Business and Organizational Impacts for Modular Flexible Ships

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ABSTRACT

Ships and the supporting environment in those ships of the U.S. Surface Navy should be built to optimize rapid removal and replacement of modularized capability. We propose a new business and acquisition environment that will deliver new capability faster, in smaller increments, with higher performance and greater quality. The organization performing this would need to manage a continuum of frequent updates of reusable product line capability commodities. These capability commodities would be deployed on a widely distributed and sustained architecture in use throughout the fleet. We discuss the value of focusing on replaceable commodity capability innovations in the warfighting domain for one part of the organization, while a partner group works on delivering infrastructure innovation that would be the highly flexible landing pad for hosting those capabilities.

We provide example programs that have performed similar transformations and illuminate similar organizational context. Using those best practices, we recommend that a different programmatic alignment is needed that matches the technical architecture for delivery new software functionality and modular hardware capabilities. These updates should be quickly installable and come with intuitive operations, self-contained testing, training and support and certified for use when delivered. This new approach is enabled by leveraging commercial investment in data center technologies, modularization techniques and newer Agile development practices.

We then explore business practices that should be adopted, and acquisition challenges that would need to be overcome. We conclude with an overarching model of business, contracting, intellectual property strategies and a technical underpinnings for acquiring and continuously updating software-intensive capabilities that would support a flexible modular ship design which would deliver fast, frequent and excellent capability delivery throughout the fleet.

INTRODUCTION

We propose a plan for a new business and acquisition process that will deliver new capability to all U.S. surface combatants ships with the goal of making affordable and frequent product deliveries that are higher in performance and quality. By using this process, military value can be provided to both newly commissioned and older in-service ships, in smaller, more frequent increments, as rapidly as products are available and safe for use. This paper proposes that meeting this challenge can only be done by focusing on using modular architectural and design approaches. To make this process effective, the engineering of the capability should be composed of modular components that are both interoperable and built nearly free of defects.

This paper also addresses methods to certify the systems such that confidence of the operational fleet is maintained. A key to the success of this approach involves applying Agile and DevOps principles throughout the development, test, and certification cycle. While technology and engineering are key to success, this paper explores the business and organizational best practices and challenges when using modular acquisition approaches along with agile development techniques. People and funding drive the naval enterprise, so these must also be aligned to support the desired goals of frequent modular deliveries of high quality products.

BACKGROUND

Previous efforts have attempted to improve warfighting performance in the surface Navy. Examples include hardware rehosting using *commercial off-the-shelf* (COTS) electronics, early attempts at an open architecture implementation, establishing an objective architecture for transition of future capability, and improving reuse and interoperability through a "common source library."All these approaches have made incremental changes and improvements in delivering capability, but fall short of rapid and agile capability delivery.

For example, the Aegis system designed for use on the USS Ticonderoga and Arleigh Burke class ships has been upgraded in stages over the life of the system. *Ballistic missile defense* (BMD) was added to the Aegis capability through cooperation with the *Missile Defense Agency* (MDA). The cycle time for upgrading Aegis/BMD is several years, with additional time devoted to full end-to-end development and operational testing with subsequent efforts required for full-use certification. While still challenged to deliver at a significantly increased tempo, the Aegis system was able to evolve and deliver capability quicker through its use of product-line concepts.

Other *program executive offices* (PEOs) have made related efforts to accelerate performance improvement and deliver enabling technologies. A notable example is PEO Submarines' trail-blazing efforts through the *Acoustic Rapid COTS Insertion (ARCI)*'s *Technology Insertion* (TI) and companion *Advanced Processor Build* (APB) processes, which were extended to other submarine-related programs in a bundling referred to as the *Submarine Warfare Federated Tactical System* (SWFTS). Another leader in establishing an enterprise approach to capability delivery is the Navy's PEO C4I with its *Common Afloat Network Enterprise Services* (CANES) program.

The SWFTS and CANES programs had organizational and technical architectures that enabled multiple program office and contracting teams to build components that could be integrated easily. Both efforts improved speed of delivery for capability over legacy approaches, though both are still short of today's operational and tactical need for delivering capability improvements and ensuring cyber security protections to achieve the current goal of "compile to combat in 24 hours." (Katz, 2018).

