Software Engineering Institute

Schedule Considerations for Interoperable Acquisition

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Abstract

The role of schedule is fundamental to the acquisition of a particular system. This topic is of even more importance to acquisition in a system-of-systems environment. This report examines the issue of schedule considerations for interoperable acquisition. First, a *Gedanken* red team project is used to explore concerns about schedule in interoperable acquisition. Then, those concerns are examined in light of current requirements regarding schedule. From that examination, several research questions are proposed.

1 Introduction

There is little question of the importance of a schedule to an acquisition, and much has been written about it; see, for example, the *Scheduling Guide for Program Managers* [DSMC 01]. The term *schedule* can convey different meanings, depending on the context. One definition is

> **schedule:** a series of things to be done in a sequence of events within a given period; a timetable [DAU 05a].

The importance of a schedule is that it sets dates of major importance to the organization(s) responsible for it. However, a schedule also creates expectations in other organizations.

This report addresses the topic of schedule in the context of interoperable acquisition. We introduce the following definition:

> **interoperable acquisition:** the set of practices that enable acquisition, development, and operational organizations to more effectively collaborate to field interoperable systems. This is achieved through sharing relevant information and performing necessary activities that enable the collective behavior of these organizations to successfully deliver systems-of-systems capabilities.

An overview discussion of the challenges of interoperable acquisition is presented in *Interoperable Acquisition for Systems of Systems: The Challenges*. That technical note outlines the critical aspects of systems of systems and interoperability that affect the acquisition, deployment, sustainment, and operational use of systems of systems [Smith 06].[1]

Schedule concerns are of special importance to interoperable acquisition for several reasons, including:

- Several distributed organizations (such as program offices, decision agencies, contractors, and users) often have interest in a schedule, motivated by dependencies among them. These organizations may not be known to one another until later in the development, revealing the need to address issues of trust and culture.
- There is a need to exchange information about schedule and its dependencies to parties of interest. However, terminology used to describe a schedule may be different across different organizations.
- Changes made to a schedule by one organization can have ramifications for other organizations that have dependencies reflected in the schedule.

Each of those reasons pushes schedule considerations to the forefront in any discussion of interoperable acquisition.

1. In addition to this technical note on schedule considerations and *Interoperable Acquisition for Systems of Systems: The Challenges* (CMU/SEI-2006-TN-034), there are two other technical notes resulting from an independent research and development (IR&D) project supported by the Software Engineering Institute (SEI).The other technical notes describe process (CMU-SEI-2006-TN-033) and risk management (CMU/SEI-2006-TN-032) considerations. A fifth technical note, partially supported by the IR&D effort, will deal with programmatic interoperability issues.

This technical note is organized as follows:

- Section 2 provides some background on interoperable acquisition.
- Section 3 provides a motivating example of a *Gedanken* red team looking at questions of schedule.
- Section 4 looks at elements of a schedule from the viewpoint of interoperable acquisition.
- Section 5 provides a retrospective view and identifies some research questions.
- Section 6 contains a brief summary of the report.

2 Background

2.1 NETWORK-CENTRIC AND SYSTEMS OF SYSTEMS

The terms *network-centric* and *systems of systems* have received considerable notice in the commercial and U.S. Department of Defense (DoD) domains. These terms are used in contrast to *monolithic system*—a system designed for a particular set of tasks, managed by a single agency, and composed of components that are tightly coupled. The hope in the commercial and DoD domains is that a network-centric, system-of-systems approach will permit flexibility in dealing with changes in requirements, technology, or operational environment and reduce the time needed to provide a new capability.

In essence, network-centric operations attempt to derive power from distributed, interacting entities based on a significantly improved access to information. For example, network-centric operations are expected to feature

- **shared awareness** through the fusion of data from many different types of sensors
  In this context, the phrase *common operational picture* is often encountered.
- **virtual collaboration** among organizations designed to accomplish a specific purpose
- **execution of activities by other, often distributed, organizations** consistent with management intent [Alberts 99]

The term *network-centric operations* is a postulate of principles such as shared awareness. In contrast, the term *system of systems* represents the realization of those concepts in some operational context. There are various definitions for systems of systems, including the following:

> **system of systems:** a set or arrangement of interdependent systems that are related or connected to provide a given capability [Levine 03].

A related term is a *family of systems*. In this technical note, we will not distinguish between the two terms. Some discussion about them appears in *Requirements Management in a System-of-Systems Context: A Workshop* [Meyers 06a].

