Robustness of decentralized decision-making architectures in command and control systems

RESEARCH TEAM

The Gralla Laboratory at The George Washington University School of Engineering and Applied Science draws on methods from systems engineering and supply chain and operations management in order to understand and make better decisions in the design and operation of complex engineering systems.

RESEARCH TASK & OVERVIEW

Organizations use command and control (C2) systems to collect, organize, and disseminate information, in order to make decisions, impart instructions, and manage resources to accomplish a mission. C2 agility and *robustness* are critical to ensure that a C2 system can perform well in a variety of environments. The way these systems are architected exerts considerable influence on these outcomes and others. In this study, we explore C2 system decision-making architectures—ranging from fully *centralized* to fully *decentralized* archetypes, and hybrid architectures (Fig 1)—to assess their performance and robustness characteristics across a spectrum of operating environments.

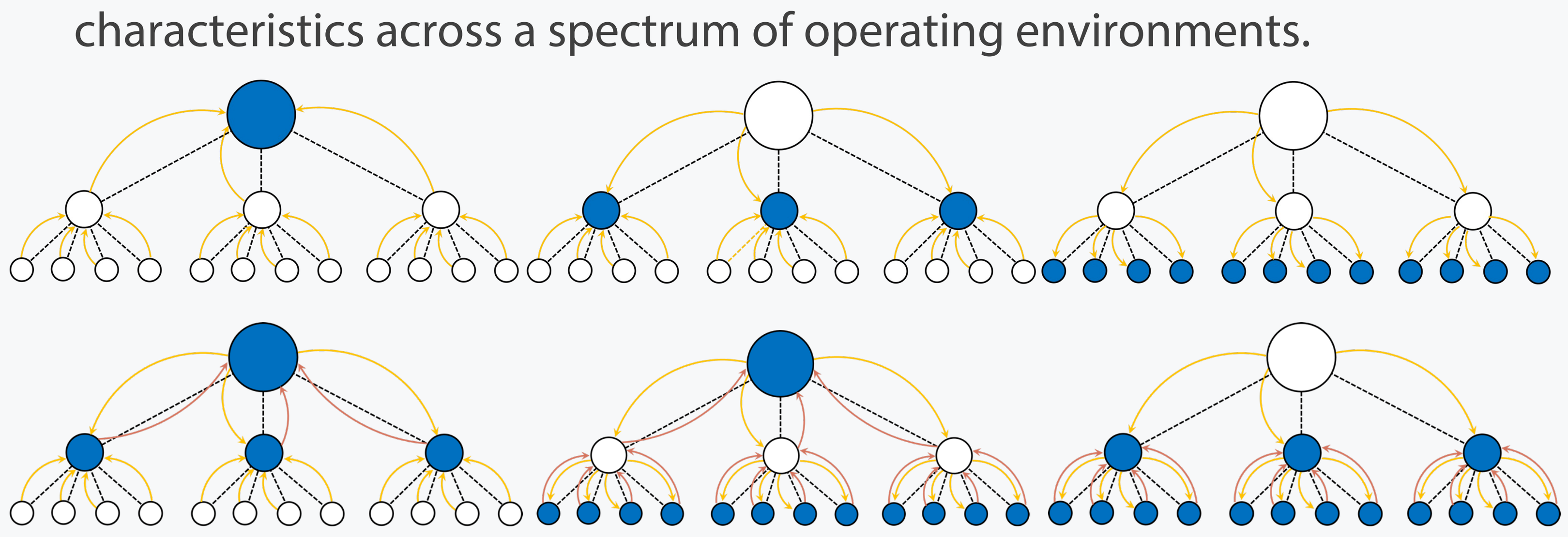


Figure 1. Centralized to decentralized decision-making structures (top), and hybrid structures where parts of decisions are delegated (bottom). Blue nodes indicate decision-making authority.

DATA & ANALYSIS

We measure a C2 system's performance across a wide spectrum of operating environments. Robustness is assessed as the portion of the operating environment within which the system can meet a performance requirement. Indeed, different degrees of decentralization are appropriate for different environmental conditions. Centralized systems achieve high performance, but quickly degrade when conditions worsen. Decentralized architectures generate lower but more stable performance, exhibiting more robustness under lower performance requirements (Fig 2). We then explore hybrid architectures which centralized system-consequential functions – such as resource allocation – but decentralized routine, local decision-making. These hybrid architectures generally outperform the archetypes, and exhibit higher robustness across the spectrum of performance requirements (Fig 4).

