Assessing Needed Capabilities and Metrics for Future Maritime Reconnaissance: A Case Study in Collaborative Systems Analysis

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Collaborative systems analysis is a deliberately broad, interdisciplinary view of a system. It plays a critical role in APL's systems engineering approach by providing the key stakeholders—the system operators, system developers, and program managers—an analytical forum in which to examine the important issues and explore the necessary trade-offs and "what-ifs" within each of the six phases of APL's systems engineering approach. A recent example of collaborative systems analysis assessed the capabilities and metrics needed for maritime reconnaissance. This effort highlights the value of collaborative systems analysis in delivering a system-level view that both vets and contributes to systems analysis and ultimately leads to a better understanding of the systems engineering problem and its potential solutions.

INTRODUCTION

In the introduction to their textbook, *Systems Engineering Principles and Practice,* Alexander Kossiakoff and William Sweet describe how a systems engineer must think in a special way to acquire the "systems engineering" viewpoint:

> The systems engineer faces in three directions—the system user's needs and concerns, the project manager's financial and schedule constraints, and the capabilities and ambitions of the engineering specialists who have to develop and build the elements of the system (p. xvii in Ref. 1).

Kossiakoff and Sweet advise the systems engineer to learn enough of the languages and basic principles of these three constituencies—the customer, the project manager, and the engineering specialists—to negotiate a balanced solution. They describe "interdisciplinary leadership" as the key challenge and principal contribution of systems engineering.

The ideas of Kossiakoff and Sweet are not surprising given their years of work and accomplishment at APL. Since its establishment during World War II, the

Laboratory has prided itself on its systems engineering approach: viewing complex engineering problems in their entirety and collaborating across multiple disciplines (physical chemistry, electrical engineering, mechanical engineering, etc.) to achieve solutions in rocketry, electronics, and other endeavors.

This article describes how this multiperspective, multidisciplinary approach is the central theme of collaborative systems analysis and how, through Warfare Analysis Laboratory exercises (known as WALEXs), it is applied to APL's systems engineering approach. After general descriptions of WALEXs and collaborative systems analysis, this article describes a recent case study in which these methods assessed the capabilities and metrics needed for maritime reconnaissance.

BACKGROUND

WALEXs trace their origin to the study of complex problems in warfare analysis. In the late 1950s and early 1960s, APL conducted a number of studies for the U.S. Navy addressing fleet air defense against Soviet bombers equipped with antiship missiles. To examine the full scope of this problem and the full range of possible solutions, the Laboratory developed an analysis methodology by using computers, scenarios, and a multidisciplinary set of participants. This methodology eventually became a formal process known as the Air Battle Analyzer, and for the next 20 years APL used this methodology to address a variety of air defense problems. In 1981, a special APL leadership committee recommended that APL develop a central facility for warfare analysis, incorporating the processes and techniques developed in the preceding two decades. The facility became known as the Warfare Analysis Laboratory, or the WAL.[2]

WALEX OVERVIEW

Over the years, the WAL has undergone a number of evolutions in its location, size, and resident capabilities (see Box 1). Although the physical features of the WAL have evolved over time, WALEXs have remained fairly uniform. WALEXs foster collaboration through a disciplined, analytical approach that presents a common problem, often as a scenario, and solicits an open discussion encompassing the multiple perspectives of a diverse set of participants.

A facilitator performs a key role in this process by ensuring a balanced expression of views, suggesting lines of discussion, and framing issues for further exploration. The facilitator strives to keep the event focused on a set of objectives but must be willing to deviate from the formal agenda to explore new issues as they emerge. Depending on the objectives of the exercise, discussion

BOX 1. THE WAL

The current WAL facility, completed in June 2000, is located on the west side of the APL campus in Building 26. The WAL can seat ~100 participants, and 53 seats are equipped with laptop computers networked to a set of collaborative software tools, known collectively as GroupWare. An additional 50 people can participate without computers in an observer area.

The WAL has four large display screens in the front of the room augmented by four flat-panel displays in the observer area. A sophisticated video-switching system enables the facility to display a variety of content, from the typical briefing slides and documents to full-motion video, animation, and high-end visualization. Information (diagrams, maps, outlines, photographs, etc.) can be mixed and matched across the four display screens to meet the specific needs of the audience. A sound system that is always powered on and the V-shaped seating configuration of the room promote the verbal exchange of ideas.