There are a number of characteristics of systems of systems. One set of characteristics, provided by Maier, includes the following:[2]

- managerial independence
  The management of each system in a system of systems is independent of the management of the other systems.

2. A reference to Maier's work, as discussed here, can be found at http://www.infoed.com/Open/PAPERS/systems.htm. Maier no longer specifically includes emergent behavior and geographic distribution as fundamental characteristics. However, emergent behavior results from considerations of *autonomy* of managerial and operational independence. An oversimplifying view, but one to keep in mind, is that a system of systems is characterized by loose coupling rather than the traditional tight coupling of a monolithic system.

- operational independence
  Each system within the system of systems can function usefully in the absence of other systems.
- evolutionary character
  Each system within the system of systems evolves independently from other systems.
- emergent behavior
  A system of systems' behavior is a consequence of the interactions among the individual systems that compose it; the behavior is not embodied in any particular system but is a consequence of the interactions that take place among various systems. This emergent behavior often appears at runtime and gives a system of systems a dynamic character.
- geographic distribution
  The systems in the system of systems are not required to be located at the same place.

The combination of these characteristics means that the policies, practices, procedures, and techniques used to acquire, develop, field, use, and sustain stand-alone systems—while still vitally important—must be reinterpreted for a system-of-systems context. In addition, new policies, practices, procedures, and techniques must be developed and integrated throughout the system acquisition life cycle.

2.2 INTEROPERABLE ACQUISITION

The concept of interoperable acquisition was introduced in Section 1. The purpose of interoperable acquisition is to more effectively allow organizations to share information and perform activities that may affect their collective behavior in achieving interoperability. It is generally agreed that the acquisition process is focused on a particular acquisition program, leading to the well-known stovepipe approach to acquisition. Systems of systems, with network-centric character, are dramatically different from traditional systems. Interoperable acquisition seeks to broaden the scope, role, and interaction of participants who engage in the acquisition process. Simply stated, interoperable acquisition is about achieving interoperability in the acquisition process.

The term interoperability has been used primarily with respect to operational systems. In the literature, one finds many examples where the term interoperability is used. However, such usage is almost entirely restricted to the domain of operational systems. One theme that runs through the current definitions is *the ability of systems to work together*. This notion has led to an emphasis on a syntactic view of interoperability ("bits on a wire"), although semantic considerations are quite relevant ("what do the bits mean?").

However, we believe a more general approach to interoperability is warranted. Treating interoperability only in the context of an operational system limits its potential application and benefit. Interoperability is about the communicating entities, the

information they share, and the operations that are performed based on that information. Toward this end, we offer a more general definition:

> **interoperability:** The ability of a set of communicating entities to (1) exchange specified information and (2) operate on that information according to a specified, agreed-upon, operational semantics.

Although it applies to the context of operational systems, the above definition is intended to encompass a broader scope of interoperability in systems of systems. This perspective is shown in Figure 1, a view that was developed in earlier work ([Levine 03], [Meyers 05], [Meyers 05], [Smith 05]) and leads to the consideration of **programmatic interoperability** and **constructive interoperability**, in addition to **operational interoperability**. We suggest that acquisition can be addressed in terms of functional domains in the management, construction, or operation of a system.

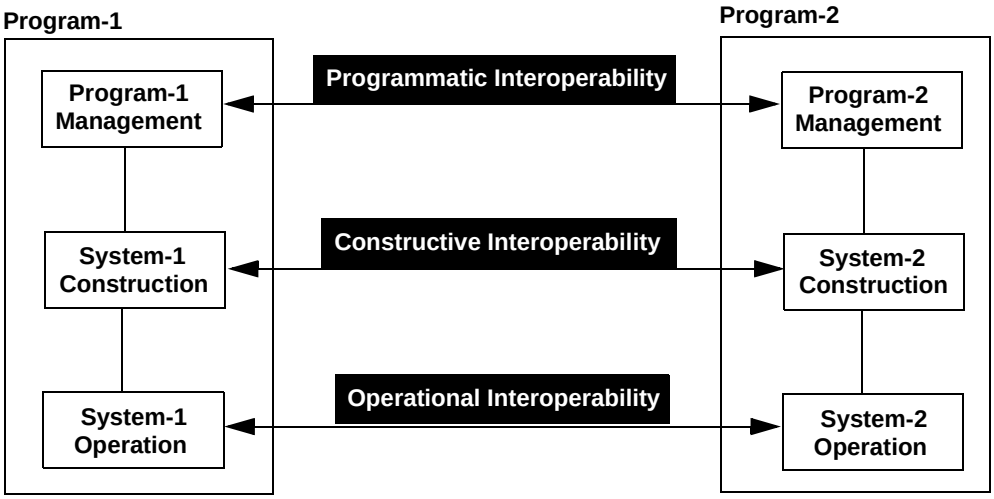

Figure 1: System-of-Systems Interoperability (SOSI) Model

Programmatic interoperability, constructive interoperability, and operational interoperability represent interoperability between different domains that compose an acquisition. In particular, these domains are characterized by

