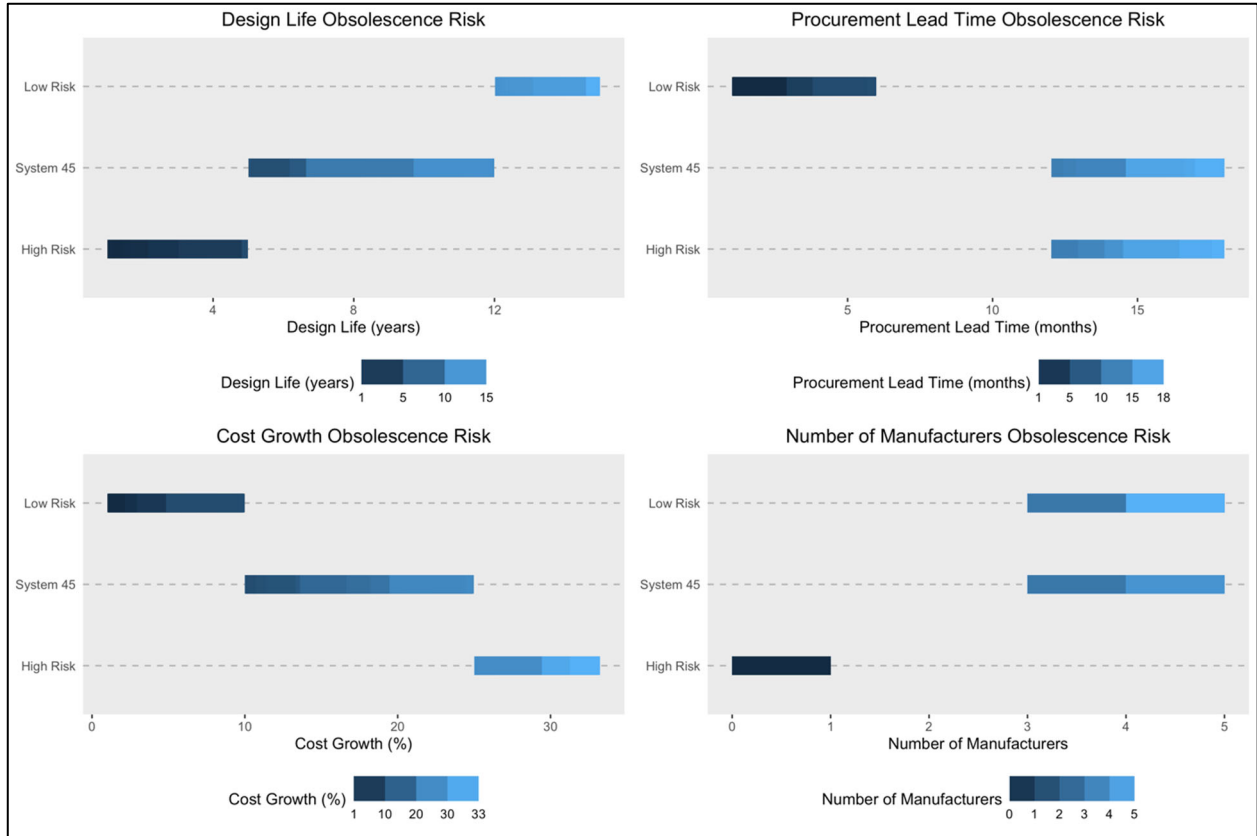


Figure 12. Visualization tool output for simulated system 45

4.6.2. VISUALIZATION TOOL FOR DRONE CASE STUDY

Next, a validation of the tool was performed using a case study with the real drone system, which is illustrated in Figure 13. This validates the applicability of the tool beyond simulations to engineered systems, as represented by the drone in this case study. This validation depicts how the visualization tool can be used to characterize the obsolescence risk for a system. The versatility of this tool is further demonstrated by visualizing datasets outside the parameters of the predefined reactive reference system. For example, the drone’s obsolescence cost growth well exceeds the simulated high risk parameters. In this case, the practitioner would need to decide if the reference system should be revised for these types of systems or if this is a characteristic outcome due to other factors, e.g., supply chain disruptions and/or high inflation.

However, in either case, the obsolescence cost growth for this drone is fully visualized and this ability to visualize it increases the likelihood for successfully mitigating its obsolescence risk.

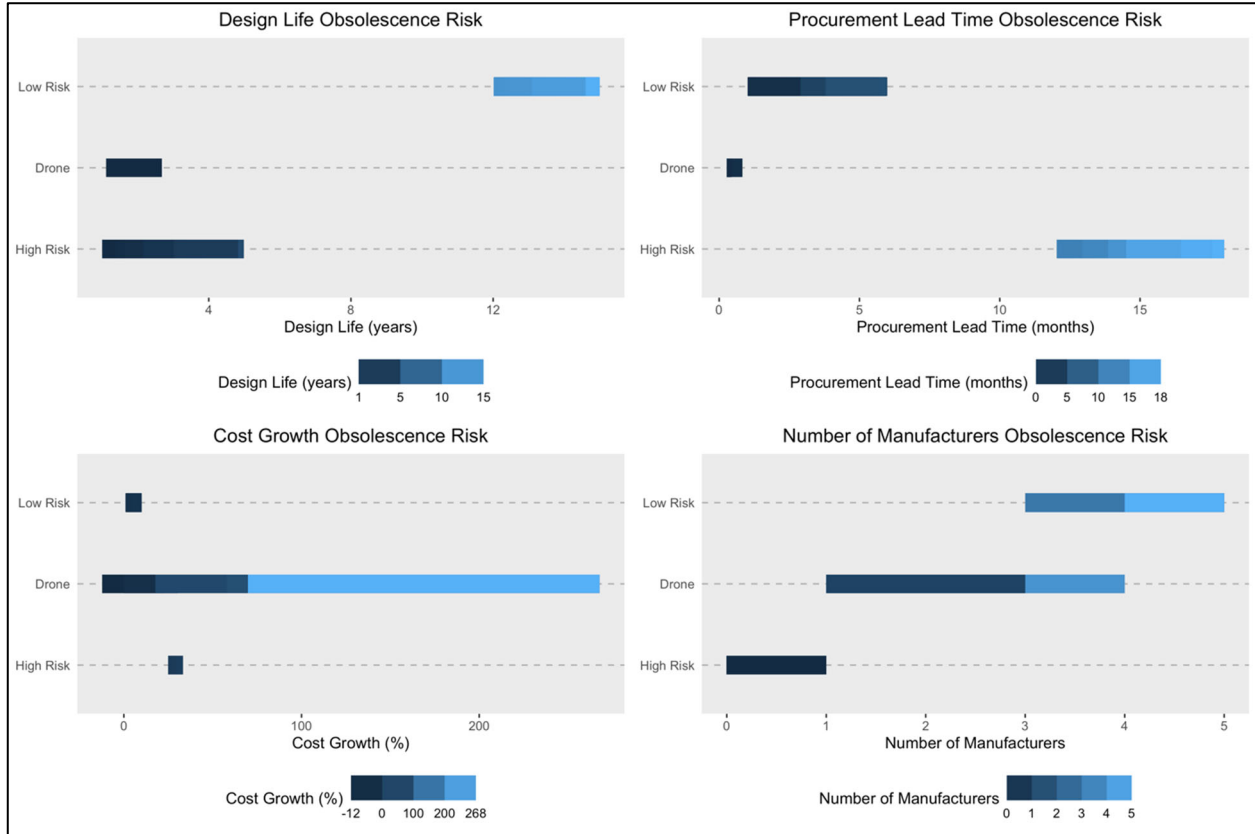


Figure 13. Visualization tool output for the drone's obsolescence risk

4.6.3. VISUALIZATION TOOL USER EVALUATION STUDY

The user evaluation was conducted with 21 subject matter experts, where 10 were government employees and 11 were employees from industry partners. Out of these 21 participants, 14 were male and 7 were female. The participants included 10 engineers, 9 logisticians, 5 project managers, and 1 resource manager. All of the participants had at least 1 year of experience in their area of expertise, for which 16 of the participants reported at least 15 years of experience.

Participant accuracy was assessed based on whether they identified the correct level of risk for each system, where a 1 represented correct and 0 for incorrect. Each participant's scores were summed for the visualization tool (our novel method) and the table tool (the traditional method). Since each participant assessed five systems using the visualization tool and five using the table tool, their accuracy scores could range from 0 (worst) to 5 (best). A Wilcoxon signed-rank test was used to compare these scores, where the paired test was used since each participant had a score for visualization and table methods. Participants' overall accuracy scores were significantly better using the visualization tool (mean = 4.28, SD = 0.78) compared to the table tool (mean = 2.57, SD = 1.72), $W = 2.5$, $p = .0011$.

The time it took participants to determine the obsolescence risk of each system was also evaluated. Since participants completed the task for systems with 10, 25, 50, 75, and 100 components using each the visualization tool and the table, their completion times were paired by visualization/table for each component number. There was no statistically significant difference in the time it took to determine obsolescence risk with only 10 components. However, for 25, 50, 75, and 100 components, the data visualization tool method was significantly quicker than the [traditional] table method. These results of these Wilcoxon signed rank tests are summarized in Table 10.

Table 10. Comparison of Task Completion Times (in seconds) for Visualization and Table Tools

Number of Components	Visualization Time <i>Mean (SD)</i>	Table Time <i>Mean (SD)</i>	p-value
10	101.37 (79.70)	138.82 (149.42)	.7079 (ns)
25	46.90 (97.92)	68.29 (91.39)	.0263
50	23.62 (23.86)	56.63 (54.84)	.0038
75	27.22 (34.87)	50.72 (39.20)	.0101
100	12.81 (6.53)	51.48 (42.09)	.0002

Similar to completion time, participant confidence level in their assessment was also compared at each component number for visualization versus table method, paired for each participant. There was no statistically significant difference in self-reported confidence between the two methods for 10, 25, 50, and 75 components. However, participants were significantly more confident in their assessment of obsolescence risk for 100 components using the data visualization tool method. Therefore, the participants were mostly unaware of their improved performance using the data visualization tool method compared to the traditional method.

Table 11. Comparison of Confidence (1 extremely unconfident to 5 extremely confident) in Assessment for Visualization and Table Tools

Number of Components	Visualization Confidence <i>Mean (SD)</i>	Table Confidence <i>Mean (SD)</i>	p-value
10	4.10 (0.83)	3.86 (1.06)	.1675 (ns)
25	3.76 (0.83)	3.71 (1.19)	.7609 (ns)
50	4.14 (0.91)	3.90 (1.09)	.1875 (ns)
75	4.14 (0.48)	4.10 (0.83)	.7825 (ns)
100	4.48 (0.60)	3.86 (0.65)	.0093

Lastly, at the end of the study, participants were asked what method they preferred. The vast majority, 71.43% of the participants, reported that they preferred the visualization tool method when analyzing the obsolescence risk of multiple systems.

4.7. CHAPTER DISCUSSION

The objective of this chapter was to demonstrate how visualization techniques could be used to improve obsolescence risk management. Managing obsolescence risk is an area that can benefit greatly from data visualization because of the many components and variables that need to be considered when managing the obsolescence risk of a system. There are multiple variables to consider for a system's obsolescence risk; in some cases a lower number is better (e.g.,

procurement lead time), and in other cases a higher number is better (e.g., design life). The ability to visualize these and other variables among many components within a system is a powerful risk management tool. Furthermore, the tool presented in this chapter provides simulated reference systems visualizing the goal of proactive and the undesired state of reactive obsolescence risk management.

This ability to visualize the obsolescence risk for one or more systems fills a current gap in the literature and in the practice of obsolescence management. Adding visualizations for variables that indicate the risk of obsolescence for a system's components will assist with the technical analysis and focus needed to proactively mitigate an underlying obsolescence challenge for a system's components. Components within a system in the long-lived systems in the Army's C5ISR community are repeatedly challenged by obsolete components (Chellin and Miller, in press). This challenge requires focused effort to both identify and mitigate obsolescence challenges. Furthermore, understanding the obsolescence status of a system is cognitively burdensome because the data is usually captured in a spreadsheet with many lines to consider. Therefore, intense focus is required to understand the size and multiple properties of an obsolescence challenge.

The range of these visualizations can be applied from a small team focusing on one system to many large teams which focus on many systems. This visualization tool presented can enable researchers and practitioners to gain a deeper understanding of areas that shape the obsolescence risk management position of one or more systems using risk and several variables that indicate the availability of the system's components. This research provides visualizations of systems that are proactively managed, reactively managed, and systems that exhibit the characteristics of both. Furthermore, this research further complements, builds upon, and can

provide feedback to the ontology, mapping, and DoD policy that seeks to improve the obsolescence management of C5ISR systems.

The longer the lifecycle of a system, the more likely the system is to have more obsolescence challenges. The objective of this research is to visualize the obsolescence of a single system, several systems, and many systems by providing a tool to assist with the visualization of obsolescence risk. The ability to model and understand several properties that contribute to obsolescence, as well as to visualize these properties as variables provides an opportunity to understand the obsolescence status of a system and assists with the planning of mitigations to resolve or lessen the negative impacts of obsolescence. Furthermore, the application of visualizing key aspects of obsolescence and risk provides a powerful tool that can aid stakeholders with understanding and mitigating the obsolescence risk.

This research demonstrates data visualization as a tool to facilitate proactive obsolescence risk management and highlights several areas to focus on to mitigate reactive obsolescence risk management. The software tool developed in R supports data visualization in the context of gaining a deeper understanding of the component level obsolescence risk of a system. Furthermore, the visualizing obsolescence risk improves understanding, forecasting, and mitigating of system obsolescence by visualizing the obsolescence risk of a system's components. For example, if the obsolescence visualization tool indicated high risk due to one supplier and long procurement lead times, a potential mitigation is an early redesign of the components using a common standard that multiple suppliers could produce and facilitate quicker adjustments to future changes in technology by following the standard. This would assist with increasing the number of suppliers and shortening the procurement lead time. Similarly, suppose the same system also had medium to high risk in cost growth, this same mitigation

would also assist with decreasing that risk because by increasing the number of suppliers there is now competition to assist with decreasing the supply and demand systemic pressures that are contributing to the cost growth. This would also mitigate a capacity issue because now the orders for the components can be spread among the multiple suppliers, as well as contributing to shortening the procurement lead time because now multiple suppliers can produce the components in parallel.

This chapter validated the use of the visualization tool over traditional methods of tables through subject matter experts in the area of C5ISR systems and obsolescence. The results showed that users were more accurate, quicker, and confident in their obsolescence risk assessments using the visualization tool. They also overwhelmingly preferred the visualization tool.

One limitation of this chapter's approach is that the obsolescence properties and their ranges were developed with a relatively small sample size focused on the U.S. Army's C5ISR systems (Chellin and Miller, in press). However, the tool allows users to add or modify the existing obsolescence parameters to provide flexibility in this limitation. Another limitation is that this research focuses on visualizing a small set of variables (i.e., four obsolescence properties). Future research could be conducted with additional variables to gain deeper insights. Additionally, future research could be conducted with a larger sample size and in an area outside of C5ISR systems. Moreover, the presented obsolescence visualization tool could be paired with data sources internal to an organization and adjusted to include additional categories to better align with an organization's needs.

4.8. CHAPTER CONCLUSION

In conclusion, this chapter provides a new method using visualizations in R to aid systems obsolescence management for practitioners and researchers. The data visualization tool allows one to see if the obsolescence risk posture of a system is reactive or proactive and this gives the team the ability to focus on the parameters which contribute to higher obsolescence risk and to take an action to mitigate the risk. The visualizations of obsolescence risk improve the understanding of practitioners and researchers to forecast their obsolescence risk of a system and implement one or more mitigations to address both the short-term and long term-obsolescence challenges. This method informs the practitioner, researcher, and management early to assist with implementing activities to mitigate obsolescence risks. Lastly, this obsolescence visualization tool will deepen the knowledge and understanding of obsolescence management supporting the supply availability of the components for all the stakeholders.

CHAPTER 5: VALIDATION OF MENTAL MODELS

5.1. CHAPTER INTRODUCTION

Obsolescence in Command, Control, Communications, Computers, Cyber, Intelligence, Surveillance and Reconnaissance (C5ISR) systems is a challenge that often frustrates practitioners. Obsolescence challenges require solutions many times over the life cycle of a system due to the constant changes in technology. The motivation for writing this article is to increase the likelihood of successful obsolescence mitigation for C5ISR systems. This can be accomplished by using mental models to understand and change system behaviors that are the underpinnings of obsolescence management. Additionally, changing an organization's mental model will complement training provided to practitioners that routinely mitigate obsolescence challenges from short-term to long-term solutions. These gains are furthered by using the tools to adjust the teams' and organization's mental model to achieve obsolescence mitigation within the underlying system that supports the activities of obsolescence management, i.e. system of interest, system context, and enabling systems. This chapter discusses the mental models that guides an organization's behavior toward mitigating obsolescence for C5ISR systems. The goal is to transform the obsolescence management practices of an organization and its teams using a systems thinking approach to achieve effective and efficient obsolescence mitigation with systemic change by adopting a risk based proactive obsolescence management mental model. This research focuses on the system modeling of obsolescence management using systems thinking tools to guide future changes to the fundamentals of our Diminishing Manufacturing Sources and Materials Shortages (DMSMS) management system. This modeling will enable the defense acquisition community to achieve shorter schedules, lower costs, and higher availability of system components for the sustainment of C5ISR systems. The modeling in this chapter

shows the complexity of the obsolescence management challenge, as well as offers a risk based proactive obsolescence model that improves the odds of mitigating obsolescence challenges. Many C5ISR practitioners are well trained in the methods and tools to mitigate obsolescence. However, this is not adequate to systematically achieve governance over the obsolescence challenges that are routinely encountered by C5ISR systems. This is also an area that is deserving of more research to develop tools that are more robust to assist the practitioners that are assigned to mitigate the obsolescence challenges for C5ISR systems. The training and tools are powerful enablers to manage obsolescence. The purpose of this chapter goes deeper systemically and its main focus is on characterizing the mental models of obsolescence management and provide a framework to achieve risk based proactive obsolescence management for C5ISR systems to successfully mitigate obsolescence. This research chapter uses the tools of systems thinking to provide a path to affect change with mental models that are applicable to an individual, a team, and an organization to make fundamental system adjustments from a reactive obsolescence management approach to a proactive risk based obsolescence management approach that will allow a broad spectrum of successful mitigations across a multitude of systems. There are training and tools available to assist practitioners with the mitigation of obsolescence challenges. However, there is a gap in the research that explores the systemic behaviors in the acquisition community to mitigate obsolescence challenges.

Obsolescence management as a system tends to default as reactionary loop. This loop leads to more of the same fundamental challenge of a lack of availability of system components when needed. This challenge is often discussed in the literature in the area of DMSMS. The challenge of sustaining long lived systems in the area of C5ISR does not immediately appear to be a complex problem; however, it is a deceptively complex problem, i.e. one does not recognize

an obsolescence challenge until it becomes an immediate issues. This chapter is intended to assist with incorporating a risk based proactive obsolescence management model that will enable organizations to better understand and manage its obsolescence risk.

5.2. CHAPTER PROBLEM STATEMENT

The importance of proactive obsolescence management rather than reactive obsolescence management is recognized among the practitioners; however, the system supports reactive obsolescence management because the challenges that occur from quick fixes and the focus on resources and applying expertise to immediate obsolescence challenges slows an organization and its many teams from being able to proactively plan the long-term obsolescence mitigation future. There are tools to address the patterns and structure to assist with transitioning from reactive to proactive obsolescence management. However, it is essential to understand this challenge deeper from a systems thinking perspective to address deep structural change and change the mental models to transform an entire organizations to succeed with risk based proactive obsolescence management. This will require a new mental model to sustain the long-lived systems within the C5ISR community. Unfortunately, the necessity of addressing immediate obsolescence challenges is more expensive and requires a longer schedule to resolve, as well as severely limits a practitioner's ability to focus on risk based proactive obsolescence management. A better understanding of this complexity would lead to more meaningful and longer lasting mitigation strategies. The challenge of successfully managing the obsolescence challenges of systems is deceptively complex. The research to date supports proactive obsolescence mitigations and fills several gap areas. However, this research can be further complemented by conducting systems thinking research to contribute to understanding the complexity of the behaviors that contribute to both reactive obsolescence management and risk

based proactive obsolescence management. It is essential to understand the broader and deeper systemic behavior that is a barrier to proactively managing obsolescence for the C5ISR systems and the mental model transformation required for teams and organizations to achieve risk based proactive obsolescence management.

5.3. CHAPTER RESEARCH QUESTIONS

1. What are the main relationships that predict obsolescence management outcomes?
2. What are the systems that govern obsolescence management behavior?
3. What are the underlying mental models that guide one's approach to obsolescence management?

5.4 CHAPTER METHODOLOGY

A qualitative research design using a phenomenological research methodology was used for this study. Experienced practitioners were shown elements and interconnections between parameters that impact the availability of components for C5ISR systems. The participants included a total of 10 government employees: 5 engineers and 5 logisticians from the U.S. Army located at Aberdeen Proving Ground, Maryland. At the time of the study, the participants were each supporting C5ISR systems, specifically C5ISR systems in the operations and support phase of the system life cycle. The participant's input was used to develop the models. The participants were asked several open-ended questions and provided feedback on the relationships to validate the completed models. The interviews lasted approximately 30-45 minutes. Each interview was conducted separately with each participant.

5.5. CHAPTER ANALYSIS AND RESULTS

5.5.1. PATTERN OF BEHAVIOR

The behavior at various tiers within the supply chain is used to forecast how many obsolete or near obsolete components are needed for the estimated life of the system and buy all the obsolete components. This behavior intuitively makes sense; however, the results are often counterintuitive, because the forecasts often predict far into the future which diminishes the accuracy of the estimate. For a variety of reasons, the life of the system is extended, e.g. the replacement system is not ready or was abandoned due to technical maturity challenges, and/or financial challenges.

5.5.2. SYSTEMIC IDENTIFICATION

The next area of this chapter explores the obsolescence challenge within the framework of the system of interest (SOI), a system context, and enabling systems. In this paper, the system of interest is the DMSMS Management System, the system context is the Engineering Systems, and the three enabling systems are Supply Chain, Configuration Management, and Budget System.

5.5.3. RATIONALE FOR COMPLEXITY

The following table applies the areas that define systems for a baseline understanding of the system of interest (DMSMS Management System), system context (Engineered Systems), and enabling systems (*i* Supply Chain, *ii* Configuration Management, *iii* Budget System). This baseline understanding of these systems supported the subsequent development of the mental models.

Table 12. Purpose, Elements, and Interconnects of Systems

System	Elements	Interconnects	Purpose
DMSMS Management System (system of interest)	Engineers, Logisticians, Financial Analysts, management, databases, plans, reports, and contracts	Team communication, policy, funding rules, and strategy	Maintain availability of components to support the procurement and repair of systems
Engineered Systems (system context)	Parts, components, subsystems, systems, system of systems	Team communication, engineering principles, engineering coordination with other teams	Perform in accordance with system requirements
Supply Chain (enabling systems)	Suppliers, customers, engineers, logisticians, and other analysts	Communication between suppliers and customers at multiple points of the supply chain.	The flow of materials from suppliers to customers
Configuration Management (enabling systems)	Configuration management tool, technical data, engineers, and logisticians	Team communication (internal & external), policy, and strategy	Approves engineered system changes without breaking any functionality for its users
Budget System (enabling systems)	Financial database, financial analysts, management, and stakeholders	Team communication (internal & external), funding rules, policy, and strategy	Efficiently spends resources and balances the resource needs of many systems

Obtaining components for long lived systems in the area of C5ISR is a complex challenge that has historically been challenging and continues to become more complex as the rate of technical change continues to accelerate. This challenge is more commonly known as diminishing manufacturing sources and material shortages (DMSMS). This is a complex problem because of the interactions between the system of interest (DMSMS management system), system context (engineered systems), and three enabling systems (supply chain,

configuration management, and budget system). Furthermore, these systems have misaligned or different purposes from the goal purpose of successfully mitigating obsolescence for C5ISR systems. The dominant current mental model is reactive obsolescence management. The upcoming modeling in this chapter shows the obsolescence mitigation advantage for a C5ISR system by transforming the obsolescence management mental model to risk based proactive obsolescence management. This will assist with adapting an organization's obsolescence management approach to successfully adjust to the systemic complexity which stems from the interconnections and purposes among the many stakeholders. The different or misaligned purposes are identifiable as reactive obsolescence mitigation behavior because the interactions of the stakeholders are focused on immediate obsolescence fixes and are unaware of the tradeoff for predictable long-term obsolescence mitigation solutions. This intense focus hides the true relationships from the stakeholders; they are unable to find the true purpose of successfully mitigating obsolescence is found through risk based proactive obsolescence mitigation behaviors. Furthermore, the mental model must change to achieve sustainable obsolescence mitigation outcomes. The modeling and analysis in this chapter propose a new mental model of risk based proactive obsolescence management that allows an organization to efficiently and effectively mitigate the obsolescence challenges for C5ISR systems.

5.6. MENTAL MODEL TRANSFORMATION

The following analysis is based on participant feedback and validation. The tools of systems thinking are employed to understand and change the mental models which are guided by the practitioner experiences with the system of interest (DMSMS management system), the context systems (C5ISR engineered systems), and the enabling systems (supply chain, configuration management, budget system). Figure 1 utilizes an iceberg model to provide an

overview of the complex structure of the DMSMS management system operating under a reactive obsolescence management mental model. Using an iceberg model, a practitioner, a team, and an organization can more easily and quickly obtain information from the top of the model, i.e. the event. However, the deeper one goes into an iceberg model, the greater the leverage to affect lasting and meaningful change with the affected systems (Stroh, 2015). The greater leverage areas include patterns of behavior followed by the underlying systemic structure with the greatest leverage area at the bottom (Stroh, 2015). The changing of the mental model from a reactive obsolescence management to a risk based obsolescence management mental model is noted in the following figure to provide an analysis from the starting point to the final transformed state. This contents of this iceberg model were developed through interviews with the participants.

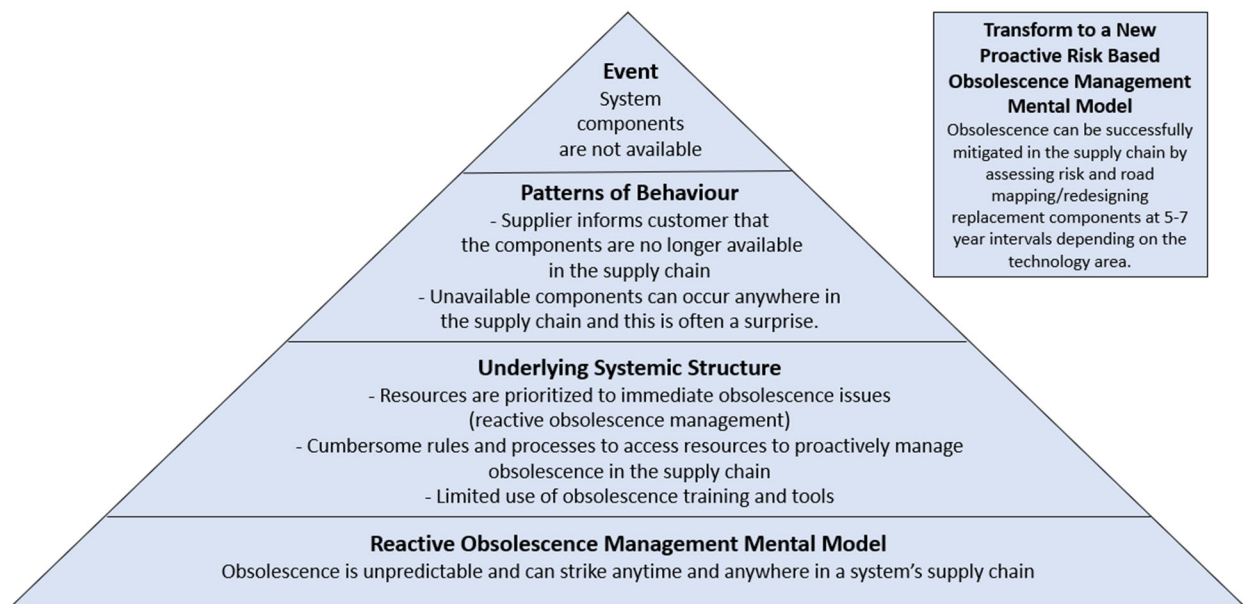


Figure 14. Reactive Obsolescence Management Iceberg Model and Transformation

It is not cost effective to proactively mitigate all the parts and components of a system. Therefore, based on this consideration, the mental model is updated to reflect risk based proactive obsolescence management. After a practitioner, a team, and an organization transitions from a reactive obsolescence management mental model to a proactive obsolescence management mental model, the reality of a resource constrained environment will still be present; this is why proactive obsolescence management needs to be guided by risk in the mental model. Therefore, the early assessment of where to focus proactive obsolescence management efforts are based on risk. The C5ISR participants had previously stressed risk management as a key aspect of supporting proactive obsolescence mitigation. They highlighted that the components that change often due to frequent technology advances, and have one or few suppliers at high risk and require focused expertise to mitigate.

Proactive obsolescence management can also benefit lower risk components that have a predictable useful life with planned replacements; however, not at the expense of medium and high obsolescence risk components. The least risk are components and parts which rarely change, e.g. assembly hardware (nuts, bolts, etc.), this does not merit any obsolescence risk management mitigation activities. Additionally, extending the transformation of the mental model beyond reactive obsolescence management to proactive obsolescence management to risk based proactive obsolescence management.

The following table shows the evolution of the mental model incorporating double-looped learning. It was through modeling and the gaining deeper systems knowledge to understand the mental models changes required considering the behavior of the system of interest (DMSMS Management System), system context (Engineered Systems), and enabling systems (Supply Chain, Configuration Management, and Budget System).

Table 13. Obsolescence Management Mental Model Evolution

Iceberg Model Elements	Model: Reactive Obsolescence Management	Model: Proactive Obsolescence Management	Model: Risk Based Proactive Obsolescence Management
<i>Events:</i> What is happening	Can no longer order the needed component(s) for the system(s)	Can no longer order the needed component(s) for the system(s)	Can no longer order the needed component(s) for the system(s)
<i>Patterns of Behavior:</i> Trends over time	The team does not worry about obsolescence until it is an immediate problem	The team plans as early as possible to address obsolescence	The team plans as early as possible to address obsolescence considering risk
<i>Systems Structure:</i> Structural forces contributing to these	Funding is not available until an immediate impact can be characterized, lack of technical data/foresight, design team see is as someone else's problem	Not enough funding to mitigate every component, characterize the obsolescence early, design team plans/partitioned the systems for component replacement, plans in the interface control document	Early funding of high/medium risk components, characterize the obsolescence early, the design team redesign's alternate components for early high/medium risk components
<i>Mental Models:</i> Assumptions, beliefs that shape the system	Manage obsolescence on an as needed basis late in a system's life cycle	Manage obsolescence as early as possible in a system's life cycle	Manage obsolescence as early as possible based on risk in a system's life cycle

The final evolution from a proactive obsolescence management system to a risk based proactive obsolescence management system is essential to make the most effective and efficient use of the resources and expertise of the teams assigned with mitigating the obsolescence challenges.

The causal loop diagrams in Figures 15 and 16 shows the modeling that was developed and refined based on the insights of our participants, who, recall, are practitioners routinely

assigned with finding solutions to mitigate the challenges of C5ISR systems. The first casual loop diagram (Figure 15) models reactive obsolescence management and the second causal loop diagram (Figure 16) models risk based proactive obsolescence management.

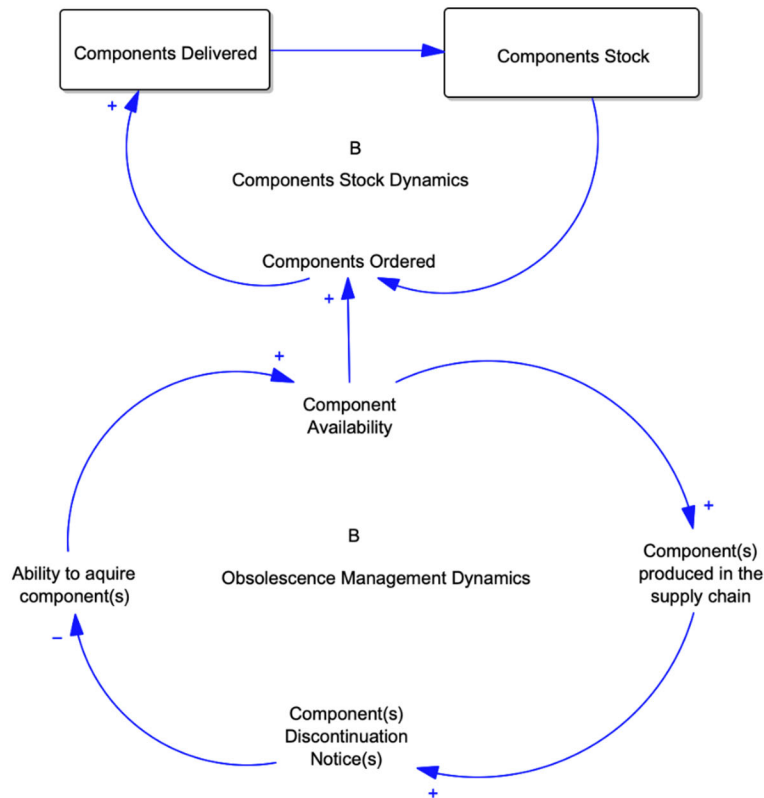


Figure 15. Reactive Obsolescence Management Causal Loop Diagram

The above causal loop diagram in Figure 15 depicts two balancing loops. The top loop shows the flow of components that are used within C5ISR systems. The bottom loop depicts the relationship of decreasing availability of components based on obsolescence. At this point the options to mitigate obsolescence are limited and require significant effort to solve immediate challenges which drives higher costs, longer schedules, lower availability, and the risk of not being able to acquire replacement components. The research participants validated the reactive obsolescence management causal loop diagram: six research participants strongly agreed with

the model and four research participants agreed with the model; no one disagreed with the model.

The next figure, Figure 16, is the risk based proactive obsolescence management causal loop diagram. The research participants validated the risk based proactive obsolescence management causal loop diagram: seven research participants strongly agreed with the model and three research participants agreed with the model; no one disagreed with the model.

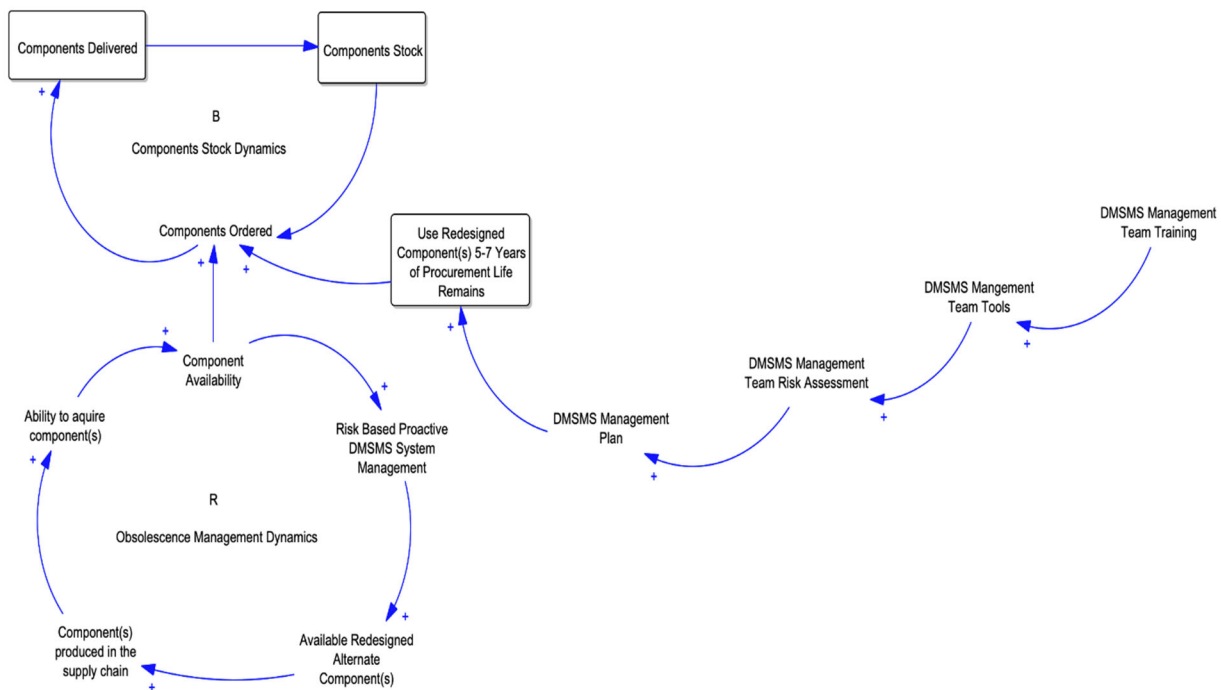


Figure 16. Risk Based Proactive Obsolescence Management Causal Loop Diagram

This causal loop diagram models the methods for a team to use the tools and assess risk to redesign components 5-7 years in advance. The top balancing loop, as in the previous model, captures the flow of components that are used within C5ISR systems. However, in this model the team and the organization are well ahead of being limited to select a shortsighted solution to address an immediate need. Furthermore, the bottom loop is a reinforcing loop that support the

continuous flow of redesigned alternate components that can be redesigned at lower costs, optimal schedules, and support higher availability.