While there are development and testing challenges for delivering real-time, weapon-safety critical and cyber-secure products, there exist Agile and DevOps techniques that can be applied to deliver faster releases more frequently. These new technical approaches will fail, however, if they are not coupled with the process and policy change for adoption of Agile/DevOps principles in the business practices and the organizations involved across the enterprise. The improvements we describe in this paper to the technical, business, and organizational practices will enable the surface Navy to deliver capability to ships on a monthly or weekly basis, be they deployed or in home waters. The remainder of this paper will describe the organizational impacts of employing an open technical architecture to support deploying of modular functionality, for continuously delivering capability—safely and securely—onto naval surface platforms.

The Need to Change

The recent breakup of the *Defense Acquisition Executive office* (USD (AT&L)) into the undersecretaries of *Research and Engineering* (R&E) and *Acquisition and Sustainment* (A&S) is instructional on how to organize around the following two principles:

- focusing on replaceable commodity capability innovations in the warfighting domain (similar to USD (R&E))
- innovating on the infrastructure and interoperability architecture for a highly reliable and flexible landing pad to host those capabilities (analogous to USD(A&S))

The most valuable part of splitting these activities is the acknowledgement that each entity works on different technology problems using different vendor bases that deliver the specific skillsets and each are motivated with the appropriate business drivers. Yet each must depend on the other if either is to succeed.

Sustaining an affordable suite of mission systems is predicated on maximizing a common set of features and functions on as many platforms as possible. The acquisition patterns of the past focused on delivering new ships with specific improved capability. Maximizing commonality and in-service affordability has been blurred by artificial programmatic boundaries such as colors of money and a primary focus on new ship construction. The current pattern has put a strain on delivering both affordable new construction and evolving capability for in-service ships when the budget is viewed holistically.

Addressing these problems will require the full commitment of all members of the acquisition community, in concert with the fleet operators. Organizations make these kinds of transformations most gracefully when all members of the organization can see their future in the implementation of the next model. New models for change management have progressed out of the neuroscience and human-centered design communities. These more nuanced approaches draw people in the change strategy such that they become stakeholders in the new approach, which in turn enables more pervasive buy-in and thus more effective outcomes.

We recommend that a different programmatic alignment is needed that matches the technical architecture for delivery of smaller hardware updates. These updates should be quick to install and come with smaller, more frequent software modules that are certified for use on foundational software frameworks. This new approach enables the leveraging of commercial investment in data center technologies, along with newer Agile software development practices. It will also enable broader adoption use of automated testing tools to execute repeatable certification so the Navy only pays for unique military capability that can be delivered quickly (Figure 1).

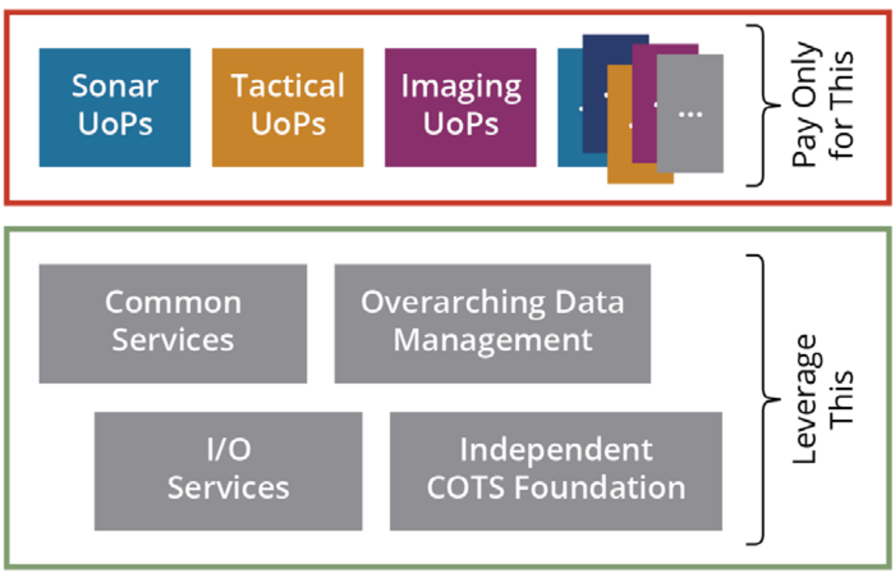

Figure 1*: Leveraging Commercial Investment and Pay Only for Military Capability*

The assumed technical architecture is based on now standard development practices of virtualization and containerization, which in turn enables the use of Agile and DevOps software development techniques. Cyber-physical and software-intensive development paradigms are constantly in motion. *Service-oriented architecture* (SOA) approaches were popular for a time, but the development methods and the underlying technologies that made SOA attractive have evolved to enable modular micro-service capabilities that can run in containers, inside virtual machines, as well as being distributed across multiple cores/compute-plant clouds that dominate the commercial development community (Kubernetes, 2018).