Participants equipped with laptop computers can enter their ideas and comments directly into a record of the proceedings, encouraging further interaction among the participants and thereby leveraging the time available. These computer-equipped participants can also complete surveys that gauge participants' views on specific topics. Survey results are quickly tabulated and displayed to further stimulate discussion. Figure 1 includes photos of the present-day WAL as well as views from 1981, 1986, and 1995.

Figure 1. Evolution of the WAL.

may be directed beyond issue identification toward more in-depth analysis, consensus building, or collaborative problem solving and decision making.[3]

Given their open, flexible approach, WALEXs can be applied to any number of complex problems.[2] Within the realm of systems engineering, this approach is described as collaborative systems analysis.

COLLABORATIVE SYSTEMS ANALYSIS

Collaborative systems analysis is a deliberately broad, interdisciplinary view of a system. It plays a critical role in APL's systems engineering approach by providing the key stakeholders—the system operators, system developers, and program managers—an analytical forum to examine the important issues and explore the necessary trade-offs and "what-ifs" within each of the six phases depicted in Fig. 2. In the critical needs phase, the analysis process facilitates identification of capability gaps and overlaps, leading to a balanced and achievable statement of system needs. In the capability assessment phase, it assembles and analyzes data from models, simulations, experiments, and field tests to derive a full understanding of current capabilities and to offer insights into additional capabilities. In the concept exploration phase, it facilitates the analysis of alternative concepts and may employ models and simulations to measure differences, assess trade-offs, and explore what-if questions. In the solution validation phase, collaborative systems analysis provides performance predictions through system-level models and simulation before critical field experiments. After experiments, collaborative systems analysis examines results within the broader operational context. In the solution implementation phase, the analysis process explores the impact of development and production trade-offs on operational capability. Finally, in the deployment phase, it evaluates operational performance data to assess deployed capabilities and to inform warfighters of system limitation and employment considerations as threats and missions evolve. The analysis performed in each phase offers insights that will probably influence the next phase of system development. These insights may also, depending on their scope and circumstances, influence the next "spiral" of system development.

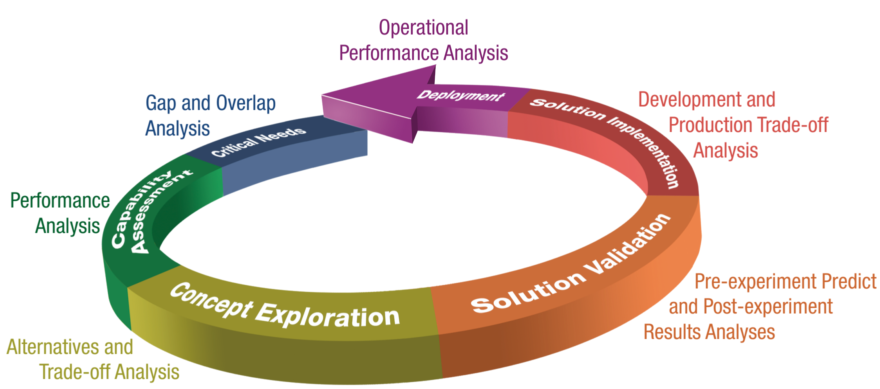

Figure 2. Collaborative systems analysis within systems development.

Value of Collaborative Systems Analysis

The value of collaborative systems analysis is the exposure of analytical products to a collaborative environment that draws upon the expertise of the different classes of system stakeholders: the customers (i.e., system users), the engineering specialists, and the program managers. For example, system users provide a richer context for interpreting engineering-focused analysis by explaining the operational significance of particular system parameters (e.g., range, weight, effects). Likewise, engineering specialists can explain the technical advantages, limitations, and trade-offs that might influence operational analyses. Finally, program managers can help bound technical and operational analyses through their perspectives of cost and schedule constraints. As a consequence, collaborative systems analysis delivers a broad, multidisciplinary view that both vets and contributes to systems analysis and ultimately leads to a better understanding of the systems engineering problem and its potential solutions.