5.7. CHAPTER DISCUSSION

The system's behavior changes based on changing the mental model from reactive obsolescence management to risk based proactive obsolescence management. All the research participants agree or strongly agree that changing to a risk based proactive obsolescence management model better supports positive obsolescence mitigation outcomes. Based on the results of this research, here are several insights towards risk based proactive obsolescence management:

- System of Interest - DMSMS Management System: Include risk based proactive obsolescence management to significantly reduce the risk of encountering any significant DMSMS challenges.
- System Context - Engineered Systems: Plan and execute replacement component development or identification 5-7 years ahead of an obsolescence issue to support the procurements and repairs of C5ISR systems.
- Enabling System - Supply Chain: Plan using a risk based proactive obsolescence management mental model supports advance planning which reinforces better supply availability across an engineered system's supply chain. This leads to a healthier ecosystem of supportability for an engineered system.
- Enabling System - Configuration Management: The risk based proactive obsolescence management mental model reinforces planning of the redesigned components within the systems configuration well in advance of the risk of surprise or shortsighted design

changes introducing a non-optimal number of configurations and/or suboptimal configurations.

- Enabling System - Budget System: Funding the activities to obtain alternate components for medium to high risk components 5-7 years ahead of an immediate obsolescence issue will avoid shock to the budget systems, as well as the cost increases resulting from the additional efforts of the government and our industry partners.

Future research could repeat our modeling of obsolescence management using systems thinking methods with other military branches, as well as replicate this study with a larger sample size. Furthermore, this study could also be expanded to other areas by using commercial systems that are not related to the military. Another area that could benefit from more research is in the area of tools to assist practitioners with assessing obsolescence, e.g. obsolescence risk analysis software to assist the team with assessing the obsolescence risk for each component of a C5ISR system. Additionally, there is an understanding by some of the participants of delays in the obsolescence management system(s); however, it is difficult to pinpoint where and how many delays are systemically within the systems that support obsolescence management. Therefore, another study focusing on delays by following the activities of samples through the process could inform future process mitigation solutions.

The U.S. Army practitioners located at Aberdeen Proving Ground, Maryland validated the mental models that guide both reactive obsolescence management and risk based proactive obsolescence management. The mental models are formed from the relationships of the interactions between the system of interest (DMSMS management system), system context (engineered systems), and three enabling systems (supply chain, configuration management, and

budget system). Based on the relationships in the causal loop diagrams, applying a risk based proactive obsolescence management mental model is a predictor of successfully mitigating obsolescence because stock levels are reenforced years in advance to create a sufficient buffer to protect from a component level nonavailability event.

A limitation of this chapter is that the model was validated based on a relatively small sample size. Another limitation is the expertise of the practitioners is specialized to the U.S. Army's C5ISR systems. However, there is also an opportunity for additional research with a larger sample size, as well as areas not related to the Army's C5ISR systems.

5.8. CHAPTER CONCLUSION

In conclusion, this chapter provides new obsolescence management mental models to assist with mitigation obsolescence for C5ISR systems. This research will strengthen the effectiveness of the teams and complement other tools for mitigating obsolescence by deepening an organization's understanding of the areas that require more focus. This research will also contribute assisting an organization with transforming into an organization that practices proactive risk based obsolescence management on all systems that are assessed with a medium to high obsolescence risk. Lastly, these obsolescence management mental models will contribute to a deeper understanding and better-informed mitigations by the system teams and their management.

CHAPTER 6: FUTURE RESEARCH OBSOLESCENCE WITH THE INTEL CORPORATION

6.1. CHAPTER INTRODUCTION

My research contributions are applicable to many domain areas; the next area I plan to focus on is to fill some of the gaps in the literature on standard ways to address software obsolescence and architecture obsolescence for long lived systems. The long-lived system is the common use case in the DoD. The Intel Corporation is one of the largest technology developers in the world and has graciously agreed to collaborate with me to further my obsolescence research. The contribution that I have made in this dissertation are directly applicable to software obsolescence and systems architecture, these contributions include:

- New Obsolescence Modeling & Simulation Technique (R code)
- New Obsolescence Risk Management Visualizations
- New Obsolescence Management Mental Model Evolution
- New Reactive Obsolescence Management Mental Model
- New Risk Based Proactive Obsolescence Management Mental Model

I am planning to present the results of my research approach applied to software systems at Intel's Federal Summit, scheduled for November 2023. The focus of this presentation is not to develop more novel contributions, but rather apply my methodology and framework to this new research application area. This will provide an opportunity to significantly further the use of the tool and models I developed across the community of practitioners and researchers in the government and industry.

6.2. PLANNED APPLICATION THE OBSOLESCENCE VISUALIZATION TOOL TO OTHER DOMAIN AREAS

Based on initial research planning with Intel, here are some variables for exploration with their development team.

Table 14. Software Proactive Obsolescence Risk Mitigation Framework

Inputs	Outputs		
<i>Indicators</i>	<i>Low Risk</i>	<i>Medium Risk</i>	<i>High Risk</i>
Openness of the System's Architecture	Open Systems Architecture (white box)	Mixed open and closed systems architecture (grey box)	Closed Systems Architecture (black box)
Number of Developers of a Similar Application	3 or more developers of a similar application	2 or more developers of a similar application	1 or more developers of a similar application
Licensing Cost	Cost growth is not more than 10% of the	Cost growth is more than 10% but less than 25% for the component/part	Cost growth is more than 25% for the component/part
Software Update Schedule	Estimated updates every 1-7 days	Estimated updates every 8-30 days	Estimated delivery schedule is more than 1 month

Table 15. Draft System Architecture Proactive Obsolescence Risk Mitigation Framework

Inputs	Outputs		
<i>Indicators</i>	<i>Low Risk</i>	<i>Medium Risk</i>	<i>High Risk</i>
Frequency of Architecture Design Changes (new replacement or next version)	Estimated architecture design changes are 5 years or greater	Estimated architecture design changes are more than 2 years but less than 5 years	Estimated architecture design changes are less than 2 years
Next Generation, Upgrade & Update Planning - Roadmaps for technology, systems, or products	Roadmaps indicate firm dates of the replacement architecture	Roadmaps indicate a date range; e.g. a span of several years for the replacement architecture	No roadmap or roadmaps do not indicate any dates

Cost of Architecture (new replacement or next version)	Cost growth is not more than 10% of the	Cost growth is more than 10% but less than 25% for the component/part	Cost growth is more than 25% for the component/part
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6.3. CHAPTER PROBLEM STATEMENT FOR SOFTWARE

OBSOLESCENCE

Overtime software becomes unusable or unable to perform its function(s) efficiently and/or effectively. This is a complex problem because the software is embedded in the hardware of components, and it is highly interconnected and needed to perform with many other systems.

6.4. CHAPTER PROBLEM STATEMENT FOR ARCHITECTURE

OBSOLESCENCE

Overtime physical architecture becomes degraded or unable to interface with new technology to perform its function(s) efficiently and/or effectively. This is a complex problem because the architecture largely determines the technical purpose of a system and is highly interconnected in a system, a system of systems, as well as an enterprise.

6.5. CHAPTER RESEARCH OBJECTIVE

Apply the following methods in this dissertation to Intel’s software and architecture obsolescence mitigation challenges. The methods include:

- New Obsolescence Modeling & Simulation Technique (R code)
- New Obsolescence Risk Management Visualizations
- New Obsolescence Management Mental Model Evolution
- New Reactive Obsolescence Management Mental Model
- New Risk Based Proactive Obsolescence Management Mental Model

6.6. CHAPTER RESEARCH QUESTIONS

1. Are the obsolescence risk management visualizations more efficient and effective than Intel's traditional obsolescence management methods?
2. Are the obsolescence mental models that guide obsolescence management predictive of Intel's obsolescence management behavior (choice experiment)?

6.7. CHAPTER CONCLUSION

In conclusion, this research will provide systems architecture and software mitigation insights from a world class company that develops state-of-the-art technology and supports state-of-the-current technology. Furthermore, it is the goal of this research to further apply many of the novel contributions detailed in this dissertation. Intel's expertise will be very valuable for refining the methods on a large scale which will be widely applicable to the government and industry.

CHAPTER 7: CONCLUSION

7.1. CHAPTER INTRODUCTION

This research has found that both the Army and industry use similar methods to mitigate the DMSMS challenges with proactive obsolescence management. These methods include a team approach, planning for DMSMS, predictive analysis tools, and contracting language. Note this is all predicated on adequately funding DMSMS activities. Otherwise, the monitoring and planning to mitigate obsolescence becomes dormant. This creates an environment of reactive obsolescence management which is the most expensive and longest schedule impact approach. This research has also identified areas where additional methods have the potential to fill gap areas within the current methods and practices of proactive obsolescence. These proactive approaches to improve obsolescence mitigation effectiveness include a proactive obsolescence management model, proactive obsolescence risk mitigation framework, and proactive obsolescence mitigation metrics, model and simulation, and supporting R code to support further research and the work of practitioners.

In areas where deep experience and profound expertise are found, there are also process gaps for obtaining data and defining criteria. This prompted the development of the several new methods that are presented in this paper, i.e. the framework, model, modeling and simulation with R code, and metrics. However, more research and data will be needed to refine these approaches. These approaches extend the participants' insights and provides the structure to refine the approaches for broader and deeper proactive obsolescence management methods and assists with a way to capture data to inform future refinement of the methods to successfully implement proactive obsolescence mitigation methods.

7.2. CONTRIBUTIONS OF THIS DISSERTATION

The culmination of this research will result in nine novel and original contributions to this field.

A list of my research contributions follows:

- New Proactive Obsolescence Management Model
- New Proactive Obsolescence Risk Mitigation Framework
- New Proactive Obsolescence Mitigation Metrics
- New obsolescence modeling & simulation technique
 - Coded in R
 - Applied to 9 risk based simulations representative of 81 possible permutations
- Applied R code model criteria successfully to 1 non-simulated example using a drone system (Newly developed and applied technique)
- New obsolescence risk management visualizations
- New Obsolescence Management Mental Model Evolution
- New Reactive Obsolescence Management Mental Model
 - Supporting Reactive Obsolescence Management Causal Loop Diagram
- New Risk Based Proactive Obsolescence Management Mental Model
 - Supporting Risk Based Obsolescence Management Causal Loop Diagram

These novel contributions are included in the manuscripts of three scholarly journal articles. The first manuscript, “Proactive Obsolescence Management Methods for C5ISR Systems: Insights from Practitioners” has been accepted for publication by the *Defense Acquisition Research Journal* in their April 2023 issue. The second manuscript, “Visualization Tool for Obsolescence Management: Reducing Supply Chain Risk for C5ISR Systems” was

submitted to *IEEE Transactions on Visualization and Computer Graphics* and is in the peer review process. The third manuscript, “Frustrated With Obsolescence – Try Changing Your Mental Model” was submitted to the *Defense Acquisition Research Journal* and is also in the peer review process.

7.3. FUTURE RESEARCH

Beyond the research plan I detailed in chapter 6 in the area of software obsolescence. Future research could replicate the studies in this dissertation with a larger sample size, as well as repeat this study with one or more of the other military service branches. A future study could focus on broadening the scope of this research to systems that are not C5ISR systems. Additionally, a future study could extend this research by implementing several or all of the top 4 proactive obsolescence management methods. Furthermore, future research could focus on experimentation with physical or simulated data using the framework, model, and metrics. The combination of the obsolescence techniques from this research provide additional tools to contribute to achieving greater system readiness, more availability, better maintainability, and lower costs for C5ISR systems.

7.4. CHAPTER CONCLUSION

The culmination of this research resulted in nine new contributions to this field. This research has found that both the Army and industry use similar methods to mitigate the DMSMS challenges with proactive obsolescence management. These methods include a team approach, planning for DMSMS, predictive analysis tools, and contracting language. Note this is all predicated on adequately funding DMSMS activities. Otherwise, the monitoring and planning to mitigate obsolescence becomes dormant. This creates an environment of reactive obsolescence management which is the most expensive and longest schedule impact approach. This research

has also identified areas where additional methods have the potential to fill gap areas within the current methods and practices of proactive obsolescence. These proactive approaches to improve obsolescence mitigation effectiveness include a proactive obsolescence management model, proactive obsolescence risk mitigation framework, and proactive obsolescence mitigation metrics, model and simulation, and supporting R code to support further research and the work of practitioners. Furthermore, this research unlocked an important prerequisite to success and that is changing one's mental model to risk based proactive obsolescence management which is essential to facilitate the successful use of the other methods and tools.

REFERENCES

- Ackoff, R. L. (2010). *Systems thinking for curious managers*. Triarchy Press.
- Anderson, E. W., Potter, K. C., Matzen, L. E., Shepherd, J. F., Preston, G. A., & Silva, C. T. (2011). A user study of visualization effectiveness using EEG and cognitive load. *Computer Graphics Forum*, 30(3), 791-800. <https://doi.org/10.1111/j.1467-8659.2011.01928.x>
- Chamorro, E. (2017). Parts List. FabDrone. Retrieved June, 27, 2022, from <http://eduardochamorro.github.io/beansreels/workshops/modulardrone/parts.html>
- Chellin, M., & Miller, E. E. (in press). Proactive Obsolescence Management Methods for C5ISR Systems: Insights from Practitioners. *Defense Acquisition Research Journal*.
- Clancey, C. (2018, September). Proactive obsolescence management. In *International Nuclear Information System, 44th Annual Meeting of the Spanish Nuclear Society*, Avila, Spain https://inis.iaea.org/search/search.aspx?orig_q=RN:51074613
- Constantine, J. A., & Solak, S. (2010). SysML modeling of off-the-shelf-option acquisition for risk mitigation in military programs. *Systems Engineering*, 13(1), 80-94. <https://doi.org/10.1002/sys.20134>
- Department of Defense. (2019). [SD-26 DMSMS Contract Language Guide Book](https://www.dau.edu/cop/dmsms/Lists/Tools/DispForm.aspx?ID=67&ContentTypeId=0x0100AE321BA2819FFD499A441F9A8F574C1600A3866BA66DC4B546AF0E2614A20E809A). Defense Standardization Program Office.
- Department of Defense. (2020). *Diminishing manufacturing sources and material shortages management* (DoDI 4245.15). Office of the Under Secretary of Defense for Acquisition

and Sustainment. <https://www.esd.whs.mil/Portals/54/Documents/DD/issuances/dodi/424515p.PDF?ver=1nGN1Q4HzmReR3-nCo59UQ%3d%3d>

Department of Defense. (2022). *SD-22 Diminishing manufacturing sources and material shortages: A guidebook of best practices for implementing a robust DMSMS management program*. Defense Standardization Program Office. [https://www.dau.edu/tools/t/SD-22-Diminishing-Manufacturing-Sources-and-Material-Shortages-\(DMSMS\)-Guidebook](https://www.dau.edu/tools/t/SD-22-Diminishing-Manufacturing-Sources-and-Material-Shortages-(DMSMS)-Guidebook)

DJZ Photography. (2018, June 27). DJI Product History Timeline (Drones, Gimbals, Cameras, & More).

<https://www.djzphoto.com/blog/dji-product-history-timeline-drones-cameras-gimbals>

Geng, F., Dubos, G. F., & Saleh, J. H. (2016). Spacecraft obsolescence: Modeling, value analysis, and implications for design and acquisition. *In the Proceedings of the 2016 IEEE Aerospace Conference*, 1-13. <https://doi.org/10.1109/AERO.2016.7500642>

Herald, T., Verma, D., Lubert, C. & Cloutier, R. (2009). An obsolescence management framework for system baseline evolution—Perspectives through the system life cycle. *Syst. Engin.*, 12: 1-20. <https://doi.org/10.1002/sys.20106>

Jackson, M. C. (2016). *Systems thinking: Creative holism for managers*.

John Wiley & Sons, Inc.

Kasser, J. E. (2015). Applying holistic thinking to the problem of determining the future availability of technology. *IEEE Transactions on Systems, Man, and Cybernetics: Systems*, 46(3), 440-444. <https://doi.org/10.1109/TSMC.2015.2438780>.

Kasser, J. E. (2015). *Holistic Thinking: creating innovative solutions to complex problems* (Vol. 1). Right Requirement.

Kenett, R., Swarz, R., & Zonnenshain A. (2020). Systems Engineering in the Fourth Industrial Revolution. <https://doi.org/10.1002/9781119513957>.

- McComb, D., Robe, S., & Crawford-Hines S. (2002). Dependency analysis and visualization as tools to prolong system life. *In the Proceedings of the 26th Annual International Computer Software and Applications*, 463-465.
<https://doi.org/10.1109/CMPSAC.2002.1045045>
- Meadows, D. (2008). *Thinking in Systems A Primer*. Chelsea Green Publishing
- Meng, X., Thörnberg, B., & Olsson, L. (2014). Strategic proactive obsolescence management model. *IEEE Transactions on Components, Packaging and Manufacturing Technology*, 4(6), 1099–1108. <https://doi.org/10.1109/TCPMT.2014.2316212>
- Meyer, A., Pretorius, L., & Pretorius, J. H. C. (2004). A model to manage electronic component obsolescence for complex or long life systems. *In the Proceedings of the 2004 IEEE International Engineering Management Conference*, 3, 1303–1309.
<https://doi.org/10.1109/IEMC.2004.1408905>
- Newman, M. (2016). Battling obsolescence in military systems from Earth to space. *Military Embedded Systems*. <https://militaryembedded.com/comms/communications/battling-obsolescence-military-systems-earth-space>
- Rittel, H. W., & Webber, M. M. (1973). Dilemmas in a general theory of planning. *Policy sciences*, 4(2), 155-169. <https://doi.org/10.1007/BF01405730>
- Rojo, F. J., Roy, R., & Kelly, S. (2012, June). Obsolescence risk assessment process best practice. In *Journal of Physics: Conference Series*, 25th International Congress on Condition Monitoring and Diagnostic Engineering (Vol. 364, pp. 1–10), Huddersfield, UK. <https://doi.org/10.1088/1742-6596/364/1/012095>

- Sandborn, P. (2004). Beyond reactive thinking—We should be developing proactive approaches to obsolescence management too. *DMSMS Center of Excellence Newsletter*, 2(3), 4, 9.
https://www.researchgate.net/publication/228901311_Beyond_reactive_thinking-We_should_be_developing_pro-active_approaches_to_obsolescence_management_too
- Sandborn, P. (2013). Design for Obsolescence Risk Management. *Procedia CIRP* 11: 15-22.
<https://doi.org/10.1016/j.procir.2013.07.073>.
- Sandborn, P. (2007). Software Obsolescence – Complicating the Part and Technology Obsolescence Management Problem. *IEEE Trans on Components and Packaging Technologies*, 30(4), 886–888. http://escml.umd.edu/Papers/IEEE_SoftwareObs.pdf
- Sandborn, P., & Terpenney, J. P. (2011, July). Forecasting and proactive management of obsolescence for sustainment-dominated systems. In *Proceedings of 2006 National Science Foundation Design, Service, and Manufacturing Grantees and Research Conference*, St. Louis, Missouri (United States).
<http://escml.umd.edu/ObsSGER/2006GranteesConf.pdf>
- Senge, P. (2006). *The Fifth Discipline: The Art & Practice of the Learning Organization*. Crown Publishing Group.
- Sterman, J. D. (2000). *Business dynamics systems thinking and modeling for a complex world*. Irwin McGraw-Hill.
- Stroh D. (2015). *Systems Thinking for Social Change A Practical Guide to Solving Complex Problems, Avoiding Unintended Consequences, and Achieving Lasting Results*. Chelsea Green Publishing.

Szyk, B., & Czernia, D. (2022). *Combination calculator*. (nCr) | Combinations Generator.

Retrieved February 16, 2023, from <https://www.omnicalculator.com/statistics/combination>

Trabelsi, I., Zolghadri, M., Zeddini, B., Barkallah, M., & Haddar, M. (2020, July). FMECA-based risk assessment approach for proactive obsolescence management. In *Proceedings of 17th IFIP International Conference on Product Lifecycle Management (PLM2020)* (pp. 215–226), Rapperswil, Switzerland. <https://hal.archives-ouvertes.fr/hal-03757775/document>

Yelizarov, A., & Gamayunov, D. (2014). Adaptive visualization interface that manages user's cognitive load based on interaction characteristics. In *the Proceedings of the 7th International Symposium on Visual Information Communication and Interaction*, 1-8. <https://doi.org/10.1145/2636240.2636844>

Zheng, L., & Terpenney, J. (2013). A hybrid ontology approach for integration of obsolescence information. *Computers & Industrial Engineering*, 65(3), 485-499. <https://doi.org/10.1016/j.cie.2013.02.011>

Zolghadri, M., Addouche, S. A., Boissie, K., & Richard, D. (2018). Obsolescence prediction: a Bayesian model. *Procedia CIRP*, 70, 392-397. <https://doi.org/10.1016/j.procir.2018.02.037>

APPENDIX A: OBSOLESECNE VISUALIZATION TOOL SIMULATION CODE & DRONE EXAMPLE

Obsolescence Visualization Code

####*This software is free; you can redistribute it and/or modify it; this is
####WITHOUT ANY WARRANTY. If you find this software useful and use it for any
####publications, we ask that you cite it. The correct citation is:
####Chellin, M., & Miller, E. (2022). Obsolescence Risk Visualization Software (Version 0) [Computer software].*

```
library(tidyverse)
```

```
## — Attaching packages —————
```

```
tidyverse 1.3.2 —
```

```
## ✓ ggplot2 3.3.6   ✓ purrr  0.3.4
```

```
## ✓ tibble 3.1.8   ✓ dplyr  1.0.9
```

```
## ✓ tidyr  1.2.0   ✓ stringr 1.4.0
```

```
## ✓ readr  2.1.2   ✓ forcats 0.5.1
```

```
## — Conflicts —————
```

```
## ✗ dplyr::filter() masks stats::filter()
```

```
## ✗ dplyr::lag()   masks stats::lag()
```

```
library(RColorBrewer)
```

```
library(ggrepel)
```

```
library(ggplot2)
```

```
library(stringr)
```

```
library(ggpubr)
```

```
library(gtable)
```

```
library(vtable)
```

```
## Loading required package: kableExtra
```

```
##
```

```
## Attaching package: 'kableExtra'
```

```
##
```

```
## The following object is masked from 'package:dplyr':
```

```
##
```

```
##   group_rows
```

```
library(ggribes)
```

```
library(writexl)
```

```
setwd("~/Desktop/Scholarly Journal 2/CSVs")
```

I used <https://www.omnicalculator.com/statistics/combination> to display all possible permutations ($n = 3$ and $r = 4$) for low risk (A), medium risk (b), and high risk (c) for the 4 variables of design life, procurement lead time, cost growth (%), and manufacturers. I included

it below for reference. The following simulations includes the lowest risk system (P), the highest risk system (R), and a representative sample of every 9th system of all the possible risk permutations (with repetitions) for the aforementioned variables.

# System	Design Life	Procurement Lead Time	Cost Growth (%)	Manufacturers (N)
#1	Low Risk	Low Risk	Low Risk	Low Risk
#2	Low Risk	Low Risk	Low Risk	Medium Risk
#3	Low Risk	Low Risk	Medium Risk	Low Risk
#4	Low Risk	Medium Risk	Low Risk	Low Risk
#5	Medium Risk	Low Risk	Low Risk	Low Risk
#6	Low Risk	Low Risk	Low Risk	High Risk
#7	Low Risk	Low Risk	High Risk	Low Risk
#8	Low Risk	High Risk	Low Risk	Low Risk
#9	High Risk	Low Risk	Low Risk	Low Risk
#10	Low Risk	Low Risk	Medium Risk	Medium Risk
#11	Low Risk	Medium Risk	Low Risk	Medium Risk
#12	Low Risk	Medium Risk	Medium Risk	Low Risk
#13	Medium Risk	Low Risk	Low Risk	Medium Risk
#14	Medium Risk	Low Risk	Medium Risk	Low Risk
#15	Medium Risk	Medium Risk	Low Risk	Low Risk
#16	Low Risk	Low Risk	Medium Risk	High Risk
#17	Low Risk	Low Risk	High Risk	Medium Risk
#18	Low Risk	Medium Risk	Low Risk	High Risk
#19	Low Risk	Medium Risk	High Risk	Low Risk
#20	Low Risk	High Risk	Low Risk	Medium Risk
#21	Low Risk	High Risk	Medium Risk	Low Risk
#22	Medium Risk	Low Risk	Low Risk	High Risk

#23	Medium Risk	Low Risk	High Risk	Low Risk
#24	Medium Risk	High Risk	Low Risk	Low Risk
#25	High Risk	Low Risk	Low Risk	Medium Risk
#26	High Risk	Low Risk	Medium Risk	Low Risk
#27	High Risk	Medium Risk	Low Risk	Low Risk
#28	Low Risk	Low Risk	High Risk	High Risk
#29	Low Risk	High Risk	Low Risk	High Risk
#30	Low Risk	High Risk	High Risk	Low Risk
#31	High Risk	Low Risk	Low Risk	High Risk
#32	High Risk	Low Risk	High Risk	Low Risk
#33	High Risk	High Risk	Low Risk	Low Risk
#34	Low Risk	Medium Risk	Medium Risk	Medium Risk
#35	Medium Risk	Low Risk	Medium Risk	Medium Risk
#36	Medium Risk	Medium Risk	Low Risk	Medium Risk
#37	Medium Risk	Medium Risk	Medium Risk	Low Risk
#38	Low Risk	Medium Risk	Medium Risk	High Risk
#39	Low Risk	Medium Risk	High Risk	Medium Risk
#40	Low Risk	High Risk	Medium Risk	Medium Risk
#41	Medium Risk	Low Risk	Medium Risk	High Risk
#42	Medium Risk	Low Risk	High Risk	Medium Risk
#43	Medium Risk	Medium Risk	Low Risk	High Risk
#44	Medium Risk	Medium Risk	High Risk	Low Risk
#45	Medium Risk	High Risk	Low Risk	Medium Risk
#46	Medium Risk	High Risk	Medium Risk	Low Risk
#47	High Risk	Low Risk	Medium Risk	Medium Risk
#48	High Risk	Medium Risk	Low Risk	Medium Risk
#49	High Risk	Medium Risk	Medium Risk	Low Risk

#50	Low Risk	Medium Risk	High Risk	High Risk
#51	Low Risk	High Risk	Medium Risk	High Risk
#52	Low Risk	High Risk	High Risk	Medium Risk
#53	Medium Risk	Low Risk	High Risk	High Risk
#54	Medium Risk	High Risk	Low Risk	High Risk
#55	Medium Risk	High Risk	High Risk	Low Risk
#56	High Risk	Low Risk	Medium Risk	High Risk
#57	High Risk	Low Risk	High Risk	Medium Risk
#58	High Risk	Medium Risk	Low Risk	High Risk
#59	High Risk	Medium Risk	High Risk	Low Risk
#60	High Risk	High Risk	Low Risk	Medium Risk
#61	High Risk	High Risk	Medium Risk	Low Risk
#62	Low Risk	High Risk	High Risk	High Risk
#63	High Risk	Low Risk	High Risk	High Risk
#64	High Risk	High Risk	Low Risk	High Risk
#65	High Risk	High Risk	High Risk	Low Risk
#66	Medium Risk	Medium Risk	Medium Risk	Medium Risk
#67	Medium Risk	Medium Risk	Medium Risk	High Risk
#68	Medium Risk	Medium Risk	High Risk	Medium Risk
#69	Medium Risk	High Risk	Medium Risk	Medium Risk
#70	High Risk	Medium Risk	Medium Risk	Medium Risk
#71	Medium Risk	Medium Risk	High Risk	High Risk
#72	Medium Risk	High Risk	Medium Risk	High Risk
#73	Medium Risk	High Risk	High Risk	Medium Risk
#74	High Risk	Medium Risk	Medium Risk	High Risk
#75	High Risk	Medium Risk	High Risk	Medium Risk
#76	High Risk	High Risk	Medium Risk	Medium Risk

#77	Medium Risk	High Risk	High Risk	High Risk
#78	High Risk	Medium Risk	High Risk	High Risk
#79	High Risk	High Risk	Medium Risk	High Risk
#80	High Risk	High Risk	High Risk	Medium Risk
#R	High Risk	High Risk	High Risk	High Risk

```
dronedata <- read_csv("DroneBOMR.csv")
```

```
## Rows: 8 Columns: 7
```

```
## — Column specification —————
```

```
## Delimiter: ","
```

```
## chr (3): System, Component, Description
```

```
## dbl (4): PLT, CostGrowth, NumberofManf, DY
```

```
##
```

```
## Code for random number generator used to create data tables
```

```
proactive_simdata <- read_csv("ProactiveDataSim.csv")
```

```
## Rows: 1000 Columns: 2
```

```
## — Column specification —————
```

```
## Delimiter: ","
```

```
## chr (2): System, Component
```

```
proactive_simdata$DY <- runif(1000, 12.01, 15) #p low risk
```

```
proactive_simdata$PLT <- runif(1000, 1, 5.99) #p low risk
```

```
proactive_simdata$CostGrowth <- runif(1000, 1, 9.99) #p low risk
```

```
proactive_simdata$NumberofManf <- sample(3:5, 1000, replace = T) #p low risk
```

```
proactive_simdata$System [proactive_simdata$System == "Proactive"] <- "Low Risk"
```

```
reactive_simdata <- read_csv("ReactiveDataSim.csv")
```

```
## Rows: 1000 Columns: 2
```

```
## — Column specification —————
```

```
## Delimiter: ","
```

```
## chr (2): System, Component
```

```
##
```

```
reactive_simdata$DY <- runif(1000, 1, 4.99) #r high risk
```

```
reactive_simdata$PLT <- runif(1000, 12.01, 18) #r high risk
```

```
reactive_simdata$CostGrowth <- runif(1000, 25.01, 33.25) #r high risk
```

```
reactive_simdata$NumberofManf <- sample(0:1, 1000, replace = T) #r high risk
```

```

reactive_simdata$System [reactive_simdata$System == "Reactive"] <- "High Risk"

system9_simdata <- read_csv("system9DataSim.csv")

## Rows: 1000 Columns: 2
## — Column specification —————
## Delimiter: ","
## chr (2): System, Component
##

system9_simdata$DY <- runif(1000, 12.01, 15) #p low risk
system9_simdata$PLT <- runif(1000, 1, 6) #p low risk
system9_simdata$CostGrowth <- runif(1000, 10, 25) #medium risk
system9_simdata$NumberofManf <- sample(2:2, 1000, replace = T) #medium risk

system18_simdata <- read_csv("system18DataSim.csv")

## Rows: 1000 Columns: 2
## — Column specification —————
## Delimiter: ","
## chr (2): System, Component
##

system18_simdata$DY <- runif(1000, 12.01, 15) #p low risk
system18_simdata$PLT <- runif(1000, 6, 12) #medium risk
system18_simdata$CostGrowth <- runif(1000, 25.01, 33.25) #r high risk
system18_simdata$NumberofManf <- sample(3:5, 1000, replace = T) #p low risk

system27_simdata <- read_csv("system27DataSim.csv")

## Rows: 1000 Columns: 2
## — Column specification —————
## Delimiter: ","
## chr (2): System, Component
##

system27_simdata$DY <- runif(1000, 12.01, 15) #p low risk
system27_simdata$PLT <- runif(1000, 1, 5.99) #p low risk
system27_simdata$CostGrowth <- runif(1000, 25.01, 33.25) #r high risk
system27_simdata$NumberofManf <- sample(0:1, 1000, replace = T) #r high risk

system36_simdata <- read_csv("system36DataSim.csv")

## Rows: 1000 Columns: 2
## — Column specification —————

```

```

## Delimiter: ","
## chr (2): System, Component
##

system36_simdata$DY <- runif(1000, 5, 12) #medium risk
system36_simdata$PLT <- runif(1000, 6, 12) #medium risk
system36_simdata$CostGrowth <- runif(1000, 10, 25) #medium risk
system36_simdata$NumberofManf <- sample(3:5, 1000, replace = T) #p low risk

system45_simdata <- read_csv("system45DataSim.csv")

## Rows: 1000 Columns: 2
## — Column specification —

```

```

## Delimiter: ","
## chr (2): System, Component
##

system45_simdata$DY <- runif(1000, 5, 12) #medium risk
system45_simdata$PLT <- runif(1000, 12.01, 18) #r high risk
system45_simdata$CostGrowth <- runif(1000, 10, 25) #medium risk
system45_simdata$NumberofManf <- sample(3:5, 1000, replace = T) #p low risk

system54_simdata <- read_csv("system54DataSim.csv")

## Rows: 1000 Columns: 2
## — Column specification —

```

```

## Delimiter: ","
## chr (2): System, Component
##

system54_simdata$DY <- runif(1000, 5, 12) #medium risk
system54_simdata$PLT <- runif(1000, 12.01, 18) #r high risk
system54_simdata$CostGrowth <- runif(1000, 25.01, 33.25) #r high risk
system54_simdata$NumberofManf <- sample(3:5, 1000, replace = T) #p low risk

system63_simdata <- read_csv("system63DataSim.csv")

## Rows: 1000 Columns: 2
## — Column specification —

```

```

## Delimiter: ","
## chr (2): System, Component
##

```

```

system63_simdata$DY <- runif(1000, 1, 4.99) #r high risk
system63_simdata$PLT <- runif(1000, 1, 6) #p low risk
system63_simdata$CostGrowth <- runif(1000, 1, 9.99) #p low risk
system63_simdata$NumberofManf <- sample(0:1, 1000, replace = T) #r high risk

system72_simdata <- read_csv("system72DataSim.csv")

## Rows: 1000 Columns: 2
## — Column specification —————
## Delimiter: ","
## chr (2): System, Component

system72_simdata$DY <- runif(1000, 5, 12) #medium risk
system72_simdata$PLT <- runif(1000, 12.01, 18) #r high risk
system72_simdata$CostGrowth <- runif(1000, 25.01, 33.25) #r high risk
system72_simdata$NumberofManf <- sample(2:2, 1000, replace = T) #medium risk

systems.samples <- combine(proactive_simdata, reactive_simdata, system9_simdata, system18_s
imdata, system27_simdata,
                          system36_simdata, system45_simdata, system54_simdata, system63_simdata, s
ystem72_simdata)

## Warning: `combine()` was deprecated in dplyr 1.0.0.
## Please use `vctrs::vec_c()` instead.
## This warning is displayed once every 8 hours.
## Call `lifecycle::last_lifecycle_warnings()` to see where this warning was generated.

systems.samples$DY <- as.numeric(round(systems.samples$DY, digits = 0))
systems.samples$PLT <- as.numeric(round(systems.samples$PLT, digits = 0))
systems.samples$CostGrowth <- as.numeric(round(systems.samples$CostGrowth, digits = 0))
as.factor(systems.samples$NumberofManf)

systems.samples$System <- factor(systems.samples$System,
                                levels=c("High Risk",
                                          "System 72",
                                          "System 63",
                                          "System 54",
                                          "System 45",
                                          "System 36",
                                          "System 27",
                                          "System 18",
                                          "System 9",
                                          "Low Risk"))

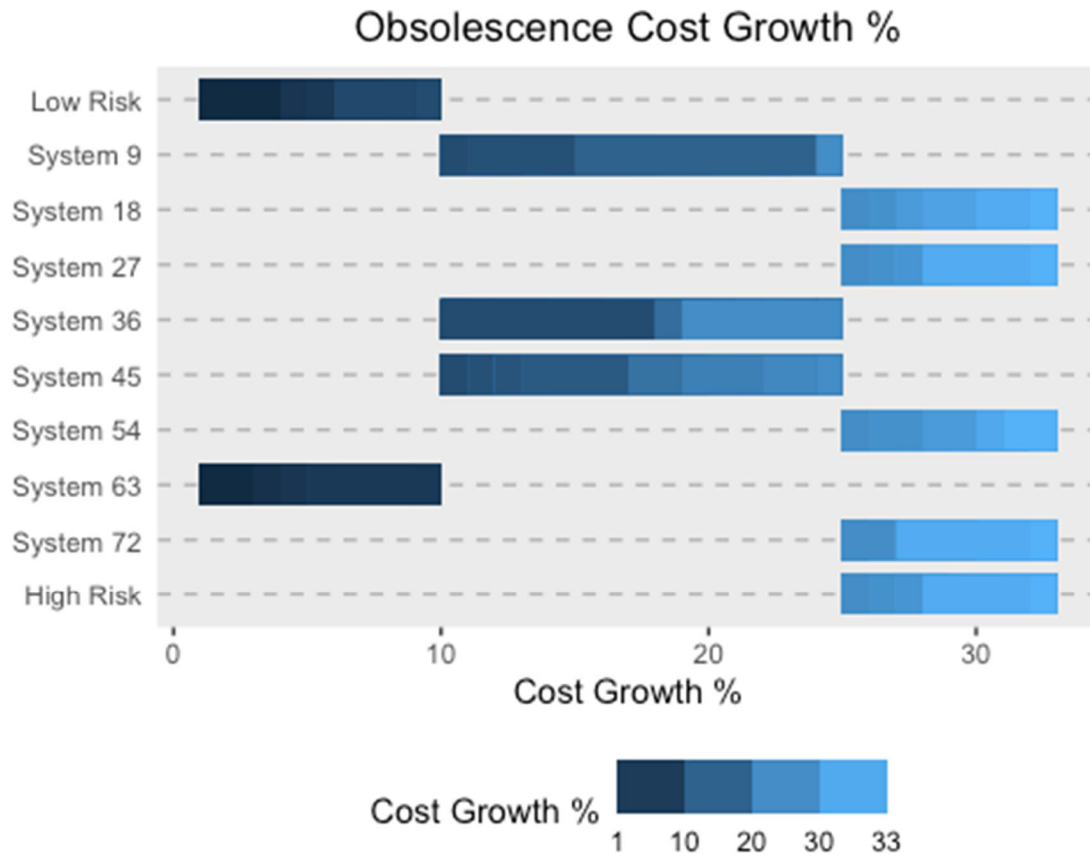
ggplot(systems.samples, aes(x = System, y = CostGrowth)) +
  geom_line(aes(color = CostGrowth), size = 6) +
  scale_color_gradient() +
  labs(y = "Cost Growth %", x = "", color = "Cost Growth %") +