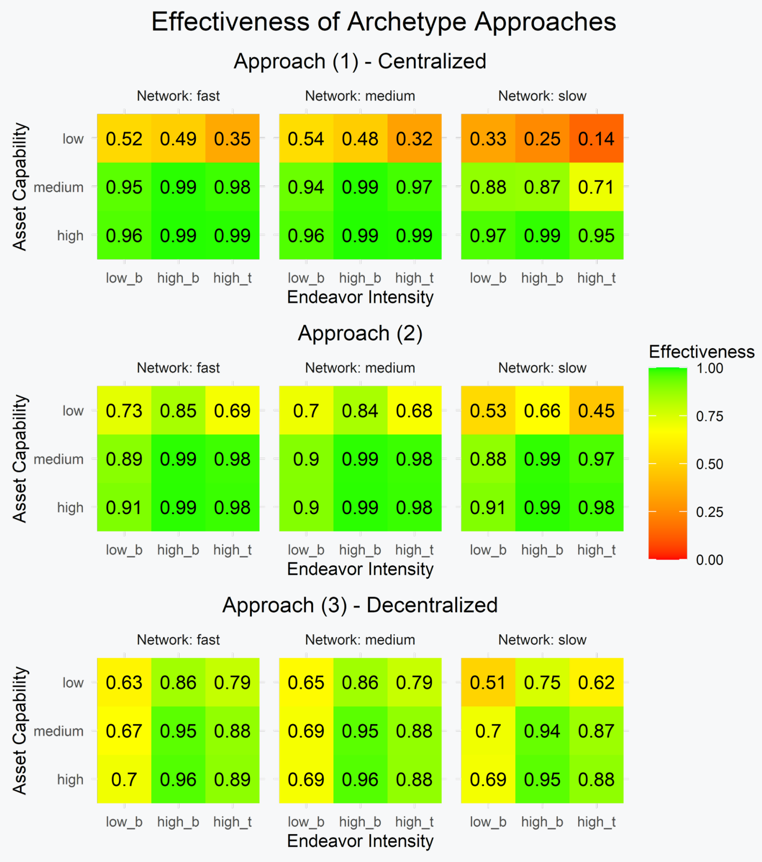


Figure 2. Performance differs for centralized and decentralized approaches for different communication speeds, asset capabilities, and intensity (number of tasks). Robustness requires meeting performance requirements in all cases.

GOALS & OBJECTIVES

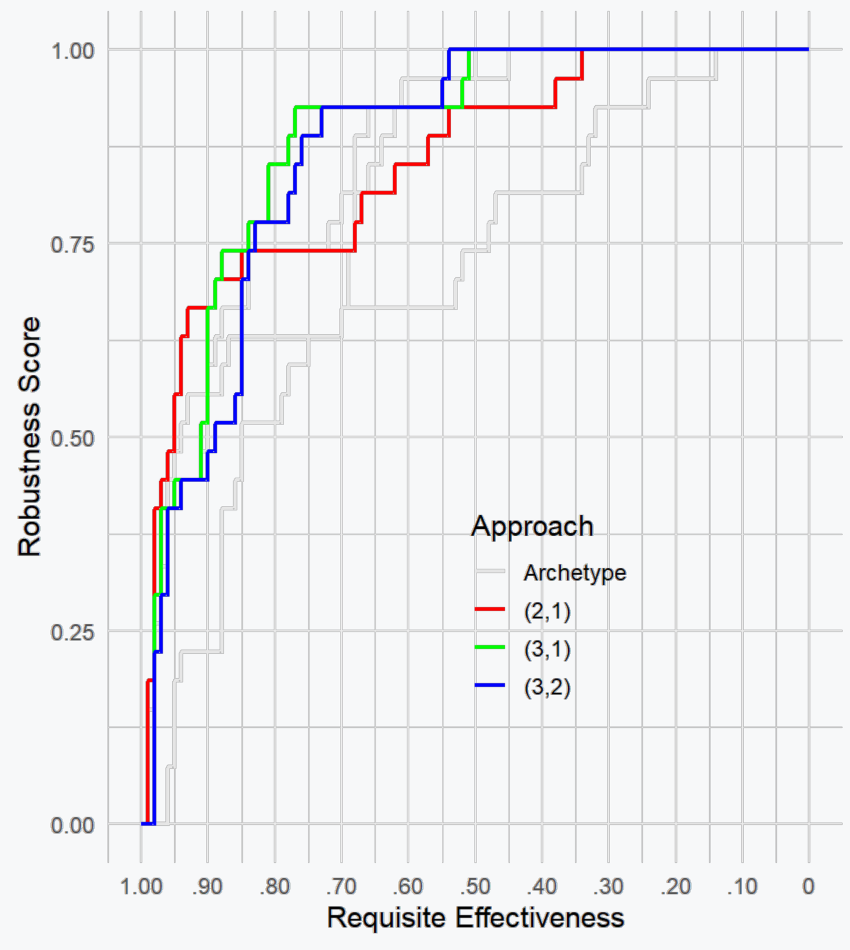
Decentralization has been tied to a number of desirable system characteristics, but its link to performance robustness – an insensitivity to varied environmental conditions – is not well established. This research establishes a relationship between decentralized decision-making, performance requirements, and robustness in a military C2 system. We hope these findings are useful for designers and practitioners of these and related socio-technical systems as they consider decentralization in the operation of their systems.

Figure 3. C2 systems support a variety of military missions.

METHODOLOGY

This research uses Discrete Event Simulation to depict a hierarchical C2 system with varying architectures, which can be operated across a range of operating environments in order to measure performance characteristics and robustness. The model is loosely based on the Air Force's Theater Air Control System.

Figure 4. Robustness increases as the requisite effectiveness decreases (right). Different approaches perform best at different values of requisite effectiveness. Only the centralized approach can reach the highest level of performance, but its robustness is low. Hybrid approaches perform better than non-hybrid.



FUTURE RESEARCH

Decentralization – like many principles surrounding system architecture – has been applied imprecisely in the literature. Ongoing and future research seeks to characterize the decentralization found in real systems, in order to enable a more precise language with which we can describe systems in terms of their decentralization. Further research also seeks to tie characteristics of a system's environment toward different forms of decentralization in C2 and related systems.

CONTACTS & REFERENCES

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