Critical Needs

The first, and often most challenging, use of collaborative systems analysis is the identification of critical needs. It is the starting point in the spiral development process with the fewest boundaries and is the point at which fresh thinking will probably have the greatest impact. The fundamental need for a new system may be driven by either the need for new capabilities or the opportunities afforded by new technologies. Hence, the need for the system may be either needs driven or technology driven. In the critical needs phase, collaborative systems analysis typically identifies deficiencies in the current system or the potential for improved performance or reduced cost by the application of new technologies.[1] For military systems, defining system needs may require collaboration across a host of entities, ranging from strategic, operational, or tactical commanders and staffs who may direct the use of a system to those who operate and maintain the system. Each of these stakeholders may have explicit needs (range, speed, responsiveness, reliability, complexity, portability, survivability, etc.) for the system to fulfill. Because modern military systems interface with command and control, logistics, transportation, training, and personnel systems, the number of stakeholders—those who affect or are affected by new systems—can be even broader. These stakeholders may also have system needs regarding compatibility with other systems or the adaptability of the system to perform in different scenarios.

CRITICAL NEEDS CASE STUDY

Over the years, many WALEXs have performed collaborative systems analysis of critical needs. The remainder of this article will focus on critical needs by describing, in some detail, a case study involving the U.S. Navy's study of a replacement system for the EP-3 Maritime Surveillance aircraft.

EP-3 Maritime Surveillance Aircraft: Background

The current EP-3 (Fig. 3) provides "fleet and theater commanders worldwide with near real-time tactical SIGINT (signals intelligence). With sensitive receivers and high-gain dish antennas, the EP-3E exploits a wide range of electronic emissions from deep within targeted territory."[4] Based on the Orion P-3 airframe, the EP-3 is powered by four turbo-prop engines, has a crew of 22 people, and can operate at a maximum mission range of more than 2380 nautical miles. The earliest variants of the EP-3 came into service in the late 1960s.[4]

The challenge now facing the Navy is how and when to replace this venerable and aging aircraft. The Navy commissioned an analysis of alternatives (AoA) study in 2009 to assess the potential options for the EP-3 replacement, commonly referred to as EP-X.[5]

EP-X AoA Study

In August and September 2009, the EP-X AoA study conducted two WALEXs focused on critical needs. Their objectives were to assess (*i*) the needed capabilities of the EP-X and (*ii*) the potential metrics for comparing candidate maritime surveillance systems. Because any detailed discussion of maritime surveillance capabilities involves highly classified information, these two events, designated as "workshops," employed a special set of laptop computers configured with collaboration software and certified by the Navy sponsor for the appropriate level of classification.

EP-X Needs Workshop: Determining Needed Capabilities and Priorities

The first analysis workshop was conducted in August 2009. Its purpose was to identify and prioritize needed

Figure 3. EP-3 aircraft.

capabilities. Joint Capability Areas (JCAs)[6] were selected as the framework for discussing EP-X capabilities. JCAs are a set of Joint Staff-approved[7] capability descriptions organized in tiers of hierarchical structure. At the highest level (Tier 1), there are nine JCA categories (force application, battlefield awareness, logistics, etc.). In successive, subordinate tiers, JCAs provide increasingly detailed capability descriptions. Admittedly, the JCAs define capabilities in general terms that are sometimes challenging to apply at the system level. Their value is that they provide a common taxonomy for examining and comparing system capabilities across the DoD. Before the first workshop, an operations working group selected a set of 47 Tier 3 and Tier 4 JCAs considered pertinent to EP-X. An example of a Tier 4 capability is "2.1.2.1 Signals Collection—The ability to gather information based on the interception of electromagnetic impulses, however transmitted" (see p. 7 in Ref. 6). The operations working group extracted the 47 JCAs from six initial capability documents, which collectively define Navy maritime reconnaissance capability needs.

Participants

The 40 participants in the two analysis workshops represented a broad community of interest. Participants from combatant commands, Navy service commands, and operational squadrons provided the operational perspective. Participants from the Naval Air Systems Command and other technical organizations provided an engineering and technology perspective. Participants from the Deputy Chief of Naval Operations (N8) provided a force-level perspective of EP-X and how it must compete for resources against other Navy systems. Other participants from the Naval Air Systems Command provided a program management perspective of EP-X, highlighting the challenges and timelines associated with aircraft procurement, testing, and evaluation. In addition, participants from the intelligence community offered their perspective on potential collection and threat environments. Participants from the aviation training and logistics communities offered their perspectives.