```

```

theme_cleveland() +
guides(color = guide_colorsteps(show.limits = TRUE)) +
coord_flip() +
theme(legend.position = "bottom") +
ggtitle("Obsolescence Cost Growth %") +
ggeasy::easy_center_title()

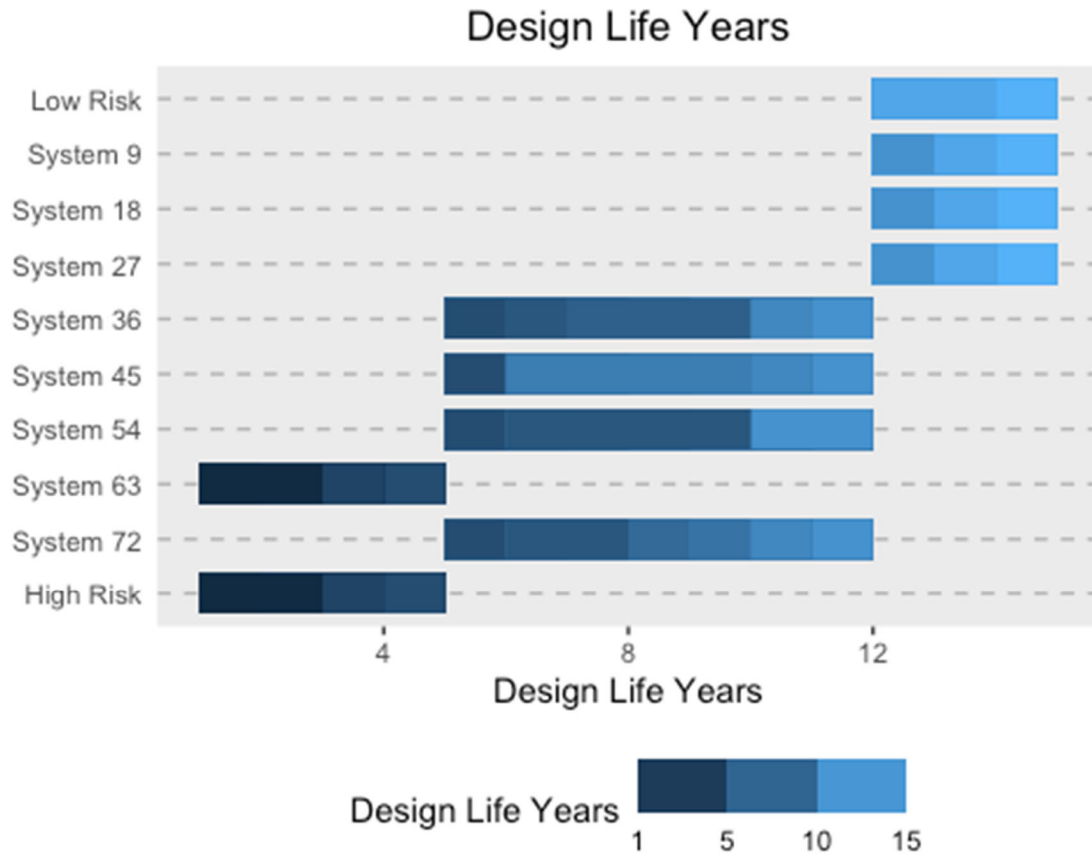
```



```

ggplot(systems.samples, aes(x = System, y = DY)) +
geom_line(aes(color = DY), size = 6) +
scale_color_gradient() +
labs(y = "Design Life Years", x = "", color = "Design Life Years") +
theme_cleveland() +
guides(color = guide_colorsteps(show.limits = TRUE)) +
coord_flip() +
theme(legend.position = "bottom") +
ggtitle("Design Life Years") +
ggeasy::easy_center_title()

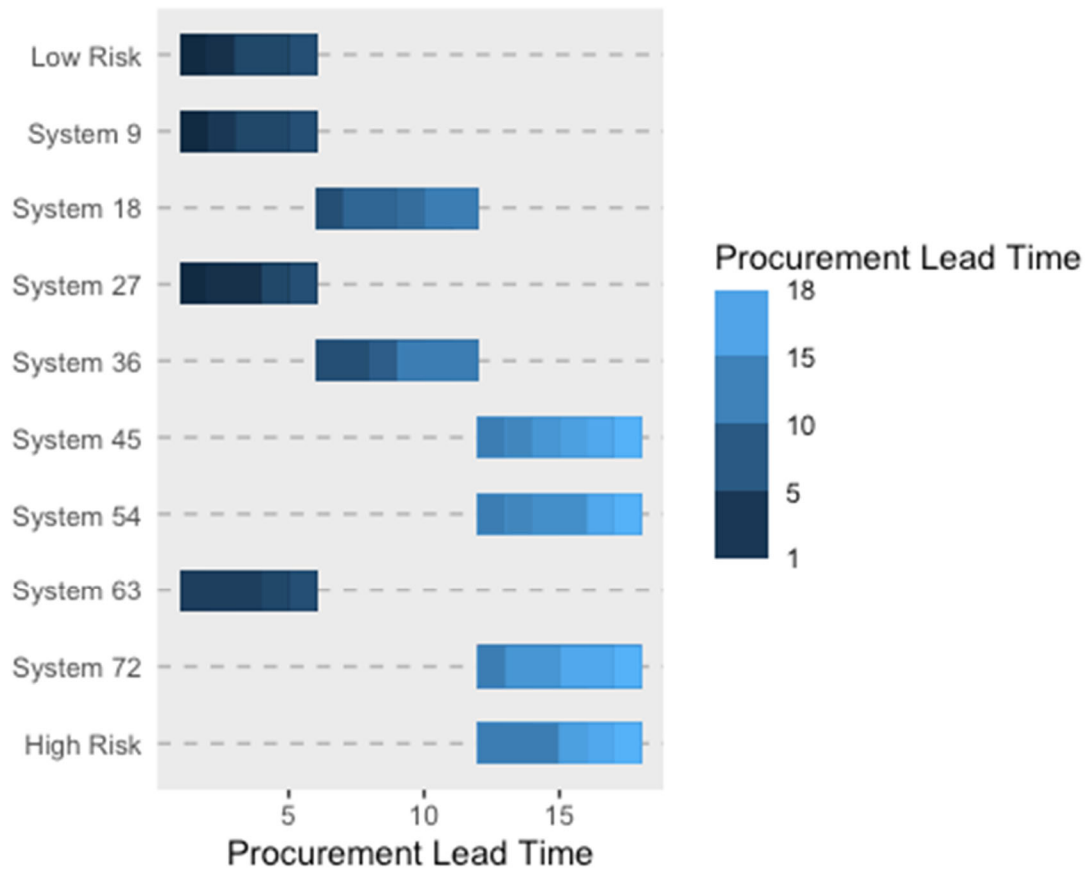
```



```

ggplot(systems.samples, aes(x = System, y = PLT)) +
  geom_line(aes(color = PLT), size = 6) +
  scale_color_gradient() +
  labs(y = "Procurement Lead Time", x = "", color = "Procurement Lead Time") +
  theme_cleveland() +
  guides(color = guide_colorsteps(show.limits = TRUE)) +
  coord_flip()

```



```

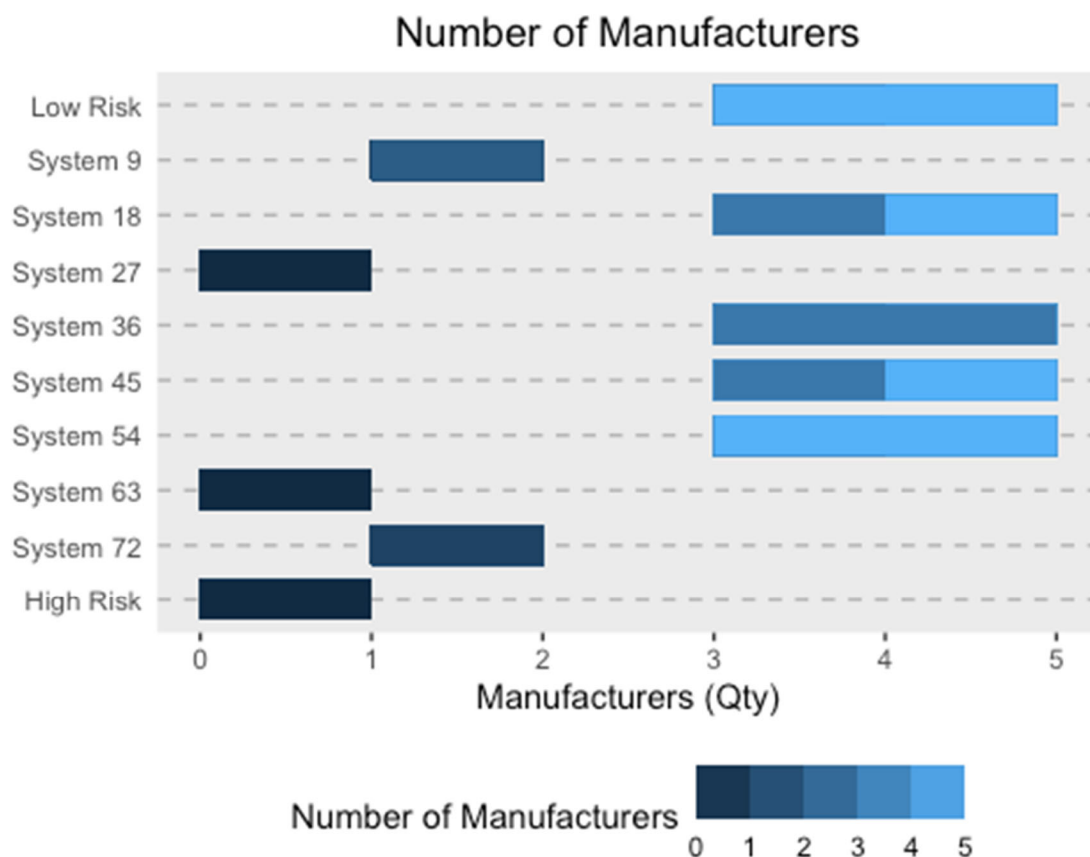
theme(legend.position = "bottom") +
  ggtitle("Procurement Lead Time (Months)") +
  ggeasy::easy_center_title()

## List of 3
## $ legend.position: chr "bottom"
## $ title          : chr "Procurement Lead Time (Months)"
## $ plot.title     :List of 11
## ..$ family      : NULL
## ..$ face        : NULL
## ..$ colour      : NULL
## ..$ size        : NULL
## ..$ hjust       : num 0.5
## ..$ vjust       : NULL
## ..$ angle       : NULL
## ..$ lineheight  : NULL
## ..$ margin      : NULL
## ..$ debug       : NULL
## ..$ inherit.blank: logi FALSE
## ..- attr(*, "class")= chr [1:2] "element_text" "element"
## - attr(*, "class")= chr [1:2] "theme" "gg"

```

```
## - attr(*, "complete")= logi FALSE
## - attr(*, "validate")= logi TRUE

ggplot(systems.samples, aes(x = System, y = NumberofManf)) +
  geom_line(aes(color = NumberofManf, size = 6) +
  scale_color_gradient() +
  labs(y = "Manufacturers (Qty)" , x = "", color = "Number of Manufacturers") +
  theme_cleveland() +
  guides(color = guide_colorsteps(show.limits = TRUE)) +
  coord_flip() +
  theme(legend.position = "bottom") +
  ggtitle("Number of Manufacturers") +
  ggeasy::easy_center_title()
```



```
systems.samplesCostPlot <- ggplot(systems.samples, aes(x = System, y = CostGrowth)) +
  geom_line(aes(color = CostGrowth) , size = 6) +
  scale_color_gradient() +
  labs(y = "Cost Growth %" , x = "", color = "Cost Growth %") +
  theme_cleveland() +
  guides(color = guide_colorsteps(show.limits = TRUE)) +
  coord_flip() +
  theme(legend.position = "bottom") +
```

```

ggtitle("Obsolescence Cost Growth %") +
ggeasy::easy_center_title()

systems.samplesDesignPlot <- ggplot(systems.samples, aes(x = System, y = DY)) +
  geom_line(aes(color = DY), size = 6) +
  scale_color_gradient() +
  labs(y = "Design Life Years", x = "", color = "Design Life Years") +
  theme_cleveland() +
  guides(color = guide_colorsteps(show.limits = TRUE)) +
  coord_flip() +
  theme(legend.position = "bottom") +
  ggtitle("Design Life Years Before Obsolescence") +
  ggeasy::easy_center_title()

systems.samplesPLTPlot <- ggplot(systems.samples, aes(x = System, y = PLT)) +
  geom_line(aes(color = PLT), size = 6) +
  scale_color_gradient() +
  labs(y = "Procurement Lead Time", x = "", color = "Procurement Lead Time") +
  theme_cleveland() +
  guides(color = guide_colorsteps(show.limits = TRUE)) +
  coord_flip() +
  theme(legend.position = "bottom") +
  ggtitle("Procurement Lead Time (Months)") +
  ggeasy::easy_center_title()

systems.samplesManfPlot <- ggplot(systems.samples, aes(x = System, y = NumberofManf)) +
  geom_line(aes(color = NumberofManf), size = 6) +
  scale_color_gradient() +
  labs(y = "Manufacturers (Qty)", x = "", color = "Manufacturers (Qty)") +
  theme_cleveland() +
  coord_flip() +
  guides(color = guide_colorsteps(show.limits = TRUE)) +
  theme(legend.position = "bottom") +
  ggtitle("Number of Manufacturers") +
  ggeasy::easy_center_title()

ggarrange(systems.samplesDesignPlot, systems.samplesPLTPlot, systems.samplesCostPlot, systems.samplesManfPlot, legend = "bottom")

```

```

ggsave("newsystems.samples.png", width = 12, height = 8, units = "in", dpi = 1000)

```

```

## System 9 data for plot

```

```

PR9_simdata <- combine(proactive_simdata, system9_simdata, reactive_simdata)

```

```

# Plot for System 9

```

```

PR9_simdata$DY <- as.numeric(round(PR9_simdata$DY, digits = 0))
PR9_simdata$PLT <- as.numeric(round(PR9_simdata$PLT, digits = 0))
PR9_simdata$CostGrowth <- as.numeric(round(PR9_simdata$CostGrowth, digits = 0))
as_factor(PR9_simdata$NumberofManf)

```

```

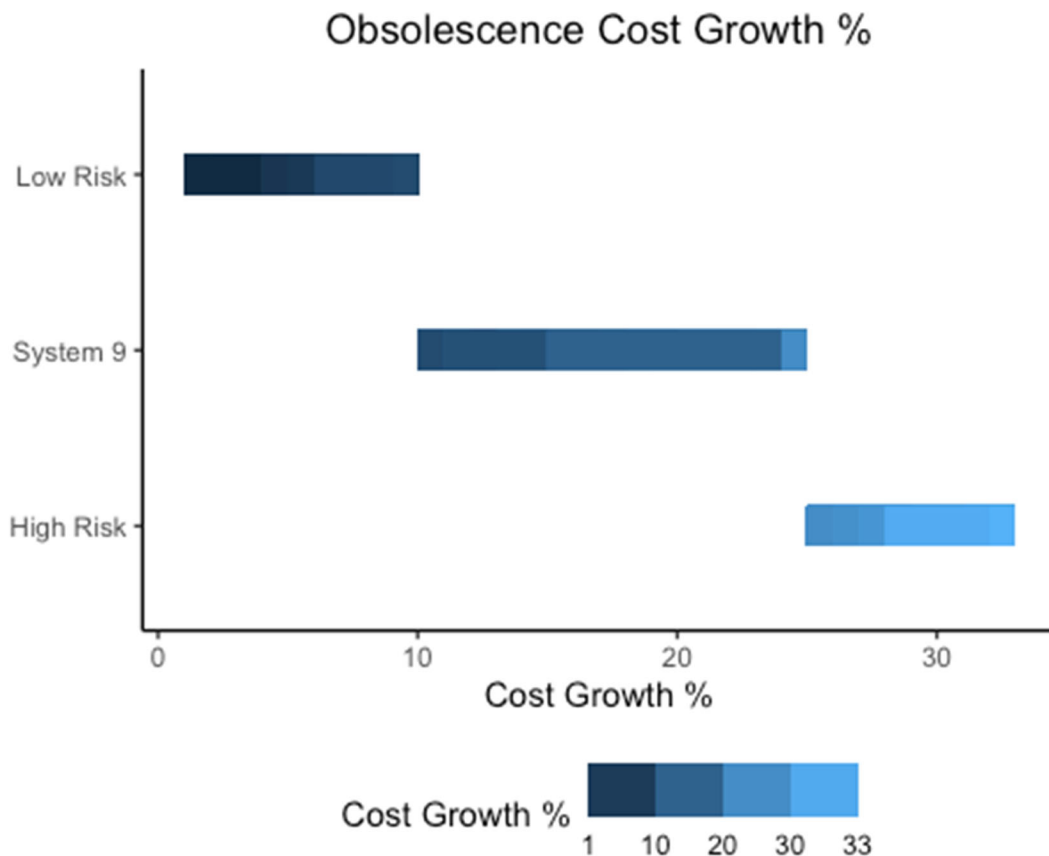
PR9_simdata$System <- factor(PR9_simdata$System, levels=c("High Risk",
                                                         "System 9",
                                                         "Low Risk"))

```

```

ggplot(PR9_simdata, aes(x = System, y = CostGrowth)) +
  geom_line(aes(color = CostGrowth), size = 6) +
  scale_color_gradient() +
  labs(y = "Cost Growth %", x = "", color = "Cost Growth %") +
  theme_classic() +
  guides(color = guide_colorsteps(show.limits = TRUE)) +
  coord_flip() +
  theme(legend.position = "bottom") +
  ggtitle("Obsolescence Cost Growth %") +
  ggeasy::easy_center_title()

```



```

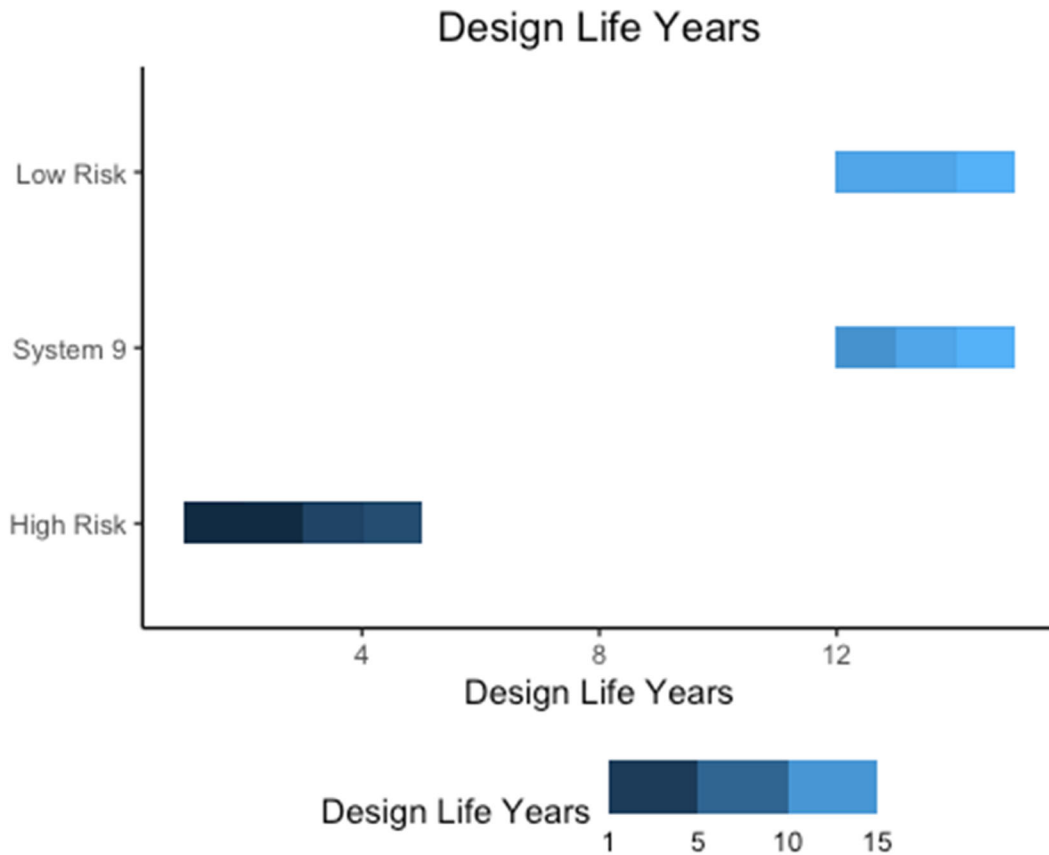
ggplot(PR9_simdata, aes(x = System, y = DY)) +
  geom_line(aes(color = DY), size = 6) +

```

```

scale_color_gradient() +
labs(y = "Design Life Years", x = "", color = "Design Life Years") +
theme_classic() +
guides(color = guide_colorsteps(show.limits = TRUE)) +
coord_flip() +
theme(legend.position = "bottom") +
ggtitle("Design Life Years") +
ggeasy::easy_center_title()

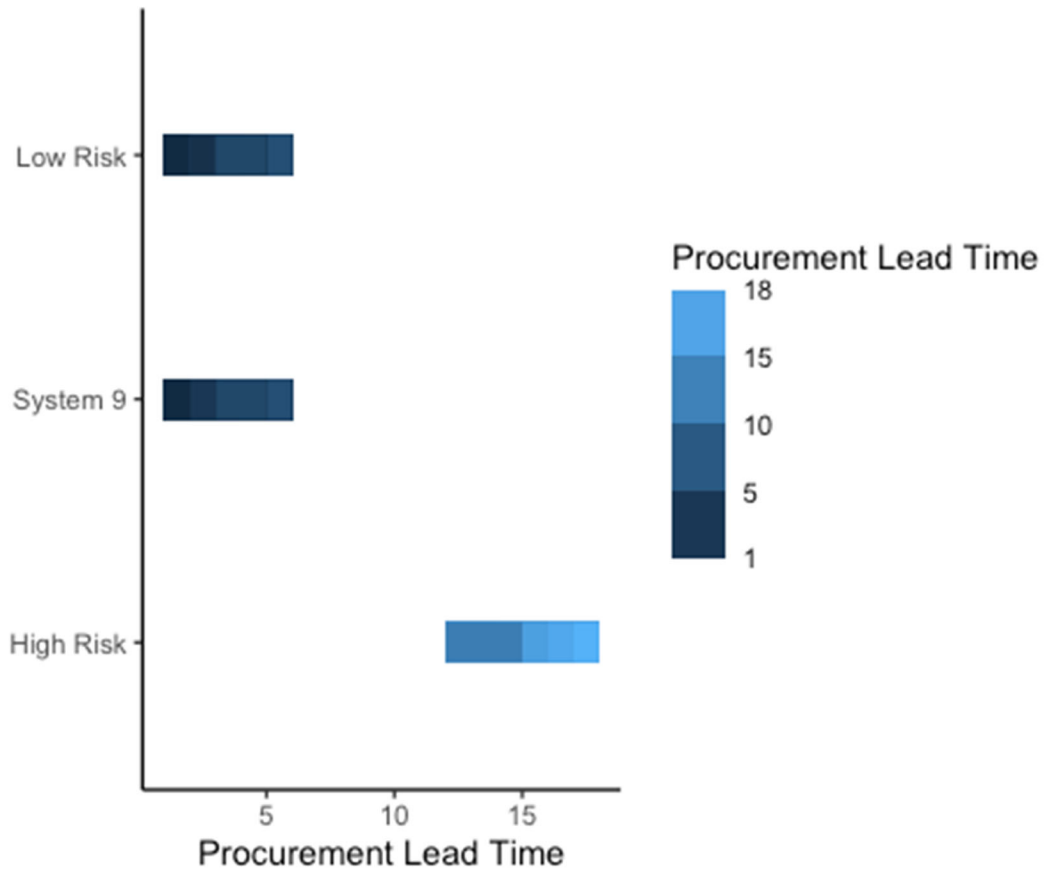
```



```

ggplot(PR9_simdata, aes(x = System, y = PLT)) +
geom_line(aes(color = PLT), size = 6) +
scale_color_gradient() +
labs(y = "Procurement Lead Time", x = "", color = "Procurement Lead Time") +
theme_classic() +
guides(color = guide_colorsteps(show.limits = TRUE)) +
coord_flip()

```



```

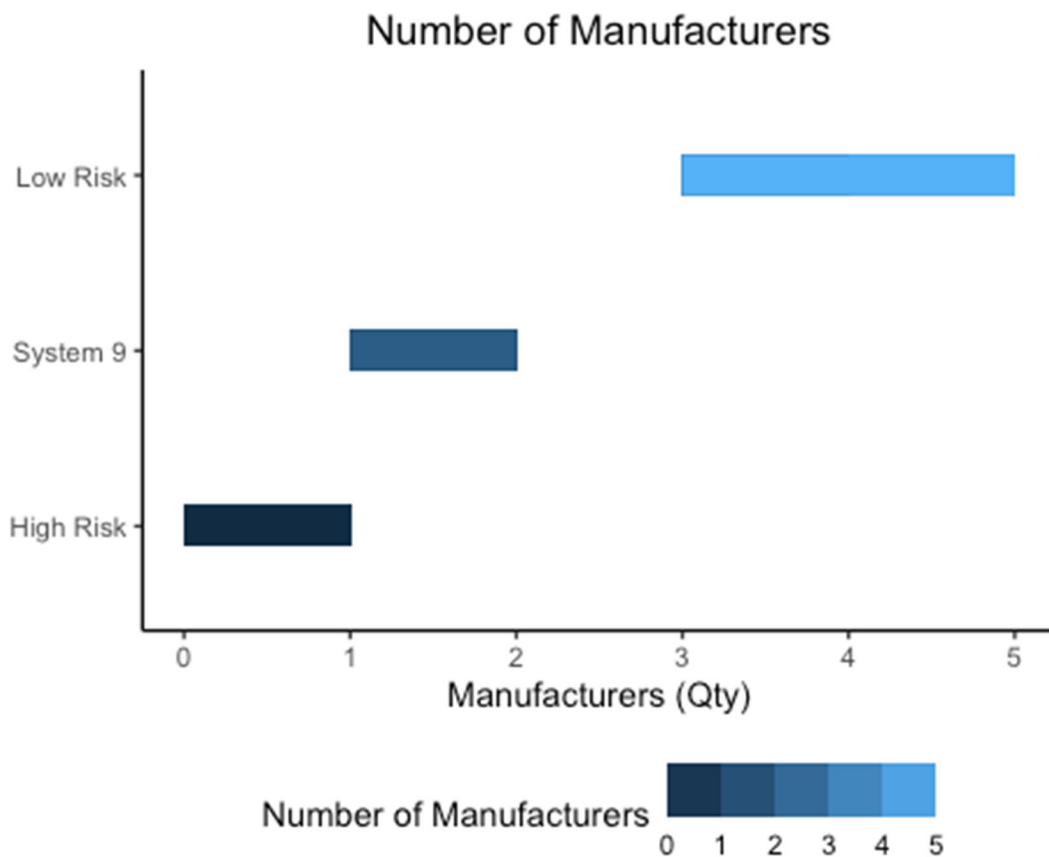
theme(legend.position = "bottom") +
  ggtitle("Procurement Lead Time (Months)") +
  ggeasy::easy_center_title()

## List of 3
## $ legend.position: chr "bottom"
## $ title          : chr "Procurement Lead Time (Months)"
## $ plot.title     :List of 11
## ..$ family      : NULL
## ..$ face        : NULL
## ..$ colour      : NULL
## ..$ size        : NULL
## ..$ hjust       : num 0.5
## ..$ vjust       : NULL
## ..$ angle       : NULL
## ..$ lineheight  : NULL
## ..$ margin      : NULL
## ..$ debug       : NULL
## ..$ inherit.blank: logi FALSE
## ..- attr(*, "class")= chr [1:2] "element_text" "element"
## - attr(*, "class")= chr [1:2] "theme" "gg"

```

```
## - attr(*, "complete")= logi FALSE
## - attr(*, "validate")= logi TRUE

ggplot(PR9_simdata, aes(x = System, y = NumberofManf)) +
  geom_line(aes(color = NumberofManf), size = 6) +
  scale_color_gradient() +
  labs(y = "Manufacturers (Qty)", x = "", color = "Number of Manufacturers") +
  theme_classic() +
  guides(color = guide_colorsteps(show.limits = TRUE)) +
  coord_flip() +
  theme(legend.position = "bottom") +
  ggtitle("Number of Manufacturers") +
  ggeasy::easy_center_title()
```



```
PR9CostPlot <- ggplot(PR9_simdata, aes(x = System, y = CostGrowth)) +
  geom_line(aes(color = CostGrowth), size = 6) +
  scale_color_gradient() +
  labs(y = "Cost Growth %", x = "", color = "Cost Growth %") +
  theme_classic() +
  guides(color = guide_colorsteps(show.limits = TRUE)) +
  coord_flip() +
  theme(legend.position = "bottom") +
```

```

ggtitle("Obsolescence Cost Growth %") +
ggeasy::easy_center_title()

PR9DesignPlot <- ggplot(PR9_simdata, aes(x = System, y = DY)) +
  geom_line(aes(color = DY), size = 6) +
  scale_color_gradient() +
  labs(y = "Design Life Years", x = "", color = "Design Life Years") +
  theme_classic() +
  guides(color = guide_colorsteps(show.limits = TRUE)) +
  coord_flip() +
  theme(legend.position = "bottom") +
  ggtitle("Design Life Years Before Obsolescence") +
  ggeasy::easy_center_title()

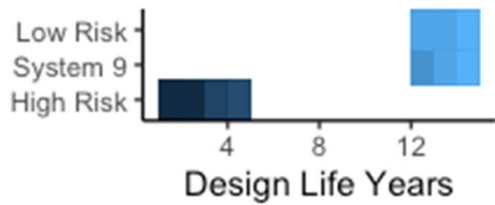
PR9PLTPlot <- ggplot(PR9_simdata, aes(x = System, y = PLT)) +
  geom_line(aes(color = PLT), size = 6) +
  scale_color_gradient() +
  labs(y = "Procurement Lead Time", x = "", color = "Procurement Lead Time") +
  theme_classic() +
  guides(color = guide_colorsteps(show.limits = TRUE)) +
  coord_flip() +
  theme(legend.position = "bottom") +
  ggtitle("Procurement Lead Time (Months)") +
  ggeasy::easy_center_title()

PR9ManfPlot <- ggplot(PR9_simdata, aes(x = System, y = NumberofManf)) +
  geom_line(aes(color = NumberofManf), size = 6) +
  scale_color_gradient() +
  labs(y = "Manufacturers (Qty)", x = "", color = "Number of Manufacturers") +
  theme_classic() +
  coord_flip() +
  guides(color = guide_colorsteps(show.limits = TRUE)) +
  theme(legend.position = "bottom") +
  ggtitle("Number of Manufacturers") +
  ggeasy::easy_center_title()

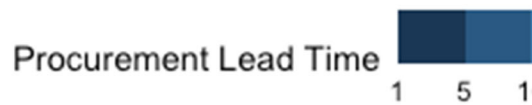
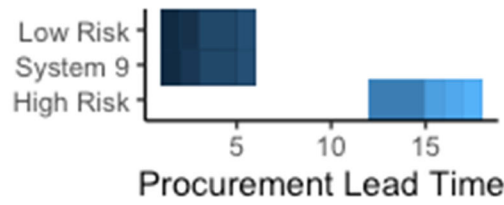
ggarrange(PR9DesignPlot, PR9PLTPlot, PR9CostPlot, PR9ManfPlot, legend = "bottom")

```

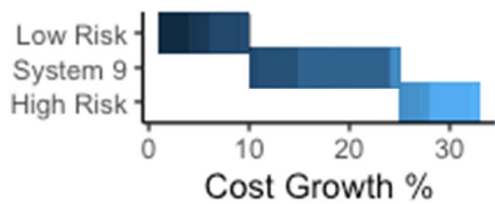
Design Life Years Before Obsc



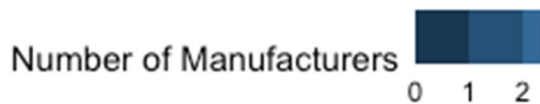
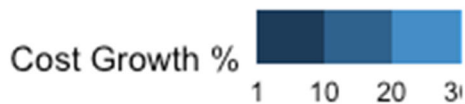
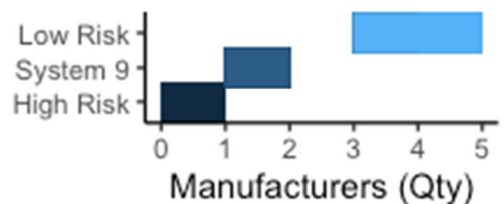
Procurement Lead Time (M



Obsolescence Cost Grow



Number of Manufacture



```
ggsave("Plot_System9.png", width = 12, height = 8, units = "in", dpi = 300)
```

```
## System 18 data for plot
```

```
PR18_simdata <- combine(proactive_simdata, system18_simdata, reactive_simdata)
```

```
# Plot for System 18
```

```
PR18_simdata$DY <- as.numeric(round(PR18_simdata$DY, digits = 0))
```

```
PR18_simdata$PLT <- as.numeric(round(PR18_simdata$PLT, digits = 0))
```

```
PR18_simdata$CostGrowth <- as.numeric(round(PR18_simdata$CostGrowth, digits = 0))
```

```
as_factor(PR18_simdata$NumberofManf)
```

```
## [2998] 1 0 1
```

```
## Levels: 0 1 3 4 5
```

```
PR18_simdata$System <- factor(PR18_simdata$System, levels=c("High Risk",  
"System 18",  
"Low Risk"))
```

```
ggplot(PR18_simdata, aes(x = System, y = CostGrowth)) +
```

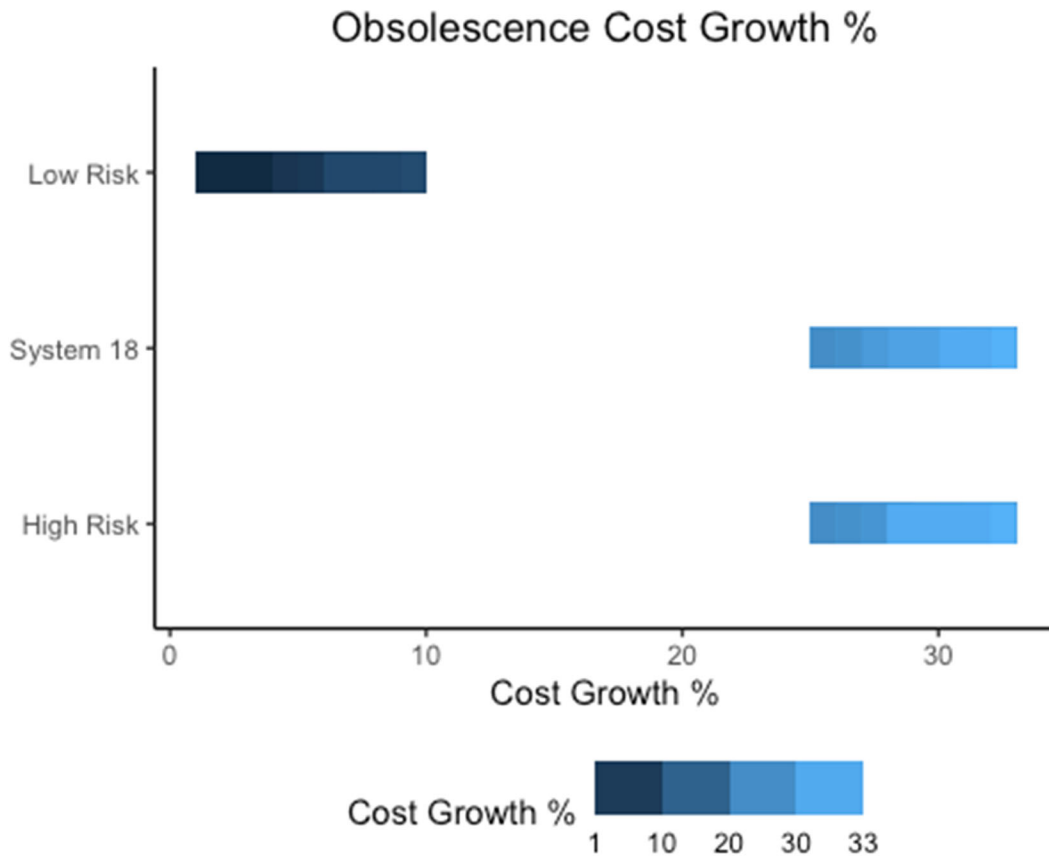
```
  geom_line(aes(color = CostGrowth), size = 6) +
```

```
  scale_color_gradient() +
```