Containerization also helps to reduce development risk, increase overall product robustness, and is tailor-made to work with Agile development methodologies (which achieved broad adoption after SOA was the way of the future). This combination of techniques enables development teams to focus on capabilities as a new unit of functionality that works with other containers as a part of a capability architecture (Kubernetes, 2018).

The operations of the naval enterprise must therefore evolve from a *Program-of-Record* (PoR) and system-centric approach to one that focuses on cohesive inter-organizational values, shared resources and strategic investment all focused on rapidly deploying military capability (Golden-Biddle, 2012). Eventually, the operational changes recommended below must lead to organizational change. However, research on maximizing performance improvement in organizations undergoing transformation show greater value in focusing initially on behavioral changes in advance of any large-scale organizational rewiring (Nobl, 2018). This paper therefore focuses on the impacts to functions that must be performed.

Evolving the Enterprise

New and emerging development methodologies and technologies are being applied in commercial sectors to create and deliver new capabilities. The challenge for the Navy is that these newer private-sector solutions in development techniques and hardware performance require different funding and lifecycle approaches. In particular, the COTS market has evolved to fundamentally alter the hardware/software architecture of data centers and modularize capabilities to reduce risk and increase customer satisfaction for the use of exquisite and highly reliable products (Janakiram, 2016). Due to the extra effort and complexity associated with the current approach to baseline management, the cycle time of technology delivery has not kept pace with today's desired program lifecycle, despite 20 years of refinement. For example, future Navy systems need to deliver modular software changes along with companion focused hardware updates, much like the way commercial data centers are managed.

Federal government relationships with contractors must also be aligned since existing commercial business practices bring significant value that frequently enable rapid deployment of innovative solutions. This relationship requires significant changes on the government side to enable the speed and frequency benefits of Agile and DevOps methods and tools.

If implemented well, the new principles and practices arising from this comprehensive approach will remove the impediments for small business and non-traditional suppliers. An architecture that drives a modular capability improvement paradigm means that functionality can be replaced, tested, and fielded at much lower risk than in the past. This will expand opportunities to capture innovation from a wider array of sources, which brings stronger market forces for driving down cost and increase capability via a new procurement and delivery strategy. The operating model will require greater shared responsibility and promote an engine of continuous improvement. This strategy can be implemented to deliver ship systems that are tested and certified, are fully supported for fleet use, are highly reliable, and can continue to provide the required capability in the face of component failures for protracted periods of time (Guertin et. al, 2015).

Overarching Business Model

The Surface Navy Acquisition environment should operate to optimize modularized capability that will be frequently deployed across the fleet. All else flows from this premise to enable the ability to continuously update the fleet in smaller increments of decoupled hardware and software. In particular,

- Hardware and software capability should be expressed in loosely coupled modules that are built to plug into the system's architecture and manage interfaces through discovery.

- Certification of the capability is performed as an overall product line, with ship-specific uniqueness certification addressed prior to shipment through a virtual test-bed/digital-twin (Naveen, 2017) construct.

- The new capability is delivered as a certified package, along with targeted hardware changes. Packages can be installed by the crew through simple instructions. The install will automatically be tested to validate that the certified configuration was accurately completed and the ship is ready for all assigned missions (Guertin and Hunt, 2017).

We propose that three major organizational entities will replace the PoR environment that currently exists (Figure 2). Each Platform Acquisition will perform the capability management to shepherd the appropriate set of Capability Commodities and ensure that interoperability and cooperation pervades the enterprise so that the Deployment Environment can integrate and deliver working platform solutions. In particular:

- Capability Commodity Managers will be populated with program managers who focus on delivering a set of coordinated modular products that are decoupled from hardware implementation and integrate with a common framework.