Mission Areas and Potential Threats

To give operational context to the JCA discussions, the participants received an initial briefing on three generalized maritime reconnaissance mission areas: (*i*) Intelligence Preparation of the Battlefield, (*ii*) Major Contingency Operations, and (*iii*) Irregular Warfare. The use of three mission areas, in lieu of six to eight scenarios, greatly simplified the evaluation of the JCAs and offered a sufficient range of missions for comparing capabilities. The participants also received briefings on the likely threat and collection environments in which the EP-X would operate.

JCA Assessment

For each of the 47 JCAs, the participants reviewed the JCA description and its place within the JCA taxonomy. They discussed each JCA's validity to maritime surveillance, potential comparison metrics, and other relevant issues. The JCA discussion process is illustrated in Fig. 4. These discussions provided an operational context and the system-level perspective to the JCA framework. Over the 3-day workshop, participants responded to three electronic surveys in which they rated the importance of the 47 JCAs against each of the three mission areas. In the final summary session, the participants reviewed the overall JCA ratings, which were summarized in a 47 × 3 matrix. This matrix was not presented as a refined statement of needed capabilities, but rather as a visualization tool for stimulating further discussion. These discussions confirmed points made during the previous JCA discussions that certain capabilities had a high priority across the three mission areas, whereas other capabilities were focused on specific missions.

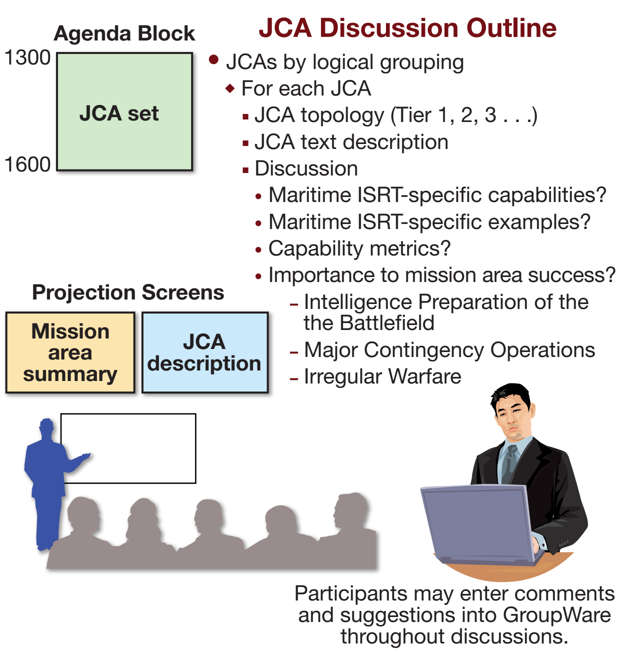

Figure 4. Process for reviewing JCAs in EP-X needs workshop.

After the first workshop, the 47 JCAs were examined in eight excursions in which different weighting factors were applied to the three mission areas. These excursions included an equal weighting of mission areas (e.g., 33% for each mission) and a number of unequal weightings that emphasized certain missions over others. For example, one excursion weighted the Major Contingency Operations mission—EP-X support of major naval operations—more heavily than either the Intelligence Preparation of the Battlefield or Irregular Warfare missions. A comparison of the various weighting options yielded a set of consistently higher-rated JCAs, consistently lower-rated JCAs, and a subset of JCAs that varied over the particular mission areas.

EP-X Metrics Workshop: Developing Metrics for Comparing Candidate Systems

The second analysis workshop was conducted in September 2009. Its purpose was to identify key measures of effectiveness (MOEs) and measures of performance (MOPs) for comparing maritime reconnaissance systems. Participants received the following working definitions: MOEs are qualitative or quantitative measures of a system's performance or characteristic that indicate the degree to which it performs the task or meets a requirement under specific conditions. They are a measure of operational success that must be closely related to the objective of the mission or operation being evaluated. MOPs are typically a quantitative measure of a system characteristic (e.g., range, velocity, mass, scan rate, weapon load-out, etc.) chosen to enable calculation of one or more MOE.[8]

The participants were approximately the same as those who participated in the first workshop. Before this event, an engineering working group developed 10 candidate MOEs and 16 candidate MOPs. In parallel to this preevent work, an operations working group aggregated the 47 JCAs reviewed in the first workshop into 13 capability areas for use in the assessment process.