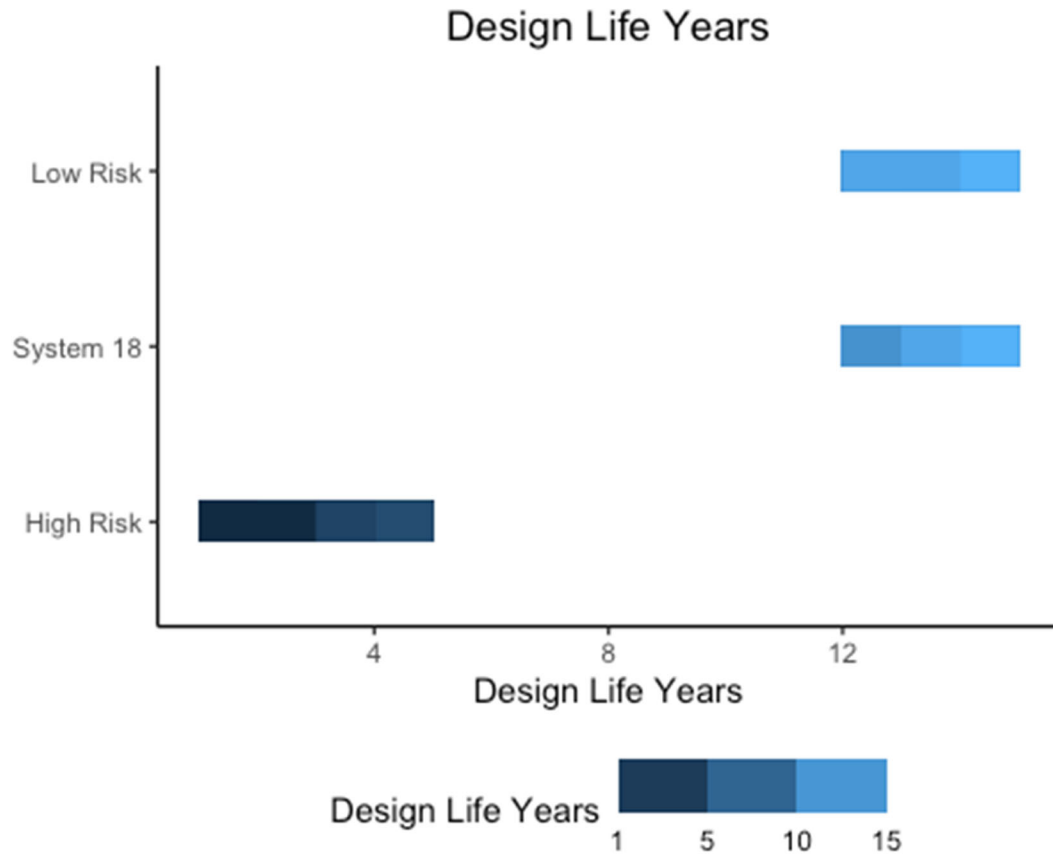
```
  labs(y = "Cost Growth %", x = "", color = "Cost Growth %") +
```

```
  theme_classic() +
```

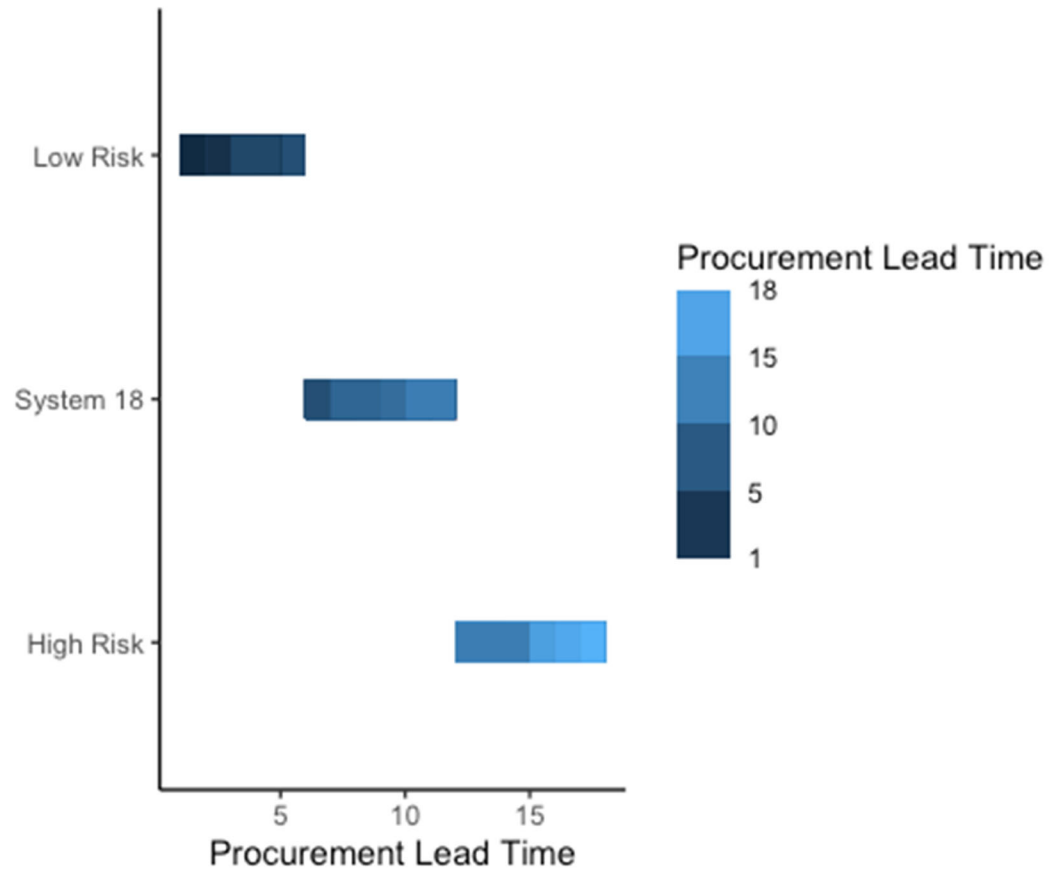
```
guides(color = guide_colorsteps(show.limits = TRUE)) +
coord_flip() +
theme(legend.position = "bottom") +
ggtitle("Obsolescence Cost Growth %") +
ggeasy::easy_center_title()
```



```
ggplot(PR18_simdata, aes(x = System, y = DY)) +
geom_line(aes(color = DY), size = 6) +
scale_color_gradient() +
labs(y = "Design Life Years", x = "", color = "Design Life Years") +
theme_classic() +
guides(color = guide_colorsteps(show.limits = TRUE)) +
coord_flip() +
theme(legend.position = "bottom") +
ggtitle("Design Life Years") +
ggeasy::easy_center_title()
```



```
ggplot(PR18_simdata, aes(x = System, y = PLT)) +
  geom_line(aes(color = PLT), size = 6) +
  scale_color_gradient() +
  labs(y = "Procurement Lead Time", x = "", color = "Procurement Lead Time") +
  theme_classic() +
  guides(color = guide_colorsteps(show.limits = TRUE)) +
  coord_flip()
```



```

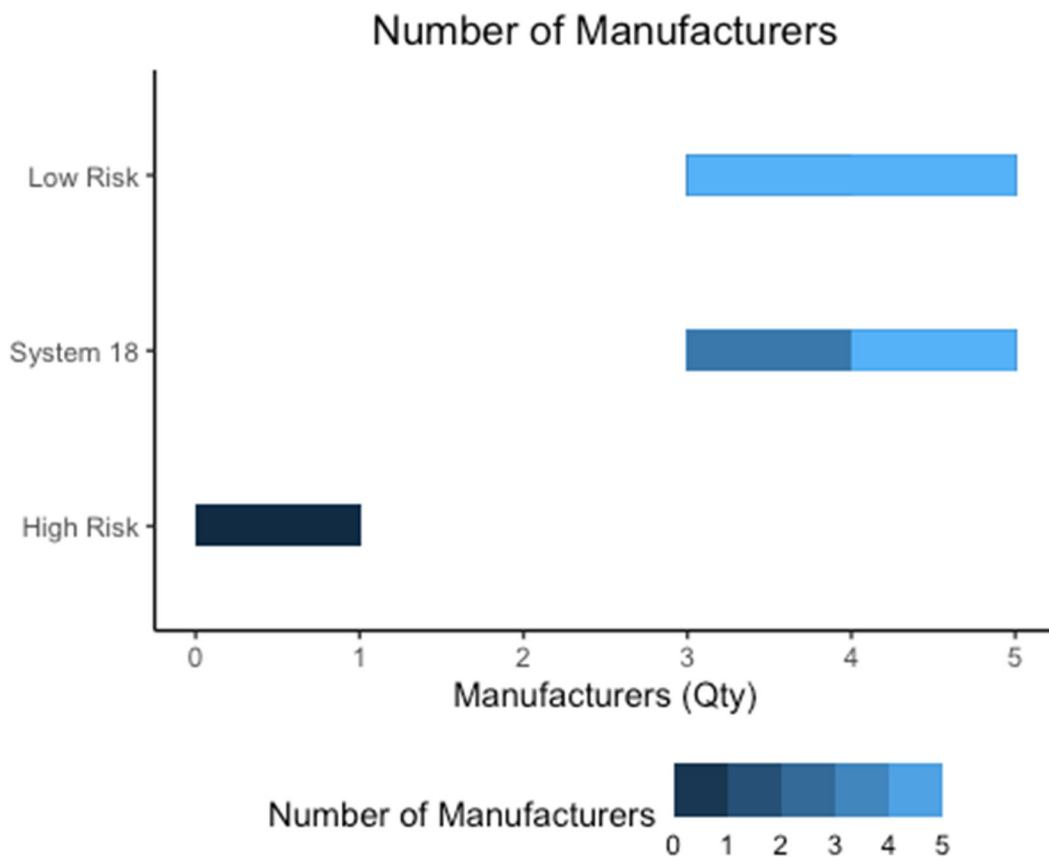
theme(legend.position = "bottom") +
  ggtitle("Procurement Lead Time (Months)") +
  ggeasy::easy_center_title()

## List of 3
## $ legend.position: chr "bottom"
## $ title          : chr "Procurement Lead Time (Months)"
## $ plot.title     :List of 11
## ..$ family      : NULL
## ..$ face        : NULL
## ..$ colour      : NULL
## ..$ size        : NULL
## ..$ hjust       : num 0.5
## ..$ vjust       : NULL
## ..$ angle       : NULL
## ..$ lineheight  : NULL
## ..$ margin      : NULL
## ..$ debug       : NULL
## ..$ inherit.blank: logi FALSE
## ..- attr(*, "class")= chr [1:2] "element_text" "element"
## - attr(*, "class")= chr [1:2] "theme" "gg"

```

```
## - attr(*, "complete")= logi FALSE
## - attr(*, "validate")= logi TRUE

ggplot(PR18_simdata, aes(x = System, y = NumberofManf)) +
  geom_line(aes(color = NumberofManf, size = 6) +
  scale_color_gradient() +
  labs(y = "Manufacturers (Qty)", x = "", color = "Number of Manufacturers") +
  theme_classic() +
  guides(color = guide_colorsteps(show.limits = TRUE)) +
  coord_flip() +
  theme(legend.position = "bottom") +
  ggtitle("Number of Manufacturers") +
  ggeasy::easy_center_title()
```



```
PR18CostPlot <- ggplot(PR18_simdata, aes(x = System, y = CostGrowth)) +
  geom_line(aes(color = CostGrowth, size = 6) +
  scale_color_gradient() +
  labs(y = "Cost Growth %", x = "", color = "Cost Growth %") +
  theme_classic() +
  guides(color = guide_colorsteps(show.limits = TRUE)) +
  coord_flip() +
  theme(legend.position = "bottom") +
```

```

ggtitle("Obsolescence Cost Growth %") +
ggeasy::easy_center_title()

PR18DesignPlot <- ggplot(PR18_simdata, aes(x = System, y = DY)) +
  geom_line(aes(color = DY), size = 6) +
  scale_color_gradient() +
  labs(y = "Design Life Years", x = "", color = "Design Life Years") +
  theme_classic() +
  guides(color = guide_colorsteps(show.limits = TRUE)) +
  coord_flip() +
  theme(legend.position = "bottom") +
  ggtitle("Design Life Years Before Obsolescence") +
  ggeasy::easy_center_title()

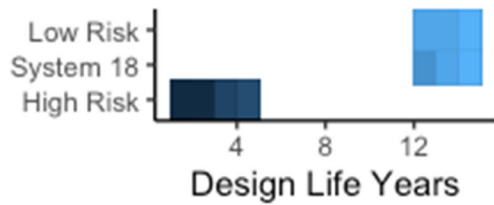
PR18PLTPlot <- ggplot(PR18_simdata, aes(x = System, y = PLT)) +
  geom_line(aes(color = PLT), size = 6) +
  scale_color_gradient() +
  labs(y = "Procurement Lead Time", x = "", color = "Procurement Lead Time") +
  theme_classic() +
  guides(color = guide_colorsteps(show.limits = TRUE)) +
  coord_flip() +
  theme(legend.position = "bottom") +
  ggtitle("Procurement Lead Time (Months)") +
  ggeasy::easy_center_title()

PR18ManfPlot <- ggplot(PR18_simdata, aes(x = System, y = NumberofManf)) +
  geom_line(aes(color = NumberofManf), size = 6) +
  scale_color_gradient() +
  labs(y = "Manufacturers (Qty)", x = "", color = "Number of Manufacturers") +
  theme_classic() +
  coord_flip() +
  guides(color = guide_colorsteps(show.limits = TRUE)) +
  theme(legend.position = "bottom") +
  ggtitle("Number of Manufacturers") +
  ggeasy::easy_center_title()

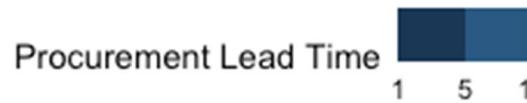
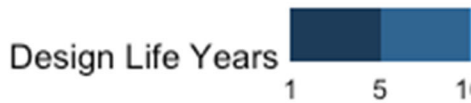
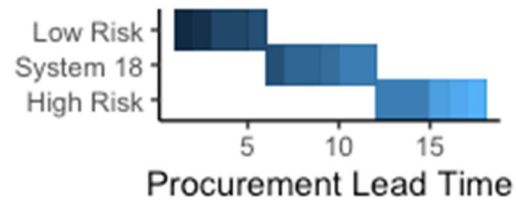
ggarrange(PR18DesignPlot, PR18PLTPlot, PR18CostPlot, PR18ManfPlot, legend = "bottom")

```

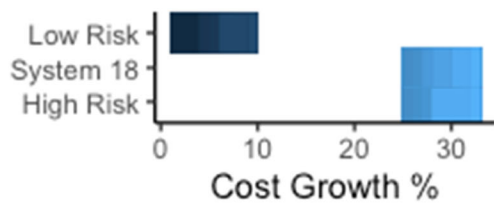
Design Life Years Before Obsc



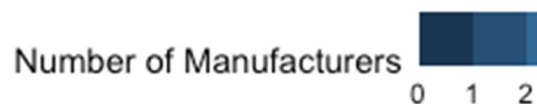
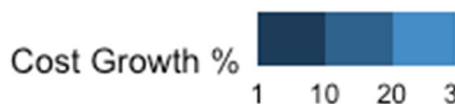
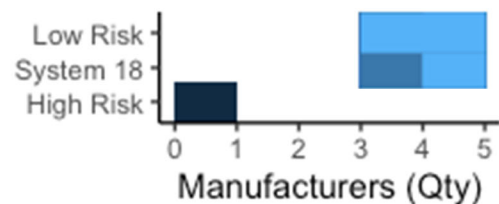
Procurement Lead Time (M



Obsolescence Cost Grow



Number of Manufacture



```
ggsave("Plot_System18.png", width = 12, height = 8, units = "in", dpi = 300)
```

```
## System 27 data for plot
```

```
PR27_simdata <- combine(proactive_simdata, system27_simdata, reactive_simdata)
```

```
# Plot for System 27
```

```
PR27_simdata$DY <- as.numeric(round(PR27_simdata$DY, digits = 0))
```

```
PR27_simdata$PLT <- as.numeric(round(PR27_simdata$PLT, digits = 0))
```

```
PR27_simdata$CostGrowth <- as.numeric(round(PR27_simdata$CostGrowth, digits = 0))
```

```
as_factor(PR27_simdata$NumberofManf)
```

```
## [2998] 1 0 1
```

```
## Levels: 0 1 3 4 5
```

```
PR27_simdata$System <- factor(PR27_simdata$System, levels=c("High Risk",  
"System 27",  
"Low Risk"))
```

```
ggplot(PR27_simdata, aes(x = System, y = CostGrowth)) +
```

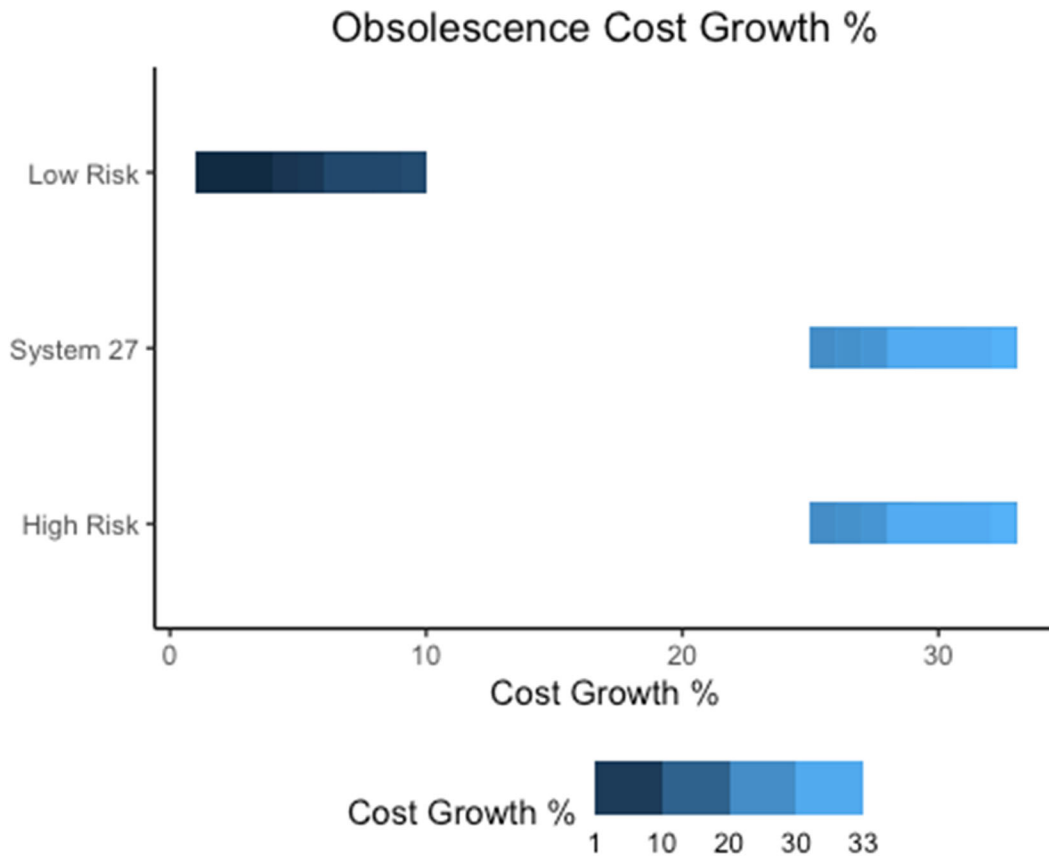
```
  geom_line(aes(color = CostGrowth), size = 6) +
```

```
  scale_color_gradient() +
```

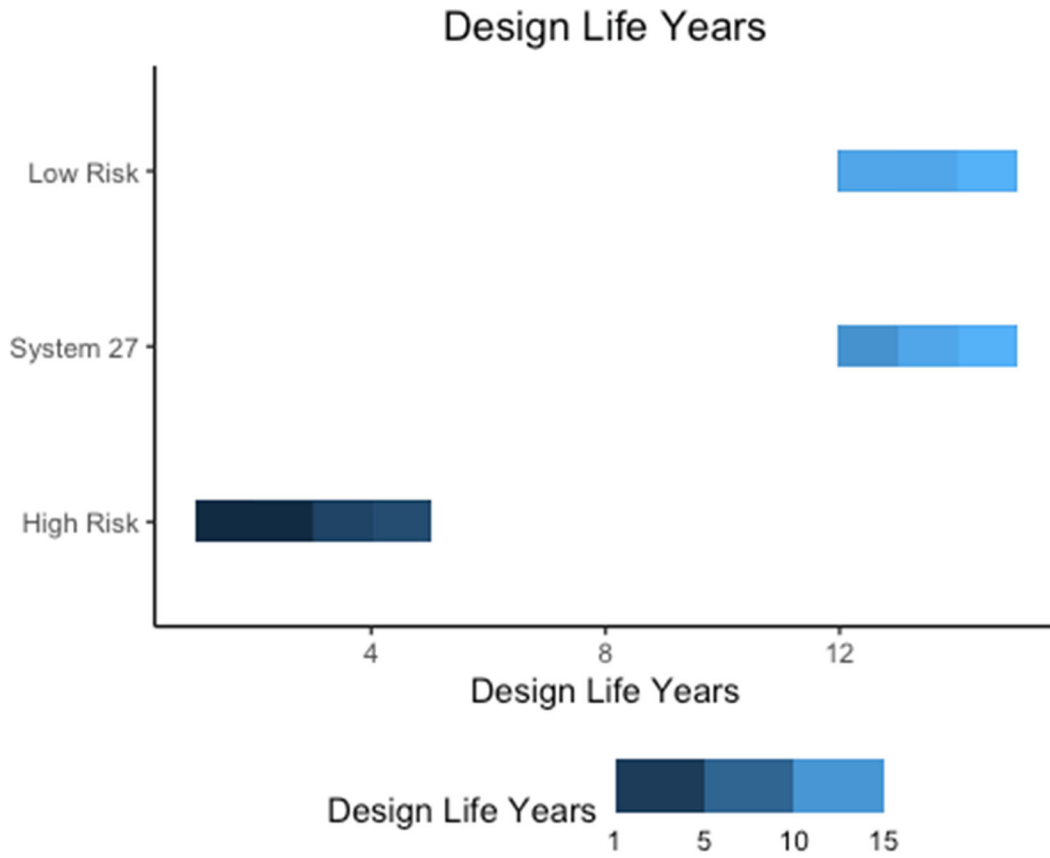
```
  labs(y = "Cost Growth %", x = "", color = "Cost Growth %") +
```

```
  theme_classic() +
```

```
guides(color = guide_colorsteps(show.limits = TRUE)) +
coord_flip() +
theme(legend.position = "bottom") +
ggtitle("Obsolescence Cost Growth %") +
ggeasy::easy_center_title()
```



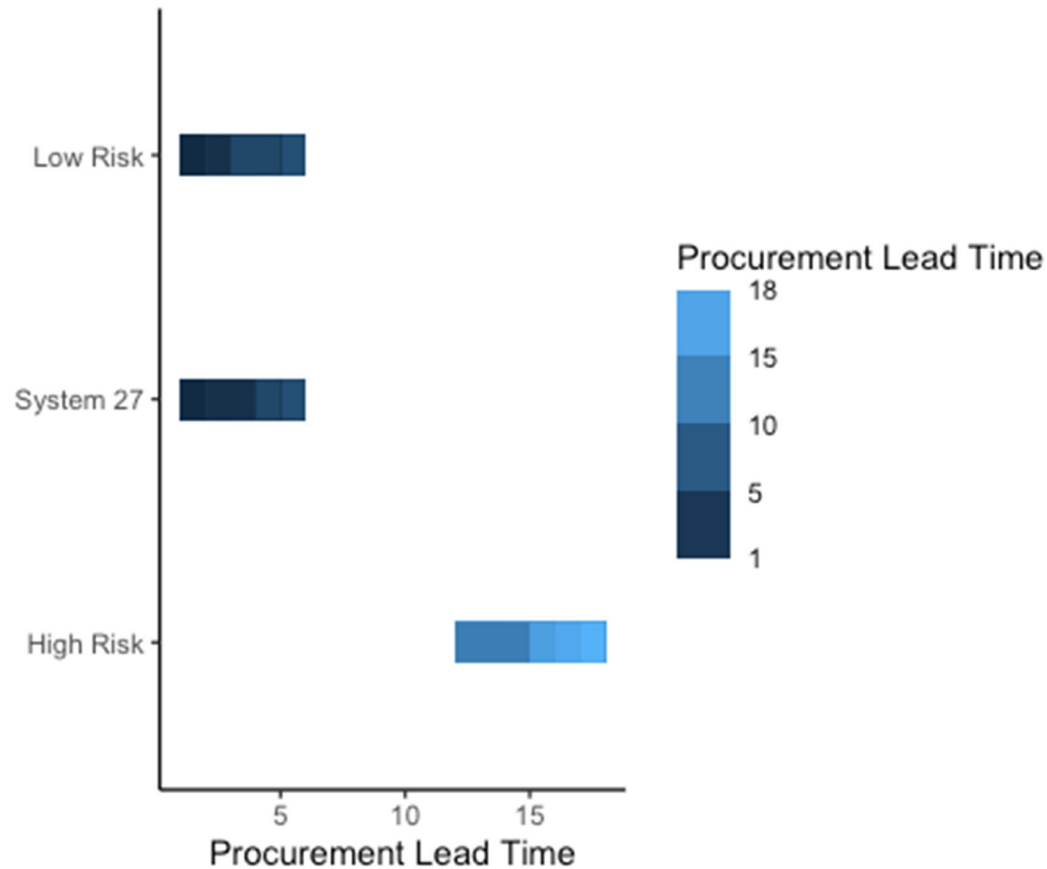
```
ggplot(PR27_simdata, aes(x = System, y = DY)) +
geom_line(aes(color = DY), size = 6) +
scale_color_gradient() +
labs(y = "Design Life Years", x = "", color = "Design Life Years") +
theme_classic() +
guides(color = guide_colorsteps(show.limits = TRUE)) +
coord_flip() +
theme(legend.position = "bottom") +
ggtitle("Design Life Years") +
ggeasy::easy_center_title()
```



```

ggplot(PR27_simdata, aes(x = System, y = PLT)) +
  geom_line(aes(color = PLT), size = 6) +
  scale_color_gradient() +
  labs(y = "Procurement Lead Time", x = "", color = "Procurement Lead Time") +
  theme_classic() +
  guides(color = guide_colorsteps(show.limits = TRUE)) +
  coord_flip()

```



```

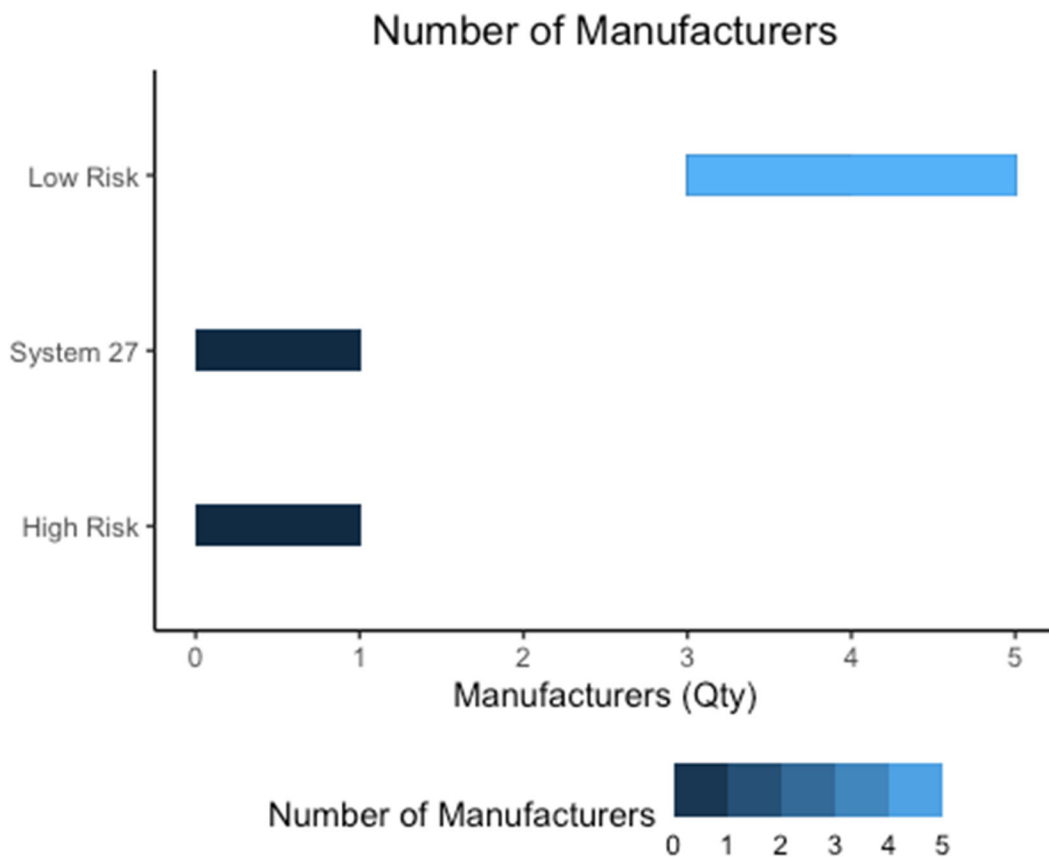
theme(legend.position = "bottom") +
  ggtitle("Procurement Lead Time (Months)") +
  ggeasy::easy_center_title()

## List of 3
## $ legend.position: chr "bottom"
## $ title          : chr "Procurement Lead Time (Months)"
## $ plot.title     :List of 11
## ..$ family      : NULL
## ..$ face        : NULL
## ..$ colour      : NULL
## ..$ size        : NULL
## ..$ hjust       : num 0.5
## ..$ vjust       : NULL
## ..$ angle       : NULL
## ..$ lineheight  : NULL
## ..$ margin      : NULL
## ..$ debug       : NULL
## ..$ inherit.blank: logi FALSE
## ..- attr(*, "class")= chr [1:2] "element_text" "element"
## - attr(*, "class")= chr [1:2] "theme" "gg"

```

```
## - attr(*, "complete")= logi FALSE
## - attr(*, "validate")= logi TRUE

ggplot(PR27_simdata, aes(x = System, y = NumberofManf)) +
  geom_line(aes(color = NumberofManf, size = 6)) +
  scale_color_gradient() +
  labs(y = "Manufacturers (Qty)", x = "", color = "Number of Manufacturers") +
  theme_classic() +
  guides(color = guide_colorsteps(show.limits = TRUE)) +
  coord_flip() +
  theme(legend.position = "bottom") +
  ggtitle("Number of Manufacturers") +
  ggeasy::easy_center_title()
```



```
PR27CostPlot <- ggplot(PR27_simdata, aes(x = System, y = CostGrowth)) +
  geom_line(aes(color = CostGrowth, size = 6)) +
  scale_color_gradient() +
  labs(y = "Cost Growth %", x = "", color = "Cost Growth %") +
  theme_classic() +
  guides(color = guide_colorsteps(show.limits = TRUE)) +
  coord_flip() +
  theme(legend.position = "bottom") +
```

```

ggtitle("Obsolescence Cost Growth %") +
ggeasy::easy_center_title()

PR27DesignPlot <- ggplot(PR27_simdata, aes(x = System, y = DY)) +
  geom_line(aes(color = DY), size = 6) +
  scale_color_gradient() +
  labs(y = "Design Life Years", x = "", color = "Design Life Years") +
  theme_classic() +
  guides(color = guide_colorsteps(show.limits = TRUE)) +
  coord_flip() +
  theme(legend.position = "bottom") +
  ggtitle("Design Life Years Before Obsolescence") +
  ggeasy::easy_center_title()

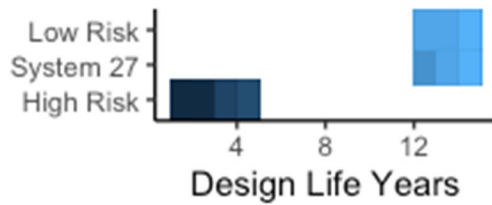
PR27PLTPlot <- ggplot(PR27_simdata, aes(x = System, y = PLT)) +
  geom_line(aes(color = PLT), size = 6) +
  scale_color_gradient() +
  labs(y = "Procurement Lead Time", x = "", color = "Procurement Lead Time") +
  theme_classic() +
  guides(color = guide_colorsteps(show.limits = TRUE)) +
  coord_flip() +
  theme(legend.position = "bottom") +
  ggtitle("Procurement Lead Time (Months)") +
  ggeasy::easy_center_title()

PR27ManfPlot <- ggplot(PR27_simdata, aes(x = System, y = NumberofManf)) +
  geom_line(aes(color = NumberofManf), size = 6) +
  scale_color_gradient() +
  labs(y = "Manufacturers (Qty)", x = "", color = "Number of Manufacturers") +
  theme_classic() +
  coord_flip() +
  guides(color = guide_colorsteps(show.limits = TRUE)) +
  theme(legend.position = "bottom") +
  ggtitle("Number of Manufacturers") +
  ggeasy::easy_center_title()

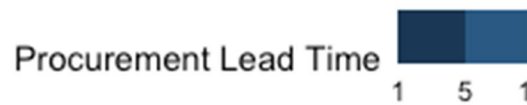
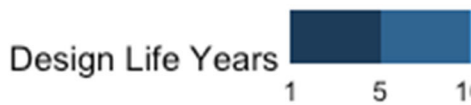
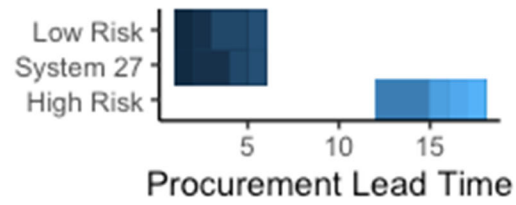
ggarrange(PR27DesignPlot, PR27PLTPlot, PR27CostPlot, PR27ManfPlot, legend = "bottom")

```

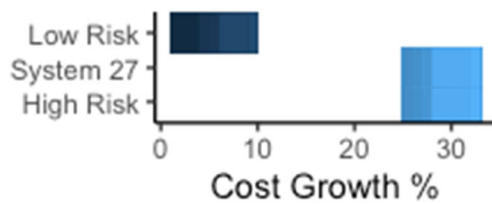
Design Life Years Before Obsc



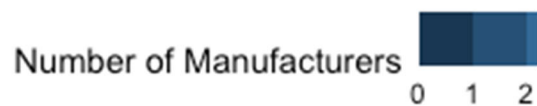
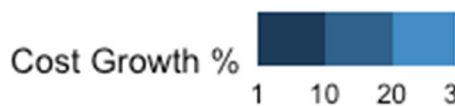
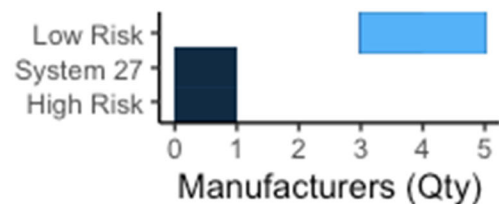
Procurement Lead Time (M



Obsolescence Cost Grow



Number of Manufacture



```
ggsave("Plot_System27.png", width = 12, height = 8, units = "in", dpi = 300)
```

```
## System 36 data for plot
```

```
PR36_simdata <- combine(proactive_simdata, system36_simdata, reactive_simdata)
```

```
# Plot for System 36
```

```
PR36_simdata$DY <- as.numeric(round(PR36_simdata$DY, digits = 0))
```

```
PR36_simdata$PLT <- as.numeric(round(PR36_simdata$PLT, digits = 0))
```

```
PR36_simdata$CostGrowth <- as.numeric(round(PR36_simdata$CostGrowth, digits = 0))
```

```
as_factor(PR36_simdata$NumberofManf)
```

```
## [2998] 1 0 1
```

```
## Levels: 0 1 3 4 5
```

```
PR36_simdata$System <- factor(PR36_simdata$System, levels=c("High Risk",
  "System 36",
  "Low Risk"))
```

```
ggplot(PR36_simdata, aes(x = System, y = CostGrowth)) +
```

```
  geom_line(aes(color = CostGrowth), size = 6) +
```

```
  scale_color_gradient() +
```