- The Deployment Environment should be staffed by architects, as well as software and systems engineers who manage the technical framework for data interoperability, product development support, module integration, and hardware acquisition—providing such things as development kits, integration engines, test harnesses, compliance tools, virtual test bed and hardware definitions, as well as certification platforms to deliver capability modules to the fleet.

- The Platform Acquisition arm will be responsible for acquisition and sustainment of the platforms that host the capability payloads. Each also owns the platform-unique capability requirements that flow down to both Capability Commodity Managers for functional changes and to the Deployment Environment Community for overall performance and platform integration requirements.

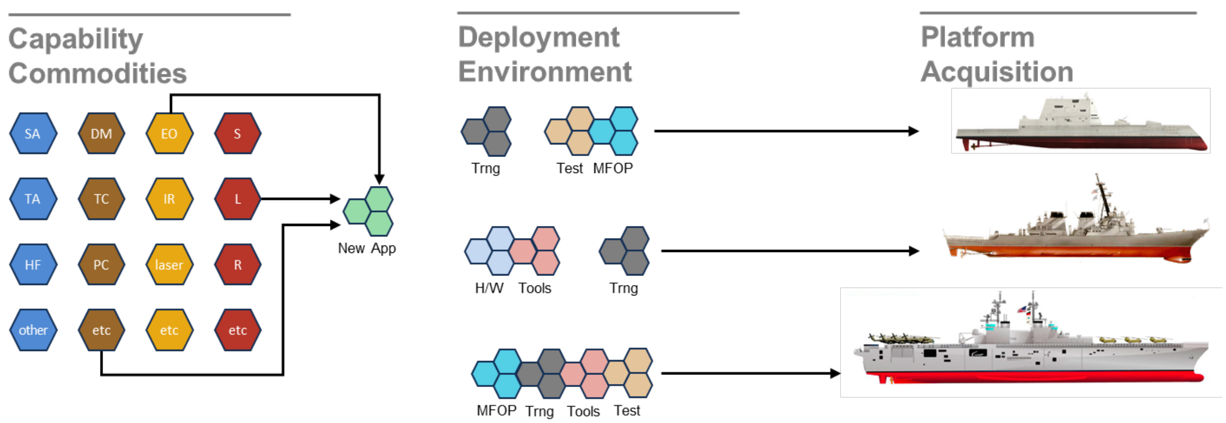

Figure 2: Future Surface Navy Acquisition Alignment

Acquisition Challenges

The acquisition model should be based on having a robust and sustained landing pad for modules of capability that can, at prudent risk and affordable expense, be removed, replaced, added, certified for use, and deployed as discrete severable elements that perform integrated functions. There are several distinct contracting models that should be considered, all of which are already in place and supported by policy or statute:

- **Deployment Environment**. The overarching hardware and software framework should be procured by the Deployment Environment arm. All innovators who want to deliver capability to the surface force need to participate in evolving this foundation as a living standard. The design and implementation for these capabilities can be acquired through a consortium model, e.g., one that is based on Other Transaction Authority (OTA, 2018). These hardware and software frameworks should leverage industry standards, e.g., the FACE *Technical Reference Framework* (TRF) (Open Group, 2018), Open Messaging System, Sensor Open Systems Architecture TRF, the CANES architecture, and the like. The intellectual property strategy for this business environment should be based on sharing, collaboration and consensus both within the government and between the government and industry. Open Standards offer a common language and implementation that should be used wherever possible.

  While the technical architecture for development and integration will support loosely coupled modules of capability that can be integrated or removed quickly, the resulting business and financial model needs to enable the base capability of the infrastructure/ framework to grow and mature over time. Achieving this goal will support flexibility, rapid installation, testing and certification, and continuous deployment of new capability commodities. The goal of the Deployment Environment is to manage the common software and hardware so that all systems can use the latest common capabilities including data management, security, and user interfaces.