Metrics

The EP-X stakeholders in the second workshop refined and expanded the original 10 candidate MOEs into a set of 16. An example of an MOE is: "Detection: the ability to determine the presence or absence of targets of interest." The stakeholders reviewed and expanded the original 16 candidate MOPs into a set of 28. The MOP discussion process is illustrated in Fig. 5.

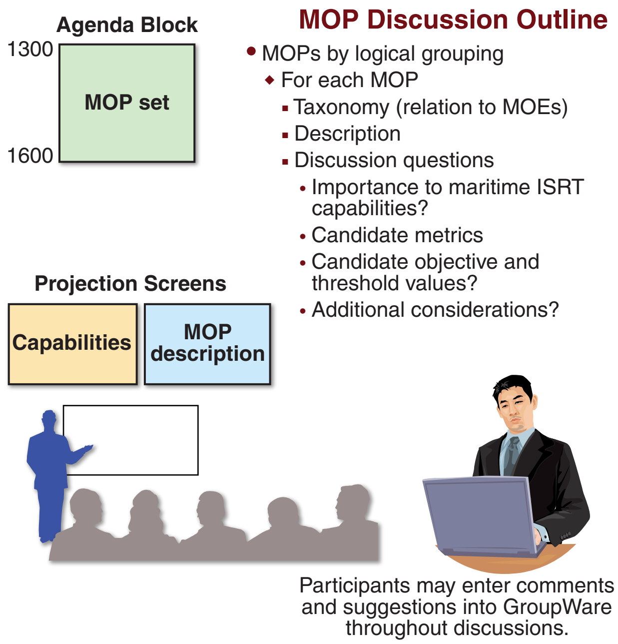

Figure 5. Process for reviewing MOPs in EP-X metrics workshop.

An example of a refined MOP is: "The range(s) of frequencies/wavelengths over which a sensor must operate." It must be remembered that the intent of the MOE and MOP discussions was not to set engineering requirements for EP-X, but to identify reasonable measures of effectiveness and performance for comparing competing systems. Nevertheless, these discussions were dynamic and wide-ranging as operators, engineers, program managers, and others aired their perspectives of what EP-X needed to do, how it would do it, and what the cost and schedule constraints were likely to be. The second workshop included three surveys. The first survey rated the value of the 16 refined MOEs for comparing candidate systems. The second survey rated the value of the 28 MOPs in each of the 13 capability areas. As stated above, these 13 capability areas were developed by an operations working group beforehand and were an aggregation of the 47 JCAs assessed in the first workshop. The final survey was a simplified rating of the 28 MOPs without regard to the 13 capability areas. The results of the surveys were summarized to the participants and, as in the first workshop, used as visualization tools for stimulating further discussions.

Workshop Analysis Results

The two EP-X collaborative analysis workshops produced an extensive set of insightful GroupWare comments, either as interactive text comments submitted during the discussions or as answers to survey questions. These comments included descriptions of needed capabilities for maritime reconnaissance and detailed technical descriptions of capabilities and the metrics used to compare them. The numeric survey results from the two workshops have been used to summarize general findings on the priorities of capabilities across mission areas and the relative value of MOEs and MOPs. As might be expected from such an interactive, collaborative event, a number of additional questions and issues emerged from the discussions. Many participants thought that additional perspectives were needed and recommended additional organizations that should provide participants for future events. The net result of the two collaborative analysis workshops is that the AoA effort has a prioritized system-level view of critical needs—both the needed capabilities and the metrics for comparing candidate systems. Much work lies ahead, but the EP-X AoA effort has performed a collaborative systems analysis, providing prioritized capabilities and metrics that will guide the preparation of credible analysis scenarios and a smaller, refined set of MOEs and MOPs.