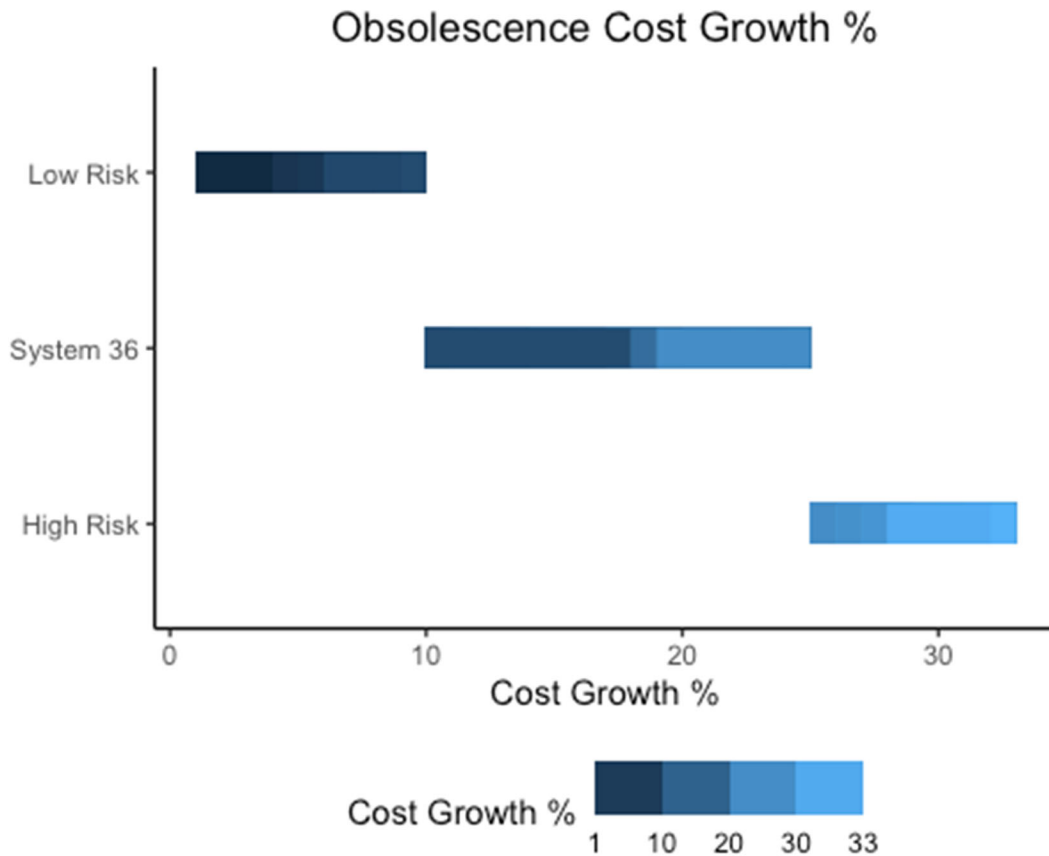
```
  labs(y = "Cost Growth %", x = "", color = "Cost Growth %") +
```

```
  theme_classic() +
```

```

guides(color = guide_colorsteps(show.limits = TRUE)) +
coord_flip() +
theme(legend.position = "bottom") +
ggtitle("Obsolescence Cost Growth %") +
ggeasy::easy_center_title()

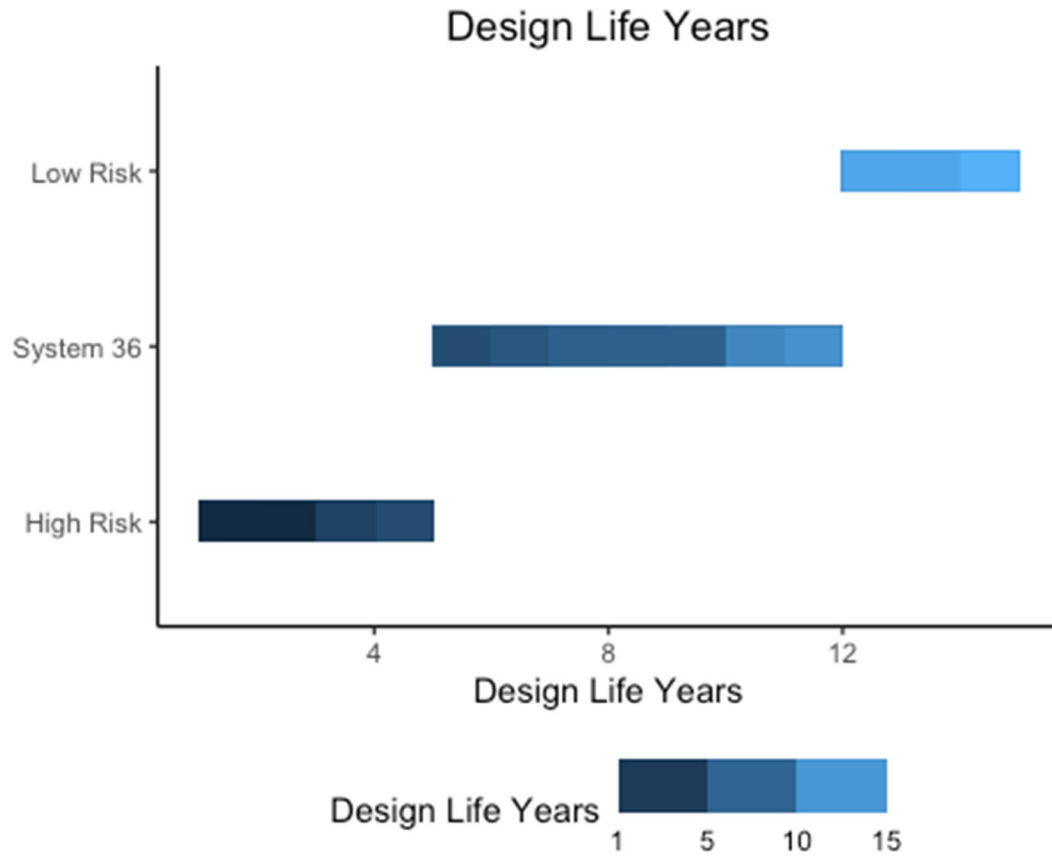
```



```

ggplot(PR36_simdata, aes(x = System, y = DY)) +
geom_line(aes(color = DY), size = 6) +
scale_color_gradient() +
labs(y = "Design Life Years", x = "", color = "Design Life Years") +
theme_classic() +
guides(color = guide_colorsteps(show.limits = TRUE)) +
coord_flip() +
theme(legend.position = "bottom") +
ggtitle("Design Life Years") +
ggeasy::easy_center_title()

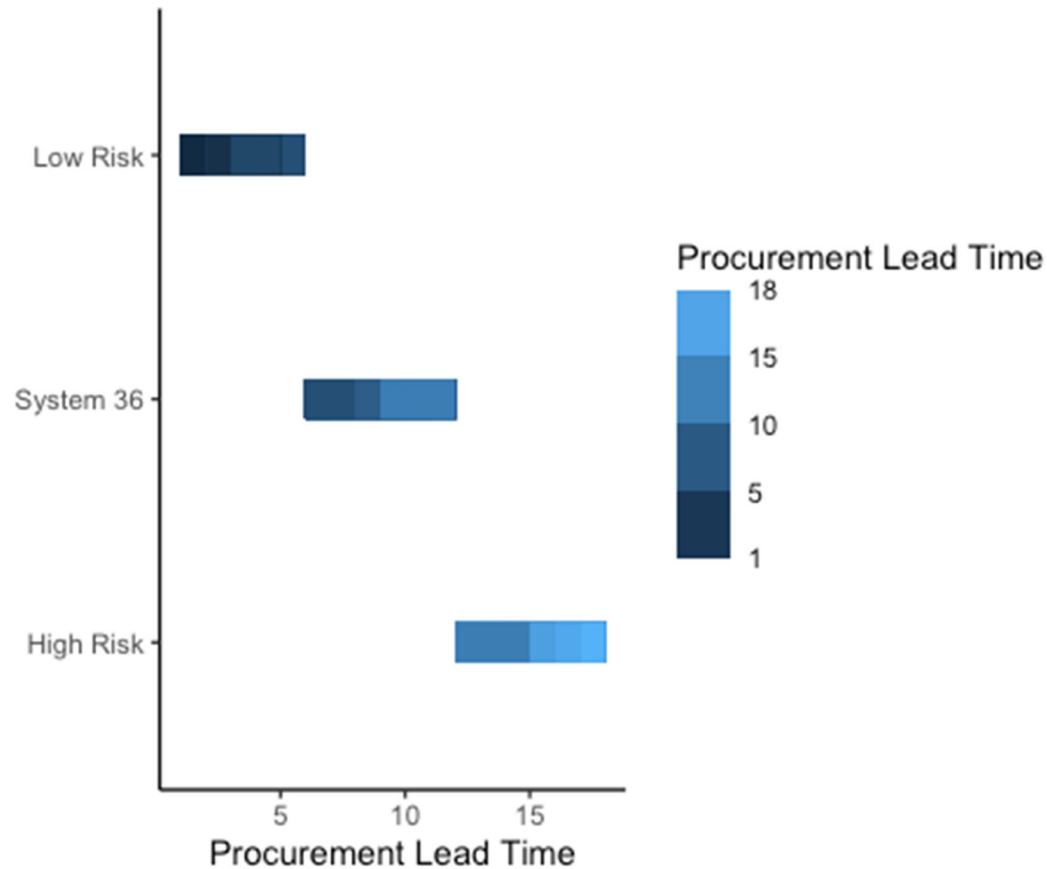
```



```

ggplot(PR36_simdata, aes(x = System, y = PLT)) +
  geom_line(aes(color = PLT), size = 6) +
  scale_color_gradient() +
  labs(y = "Procurement Lead Time", x = "", color = "Procurement Lead Time") +
  theme_classic() +
  guides(color = guide_colorsteps(show.limits = TRUE)) +
  coord_flip()

```



```

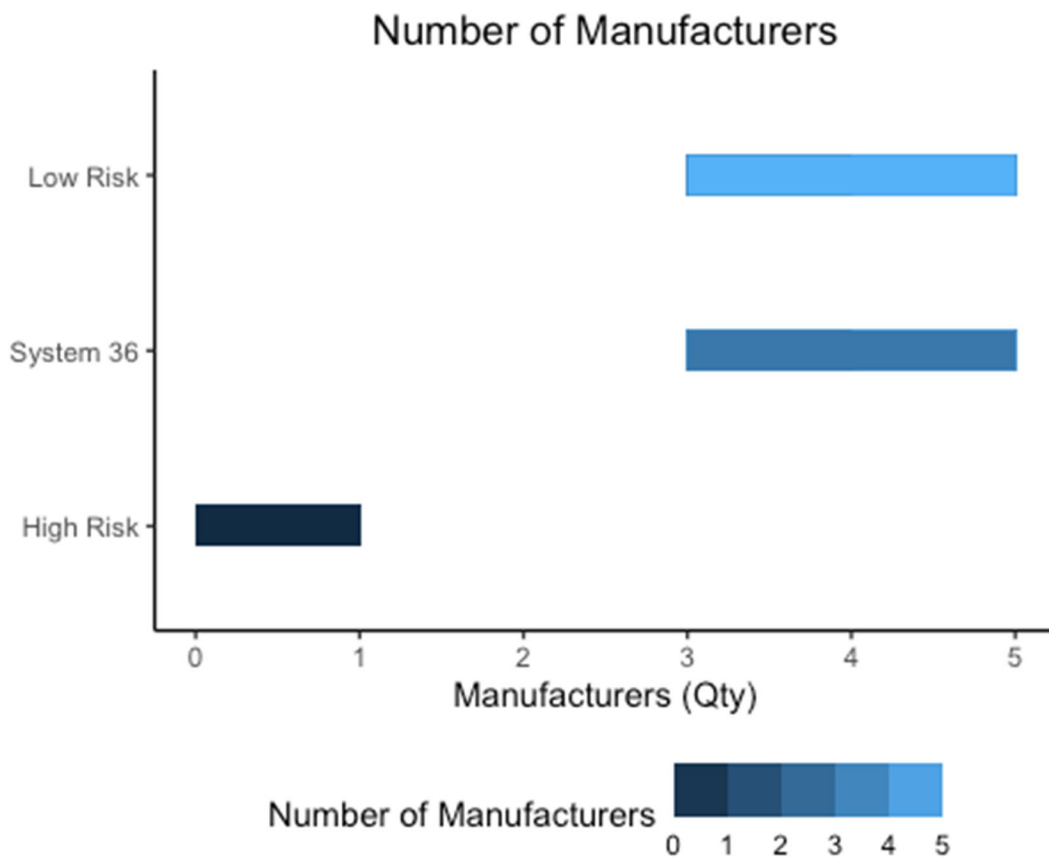
theme(legend.position = "bottom") +
  ggtitle("Procurement Lead Time (Months)") +
  ggeasy::easy_center_title()

## List of 3
## $ legend.position: chr "bottom"
## $ title          : chr "Procurement Lead Time (Months)"
## $ plot.title     :List of 11
## ..$ family      : NULL
## ..$ face        : NULL
## ..$ colour      : NULL
## ..$ size        : NULL
## ..$ hjust       : num 0.5
## ..$ vjust       : NULL
## ..$ angle       : NULL
## ..$ lineheight  : NULL
## ..$ margin      : NULL
## ..$ debug       : NULL
## ..$ inherit.blank: logi FALSE
## ..- attr(*, "class")= chr [1:2] "element_text" "element"
## - attr(*, "class")= chr [1:2] "theme" "gg"

```

```
## - attr(*, "complete")= logi FALSE
## - attr(*, "validate")= logi TRUE

ggplot(PR36_simdata, aes(x = System, y = NumberofManf)) +
  geom_line(aes(color = NumberofManf, size = 6) +
  scale_color_gradient() +
  labs(y = "Manufacturers (Qty)", x = "", color = "Number of Manufacturers") +
  theme_classic() +
  guides(color = guide_colorsteps(show.limits = TRUE)) +
  coord_flip() +
  theme(legend.position = "bottom") +
  ggtitle("Number of Manufacturers") +
  ggeasy::easy_center_title()
```



```
PR36CostPlot <- ggplot(PR36_simdata, aes(x = System, y = CostGrowth)) +
  geom_line(aes(color = CostGrowth, size = 6) +
  scale_color_gradient() +
  labs(y = "Cost Growth %", x = "", color = "Cost Growth %") +
  theme_classic() +
  guides(color = guide_colorsteps(show.limits = TRUE)) +
  coord_flip() +
  theme(legend.position = "bottom") +
```

```

ggtitle("Obsolescence Cost Growth %") +
ggeasy::easy_center_title()

PR36DesignPlot <- ggplot(PR36_simdata, aes(x = System, y = DY)) +
geom_line(aes(color = DY), size = 6) +
scale_color_gradient() +
labs(y = "Design Life Years", x = "", color = "Design Life Years") +
theme_classic() +
guides(color = guide_colorsteps(show.limits = TRUE)) +
coord_flip() +
theme(legend.position = "bottom") +
ggtitle("Design Life Years Before Obsolescence") +
ggeasy::easy_center_title()

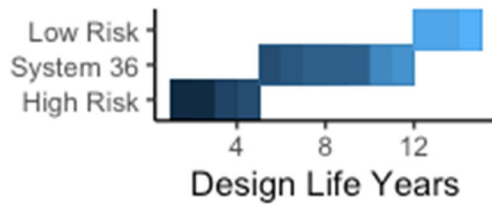
PR36PLTPlot <- ggplot(PR36_simdata, aes(x = System, y = PLT)) +
geom_line(aes(color = PLT), size = 6) +
scale_color_gradient() +
labs(y = "Procurement Lead Time", x = "", color = "Procurement Lead Time") +
theme_classic() +
guides(color = guide_colorsteps(show.limits = TRUE)) +
coord_flip() +
theme(legend.position = "bottom") +
ggtitle("Procurement Lead Time (Months)") +
ggeasy::easy_center_title()

PR36ManfPlot <- ggplot(PR36_simdata, aes(x = System, y = NumberofManf)) +
geom_line(aes(color = NumberofManf), size = 6) +
scale_color_gradient() +
labs(y = "Manufacturers (Qty)", x = "", color = "Number of Manufacturers") +
theme_classic() +
coord_flip() +
guides(color = guide_colorsteps(show.limits = TRUE)) +
theme(legend.position = "bottom") +
ggtitle("Number of Manufacturers") +
ggeasy::easy_center_title()

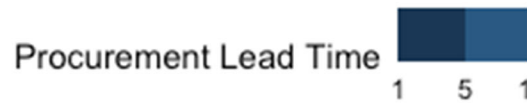
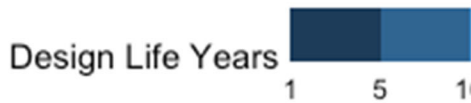
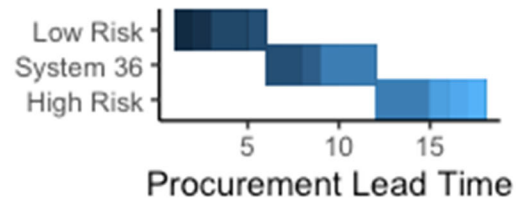
ggarrange(PR36DesignPlot, PR36PLTPlot, PR36CostPlot, PR36ManfPlot, legend = "bottom")

```

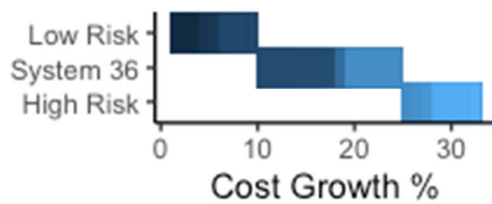
Design Life Years Before Obsc



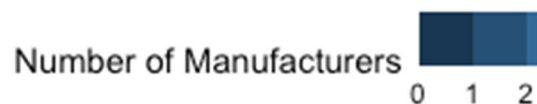
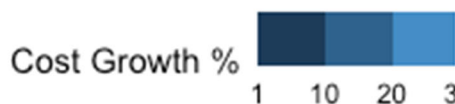
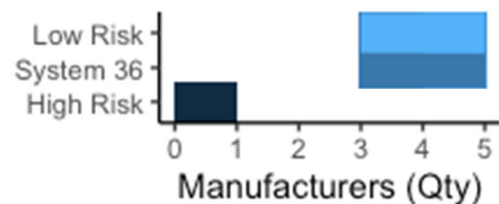
Procurement Lead Time (M



Obsolescence Cost Grow



Number of Manufacture



```
ggsave("Plot_System36.png", width = 12, height = 8, units = "in", dpi = 300)
```

```
## System 45 data for plot
```

```
PR45_simdata <- combine(proactive_simdata, system45_simdata, reactive_simdata)
```

```
# Plot for System 45
```

```
PR45_simdata$DY <- as.numeric(round(PR45_simdata$DY, digits = 0))
```

```
PR45_simdata$PLT <- as.numeric(round(PR45_simdata$PLT, digits = 0))
```

```
PR45_simdata$CostGrowth <- as.numeric(round(PR45_simdata$CostGrowth, digits = 0))
```

```
as_factor(PR45_simdata$NumberofManf)
```

```
## [2998] 1 0 1
```

```
## Levels: 0 1 3 4 5
```

```
PR45_simdata$System <- factor(PR45_simdata$System, levels=c("High Risk",  
"System 45",  
"Low Risk"))
```

```
ggplot(PR45_simdata, aes(x = System, y = CostGrowth)) +
```

```
  geom_line(aes(color = CostGrowth), size = 6) +
```

```
  scale_color_gradient() +
```

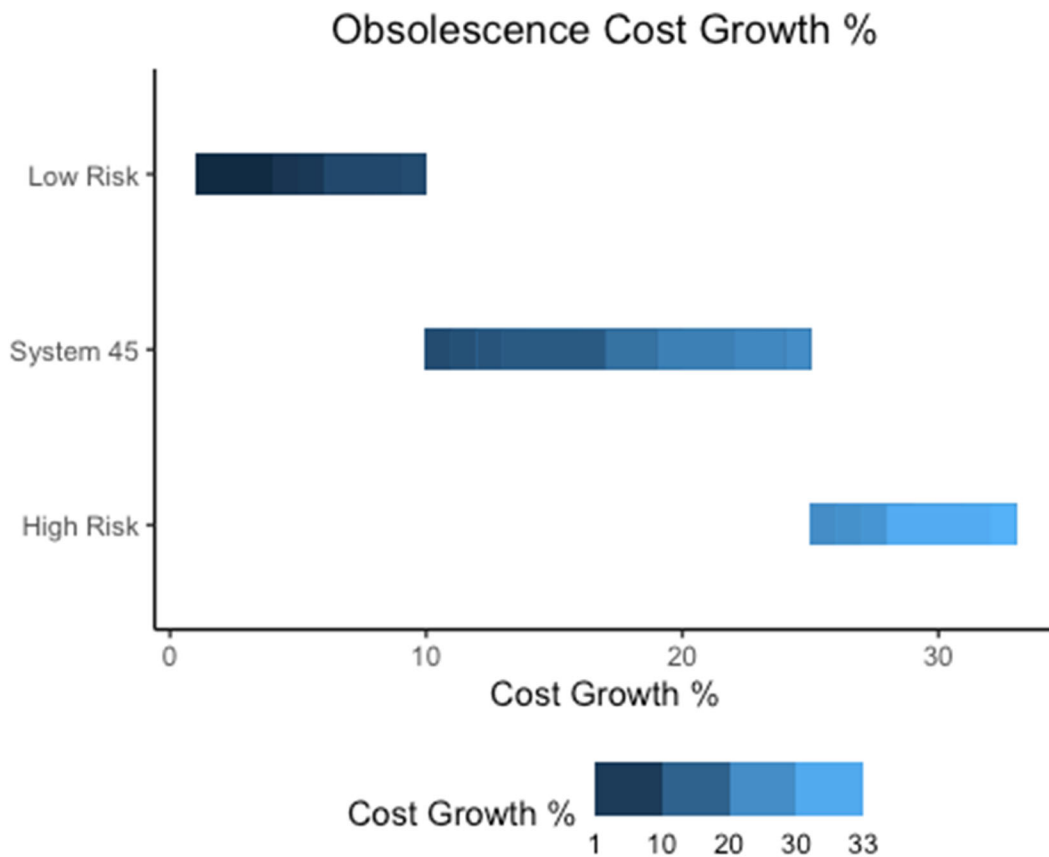
```
  labs(y = "Cost Growth %", x = "", color = "Cost Growth %") +
```

```
  theme_classic() +
```

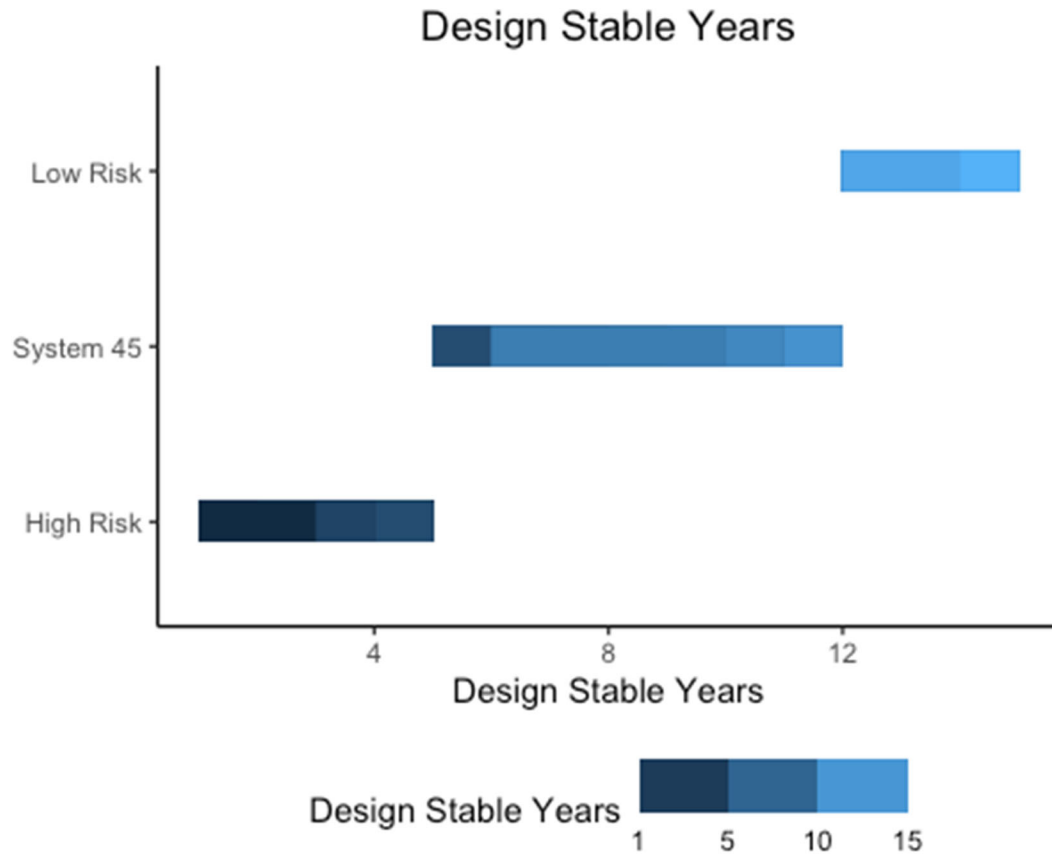
```
  guides(color = guide_colorsteps(show.limits = TRUE)) +
```

```
  coord_flip() +
```

```
theme(legend.position = "bottom") +
ggtitle("Obsolescence Cost Growth %") +
ggeasy::easy_center_title()
```



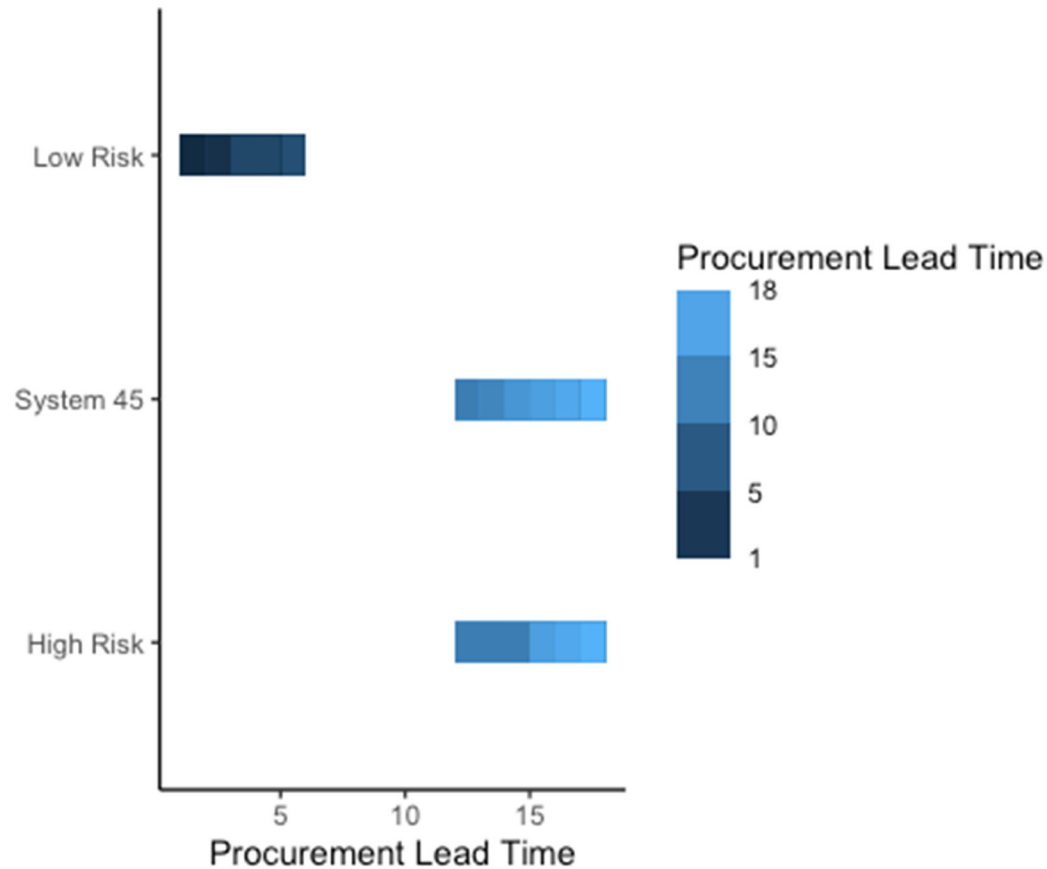
```
ggplot(PR45_simdata, aes(x = System, y = DY)) +
geom_line(aes(color = DY), size = 6) +
scale_color_gradient() +
labs(y = "Design Stable Years", x = "", color = "Design Stable Years") +
theme_classic() +
guides(color = guide_colorsteps(show.limits = TRUE)) +
coord_flip() +
theme(legend.position = "bottom") +
ggtitle("Design Stable Years") +
ggeasy::easy_center_title()
```



```

ggplot(PR45_simdata, aes(x = System, y = PLT)) +
  geom_line(aes(color = PLT), size = 6) +
  scale_color_gradient() +
  labs(y = "Procurement Lead Time", x = "", color = "Procurement Lead Time") +
  theme_classic() +
  guides(color = guide_colorsteps(show.limits = TRUE)) +
  coord_flip()

```



```

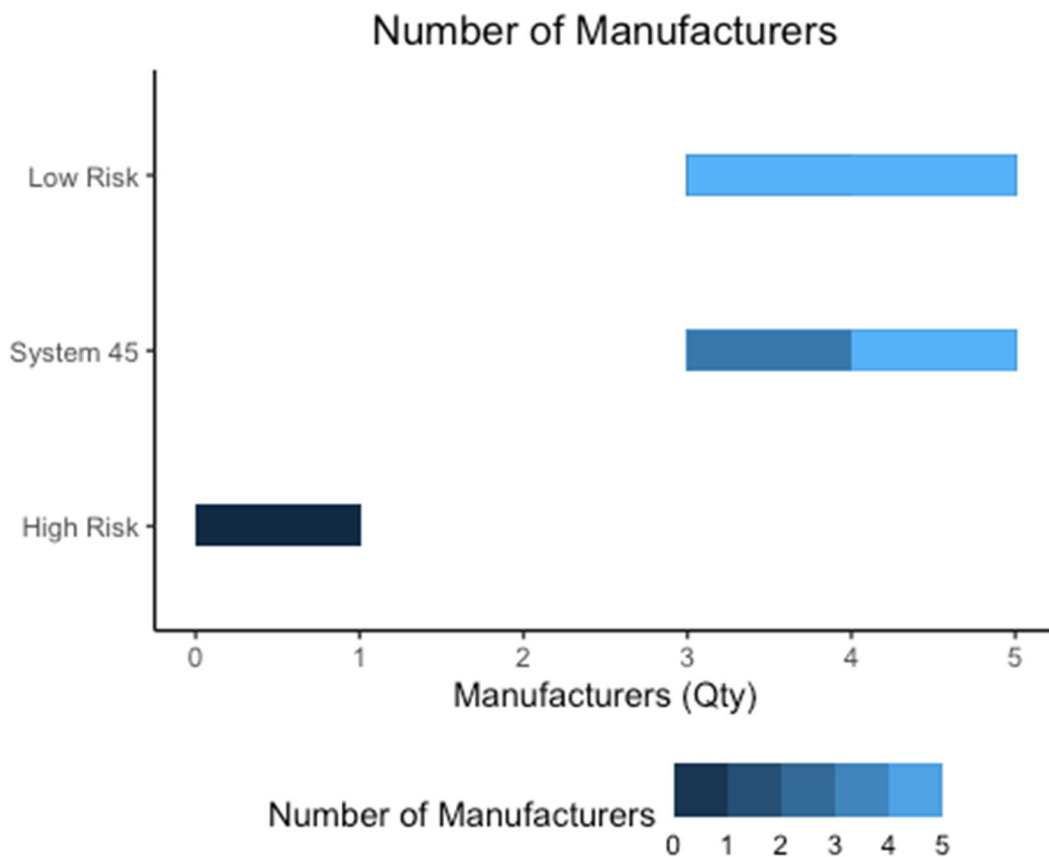
theme(legend.position = "bottom") +
  ggtitle("Procurement Lead Time (Months)") +
  ggeasy::easy_center_title()

## List of 3
## $ legend.position: chr "bottom"
## $ title          : chr "Procurement Lead Time (Months)"
## $ plot.title     :List of 11
## ..$ family      : NULL
## ..$ face        : NULL
## ..$ colour      : NULL
## ..$ size        : NULL
## ..$ hjust       : num 0.5
## ..$ vjust       : NULL
## ..$ angle       : NULL
## ..$ lineheight  : NULL
## ..$ margin      : NULL
## ..$ debug       : NULL
## ..$ inherit.blank: logi FALSE
## ..- attr(*, "class")= chr [1:2] "element_text" "element"
## - attr(*, "class")= chr [1:2] "theme" "gg"

```

```
## - attr(*, "complete")= logi FALSE
## - attr(*, "validate")= logi TRUE

ggplot(PR45_simdata, aes(x = System, y = NumberofManf)) +
  geom_line(aes(color = NumberofManf, size = 6) +
  scale_color_gradient() +
  labs(y = "Manufacturers (Qty)", x = "", color = "Number of Manufacturers") +
  theme_classic() +
  guides(color = guide_colorsteps(show.limits = TRUE)) +
  coord_flip() +
  theme(legend.position = "bottom") +
  ggtitle("Number of Manufacturers") +
  ggeasy::easy_center_title()
```



```
PR45CostPlot <- ggplot(PR45_simdata, aes(x = System, y = CostGrowth)) +
  geom_line(aes(color = CostGrowth, size = 6) +
  scale_color_gradient() +
  labs(y = "Cost Growth %", x = "", color = "Cost Growth %") +
  theme_classic() +
  guides(color = guide_colorsteps(show.limits = TRUE)) +
  coord_flip() +
  theme(legend.position = "bottom") +
```

```

ggtitle("Obsolescence Cost Growth %") +
ggeasy::easy_center_title()

PR45DesignPlot <- ggplot(PR45_simdata, aes(x = System, y = DY)) +
geom_line(aes(color = DY), size = 6) +
scale_color_gradient() +
labs(y = "Design Life Years", x = "", color = "Design Life Years") +
theme_classic() +
guides(color = guide_colorsteps(show.limits = TRUE)) +
coord_flip() +
theme(legend.position = "bottom") +
ggtitle("Design Life Years Before Obsolescence") +
ggeasy::easy_center_title()

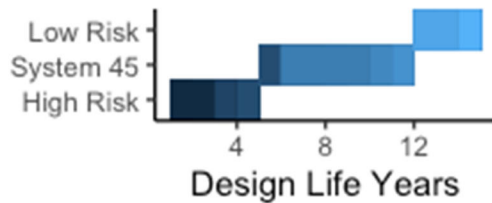
PR45PLTPlot <- ggplot(PR45_simdata, aes(x = System, y = PLT)) +
geom_line(aes(color = PLT), size = 6) +
scale_color_gradient() +
labs(y = "Procurement Lead Time", x = "", color = "Procurement Lead Time") +
theme_classic() +
guides(color = guide_colorsteps(show.limits = TRUE)) +
coord_flip() +
theme(legend.position = "bottom") +
ggtitle("Procurement Lead Time (Months)") +
ggeasy::easy_center_title()

PR45ManfPlot <- ggplot(PR45_simdata, aes(x = System, y = NumberofManf)) +
geom_line(aes(color = NumberofManf), size = 6) +
scale_color_gradient() +
labs(y = "Manufacturers (Qty)", x = "", color = "Number of Manufacturers") +
theme_classic() +
coord_flip() +
guides(color = guide_colorsteps(show.limits = TRUE)) +
theme(legend.position = "bottom") +
ggtitle("Number of Manufacturers") +
ggeasy::easy_center_title()

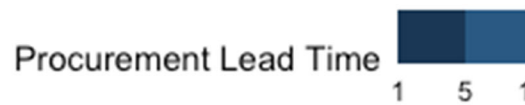
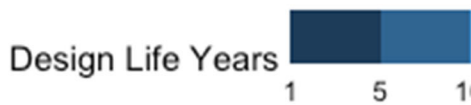
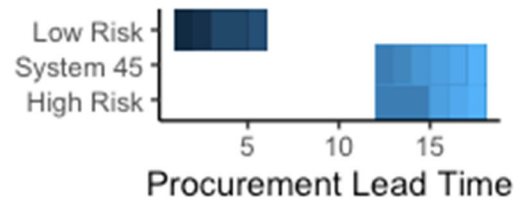
ggarrange(PR45DesignPlot, PR45PLTPlot, PR45CostPlot, PR45ManfPlot, legend = "bottom")

```

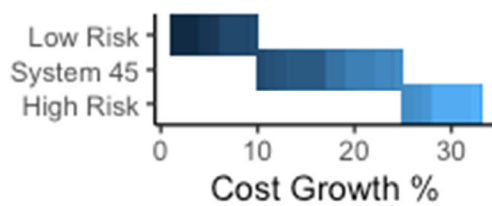
Design Life Years Before Obsc



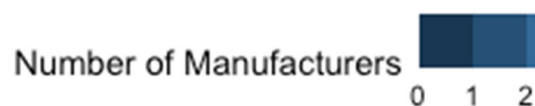
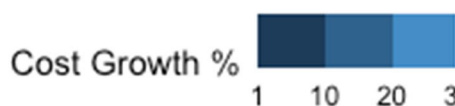
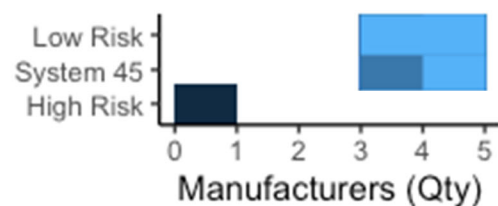
Procurement Lead Time (M



Obsolescence Cost Grow



Number of Manufacture



```
ggsave("Plot_System45.png", width = 12, height = 8, units = "in", dpi = 1000)
```

```
## System 54 data for plot
```

```
PR54_simdata <- combine(proactive_simdata, system54_simdata, reactive_simdata)
```

```
# Plot for System 54
```

```
PR54_simdata$DY <- as.numeric(round(PR54_simdata$DY, digits = 0))
```

```
PR54_simdata$PLT <- as.numeric(round(PR54_simdata$PLT, digits = 0))
```