- the entities (Program-1, Program-2, and so forth) that need to communicate
- the data they share
- the operations that are performed

There can also be interactions among the various domains as well. An example of this would be interaction between functions related to program management and system construction. Such interactions are in the vertical dimension in Figure 1.

A diagram such as Figure 1 can be easily interpreted in an overly simplistic manner. We caution against such oversimplification. While it might be a shorthand to interpret programmatic interoperability as interoperability among program management organizations, such an interpretation is incorrect. In fact, we define programmatic interoperability as

> **programmatic interoperability**: interoperability among functions appropriate to the management domain, *independent of the organization that performs those functions*

This definition suggests that programmatic interoperability may involve the program management office as well as others that are engaged in the management of a component or a system of systems—such as users, contractors, suppliers, and so on. Occasionally, there is a partitioning of activities among the participants in programmatic interoperability; for example, contracting decisions are made by a limited number of organizations. Definitions of other types of interoperability, namely constructive interoperability and operational interoperability, can be developed analogously to that of programmatic interoperability.

Given the preceding examination, it is relevant to discuss key influences that affect the acquisition process. Although there may be many such factors, our focus here is on those factors that closely relate to considerations regarding the basic elements of interoperability. The following discussion is couched at a higher level; we will examine these issues in more detail later in this report.

2.2.1 Scope of Interaction

Interoperability in the acquisition process is influenced by the scope of interaction among organizations that participate in the process. We consider the basic models shown in Figure 2.

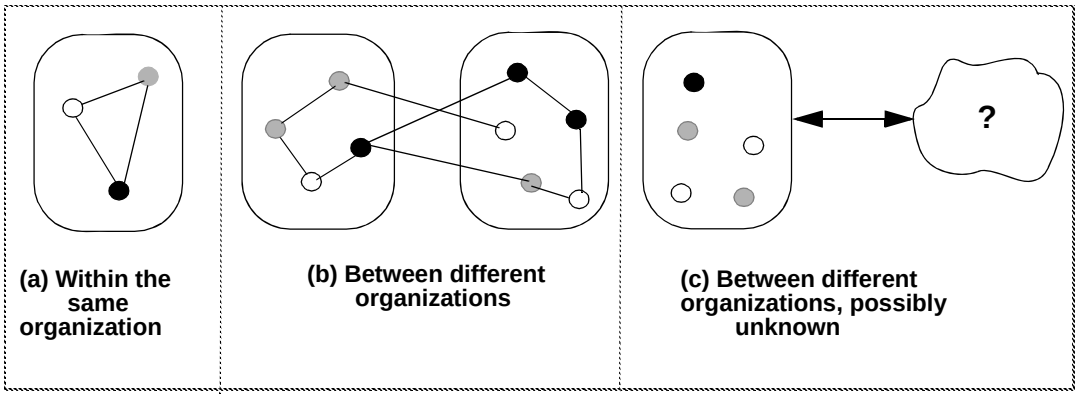

Figure 2: Models of the Scope of Interaction

The different cases are described as follows:

- Case (a) represents the interoperability that is within the context of a particular organization. In general, this is the easiest case since it is within the context of one organization.
- By contrast, in Case (b) the interoperability is between different organizations. It is assumed that the set of communicating entities is known. Dealing with different organizations brings in consideration of organizational policies and practices that might be in conflict.
- Case (c) is fundamentally different in that the identity of the other organizations may not be known. This case is analogous to an organization presenting information to others that may need such information—independently of any prior agreement about which organizations should be given that information.

The three cases can be seen as depicting two situations that are quite different. The first two cases are characteristic of a *bounded* environment, in that the communicating entities and their number are known (and assumed to be relatively stable over time). The last case is emblematic of an unbounded environment in which the identity and number of communicating entities is not known. That situation, an *unbounded* environment, is often found in network-centric operations and systems of systems.