CONCLUSION

The Laboratory's development of WALEXs evolved from the need for a broad, multidisciplinary view of complex problems. Over the years, WALEXs have addressed many complex problems. Within the realm of systems engineering, WALEXs provide collaborative systems analysis: the exposure of analytical products to a collaborative environment that draws upon the expertise of all of the system stakeholders—the customers (i.e., system users), the engineering specialists, and the program managers. Collaborative systems analysis both vets and contributes to systems analysis and ultimately leads to a better understanding of the systems engineering problem and its potential solutions. The EP-X case study described in this article illustrates the use of collaborative systems analysis to identify critical needs in the earlier phases of systems engineering. In the case of the EP-X study, these critical needs—the system capabilities and their underlying metrics—will be used to compare candidate systems and not necessarily to develop a new system. If a new system is needed, then collaborative systems analysis is the ideal analytical forum to examine the important issues and explore the necessary tradeoffs and what-ifs within each of the six phases of the systems engineering process.

Ultimately, how the Navy chooses to perform future maritime surveillance will depend on the balance it chooses between operational ideas, applied technologies, and acceptable cost and schedule. Whether a manned aircraft fits within that balance has not been finalized. The value of collaborative systems analysis, and the thrust of this article, is that the process offers a system-level view that collaboratively examines and assesses of the balance among multiple perspectives.

REFERENCES

[1]Kossiakoff, A., and Sweet, W. N., *Systems Engineering Principles and Practice*, John Wiley & Sons, Inc., Hoboken, NJ (2003).

[2]Gingras, R. E., "APL's Warfare Analysis Laboratory: Applications and Accomplishment," *Johns Hopkins APL Tech. Dig.* **21**(2), 217–224 (2000).

[3]Nolen, J. M., "The WALEX Process," *Johns Hopkins APL Tech. Dig.* **21**(2), 225–230 (2000).

[4]U.S. Navy Fact File, "EP-3E (ASIREIS II) Signals Intelligence Reconnaissance Aircraft," http://www.navy.mil/navydata/fact_display.asp?cid=1100&tid=1000&ct=1 (accessed 12 Apr 2009).

[5]Fulghum, D. A., "EP-X Program Starts to Take Shape," *Aviation Week*, http://www.aviationweek.com/aw/generic/story_generic.jsp?channel=awst&id=news/aw041409p1.xml (12 Apr 2009).

[6]J7 Joint Force Development and Integration Division (JFDID) Future Joint Warfare, "JCA Definitions and Framework," *Joint Capability Areas (JCAs)*, http://www.dtic.mil/futurejointwarfare/strategic/jca_framework_defs.doc (accessed 12 Apr 2009).

[7]Verga, P. F., and McChrystal, S. A., *Joint Capability Areas (JCAs)*, Office of the Secretary of Defense Memorandum, Washington, DC, http://www.dtic.mil/futurejointwarfare/strategic/jca_approvalmemo.pdf (12 Jan 2009).

[8]Office of Aerospace Studies, *Analysis of Alternatives (AoA) Handbook: A Practical Guide to Analyses of Alternatives*, http://www.ndia.org/Divisions/Divisions/SystemsEngineering/Documents/Committees/Mission%20Analysis%20Committee/Support%20Documentation/AoA%20Handbook%20Final.pdf (July 2008).

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John M. Nolen designed and facilitated the EP-X workshops described in this article. Mr. Nolen has more than 12 years experience in designing and facilitating collaborative events. He is a member of the Principal Professional Staff and works in the National Security Analysis Department. Before joining the Laboratory in 1997, he was a career officer in the U.S. Army. **Michael S. Moreno** was APL's project manager for the EP-X AoA study. He directed the efforts of the APL analysis team, which included the delivery of the two APL-hosted EP-X workshops. Mr. Moreno has extensive experience in all phases of the airborne intelligence, surveillance, and reconnaissance (ISR) mission. He is a member of the Senior Professional Staff in the Force Projection Department. Before joining APL in 2004, Mr. Moreno was a career officer in the U.S. Navy's airborne electronic warfare community. **Russell E. Gingras** is the Chief of Staff at APL. As the Laboratory's principal subject-matter expert on analytical wargames and the design of collaborative facilities, he provided background information and editorial advice for this article. Since joining APL in 1969, he has gained more than 30 years of analytical experience, much of it focused on the design and delivery of collaborative events. He has participated in the design and fielding of every generation of the WAL. In his previous position as the head of the Joint Warfare Analysis Department, he led the fielding effort for the current version of the WAL. For further information on the work reported here, contact John Nolen. His e-mail address is john.nolen@jhuapl.edu.

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