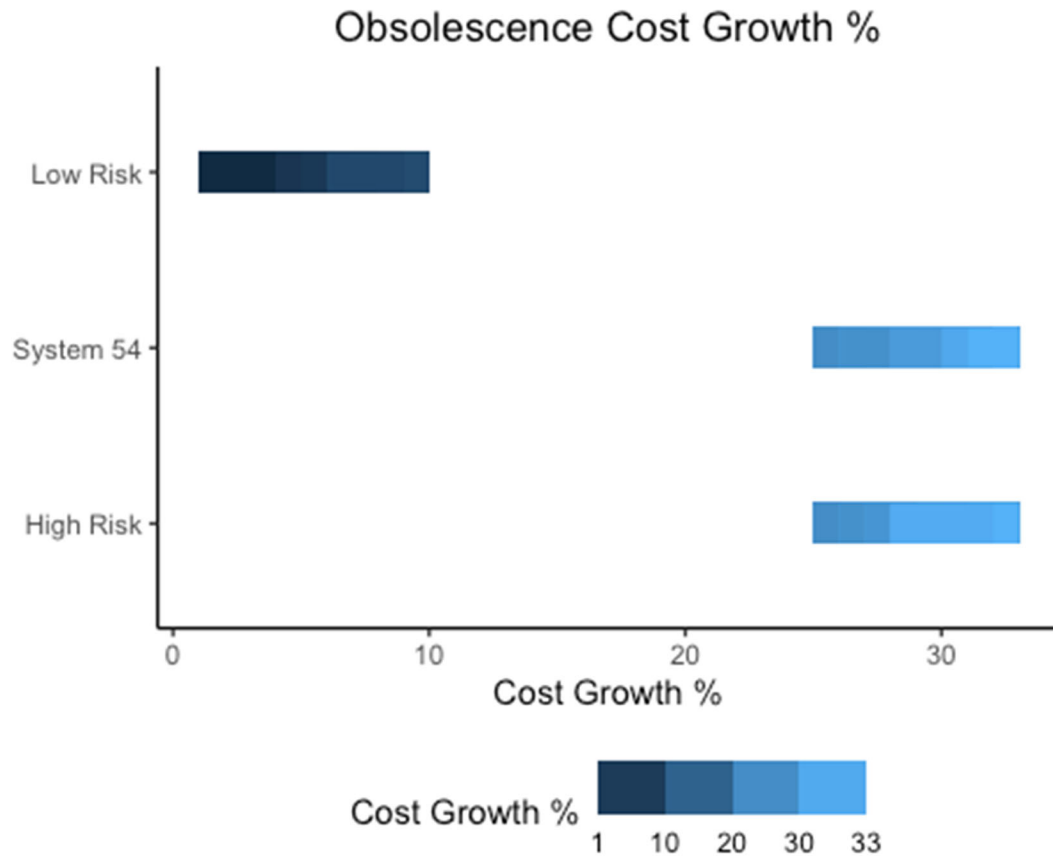
```
PR54_simdata$CostGrowth <- as.numeric(round(PR54_simdata$CostGrowth, digits = 0))
```

```
as_factor(PR54_simdata$NumberofManf)
```

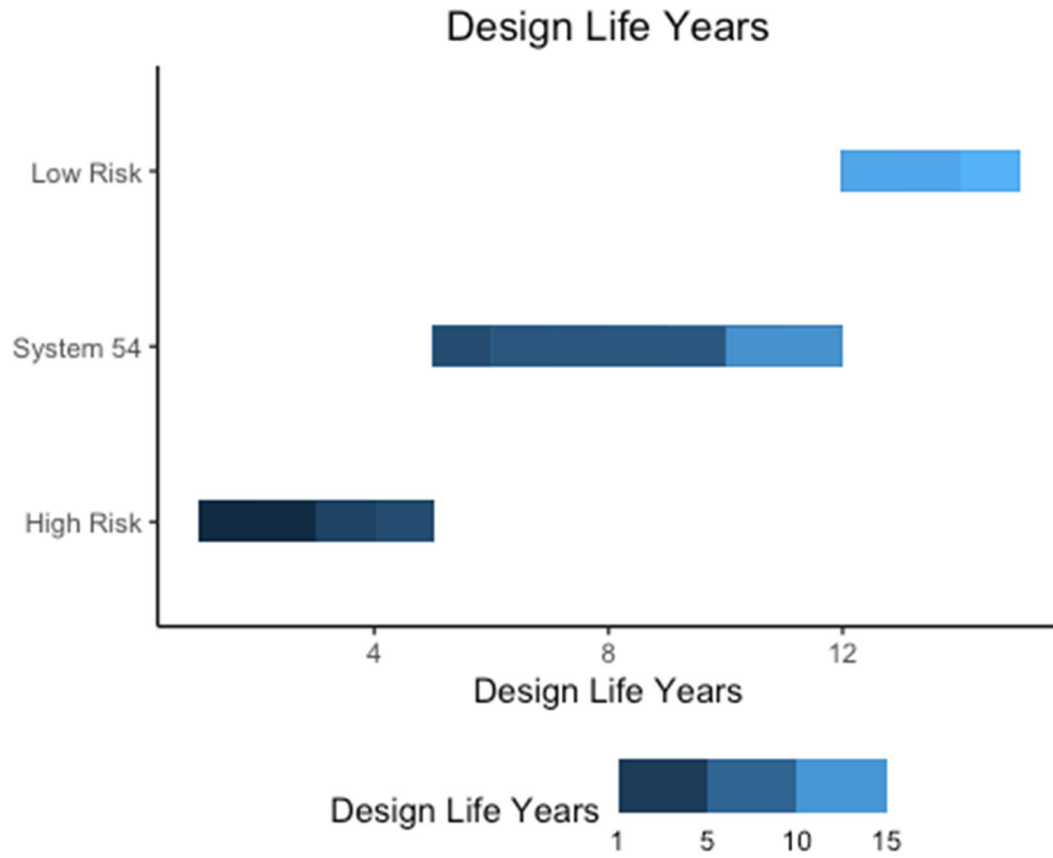
```
PR54_simdata$System <- factor(PR54_simdata$System, levels=c("High Risk",  
"System 54",  
"Low Risk"))
```

```
ggplot(PR54_simdata, aes(x = System, y = CostGrowth)) +  
  geom_line(aes(color = CostGrowth, size = 6)) +  
  scale_color_gradient() +  
  labs(y = "Cost Growth %", x = "", color = "Cost Growth %") +  
  theme_classic() +  
  guides(color = guide_colorsteps(show.limits = TRUE)) +  
  coord_flip() +  
  theme(legend.position = "bottom") +
```

```
ggtitle("Obsolescence Cost Growth %") +
ggeasy::easy_center_title()
```



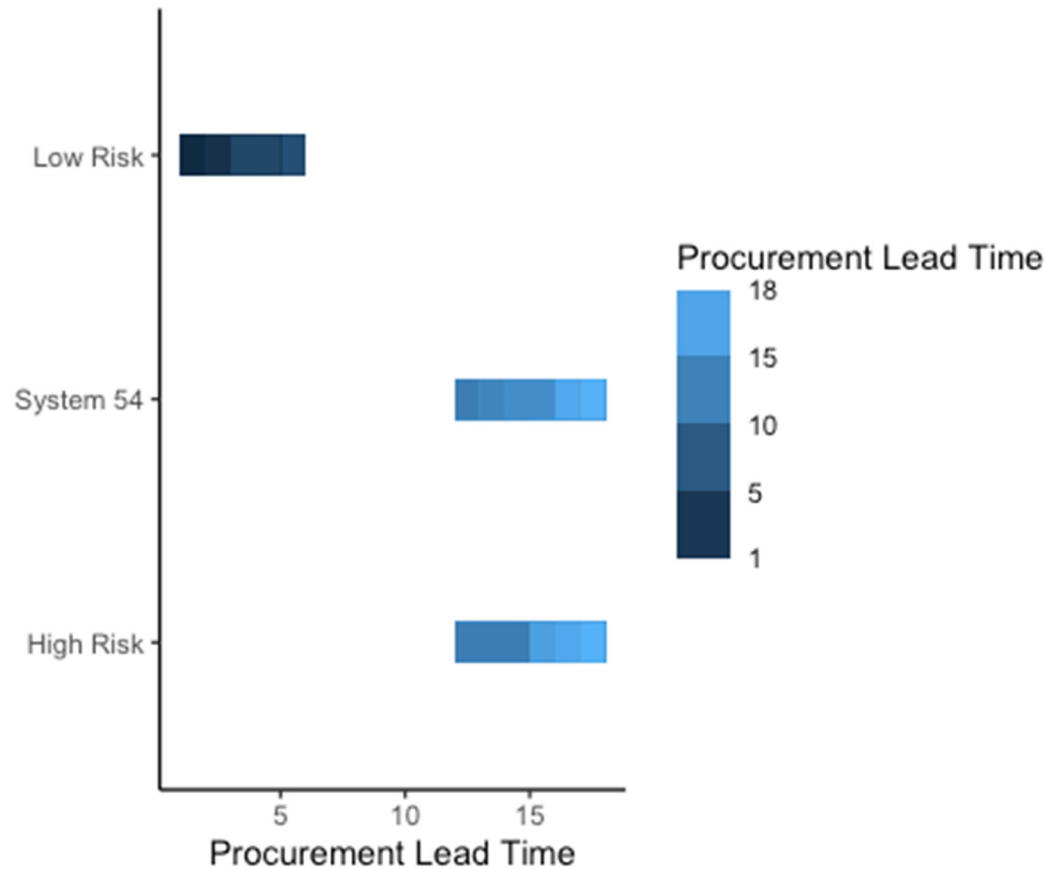
```
ggplot(PR54_simdata, aes(x = System, y = DY)) +
geom_line(aes(color = DY), size = 6) +
scale_color_gradient() +
labs(y = "Design Life Years", x = "", color = "Design Life Years") +
theme_classic() +
guides(color = guide_colorsteps(show.limits = TRUE)) +
coord_flip() +
theme(legend.position = "bottom") +
ggtitle("Design Life Years") +
ggeasy::easy_center_title()
```



```

ggplot(PR54_simdata, aes(x = System, y = PLT)) +
  geom_line(aes(color = PLT), size = 6) +
  scale_color_gradient() +
  labs(y = "Procurement Lead Time", x = "", color = "Procurement Lead Time") +
  theme_classic() +
  guides(color = guide_colorsteps(show.limits = TRUE)) +
  coord_flip()

```



```

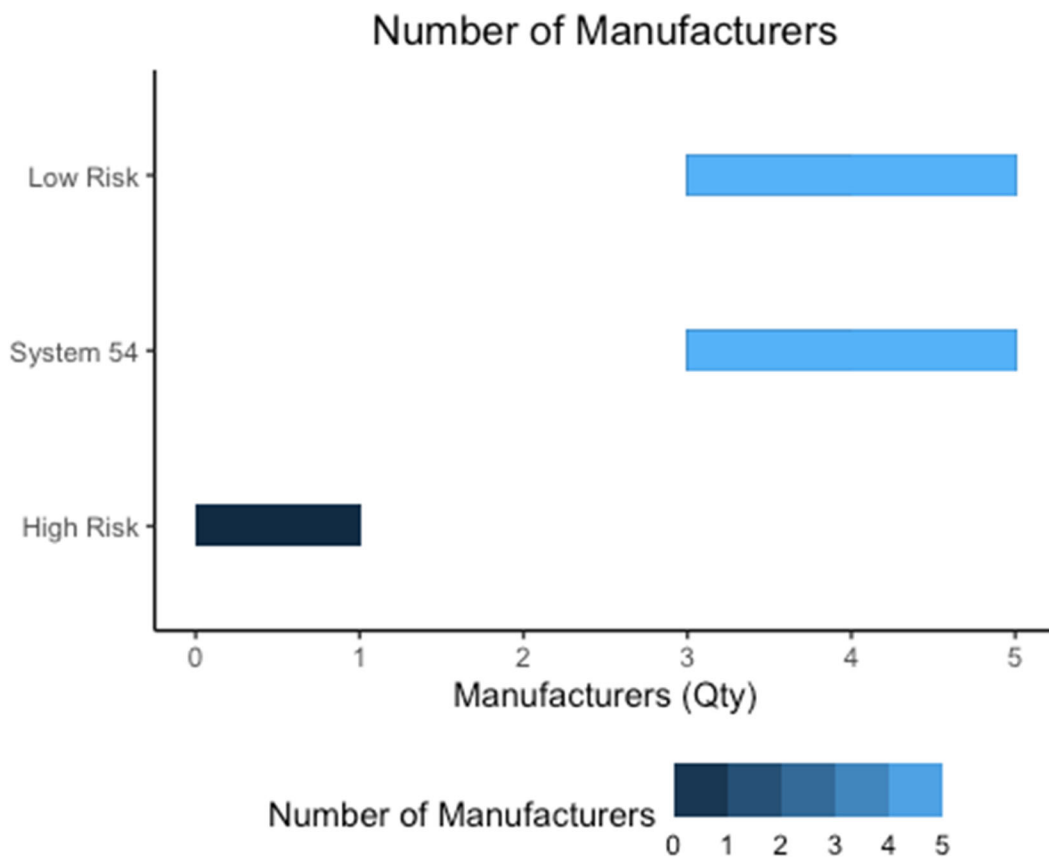
theme(legend.position = "bottom") +
  ggtitle("Procurement Lead Time (Months)") +
  ggeasy::easy_center_title()

## List of 3
## $ legend.position: chr "bottom"
## $ title          : chr "Procurement Lead Time (Months)"
## $ plot.title     :List of 11
## ..$ family       : NULL
## ..$ face         : NULL
## ..$ colour       : NULL
## ..$ size         : NULL
## ..$ hjust        : num 0.5
## ..$ vjust        : NULL
## ..$ angle        : NULL
## ..$ lineheight   : NULL
## ..$ margin       : NULL
## ..$ debug        : NULL
## ..$ inherit.blank: logi FALSE
## ..- attr(*, "class")= chr [1:2] "element_text" "element"
## - attr(*, "class")= chr [1:2] "theme" "gg"

```

```
## - attr(*, "complete")= logi FALSE
## - attr(*, "validate")= logi TRUE

ggplot(PR54_simdata, aes(x = System, y = NumberofManf)) +
  geom_line(aes(color = NumberofManf, size = 6)) +
  scale_color_gradient() +
  labs(y = "Manufacturers (Qty)", x = "", color = "Number of Manufacturers") +
  theme_classic() +
  guides(color = guide_colorsteps(show.limits = TRUE)) +
  coord_flip() +
  theme(legend.position = "bottom") +
  ggtitle("Number of Manufacturers") +
  ggeasy::easy_center_title()
```



```
PR54CostPlot <- ggplot(PR54_simdata, aes(x = System, y = CostGrowth)) +
  geom_line(aes(color = CostGrowth, size = 6)) +
  scale_color_gradient() +
  labs(y = "Cost Growth %", x = "", color = "Cost Growth %") +
  theme_classic() +
  guides(color = guide_colorsteps(show.limits = TRUE)) +
  coord_flip() +
  theme(legend.position = "bottom") +
```

```

ggtitle("Obsolescence Cost Growth %") +
ggeasy::easy_center_title()

PR54DesignPlot <- ggplot(PR54_simdata, aes(x = System, y = DY)) +
  geom_line(aes(color = DY), size = 6) +
  scale_color_gradient() +
  labs(y = "Design Life Years", x = "", color = "Design Life Years") +
  theme_classic() +
  guides(color = guide_colorsteps(show.limits = TRUE)) +
  coord_flip() +
  theme(legend.position = "bottom") +
  ggtitle("Design Life Years Before Obsolescence") +
  ggeasy::easy_center_title()

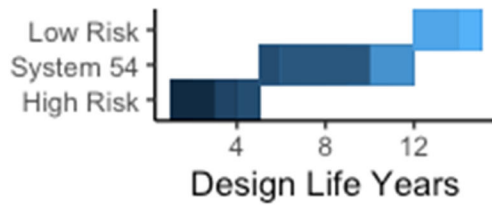
PR54PLTPlot <- ggplot(PR54_simdata, aes(x = System, y = PLT)) +
  geom_line(aes(color = PLT), size = 6) +
  scale_color_gradient() +
  labs(y = "Procurement Lead Time", x = "", color = "Procurement Lead Time") +
  theme_classic() +
  guides(color = guide_colorsteps(show.limits = TRUE)) +
  coord_flip() +
  theme(legend.position = "bottom") +
  ggtitle("Procurement Lead Time (Months)") +
  ggeasy::easy_center_title()

PR54ManfPlot <- ggplot(PR54_simdata, aes(x = System, y = NumberofManf)) +
  geom_line(aes(color = NumberofManf), size = 6) +
  scale_color_gradient() +
  labs(y = "Manufacturers (Qty)", x = "", color = "Number of Manufacturers") +
  theme_classic() +
  coord_flip() +
  guides(color = guide_colorsteps(show.limits = TRUE)) +
  theme(legend.position = "bottom") +
  ggtitle("Number of Manufacturers") +
  ggeasy::easy_center_title()

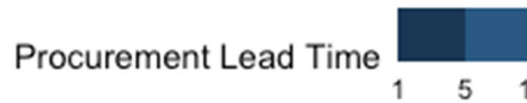
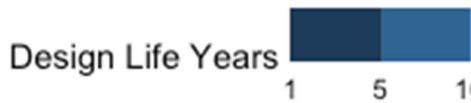
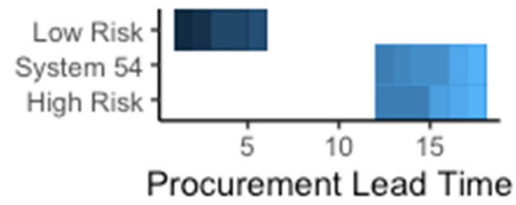
ggarrange(PR54DesignPlot, PR54PLTPlot, PR54CostPlot, PR54ManfPlot, legend = "bottom")

```

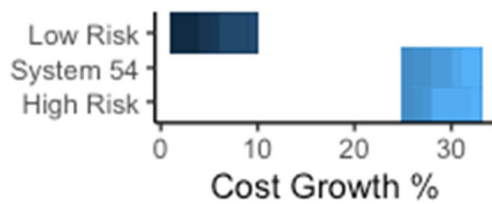
Design Life Years Before Obsc



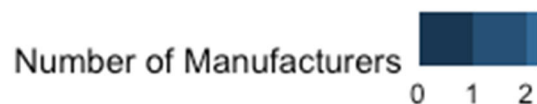
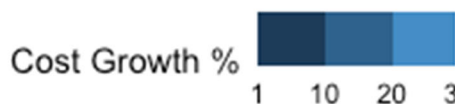
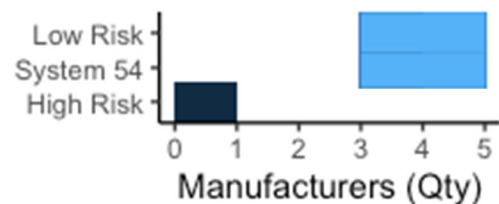
Procurement Lead Time (M



Obsolescence Cost Grow



Number of Manufacture



```
ggsave("Plot_System54.png", width = 12, height = 8, units = "in", dpi = 300)
```

```
## System 63 data for plot
```

```
PR63_simdata <- combine(proactive_simdata, system63_simdata, reactive_simdata)
```

```
# Plot for System 63
```

```
PR63_simdata$DY <- as.numeric(round(PR63_simdata$DY, digits = 0))
```

```
PR63_simdata$PLT <- as.numeric(round(PR63_simdata$PLT, digits = 0))
```

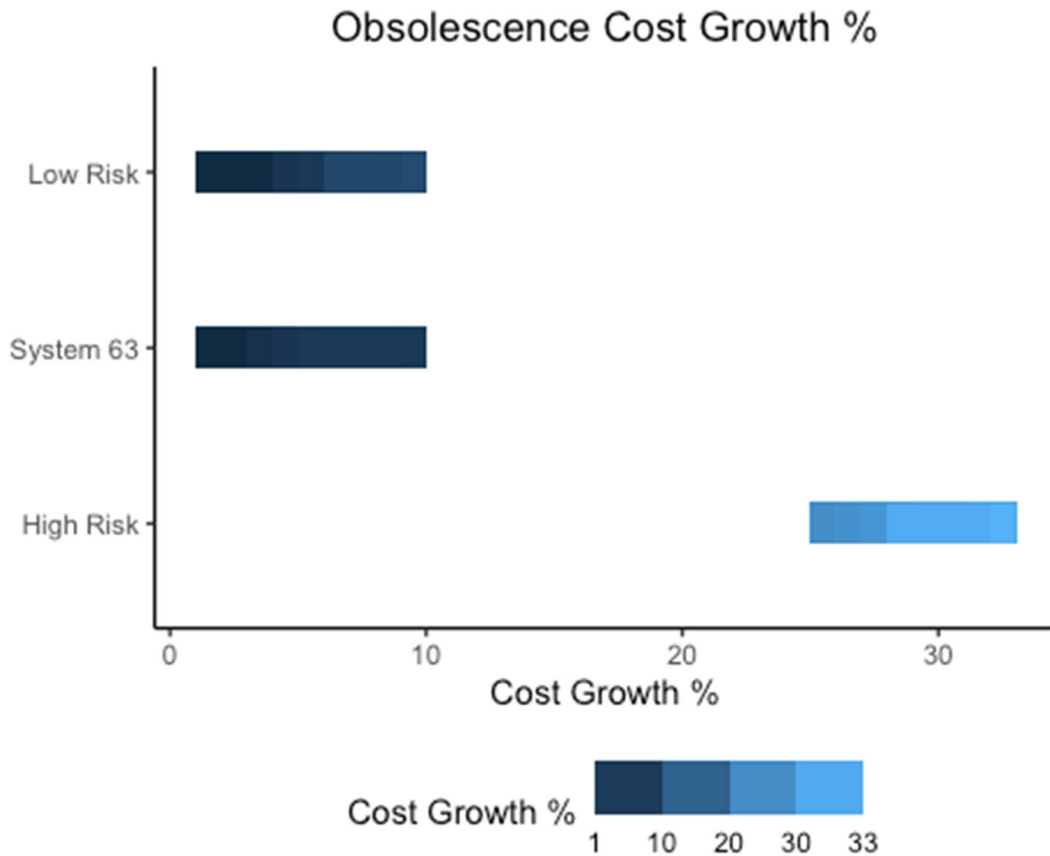
```
PR63_simdata$CostGrowth <- as.numeric(round(PR63_simdata$CostGrowth, digits = 0))
```

```
as_factor(PR63_simdata$NumberofManf)
```

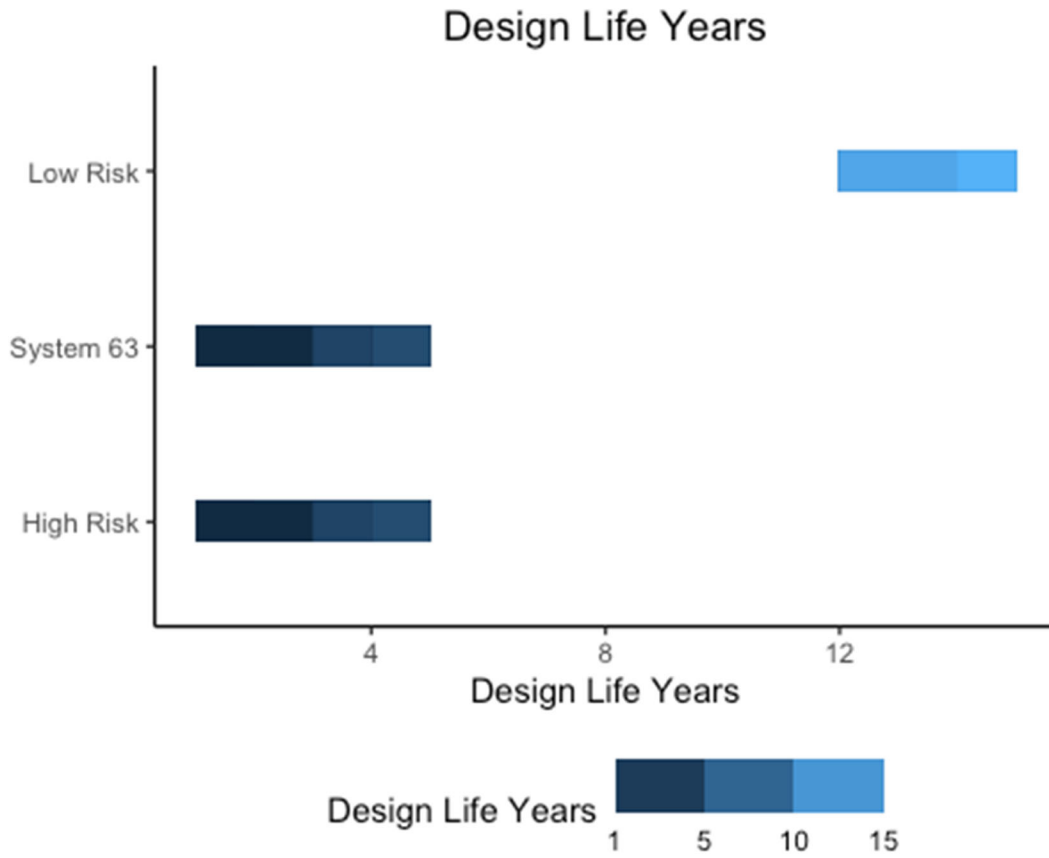
```
PR63_simdata$System <- factor(PR63_simdata$System, levels=c("High Risk",
                                                           "System 63",
                                                           "Low Risk"))
```

```
ggplot(PR63_simdata, aes(x = System, y = CostGrowth)) +
  geom_line(aes(color = CostGrowth, size = 6)) +
  scale_color_gradient() +
  labs(y = "Cost Growth %", x = "", color = "Cost Growth %") +
  theme_classic() +
  guides(color = guide_colorsteps(show.limits = TRUE)) +
  coord_flip() +
  theme(legend.position = "bottom") +
```

```
ggtitle("Obsolescence Cost Growth %") +
ggeasy::easy_center_title()
```



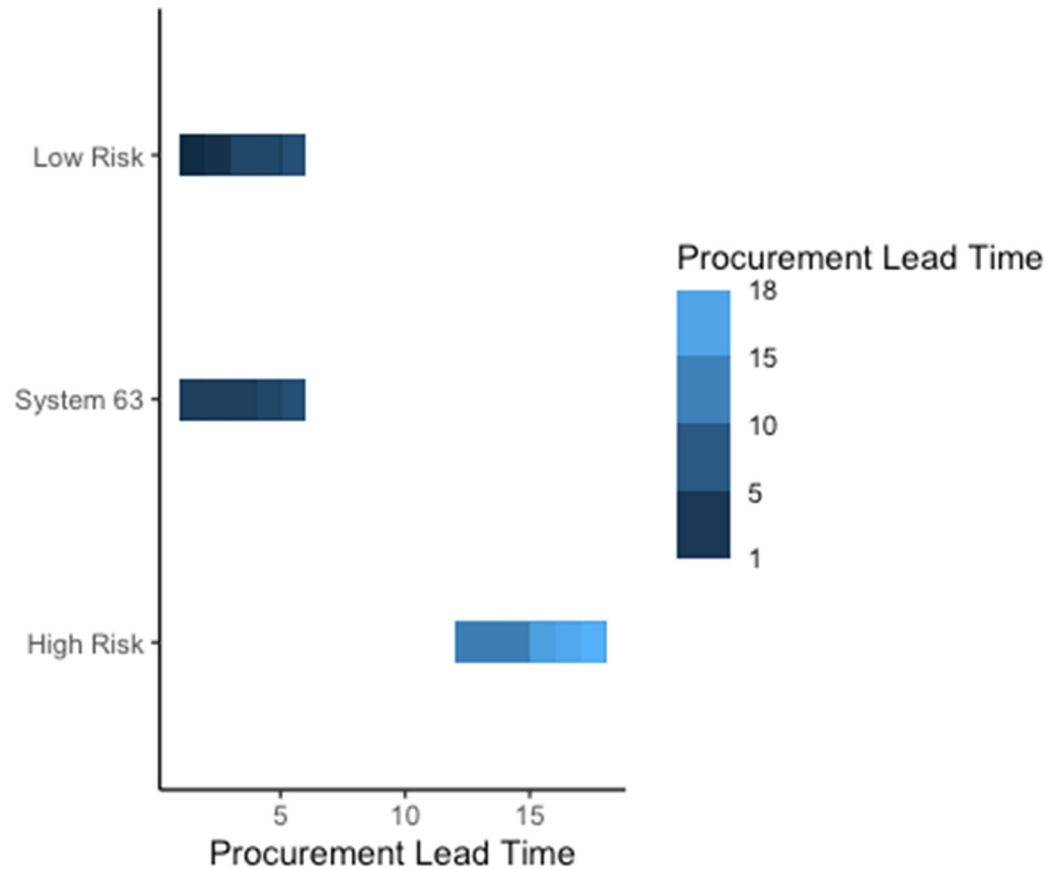
```
ggplot(PR63_simdata, aes(x = System, y = DY)) +
geom_line(aes(color = DY), size = 6) +
scale_color_gradient() +
labs(y = "Design Life Years", x = "", color = "Design Life Years") +
theme_classic() +
guides(color = guide_colorsteps(show.limits = TRUE)) +
coord_flip() +
theme(legend.position = "bottom") +
ggtitle("Design Life Years") +
ggeasy::easy_center_title()
```



```

ggplot(PR63_simdata, aes(x = System, y = PLT)) +
  geom_line(aes(color = PLT), size = 6) +
  scale_color_gradient() +
  labs(y = "Procurement Lead Time", x = "", color = "Procurement Lead Time") +
  theme_classic() +
  guides(color = guide_colorsteps(show.limits = TRUE)) +
  coord_flip()

```



```

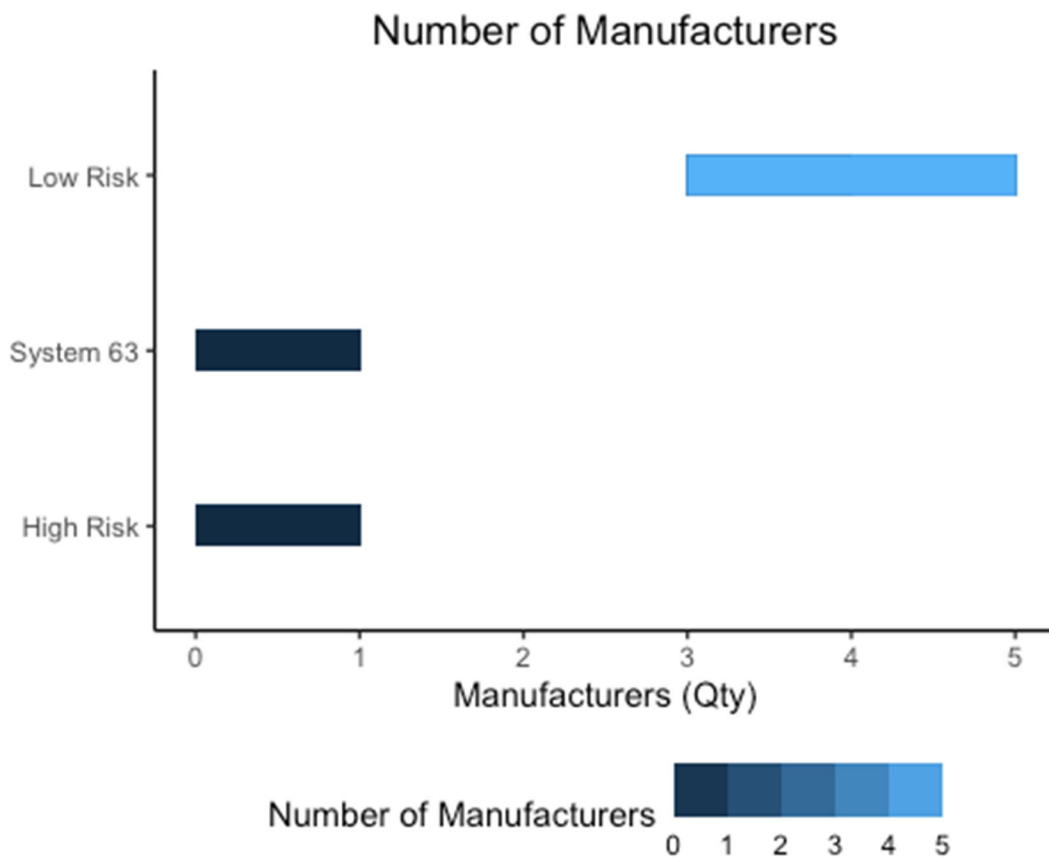
theme(legend.position = "bottom") +
  ggtitle("Procurement Lead Time (Months)") +
  ggeasy::easy_center_title()

## List of 3
## $ legend.position: chr "bottom"
## $ title          : chr "Procurement Lead Time (Months)"
## $ plot.title     :List of 11
## ..$ family      : NULL
## ..$ face        : NULL
## ..$ colour      : NULL
## ..$ size        : NULL
## ..$ hjust       : num 0.5
## ..$ vjust       : NULL
## ..$ angle       : NULL
## ..$ lineheight  : NULL
## ..$ margin      : NULL
## ..$ debug       : NULL
## ..$ inherit.blank: logi FALSE
## ..- attr(*, "class")= chr [1:2] "element_text" "element"
## - attr(*, "class")= chr [1:2] "theme" "gg"

```

```
## - attr(*, "complete")= logi FALSE
## - attr(*, "validate")= logi TRUE

ggplot(PR63_simdata, aes(x = System, y = NumberofManf)) +
  geom_line(aes(color = NumberofManf, size = 6)) +
  scale_color_gradient() +
  labs(y = "Manufacturers (Qty)", x = "", color = "Number of Manufacturers") +
  theme_classic() +
  guides(color = guide_colorsteps(show.limits = TRUE)) +
  coord_flip() +
  theme(legend.position = "bottom") +
  ggtitle("Number of Manufacturers") +
  ggeasy::easy_center_title()
```



```
PR63CostPlot <- ggplot(PR63_simdata, aes(x = System, y = CostGrowth)) +
  geom_line(aes(color = CostGrowth, size = 6)) +
  scale_color_gradient() +
  labs(y = "Cost Growth %", x = "", color = "Cost Growth %") +
  theme_classic() +
  guides(color = guide_colorsteps(show.limits = TRUE)) +
  coord_flip() +
  theme(legend.position = "bottom") +
```

```

ggtitle("Obsolescence Cost Growth %") +
ggeasy::easy_center_title()

PR63DesignPlot <- ggplot(PR63_simdata, aes(x = System, y = DY)) +
  geom_line(aes(color = DY), size = 6) +
  scale_color_gradient() +
  labs(y = "Design Life Years", x = "", color = "Design Life Years") +
  theme_classic() +
  guides(color = guide_colorsteps(show.limits = TRUE)) +
  coord_flip() +
  theme(legend.position = "bottom") +
  ggtitle("Design Life Years Before Obsolescence") +
  ggeasy::easy_center_title()

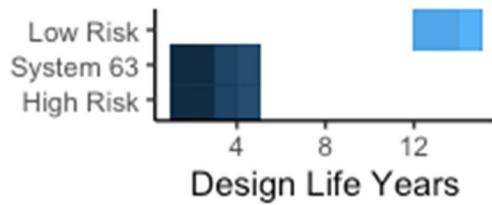
PR63PLTPlot <- ggplot(PR63_simdata, aes(x = System, y = PLT)) +
  geom_line(aes(color = PLT), size = 6) +
  scale_color_gradient() +
  labs(y = "Procurement Lead Time", x = "", color = "Procurement Lead Time") +
  theme_classic() +
  guides(color = guide_colorsteps(show.limits = TRUE)) +
  coord_flip() +
  theme(legend.position = "bottom") +
  ggtitle("Procurement Lead Time (Months)") +
  ggeasy::easy_center_title()

PR63ManfPlot <- ggplot(PR63_simdata, aes(x = System, y = NumberofManf)) +
  geom_line(aes(color = NumberofManf), size = 6) +
  scale_color_gradient() +
  labs(y = "Manufacturers (Qty)", x = "", color = "Number of Manufacturers") +
  theme_classic() +
  coord_flip() +
  guides(color = guide_colorsteps(show.limits = TRUE)) +
  theme(legend.position = "bottom") +
  ggtitle("Number of Manufacturers") +
  ggeasy::easy_center_title()

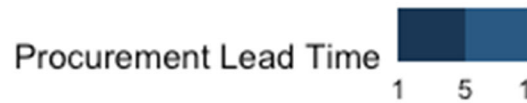
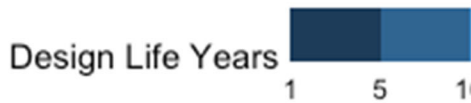
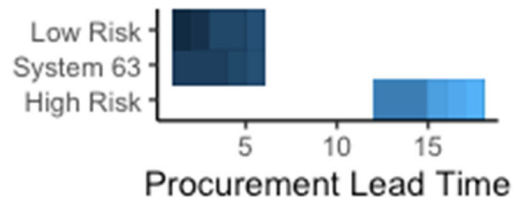
ggarrange(PR63DesignPlot, PR63PLTPlot, PR63CostPlot, PR63ManfPlot, legend = "bottom")

```

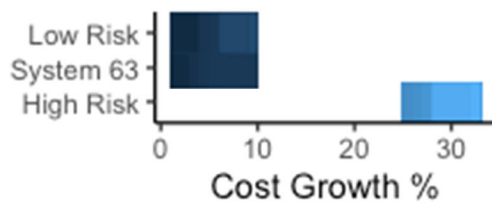
Design Life Years Before Obsc



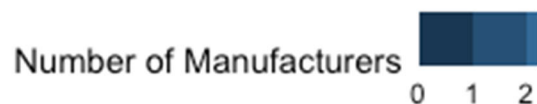
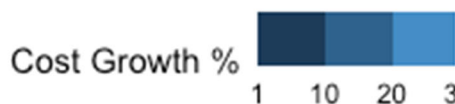
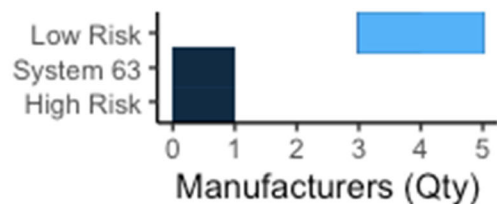
Procurement Lead Time (M