2.2.2 Nature of Agreements

Interoperability in the acquisition process is influenced by the nature of agreements among organizations that participate in the process. Various types of agreements can be considered as part of achieving interoperability:

- public law
- contractual relationships
- memoranda of understanding
- implicit agreements (For example, if two organizations agree to conform to some standard, they have in effect entered into an agreement.)

In some sense, any type of agreement can be regarded as an *influence relation*. The nature of the influence is often connected to the expected behavior of the entities that engage in an agreement. For example, a contract specifies expected behavior as agreed to by the contracting agent and the contractor. Different types of agreements are related to the character of an organization entering into an agreement. The character is determined in part by the environment in which the agreement takes place. For example, when a government agency enters into a agreement, that agreement is determined, in part, by the regulations that govern the behavior of the government agency. Such regulations are different when an agreement is undertaken by two commercial firms. Some discussion of the subject of organizations and their agreements is presented in *System-of-Systems Navigator: An Approach for Managing System-of-Systems Interoperability* [Brownsword 06].

2.2.3 Shared Information

Interoperability in the acquisition process is influenced by the information that is shared. Fundamental to any discussion of interoperability is the information that is shared. Two overarching considerations are (1) what information needs to be shared and (2) who decides that information. There are interesting parallels to the factor concerned with the scope of interaction between communicating entities described in Section 2.2.1: what are the implications for the **data** that is shared in an unbounded environment and can the determination of necessary information be made at runtime? Further, if that determination can be made at runtime, we have moved to a **dynamic** environment that is considerably more challenging—and interesting—than a static one in which the scope of information to be exchanged is bounded and known.

2.2.4 Operations

Interoperability in the acquisition process is influenced by the operations that are performed by the communicating entities. Where entities desire to interoperate, the operations performed are of ultimate concern because those operations represent the *behaviors* of the communicating entities. It is reasonable to ask:

- What behavior is expected, or required, of entities that participate in interoperable acquisition in a bounded or unbounded environment?
- Can those behaviors change over time?
- If behaviors can change, what are the implications of those changes?

2.3 DEALING WITH SCHEDULE

Dealing with schedule is just one aspect of interoperable acquisition and there are many others. In another report, we considered the case of interoperable risk management defined as:

> **interoperable risk management:** the subset of interoperable acquisition practices that enable acquisition, development, and operational organizations to identify, share, and mitigate risks that are inherent to a system of systems [Meyers 06b].

The purpose of interoperable risk management is to more effectively allow organizations to share information and perform necessary activities with regard to risk management that may affect their collective behavior.

The preceding definition could easily be modified for the case of interoperable **schedule** management. The principles introduced earlier, regarding communicating entities, information shared, and operations performed on that information, may be couched in the context of schedule, namely:

- What are the communicating entities engaged in acquisition **with regard to schedule**?
- What **schedule information** needs to be shared?
- What are the operations (or behaviors) **related to schedule**?

The above questions are a specific case of the more general questions stated in the other report regarding interoperable acquisition. Here, however, the focus is on schedule management.

3 A Motivating Example

This section will examine the role of schedule in the context of acquisition in a system-of-systems environment.[3] From this examination, one can gain an understanding of how a schedule is viewed not only by participants in some acquisition but also by others outside that acquisition. Concern for a broader audience distinguishes interoperable acquisition from traditional (system-centric) acquisition.

3.1 APPROACH

To begin to examine the role of schedule in an acquisition, we set up a *Gedanken* red team[4] experiment. We assumed a red team was being conducted that involved two programs creating products or services for an integration project. This case is the more interesting (as opposed to schedule consideration for a program acting alone) because it addresses the integration of schedule information.

The information shown in Figure 3 was first presented as a slide to the red team.