- **Capability Commodities**. Innovation warfighting functional performance should be acquired through the Capability Commodities arm. Its business relationships should be based on acquiring (relatively) small and modular units of capability that are built to integrate seamlessly with the Deployment Environment (Womack, 2003). Organizations that have deep expertise in technical or tactical areas can be retained for as long as they competitively deliver warfighting excellence. This model removes the need for time-consuming and risk-inducing cyclic competition for any one particular function because the technical architecture and business processes enable modules to be removed and replaced quickly and easily. For this business environment, vendor lock can be avoided through offerings of market-driven alternatives. In this open market of capability commodities, innovative replacements could displace existing functionality with low business and technical risk at the time and place of the government's choosing—which has the simultaneous benefit of keeping the hot breath of a competitor driving an incumbent to run faster. If a vendor is delivering excellence and creating investment in new capability, however, they can be retained as a venue of best value.

- **Agile Contracting Model**. A model for establishing this cadre of developers that are constantly innovating and striving to deliver new capability will need a lightweight, Agile contracting approach and a remuneration model that awards deployed capability and well-integrated functionality. The incentives are that as more software is delivered, selected as superior, integrated, certified, and deployed, the more money the contractor will make. This model can also generate new capability providers through direct industry investment. The intellectual property strategy for this business environment can be the full gamut of data rights (Figure 3). No attempt need be made for the government to have to negotiate for greater rights than the contractor is willing to offer, as capability value is based on replicable functional performance.

Figure 3: IP Strategy for Capability Modules

- **Data Model**. A data model is required for this environment to support module-level interoperability such that new functions can be discovered on introduction, complete with full semantic and syntactic descriptions. The culture of the whole enterprise will need to allow the governance of this model to enable growth and flexibility as the systems evolve. This data management pervades all three organizations and the success of the enterprise resides on a common, understandable interoperable data management. There are at least two data models that the DoD has already invested in standards that are suitable for this purpose: Unmanned Systems (UxS) Control Segment (UCS) (SAE, 2018) and FACE (Open Group, 2018).

- **Financial Architecture**. The Financial Architecture should initially be based on the current program element structure that requires close coordination between the PEOs and the associated OPNAV sponsors. The funding will need to support a large number of independent capability modules likely built by a large number of development teams. A primary challenge will be to obtain and maintain sufficient funding for building both the capability modules and the initial infrastructure at the same time. It is hard to justify building software frameworks since they typically deliver the unseen capability such as data management, security, and common components for user interfaces. Initially the funding for the framework will be high with little capability to show, but as the framework is built up the resources can be moved to build capability. Eventually, the funding model can shift to reflect the business model of continuous capability innovation and technology transition.

Implementation and Organization Impacts

The acquisition organizations involved in this endeavor will need to cooperate and find creative approaches to collaborate in harmony to achieve the strategic need to build a model of continuous and rapid improvement. The diversity of organizations involved in resourcing these activities is an additional complexity that will have to be managed by implementing new organizational models. Changing the principles of operation are all within the purview of Navy surface ships leaders. While changing the organization structure may not be immediately necessary to achieve an operating model, the new goals of incremental delivery will need to change the culture immediately.

The technical architecture of system-of-systems should be agile enough to support deploying customized and certified capability delivery, where and when it is needed. A recommended approach is to evolve toward a new acquisition architecture predicated on separating the concerns associated with building new capabilities associated with Common Commodities from those associated with establishing the environment by the Deployment Environment and Platform Acquisition arms. Together the enterprise will need to create a product-line architecture landing pad, associated support tools, and crossorganizational shared services for capability delivery that would host them by the platforms. Under this operating model, the Capability Commodity activities would be for cross-platform reusable product line components that have unique attributes and values, e.g., Sonar, Imaging, Radar, EM/EO/IR, Communication, Strike, Payload Launch and Control, etc. The Deployment Environment organization establishes requirements for a shared system architecture and work together to integrate products.

Likewise, the Platform Acquisition arm collects the Common Commodities and Deployment Environment infrastructure requirements and creates a common integration process that provides a secure, real-time, safety-critical and cyber-secure environment, including build tools, automated test capability, data architectures, training environments and integration frameworks. The Platform Acquisition organization would focus on designing, building and sustaining the ship, and own the requirements for ship installation and non-warfighting system integration (Guertin and Clements, 2010).

An important technical skillset that the Navy has already begun is to investigate is the application of virtualization for mission systems and the ability to perform automated testing of new modular capabilities. A necessary next step is to do a functional breakdown of system capabilities into modules. The modularized capabilities can then be packaged as containers and deployed as severable, self-healing units of performance such that new products or services can be delivered independently. The system and software architectures need to support loose coupling of those modules—so they can be extracted and replaced by new capabilities—are well practiced and available in the marketplace. The resulting product set could be changed as loosely coupled but highly cohesive capabilities that are more reliable, self-heal, and can be quickly integrated with known impacts to existing products and services (Guertin, Schmidt, and Sweeney, 2015).