Obsolescence Cost Grow



Number of Manufacture



```
ggsave("Plot_System63.png", width = 12, height = 8, units = "in", dpi = 300)
```

```
## System 72 data for plot
```

```
PR72_simdata <- combine(proactive_simdata, system72_simdata, reactive_simdata)
```

```
# Plot for System 72
```

```
PR72_simdata$DY <- as.numeric(round(PR72_simdata$DY, digits = 0))
```

```
PR72_simdata$PLT <- as.numeric(round(PR72_simdata$PLT, digits = 0))
```

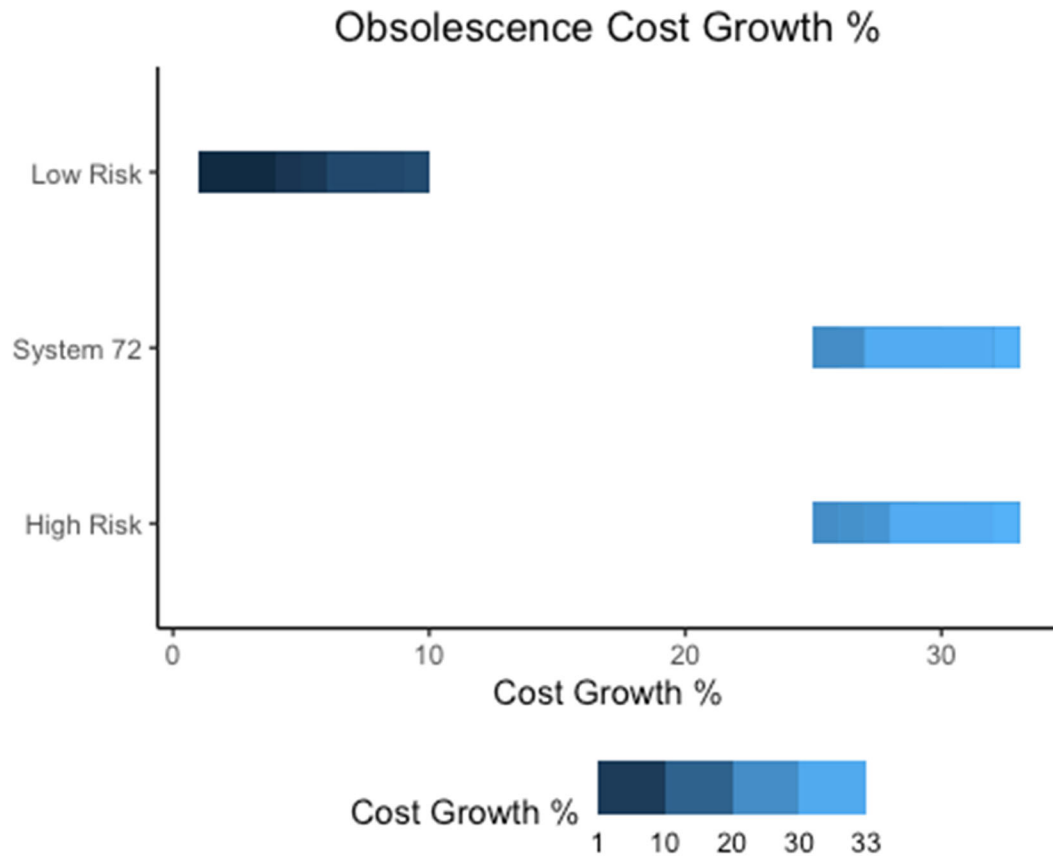
```
PR72_simdata$CostGrowth <- as.numeric(round(PR72_simdata$CostGrowth, digits = 0))
```

```
as_factor(PR72_simdata$NumberofManf)
```

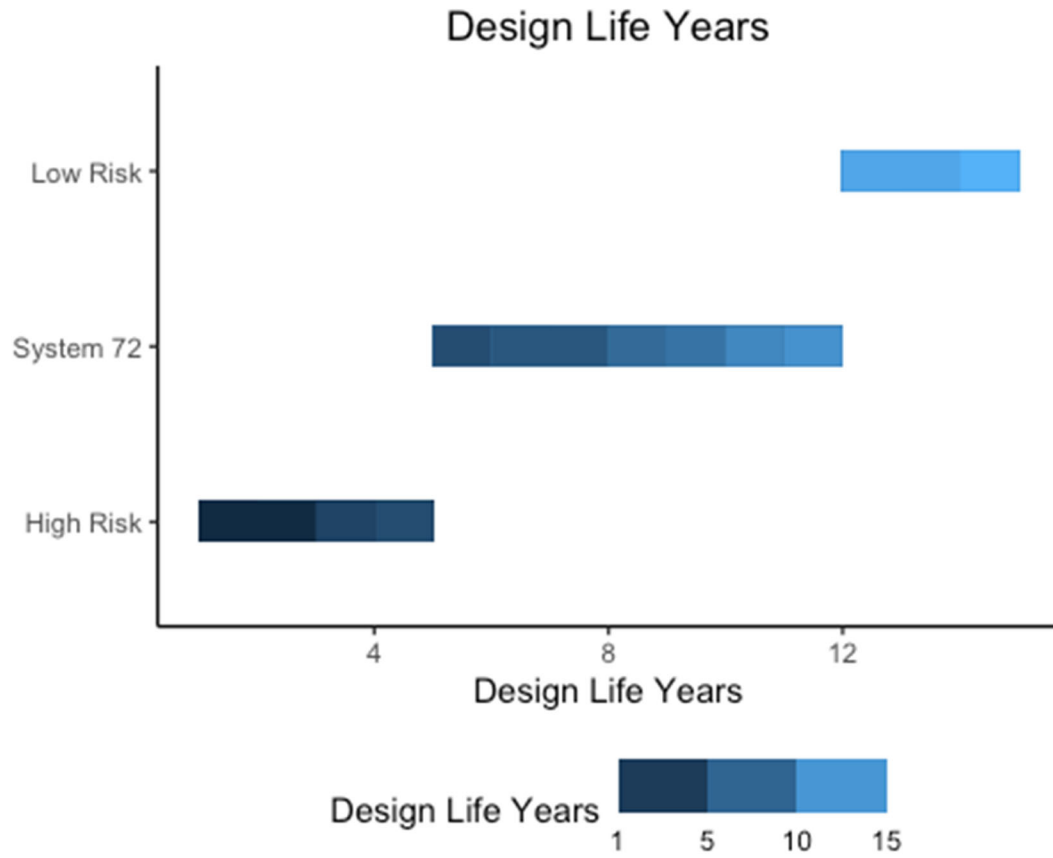
```
PR72_simdata$System <- factor(PR72_simdata$System, levels=c("High Risk",  
"System 72",  
"Low Risk"))
```

```
ggplot(PR72_simdata, aes(x = System, y = CostGrowth)) +  
  geom_line(aes(color = CostGrowth, size = 6)) +  
  scale_color_gradient() +  
  labs(y = "Cost Growth %", x = "", color = "Cost Growth %") +  
  theme_classic() +  
  guides(color = guide_colorsteps(show.limits = TRUE)) +  
  coord_flip() +  
  theme(legend.position = "bottom") +
```

```
ggtitle("Obsolescence Cost Growth %") +
ggeasy::easy_center_title()
```



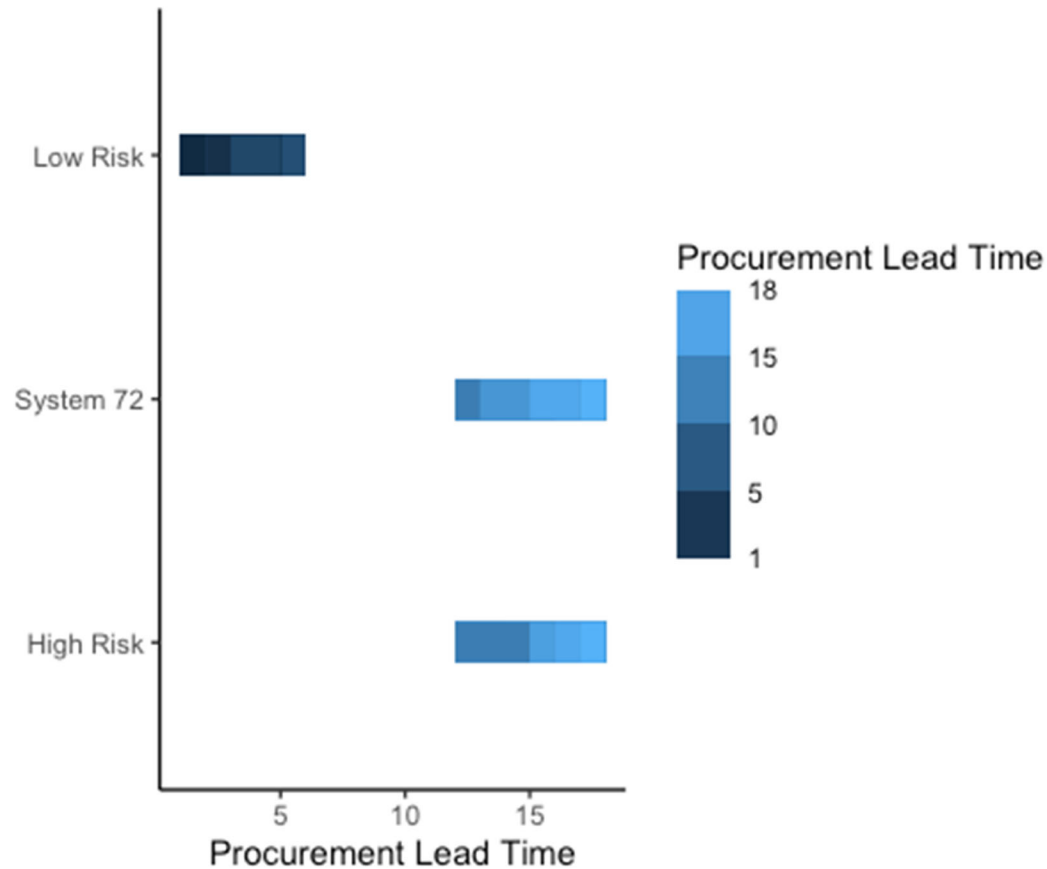
```
ggplot(PR72_simdata, aes(x = System, y = DY)) +
geom_line(aes(color = DY), size = 6) +
scale_color_gradient() +
labs(y = "Design Life Years", x = "", color = "Design Life Years") +
theme_classic() +
guides(color = guide_colorsteps(show.limits = TRUE)) +
coord_flip() +
theme(legend.position = "bottom") +
ggtitle("Design Life Years") +
ggeasy::easy_center_title()
```



```

ggplot(PR72_simdata, aes(x = System, y = PLT)) +
  geom_line(aes(color = PLT), size = 6) +
  scale_color_gradient() +
  labs(y = "Procurement Lead Time", x = "", color = "Procurement Lead Time") +
  theme_classic() +
  guides(color = guide_colorsteps(show.limits = TRUE)) +
  coord_flip()

```



```

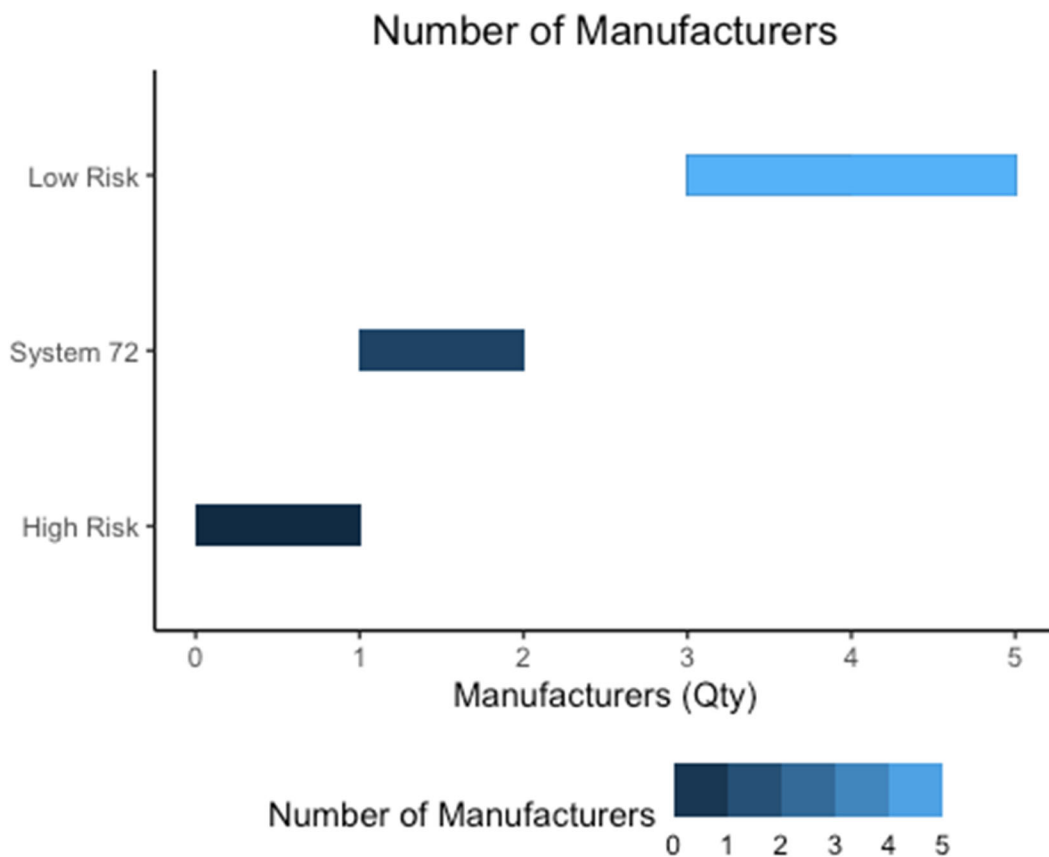
theme(legend.position = "bottom") +
  ggtitle("Procurement Lead Time (Months)") +
  ggeasy::easy_center_title()

## List of 3
## $ legend.position: chr "bottom"
## $ title       : chr "Procurement Lead Time (Months)"
## $ plot.title  :List of 11
## ..$ family    : NULL
## ..$ face      : NULL
## ..$ colour    : NULL
## ..$ size      : NULL
## ..$ hjust     : num 0.5
## ..$ vjust     : NULL
## ..$ angle     : NULL
## ..$ lineheight : NULL
## ..$ margin    : NULL
## ..$ debug     : NULL
## ..$ inherit.blank: logi FALSE
## ..- attr(*, "class")= chr [1:2] "element_text" "element"
## - attr(*, "class")= chr [1:2] "theme" "gg"

```

```
## - attr(*, "complete")= logi FALSE
## - attr(*, "validate")= logi TRUE

ggplot(PR72_simdata, aes(x = System, y = NumberofManf)) +
  geom_line(aes(color = NumberofManf, size = 6)) +
  scale_color_gradient() +
  labs(y = "Manufacturers (Qty)", x = "", color = "Number of Manufacturers") +
  theme_classic() +
  guides(color = guide_colorsteps(show.limits = TRUE)) +
  coord_flip() +
  theme(legend.position = "bottom") +
  ggtitle("Number of Manufacturers") +
  ggeasy::easy_center_title()
```



```
PR72CostPlot <- ggplot(PR72_simdata, aes(x = System, y = CostGrowth)) +
  geom_line(aes(color = CostGrowth, size = 6)) +
  scale_color_gradient() +
  labs(y = "Cost Growth %", x = "", color = "Cost Growth %") +
  theme_classic() +
  guides(color = guide_colorsteps(show.limits = TRUE)) +
  coord_flip() +
  theme(legend.position = "bottom") +
```

```

ggtitle("Obsolescence Cost Growth %") +
ggeasy::easy_center_title()

PR72DesignPlot <- ggplot(PR72_simdata, aes(x = System, y = DY)) +
  geom_line(aes(color = DY), size = 6) +
  scale_color_gradient() +
  labs(y = "Design Life Years", x = "", color = "Design Life Years") +
  theme_classic() +
  guides(color = guide_colorsteps(show.limits = TRUE)) +
  coord_flip() +
  theme(legend.position = "bottom") +
  ggtitle("Design Life Years Before Obsolescence") +
  ggeasy::easy_center_title()

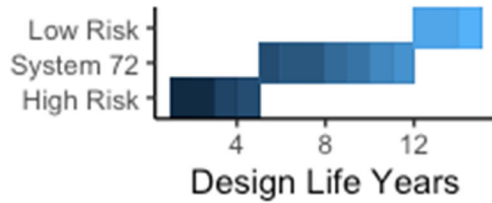
PR72PLTPlot <- ggplot(PR72_simdata, aes(x = System, y = PLT)) +
  geom_line(aes(color = PLT), size = 6) +
  scale_color_gradient() +
  labs(y = "Procurement Lead Time", x = "", color = "Procurement Lead Time") +
  theme_classic() +
  guides(color = guide_colorsteps(show.limits = TRUE)) +
  coord_flip() +
  theme(legend.position = "bottom") +
  ggtitle("Procurement Lead Time (Months)") +
  ggeasy::easy_center_title()

PR72ManfPlot <- ggplot(PR72_simdata, aes(x = System, y = NumberofManf)) +
  geom_line(aes(color = NumberofManf), size = 6) +
  scale_color_gradient() +
  labs(y = "Manufacturers (Qty)", x = "", color = "Number of Manufacturers") +
  theme_classic() +
  coord_flip() +
  guides(color = guide_colorsteps(show.limits = TRUE)) +
  theme(legend.position = "bottom") +
  ggtitle("Number of Manufacturers") +
  ggeasy::easy_center_title()

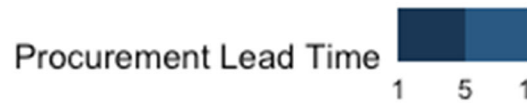
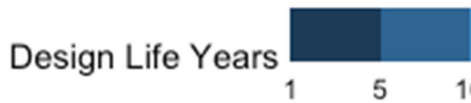
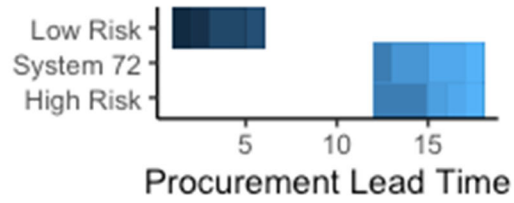
ggarrange(PR72DesignPlot, PR72PLTPlot, PR72CostPlot, PR72ManfPlot, legend = "bottom")

```

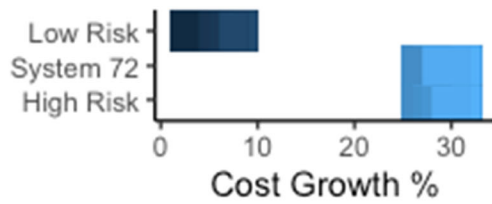
Design Life Years Before Obsc



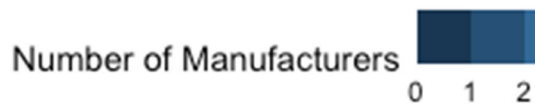
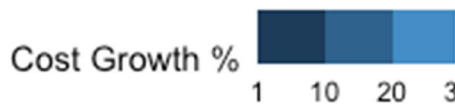
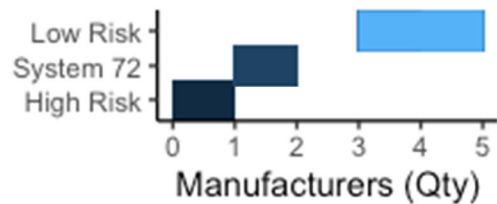
Procurement Lead Time (M



Obsolescence Cost Grow



Number of Manufacture



```
ggsave("Plot_System72.png", width = 12, height = 8, units = "in", dpi = 300)
```

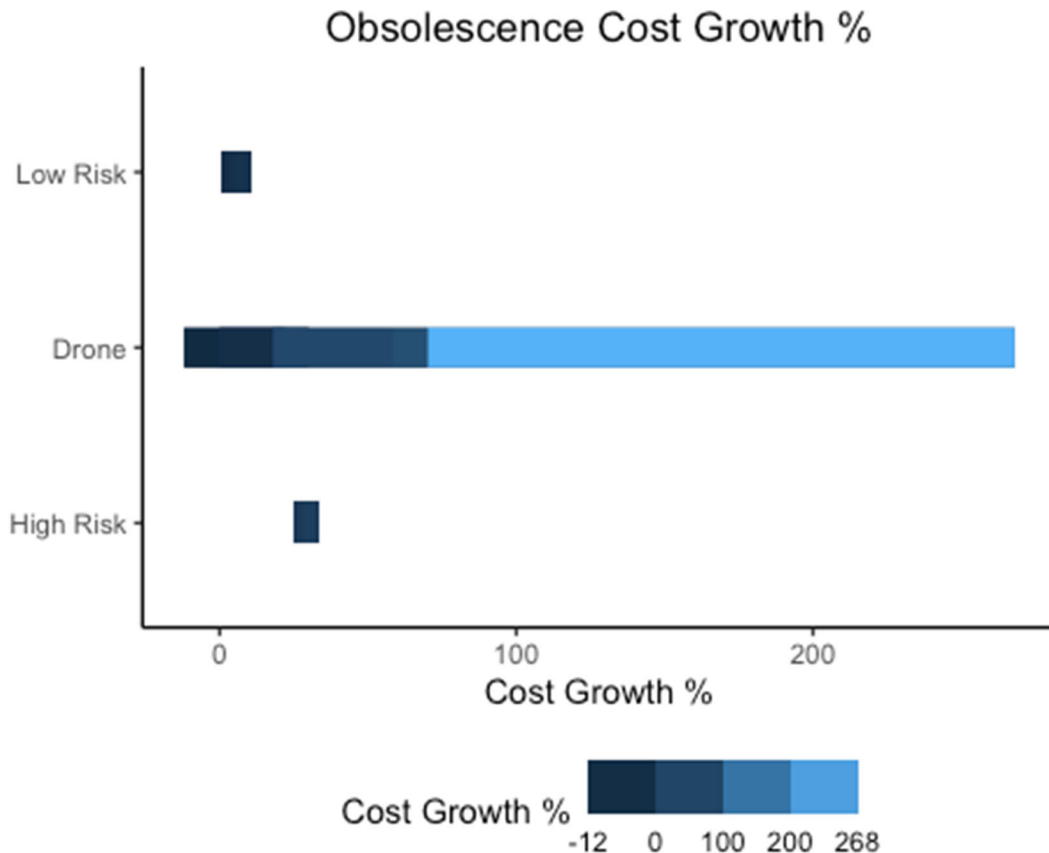
```
##### Begin Drone Example #####
#####
#
#####
#
#####
#
## Drone System data for plot
dronedata2 <- combine(proactive_simdata, dronedata, reactive_simdata)
dronedata2$PLT <- as.numeric(round(dronedata2$PLT, digits = 0))
dronedata2$DY <- as.numeric(round(dronedata2$DY, digits = 1))
dronedata2$CostGrowth <- as.numeric(round(dronedata2$CostGrowth, digits = 0))
as_factor(dronedata2$NumberofManf)

dronedata2$System <- factor(dronedata2$System, levels=c("High Risk",
              "Drone",
              "Low Risk"))
ggplot(dronedata2, aes(x = System, y = CostGrowth)) +
  geom_line(aes(color = CostGrowth, size = 6)) +
  scale_color_gradient() +
```

```

labs(y = "Cost Growth %", x = "", color = "Cost Growth %") +
theme_classic() +
scale_fill_continuous(limits = c(0,300), breaks = c(0, 50, 100, 150, 200, 250, 300),
                      labels = c(0, 50, 100, 150, 200, 250, 300)) +
guides(color = guide_colorsteps(show.limits = TRUE)) +
coord_flip() +
theme(legend.position = "bottom") +
ggtitle("Obsolescence Cost Growth %") +
ggeasy::easy_center_title()

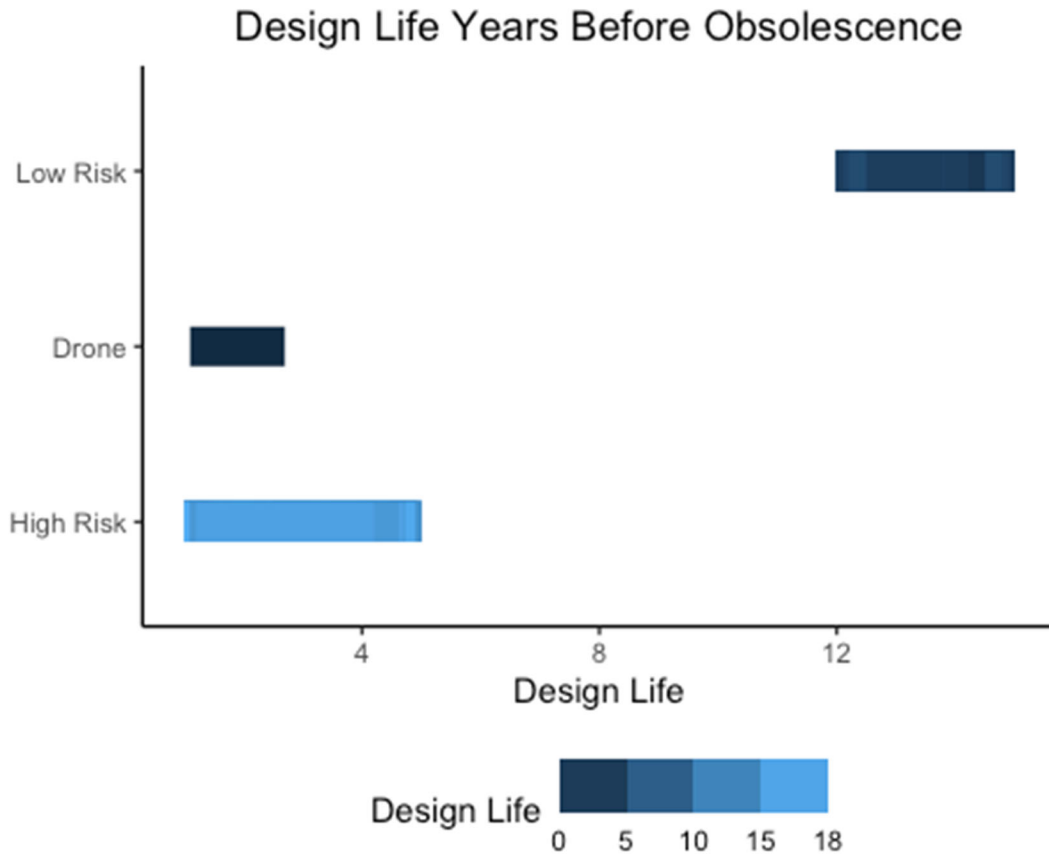
```



```

ggplot(dronedata2, aes(x = System, y = DY)) +
geom_line(aes(color = PLT), size = 6) +
scale_color_gradient() +
labs(y = "Design Life", x = "", color = "Design Life") +
theme_classic() +
scale_fill_continuous(limits = c(0, 20), breaks = c(0, 5, 10, 15, 20)) +
guides(color = guide_colorsteps(show.limits = TRUE)) +
coord_flip() +
theme(legend.position = "bottom") +
ggtitle("Design Life Years Before Obsolescence") +
ggeasy::easy_center_title()

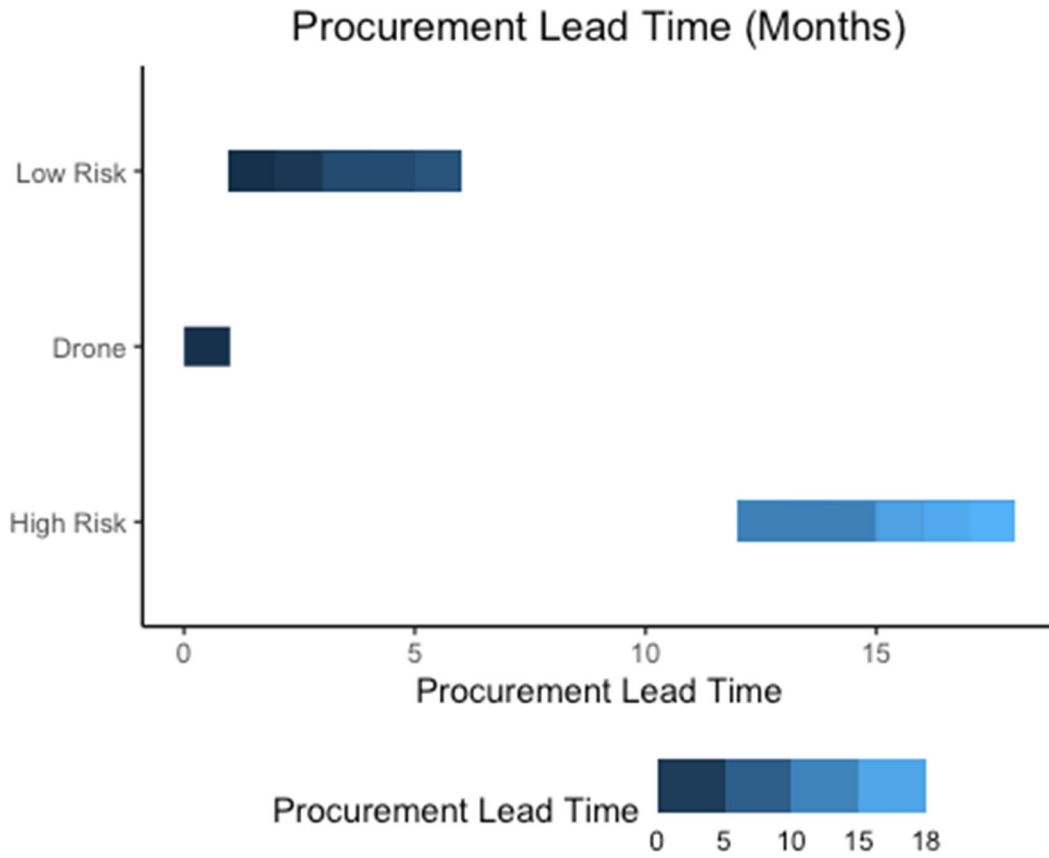
```



```

ggplot(dronedata2, aes(x = System, y = PLT)) +
  geom_line(aes(color = PLT), size = 6) +
  scale_color_gradient() +
  labs(y = "Procurement Lead Time", x = "", color = "Procurement Lead Time") +
  theme_classic() +
  scale_fill_continuous(limits = c(0, 20), breaks = c(0, 5, 10, 15, 20)) +
  guides(color = guide_colorsteps(show.limits = TRUE)) +
  coord_flip() +
  theme(legend.position = "bottom") +
  ggtitle("Procurement Lead Time (Months)") +
  ggeasy::easy_center_title()

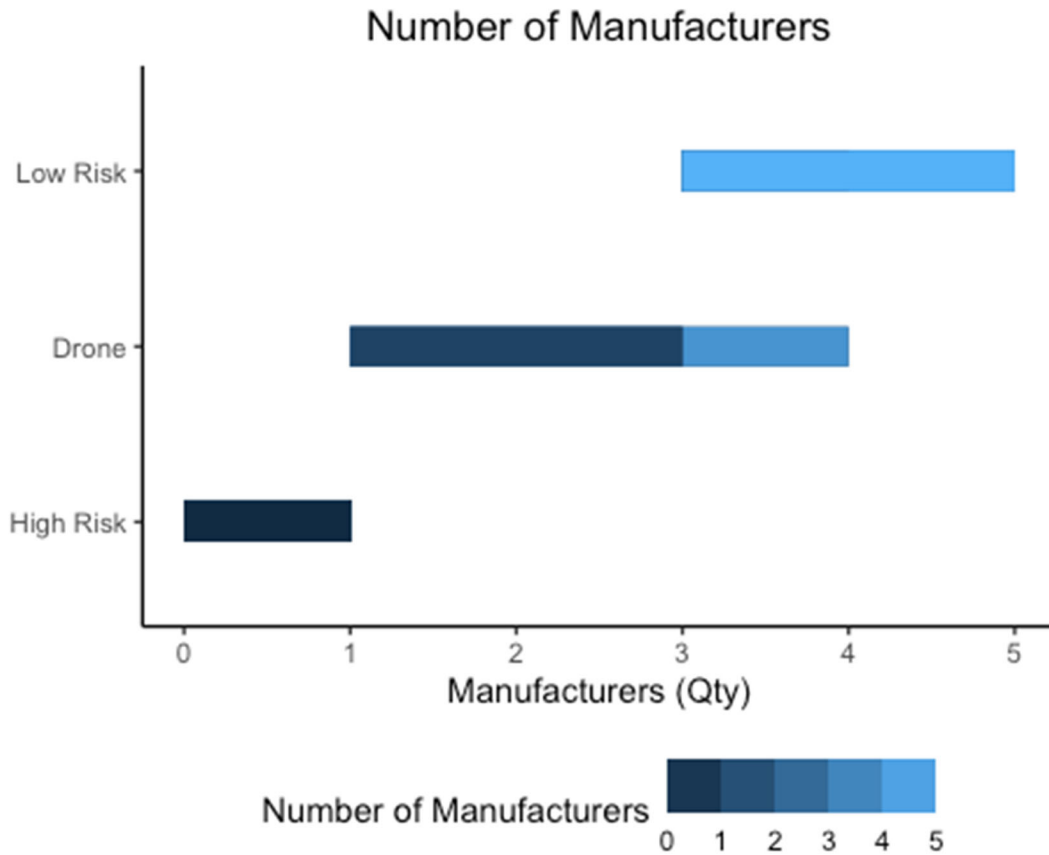
```



```

ggplot(dronedata2, aes(x = System, y = NumberofManf)) +
  geom_line(aes(color = NumberofManf), size = 6) +
  scale_color_gradient() +
  labs(y = "Manufacturers (Qty)", x = "", color = "Number of Manufacturers") +
  theme_classic() +
  guides(color = guide_colorsteps(show.limits = TRUE)) +
  coord_flip() +
  theme(legend.position = "bottom") +
  ggtitle("Number of Manufacturers") +
  ggeasy::easy_center_title()

```



```
DroneCostPlot <- ggplot(dronedata2, aes(x = System, y = CostGrowth)) +
  geom_line(aes(color = CostGrowth), size = 6) +
  scale_color_gradient() +
  labs(y = "Cost Growth %", x = "", color = "Cost Growth %") +
  theme_classic() +
  scale_fill_continuous(limits = c(0,300), breaks = c(0, 50, 100, 150, 200, 250, 300),
    labels = c(0, 50, 100, 150, 200, 250, 300)) +
  guides(color = guide_colorsteps(show.limits = TRUE)) +
  coord_flip() +
  theme(legend.position = "bottom") +
  ggtitle("Obsolescence Cost Growth %") +
  ggeasy::easy_center_title()
```

```
DroneDesignPlot <- ggplot(dronedata2, aes(x = System, y = DY)) +
  geom_line(aes(color = DY), size = 6) +
  scale_color_gradient() +
  labs(y = "Design Life Years", x = "", color = "Design Life Years") +
  theme_classic() +
  scale_fill_continuous(limits = c(0, 20), breaks = c(0, 5, 10, 15, 20)) +
  guides(color = guide_colorsteps(show.limits = TRUE)) +
  coord_flip() +
```

```

theme(legend.position = "bottom") +
ggtitle("Design Life Years Before Obsolescence") +
ggeasy::easy_center_title()

```

```

DronePLTPlot <- ggplot(dronedata2, aes(x = System, y = PLT)) +
geom_line(aes(color = PLT), size = 6) +
scale_color_gradient() +
labs(y = "Procurement Lead Time", x = "", color = "Procurement Lead Time") +
theme_classic() +
scale_fill_continuous(limits = c(0, 20), breaks = c(0, 5, 10, 15, 20)) +
guides(color = guide_colorsteps(show.limits = TRUE)) +
coord_flip() +
theme(legend.position = "bottom") +
ggtitle("Procurement Lead Time (Months)") +
ggeasy::easy_center_title()

```

```

DroneManfPlot <- ggplot(dronedata2, aes(x = System, y = NumberofManf)) +
geom_line(aes(color = NumberofManf), size = 6) +
scale_color_gradient() +
labs(y = "Manufacturers (Qty)", x = "", color = "Number of Manufacturers") +
theme_classic() +
guides(color = guide_colorsteps(show.limits = TRUE)) +
coord_flip() +
theme(legend.position = "bottom") +
ggtitle("Number of Manufacturers") +
ggeasy::easy_center_title()

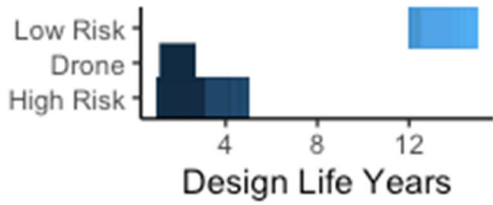
```

```

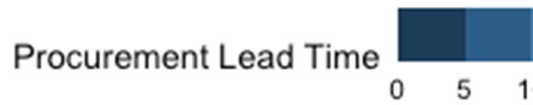
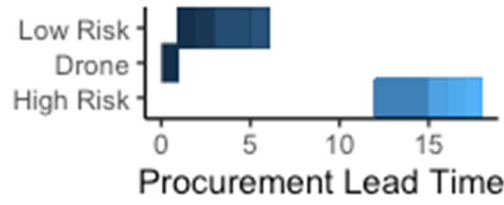
ggarrange(DroneDesignPlot, DronePLTPlot, DroneCostPlot, DroneManfPlot, legend = "bottom"
)

```

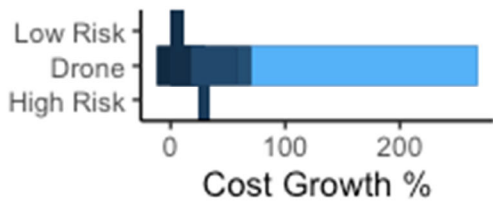
Design Life Years Before Obsc



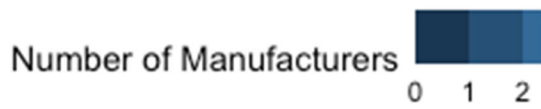
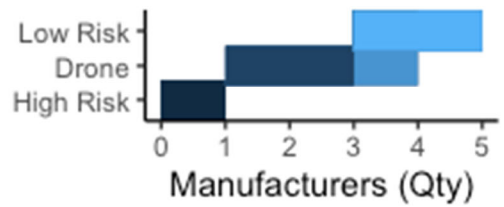
Procurement Lead Time (M



Obsolescence Cost Grow



Number of Manufacture



```
ggsave("Plot_Example_System.png", width = 12, height = 8, units = "in", dpi = 1000)
```

```
##### End Drone Example #####
#####
#
#####
#
#####
#
```

APPENDIX B: USER SURVEY

Qualtrics Survey Software

Consent

This survey will take approximately 15-25 minutes. Your participation is completely voluntary and you may withdraw from the survey at any point. Survey responses will be confidential and data from this research will be reported only in the aggregate. Your responses will be anonymous. There are no known risks or direct benefits to you, but we hope to gain more knowledge on using visualizations to assist with managing obsolescence for Command, Control, Communications, Computers, Cyber, Intelligence, Surveillance, and Reconnaissance Systems.

Demographics

Please indicate your employment area?

- Government (Army)
- Industry

Please indicate your area of professional expertise:

- Engineering
- Logistics
- Project Management
- Resource Management
- Other

How many years of experience do you have in your area of expertise?

- < 1 year
- 1-5 years
- 6-10 years
- 11-14 years
- 15+ years

Please indicate your gender:

- Male
- Female
- Non-binary / third gender
- Prefer not to say

Obsolescence Data & Visualization

Please use the following table and information for System 9 to answer the following question.

Relative Risk Level	System Component Property			
	Design Life (years)	Procurement Lead Time (months)	Cost Growth (%)	Manufacturers (N)
Low	> 12	< 6	< 10	≥ 3
Medium	5 – 12	6 – 12	10 – 25	2
High	< 5	> 12	> 25	0 – 1

System	Component	Design Life (years)	Procurement Lead Time (months)	Cost Growth (%)	Manufacturers (N)
System 9	Component 1	10.20	5.32	18.64	2
System 9	Component 2	13.65	3.10	15.74	1
System 9	Component 3	14.50	2.16	18.64	2
System 9	Component 4	12.71	5.44	24.95	2
System 9	Component 5	13.60	2.87	18.67	2
System 9	Component 6	12.09	3.50	23.45	2
System 9	Component 7	10.40	3.95	12.86	1
System 9	Component 8	12.88	1.89	24.87	2
System 9	Component 9	12.62	1.25	10.41	2
System 9	Component 10	13.29	1.30	19.91	1

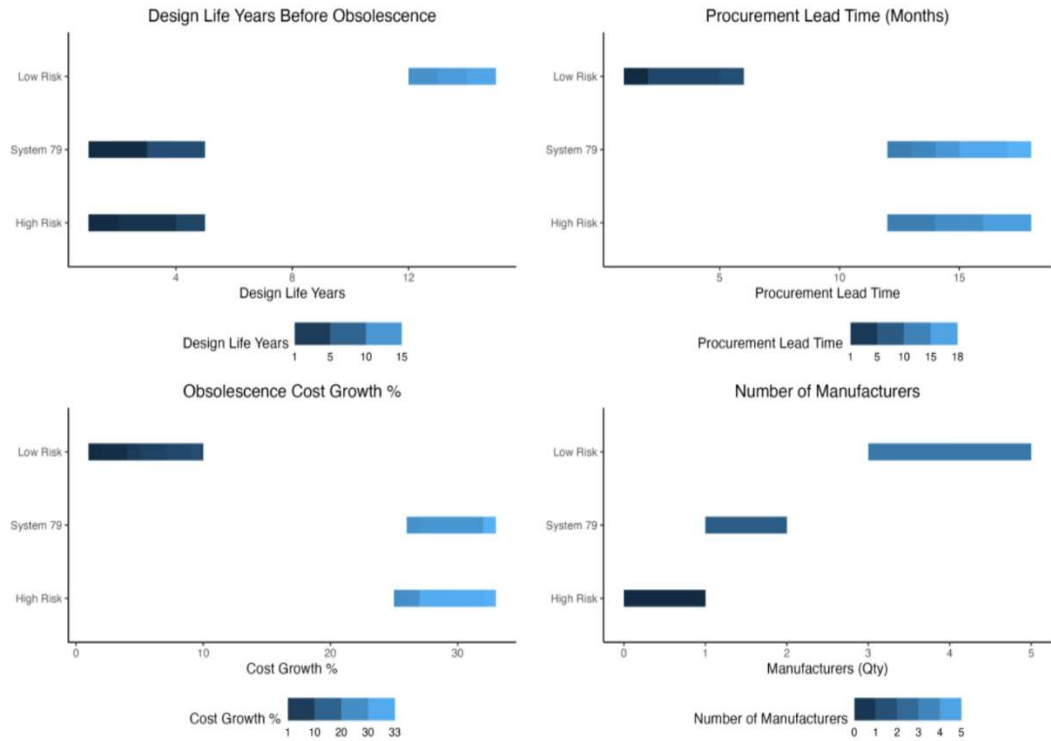
How risky do you find the Design Life (years) of System 9?

- Low Risk
- Medium Risk
- High Risk

How confident are you in your answer of System 9's Design Life (years) risk?

- Extremely Unconfident
- Somewhat Unconfident
- Neutral
- Somewhat Confident
- Extremely Confident

Please use the following visualization and legend for System 79 to answer the following question. There are high risk and low risk references to guide you at the top and bottom of each quadrant; as an aid to visually lineup a system with its level of risk.



How risky do you find the Obsolescence Cost Growth % of System 79?

- Low Risk
- Medium Risk
- High Risk

How confident are you in your answer of System 79's Obsolescence Cost Growth % risk?

- Extremely Unconfident
- Somewhat Unconfident
- Neutral
- Somewhat Confident
- Extremely Confident

Please use the following table and information for System 18 to answer the following question.

Relative Risk Level	System Component Property			
	Design Life (years)	Procurement Lead Time (months)	Cost Growth (%)	Manufacturers (N)
Low	> 12	< 6	< 10	≥ 3
Medium	5 – 12	6 – 12	10 – 25	2
High	< 5	> 12	> 25	0 – 1

System	Component	Design Life (years)	Procurement Lead Time (months)	Cost Growth (%)	Manufacturers (N)
System 18	Component 1	11.99	15.20	31.82	5
System 18	Component 2	12.01	9.90	30.82	5
System 18	Component 3	11.99	6.50	32.06	5
System 18	Component 4	13.52	7.56	27.46	5
System 18	Component 5	14.76	15.05	28.87	4
System 18	Component 6	12.65	6.66	32.78	5
System 18	Component 7	14.79	10.53	29.32	4
System 18	Component 8	14.01	8.58	28.12	3
System 18	Component 9	14.91	9.09	31.72	3
System 18	Component 10	13.60	15.50	30.73	5
System 18	Component 11	13.85	6.84	28.43	4
System 18	Component 12	14.13	7.93	31.39	5
System 18	Component 13	12.01	11.57	29.24	4
System 18	Component 14	13.84	8.27	29.15	3
System 18	Component 15	12.01	15.30	30.09	3
System 18	Component 16	14.21	11.07	26.07	4
System 18	Component 17	14.56	7.45	30.56	5
System 18	Component 18	14.16	11.10	28.26	3
System 18	Component 19	12.76	7.31	30.79	3
System 18	Component 20	12.01	15.00	26.76	4
System 18	Component 21	13.13	11.80	28.34	3
System 18	Component 22	14.18	6.01	30.22	3
System 18	Component 23	14.02	8.99	33.11	4
System 18	Component 24	13.69	9.04	32.86	5
System 18	Component 25	11.99	15.09	29.36	4

How risky do you find the Procurement Lead Time (months) of System 18?

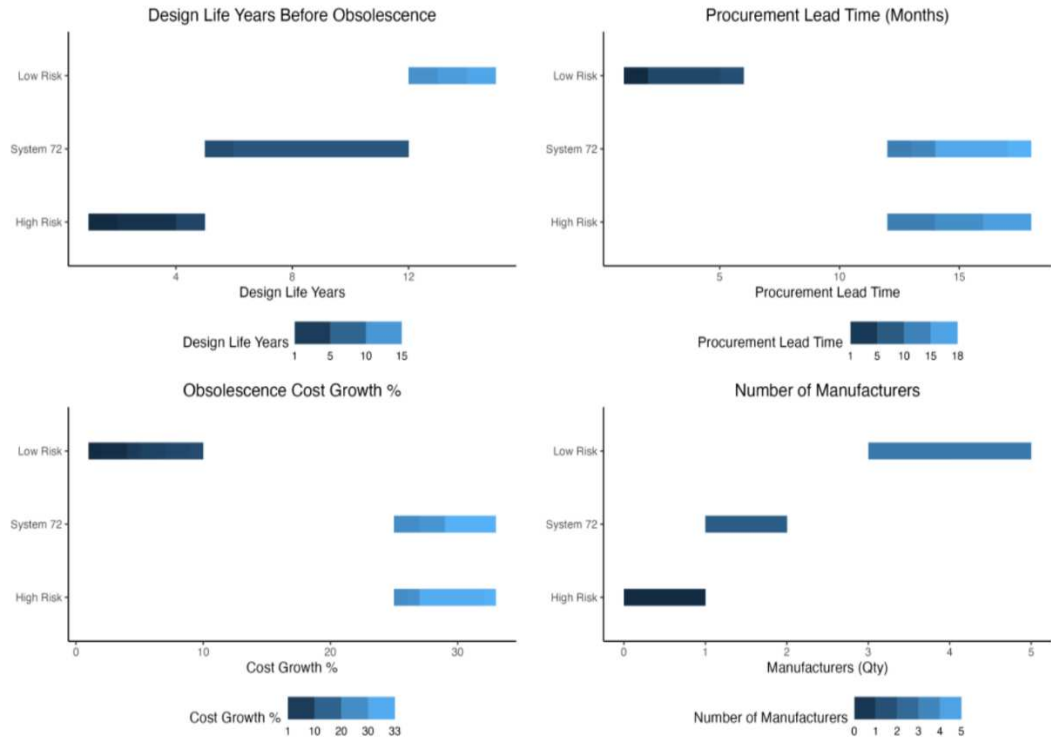
How confident are you in your answer of System 18's Procurement Lead Time (months) risk?

- Low Risk
- Medium Risk
- High Risk

How confident are you in your answer of System 18's Procurement Lead Time (months) risk?

- Extremely Unconfident
- Somewhat Unconfident
- Neutral
- Somewhat Confident
- Extremely Confident

Please use the following visualization and legend for System 72 to answer the following question. There are high risk and low risk references to guide you at the top and bottom of each quadrant; as an aid to visually lineup a system with its level of risk.



How risky do you find the Number of Manufacturers of System 72?

- Low Risk
- Medium Risk
- High Risk

How confident are you in your answer of System 72's Number of Manufacturers risk?

- Extremely Unconfident
- Somewhat Unconfident
- Neutral
- Somewhat Confident
- Extremely Confident

Please use the following table and information for System 27 to answer the following question.

Relative Risk Level	System Component Property			
	Design Life (years)	Procurement Lead Time (months)	Cost Growth (%)	Manufacturers (N)
Low	> 12	< 6	< 10	≥ 3
Medium	5 – 12	6 – 12	10 – 25	2
High	< 5	> 12	> 25	0 – 1

System	Component	Design Life (years)	Procurement Lead Time (months)	Cost Growth (%)	Manufacturers (N)
System 27	Component 1	10.00	4.75	30.71	0
System 27	Component 2	12.01	5.94	31.60	0
System 27	Component 3	12.05	3.90	27.39	0
System 27	Component 4	11.99	2.50	28.05	0
System 27	Component 5	10.05	3.16	31.47	1
System 27	Component 6	13.95	2.12	31.76	0
System 27	Component 7	12.91	4.17	25.39	1
System 27	Component 8	13.68	1.86	27.47	1
System 27	Component 9	11.99	2.41	29.62	0
System 27	Component 10	10.20	5.26	32.11	0
System 27	Component 11	14.28	3.25	28.92	1
System 27	Component 12	11.99	5.68	31.01	1
System 27	Component 13	12.74	5.08	30.27	0
System 27	Component 14	14.10	3.37	27.46	0
System 27	Component 15	10.85	5.39	27.33	1
System 27	Component 16	12.46	4.87	25.91	0
System 27	Component 17	14.57	5.85	27.14	1
System 27	Component 18	12.22	4.22	25.05	0
System 27	Component 19	13.00	2.55	29.51	0
System 27	Component 20	10.25	2.53	26.13	0
System 27	Component 21	13.31	3.64	28.42	1
System 27	Component 22	13.41	2.62	33.02	0
System 27	Component 23	12.62	5.16	25.62	1
System 27	Component 24	14.67	3.69	30.22	1
System 27	Component 25	10.11	4.58	30.61	0
System 27	Component 26	12.07	3.60	26.38	1
System 27	Component 27	14.85	3.76	29.56	0
System 27	Component 28	12.03	1.08	32.38	0
System 27	Component 29	14.83	3.92	32.79	1

System 27	Component 30	10.62	3.69	32.45	0
System 27	Component 31	14.85	2.76	28.44	0
System 27	Component 32	14.96	2.19	26.23	1
System 27	Component 33	14.37	4.66	32.44	1
System 27	Component 34	13.05	3.97	26.78	0
System 27	Component 35	9.95	3.66	30.10	0
System 27	Component 36	14.40	4.54	25.59	1
System 27	Component 37	14.94	1.46	26.12	0
System 27	Component 38	12.69	1.79	32.58	0
System 27	Component 39	14.92	2.49	32.85	0
System 27	Component 40	12.04	1.84	25.50	0
System 27	Component 41	14.23	2.91	32.05	0
System 27	Component 42	14.01	5.92	26.79	0
System 27	Component 43	12.59	3.30	28.37	0
System 27	Component 44	13.93	3.15	32.65	1
System 27	Component 45	10.60	4.69	25.05	0
System 27	Component 46	12.49	5.17	28.91	1
System 27	Component 47	14.20	4.51	29.63	0
System 27	Component 48	12.17	3.55	32.15	1
System 27	Component 49	14.58	1.45	31.31	1
System 27	Component 50	9.90	3.24	33.03	0

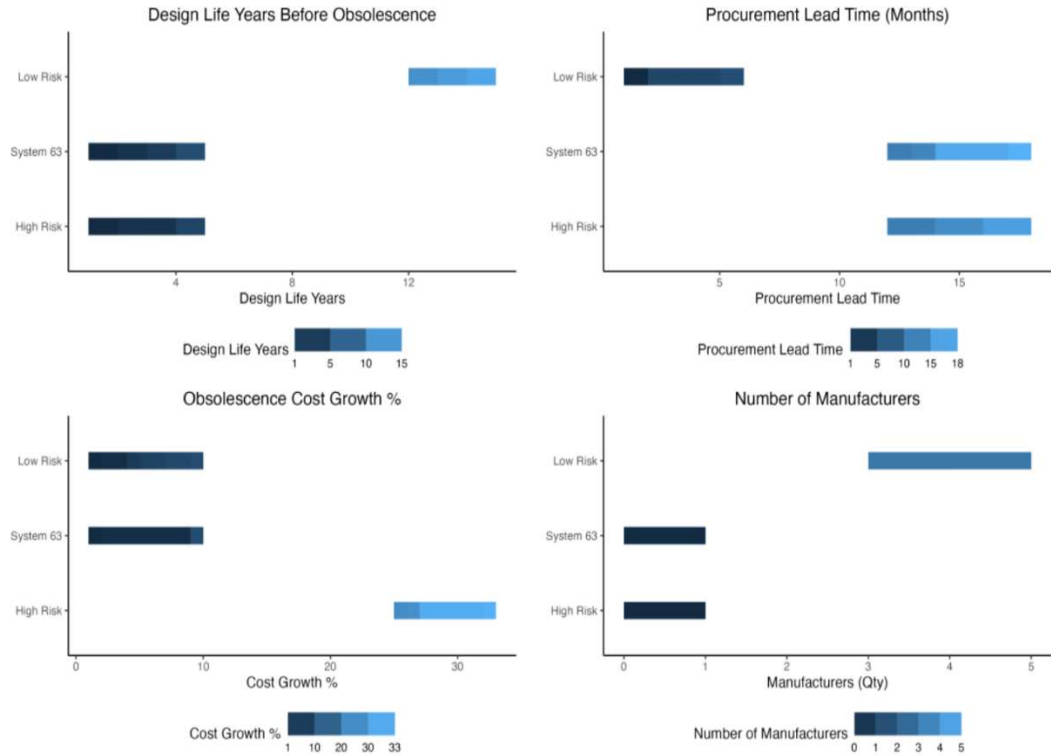
How risky do you find the Design Life (years) of System 27?

- Low Risk
- Medium Risk
- High Risk

How confident are you in your answer of System 27's Design Life (years) risk?

- Extremely Unconfident
- Somewhat Unconfident
- Neutral
- Somewhat Confident
- Extremely Confident

Please use the following visualization and legend for System 63 to answer the following question. There are high risk and low risk references to guide you at the top and bottom of each quadrant; as an aid to visually lineup a system with its level of risk.



How risky do you find the Procurement Lead Time (months) of System 63?

- Low Risk
- Medium Risk
- High Risk

How confident are you in your answer of System 63's Procurement Lead Time (months) risk?

- Extremely Unconfident
- Somewhat Unconfident
- Neutral
- Somewhat Confident
- Extremely Confident

Please use the following table and information for System 36 to answer the following question.

Relative Risk Level	System Component Property			
	Design Life (years)	Procurement Lead Time (months)	Cost Growth (%)	Manufacturers (N)
Low	> 12	< 6	< 10	≥ 3
Medium	5 – 12	6 – 12	10 – 25	2
High	< 5	> 12	> 25	0 – 1

System	Component	Design Life (years)	Procurement Lead Time (months)	Cost Growth (%)	Manufacturers (N)
System 36	Component 1	9.17	7.62	19.51	2
System 36	Component 2	11.86	7.62	22.80	5
System 36	Component 3	5.27	6.93	20.31	4
System 36	Component 4	11.63	9.25	15.58	3
System 36	Component 5	10.25	7.41	11.93	2
System 36	Component 6	5.83	10.76	15.85	5
System 36	Component 7	5.41	8.86	24.42	5
System 36	Component 8	6.71	9.79	21.32	5
System 36	Component 9	9.32	6.58	24.66	5
System 36	Component 10	8.85	10.92	22.51	2
System 36	Component 11	7.44	10.24	18.35	4
System 36	Component 12	6.16	10.28	10.41	4
System 36	Component 13	9.12	11.65	15.23	4
System 36	Component 14	10.71	7.35	14.24	4
System 36	Component 15	8.24	8.78	13.91	2
System 36	Component 16	5.26	11.32	12.90	4
System 36	Component 17	7.30	10.11	24.85	3
System 36	Component 18	11.59	9.02	23.82	5
System 36	Component 19	9.93	8.48	22.43	5
System 36	Component 20	8.83	7.08	13.57	2
System 36	Component 21	9.34	9.95	14.96	4
System 36	Component 22	10.09	10.07	12.55	5
System 36	Component 23	8.40	7.61	19.34	5
System 36	Component 24	11.47	9.34	12.12	4
System 36	Component 25	11.52	9.34	24.56	2
System 36	Component 26	11.44	11.57	10.65	2
System 36	Component 27	6.73	7.44	22.12	3
System 36	Component 28	7.10	6.75	18.71	5
System 36	Component 29	7.79	10.90	22.18	3
System 36	Component 30	11.50	10.69	19.20	5

System 36	Component 31	8.73	9.85	13.77	5
System 36	Component 32	8.09	6.61	18.69	4
System 36	Component 33	11.39	10.94	15.03	3
System 36	Component 34	6.92	6.22	23.99	5
System 36	Component 35	9.76	11.86	12.05	2
System 36	Component 36	9.41	6.32	15.74	5
System 36	Component 37	10.10	8.84	19.05	3
System 36	Component 38	7.74	6.29	19.24	4
System 36	Component 39	8.76	7.86	16.07	5
System 36	Component 40	11.70	8.33	10.06	2
System 36	Component 41	11.07	9.93	23.25	5
System 36	Component 42	5.89	8.71	20.60	3
System 36	Component 43	10.44	9.69	14.73	4
System 36	Component 44	10.13	10.04	10.04	4
System 36	Component 45	9.64	11.45	24.04	2
System 36	Component 46	9.89	11.74	23.07	3
System 36	Component 47	6.19	10.93	11.26	3
System 36	Component 48	9.62	10.19	12.29	5
System 36	Component 49	10.24	9.37	22.25	5
System 36	Component 50	10.21	10.78	22.61	2
System 36	Component 51	5.08	8.41	19.77	2
System 36	Component 52	6.81	9.59	22.47	5
System 36	Component 53	6.77	8.63	19.81	3
System 36	Component 54	10.59	11.98	23.78	3
System 36	Component 55	6.21	9.69	11.23	4
System 36	Component 56	9.21	10.06	18.44	4
System 36	Component 57	11.11	9.55	17.98	3
System 36	Component 58	11.76	8.34	23.68	4
System 36	Component 59	5.81	10.01	20.62	5
System 36	Component 60	11.65	6.05	21.64	2
System 36	Component 61	9.72	11.60	14.30	4
System 36	Component 62	5.21	11.37	24.82	5
System 36	Component 63	8.06	9.37	11.99	4
System 36	Component 64	10.37	9.01	12.80	4
System 36	Component 65	5.88	11.44	15.65	4
System 36	Component 66	11.63	7.22	18.80	3
System 36	Component 67	6.82	11.36	24.89	3
System 36	Component 68	10.31	8.20	14.43	3
System 36	Component 69	10.70	8.22	18.69	4
System 36	Component 70	9.98	6.78	20.24	2
System 36	Component 71	10.90	7.66	11.17	4
System 36	Component 72	11.39	8.27	11.02	3
System 36	Component 73	6.41	8.13	22.70	3
System 36	Component 74	9.60	6.46	12.22	4
System 36	Component 75	10.01	10.71	12.01	2

System 36	Component 75	10.01	10.71	12.51	2
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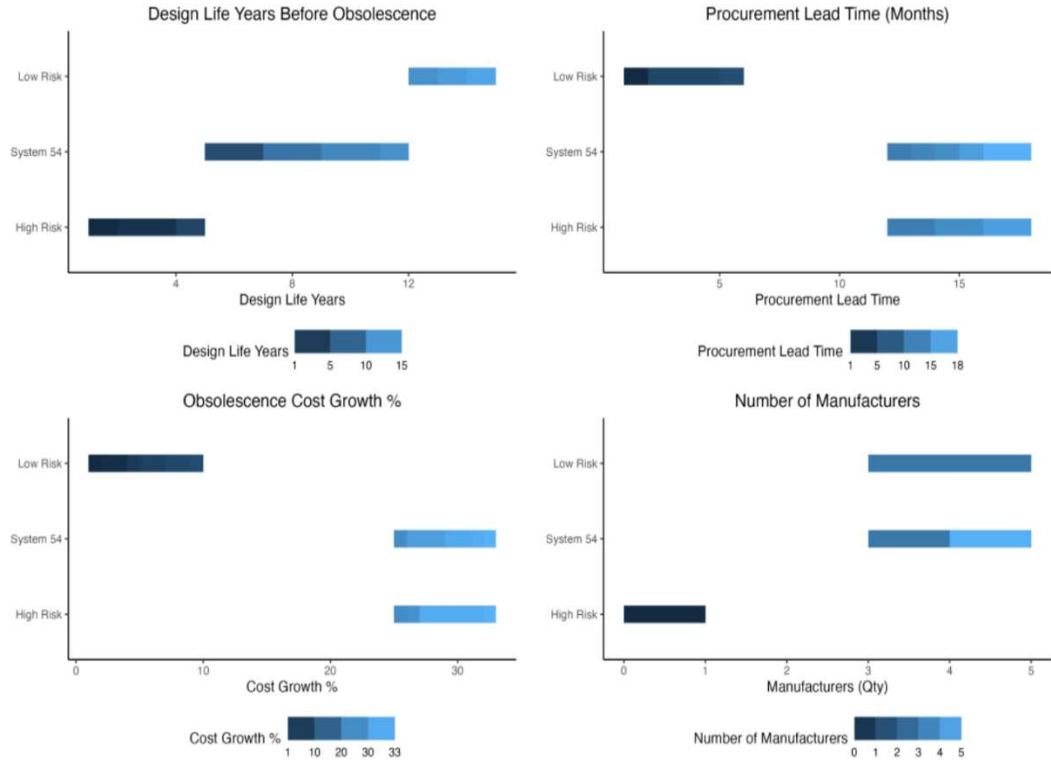
How risky do you find the Number of Manufacturers of System 36?

- Low Risk
- Medium Risk
- High Risk

How confident are you in your answer of System 36's Number of Manufacturers risk?

- Extremely Unconfident
- Somewhat Unconfident
- Neutral
- Somewhat Confident
- Extremely Confident

Please use the following visualization and legend for System 54 to answer the following question. There are high risk and low risk references to guide you at the top and bottom of each quadrant; as an aid to visually lineup a system with its level of risk.



How risky do you find the Design Life (years) of System 54?

- Low Risk
- Medium Risk
- High Risk

How confident are you in your answer of System 54's Design Life (years) risk?

- Extremely Unconfident
- Somewhat Unconfident
- Neutral
- Somewhat Confident
- Extremely Confident

Please use the following table and information for System 45 to answer the following question.

Relative Risk Level	System Component Property			
	Design Life (years)	Procurement Lead Time (months)	Cost Growth (%)	Manufacturers (N)
Low	> 12	< 6	< 10	≥ 3
Medium	5 – 12	6 – 12	10 – 25	2
High	< 5	> 12	> 25	0 – 1

System	Component	Design Life (years)	Procurement Lead Time (months)	Cost Growth (%)	Manufacturers (N)
System 45	Component 1	11.99	13.58	30.27	5
System 45	Component 2	7.65	13.96	19.52	4
System 45	Component 3	12.01	13.94	23.33	5
System 45	Component 4	5.36	17.19	13.10	4
System 45	Component 5	8.63	14.59	30.88	4
System 45	Component 6	11.73	17.81	12.64	4
System 45	Component 7	12.01	15.52	16.96	4
System 45	Component 8	6.87	13.38	19.72	4
System 45	Component 9	7.08	15.17	16.33	3
System 45	Component 10	6.83	12.03	30.68	4
System 45	Component 11	7.81	12.08	24.78	3
System 45	Component 12	7.01	17.66	17.22	5
System 45	Component 13	7.88	16.62	12.60	5
System 45	Component 14	7.43	12.79	10.17	3
System 45	Component 15	8.39	15.65	30.40	3
System 45	Component 16	9.65	15.51	11.75	3
System 45	Component 17	12.01	12.46	15.92	3
System 45	Component 18	5.48	16.76	24.30	4
System 45	Component 19	7.59	15.36	20.10	5
System 45	Component 20	9.17	16.78	30.33	5
System 45	Component 21	9.11	17.01	14.76	3
System 45	Component 22	5.64	17.40	21.76	5
System 45	Component 23	5.99	14.67	17.75	5
System 45	Component 24	9.79	15.03	22.34	5
System 45	Component 25	9.14	14.70	30.76	5
System 45	Component 26	11.51	17.54	30.08	3
System 45	Component 27	11.99	12.72	20.86	3
System 45	Component 28	10.04	14.34	16.45	5
System 45	Component 29	5.27	12.77	11.60	4
System 45	Component 30	10.31	15.12	30.90	4
System 45	Component 31	11.84	16.56	24.39	3

System 45	Component 32	10.18	15.80	11.23	5
System 45	Component 33	6.94	17.98	19.67	3
System 45	Component 34	8.36	16.94	10.28	4
System 45	Component 35	7.11	17.09	30.06	4
System 45	Component 36	11.20	14.22	13.30	4
System 45	Component 37	10.83	15.90	19.46	3
System 45	Component 38	6.78	16.51	22.02	5
System 45	Component 39	11.25	12.42	20.12	5
System 45	Component 40	8.14	15.85	30.28	3
System 45	Component 41	8.36	14.40	13.55	5
System 45	Component 42	5.94	12.19	10.59	4
System 45	Component 43	7.70	16.73	20.48	3
System 45	Component 44	8.20	17.80	10.77	3
System 45	Component 45	7.61	12.54	24.10	4
System 45	Component 46	5.49	12.25	15.94	5
System 45	Component 47	6.56	16.64	21.46	5
System 45	Component 48	5.43	13.87	19.64	5
System 45	Component 49	9.23	12.96	14.14	3
System 45	Component 50	10.68	14.11	30.93	4
System 45	Component 51	8.70	13.02	23.07	3
System 45	Component 52	6.83	15.92	22.57	4
System 45	Component 53	8.86	14.72	16.21	5
System 45	Component 54	10.38	16.16	23.57	5
System 45	Component 55	6.60	15.07	30.86	3
System 45	Component 56	10.86	16.82	19.98	4
System 45	Component 57	5.34	14.94	22.67	5
System 45	Component 58	10.40	15.47	23.41	4
System 45	Component 59	10.40	12.30	11.68	4
System 45	Component 60	7.29	13.95	30.70	4
System 45	Component 61	8.33	12.31	12.32	3
System 45	Component 62	7.07	12.88	24.30	4
System 45	Component 63	5.77	17.87	11.94	4
System 45	Component 64	8.41	17.02	24.14	5
System 45	Component 65	11.29	15.09	30.13	3
System 45	Component 66	6.50	12.61	24.50	4
System 45	Component 67	5.76	17.12	20.92	3
System 45	Component 68	8.10	13.33	21.40	3
System 45	Component 69	8.61	17.71	14.84	5
System 45	Component 70	8.85	15.52	30.88	4
System 45	Component 71	8.53	17.55	24.71	3
System 45	Component 72	8.74	17.89	19.86	4
System 45	Component 73	9.87	13.65	13.05	3
System 45	Component 74	5.64	13.81	14.92	5
System 45	Component 75	10.08	13.89	30.87	4
System 45	Component 76	6.56	13.17	30.90	4

System 45	Component 77	9.09	16.72	23.84	5
System 45	Component 78	10.14	17.57	24.01	5
System 45	Component 79	7.63	16.48	19.59	4
System 45	Component 80	6.97	17.00	30.41	4
System 45	Component 81	8.43	17.84	18.75	4
System 45	Component 82	10.25	14.97	16.91	5
System 45	Component 83	9.89	16.75	12.91	3
System 45	Component 84	6.10	13.94	22.70	3
System 45	Component 85	8.05	17.09	30.89	5
System 45	Component 86	8.87	15.73	22.24	5
System 45	Component 87	8.26	17.21	15.47	5
System 45	Component 88	9.05	16.36	19.33	4
System 45	Component 89	10.03	13.90	21.79	4
System 45	Component 90	7.99	17.12	19.20	3
System 45	Component 91	5.67	13.04	14.28	4
System 45	Component 92	6.38	17.57	10.13	5
System 45	Component 93	9.44	14.53	18.06	5
System 45	Component 94	10.15	12.35	15.05	5
System 45	Component 95	7.96	16.08	23.54	4
System 45	Component 96	11.98	17.64	24.89	5
System 45	Component 97	7.78	16.12	15.61	5
System 45	Component 98	9.69	14.22	15.91	4
System 45	Component 99	6.95	16.95	15.95	5
System 45	Component 100	6.83	17.10	30.01	4

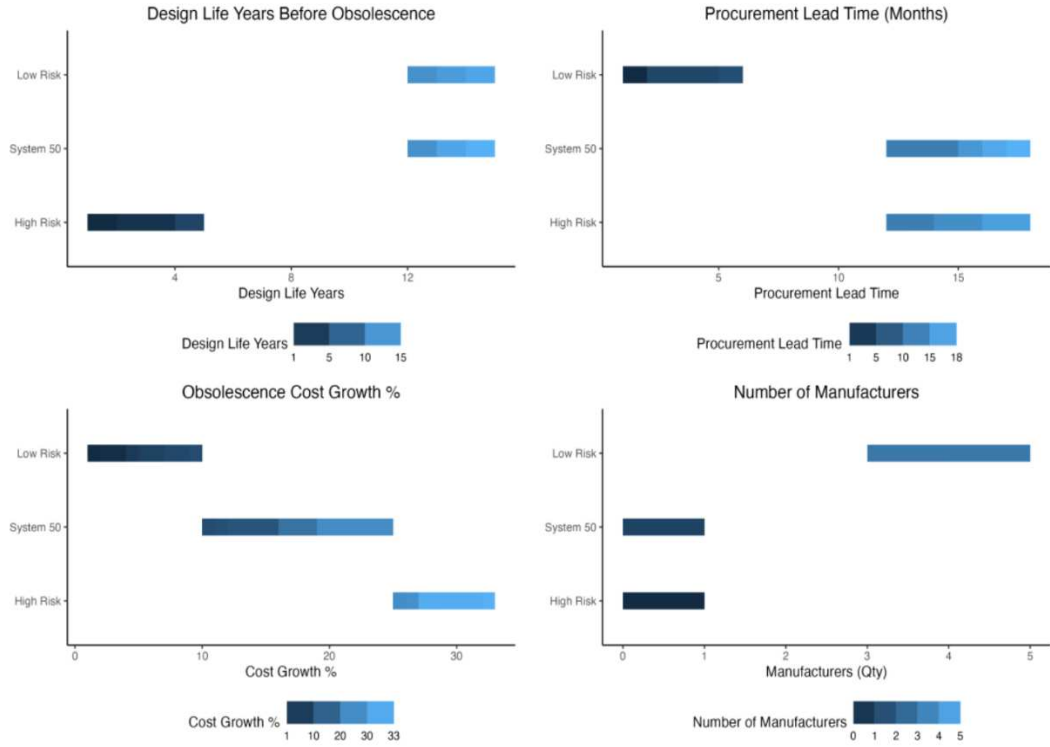
How risky do you find the Cost Growth (%) of System 45?

- Low Risk
- Medium Risk
- High Risk

How confident are you in your answer of System 45's Cost Growth (%) risk?

- Extremely Unconfident
- Somewhat Unconfident
- Neutral
- Somewhat Confident
- Extremely Confident

Please use the following visualization and legend for System 50 to answer the following question. There are high risk and low risk references to guide you at the top and bottom of each quadrant; as an aid to visually lineup a system with its level of risk.



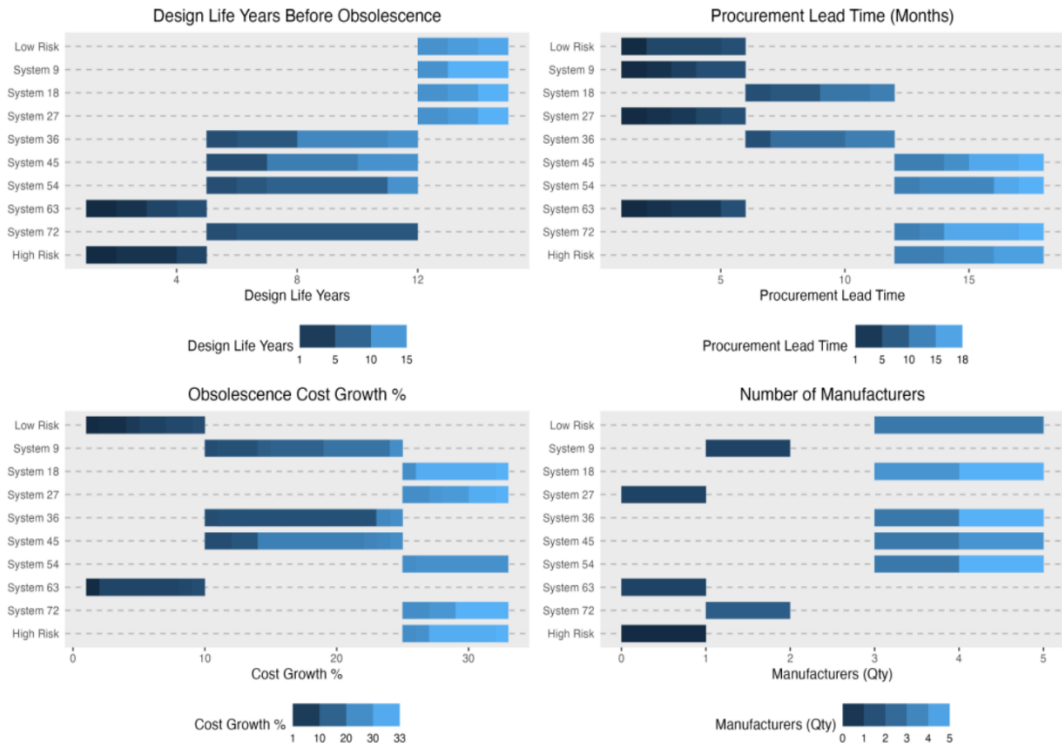
How risky do you find the Procurement Lead Time (months) of System 50?

- Low Risk
- Medium Risk
- High Risk

How confident are you in your answer of System 50's Procurement Lead Time (months) risk?

- Extremely Unconfident
- Somewhat Unconfident
- Neutral
- Somewhat Confident
- Extremely Confident

Please review the following data visualization which displays the obsolescence risk of several sample systems.



Which method do you prefer for comparing the data for the obsolescence risk of multiple systems?

- Tables & Spreadsheets
- Data Visualization Quad (shown above)
- Other, e.g. narrative style report