The current Test and Evaluation (T&E) communities must be a part of this transformation from the very beginning and be involved in setting the architecture and development constraints for all three organizations. To ensure that the integration, test, and certification activities are appropriately addressed, the testers should be a constant part of the full life-cycle of development, thus establishing a way to check that the deployed product is fully fleet-ready. There are many evolving practices in the area of testing such as basic software unit testing, static analysis, test automation, hardware and system simulation, along with the new digital twin concepts that help to ensure the deployable products work as expected when the capability is shipped for installation. The challenge for all of these test approaches is to realize that they are software and systems engineering projects unto themselves. They require well-reasoned architectures, designs, implementations, and ongoing sustainment. Only then will the delivery and installation testing be performed in days instead of weeks, with the resulting capability suite certified for full use (Guertin and Hunt, 2018).

There are clear steps needed for the surface warfare enterprise to support frequent delivery of capability to both existing and new ships. The enterprise as a whole needs to devise a plan to decompose functions into modules that can be containerized. Selecting (not developing) a containerization and technical reference framework scheme will drive a common approach to an infrastructure consolidation plan that includes hardware, networking, and storage—and adopt a data architecture that is practiced by a broad community. The beginning of the consolidation is the time to decide on the standards for architecting systems well into the future.

This kind of change is likely to imbue classic organizational resistances and textbook rejection to strategic change. These are natural human and organizational responses. The mechanisms of resistance to change are better understood now than ever before. To minimize these effects, a coordinated roadmap should be developed through human-centric-design methodologies where members of stakeholder organization are welcomed to become a part of how the overarching team-of-teams achieves its shared objectives. Likewise, a detailed communication plan should be developed that invites personnel in the existing program offices and subordinate organizations to participate in developing how and where they fit and where the growth opportunities lie.

In times of uncertainty, people in these organizations will be primarily interested in how change will affect their lives (Williams, 2017). Industry will be most interested in the impact to existing tasking and the opportunities that lie ahead. The role of the system integrator would be truncated into an overarching capability integrator, a system architect, and a hardware procurement agent. These duplicative and overlapping roles are ripe for consolidation (Guertin and Womble, 2012).

CONCLUDING REMARKS

While the technical approaches for delivering capability quicker are used frequently in commercial settings, the challenge for the Navy is to make the organizational and cultural changes necessary to support a new development model. The "burning platform" for the Surface Navy community is to change the acquisition culture to identify increments of improved capability that meet requirements for safe and effective to use and deploy this capability to the fleet at a frequency much quicker than today. Changing this culture requires a shift from the current baseline upgrade acquisition approach to a culture that provides continuous delivery of affordable, flexible, adaptable, and reliable capability increments. The naval enterprise needs to separate the concerns of payload commodity capabilities, a supporting technical architecture, and the platforms to host them. The resulting managed capability will deliver in smaller increments, be improved regularly, with higher reliability and in easy-to-install packages that come with effective training and support.

The business relationships currently employed by the Surface Navy acquisition community need to evolve to a model of decoupled capabilities developed by a variety of firms that are experts in their craft. This business model must leverage the commercial marketplace, encourage private investment, and honor the value of diverse business relationships, while also maintaining the government's fiduciary responsibility when taxpayers make investments. Any capability that comes with restrictions on sharing internal design details must come with a certification that the design can be gracefully removed from the system and replaced with equivalent capability derived by a different organization.

The overarching open systems architecture on which all this capability runs should be a shared responsibility between industry, the standards community, and government. That open systems architecture will be co-developed by the stakeholder firms in collaboration with the government, who in turn will coordinate the effort to ensure that capabilities can be replaced. The Consortium model should be investigated as a mechanism for establishing this architecture.

While there are many technical challenges to implementing an open, modular product line system for surface ships, evolving the organizational and business approaches to match the technical design will be hard. Getting the enterprise to adopt this new culture will be key to a successful transition to a surface ship enterprise that is efficient and effective at delivering new capability quickly.

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