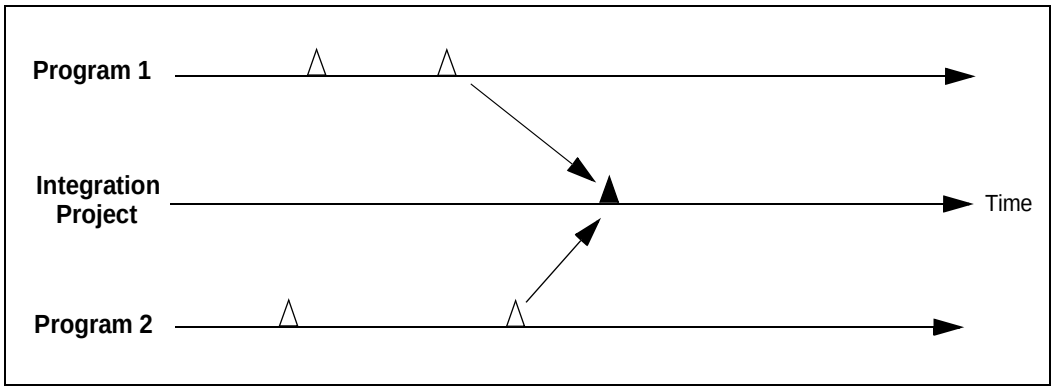

Figure 3: Integration of Acquisition Projects

The arrows shown in Figure 3 represent the dependencies between the individual programs and the integration project. They therefore reflect some deliverable that is expected to be provided to the integration effort.

3. We use the phrase *acquisition in a system-of-systems environment* to indicate that some acquisition entity is responsible for producing a system that will operate in a system-of-systems environment. We do not use the phrase *acquisition of a system of systems* because it could be construed to imply a single acquisition of a system of systems treated as a single unit.

4. The term *Gedanken* red team refers to a thought experiment involving a red team. Originally used in the sense of a *Gedanken* experiment, it refers to an imagined scenario that is used to help gain an understanding of the domain of the experiment. The methodology is *a priori* as opposed to empirical.

In addition, the members of the red team were also presented with a process perspective of the effort. This information, let's suppose, was presented in a second slide as shown in Figure 4.

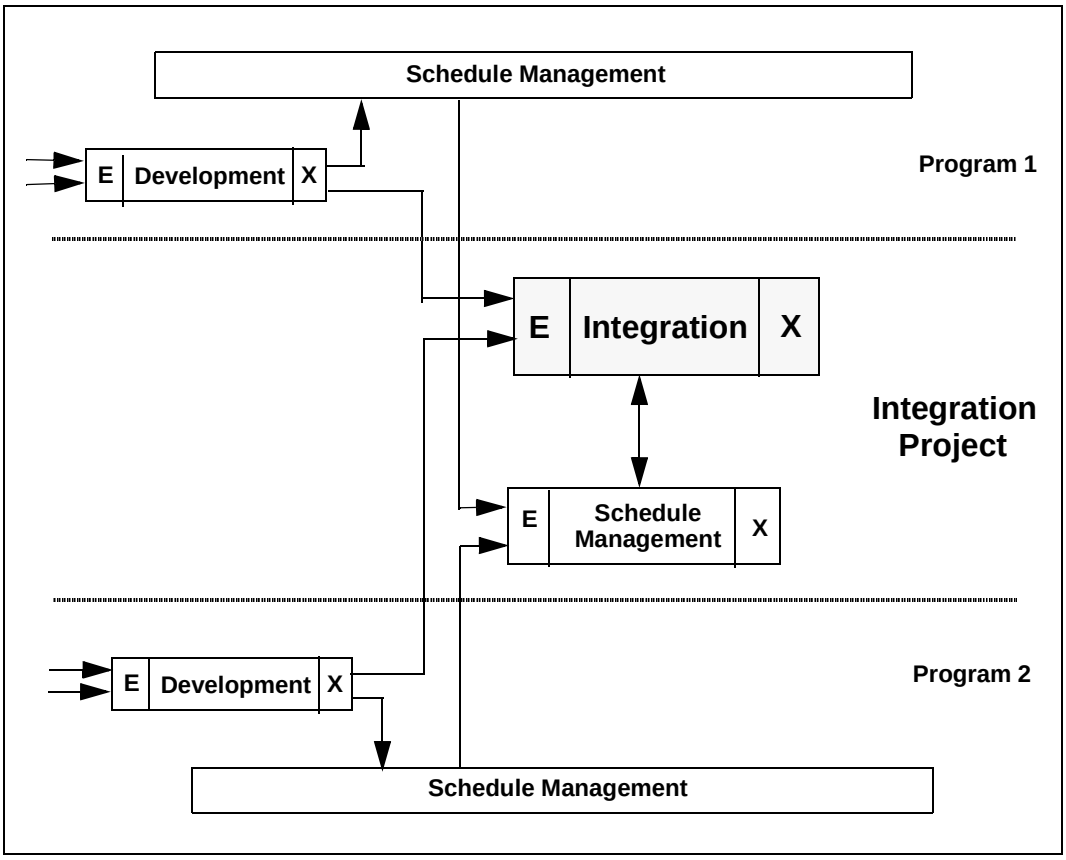

Figure 4: Integration in a Process Context

The following notes were provided about this slide:

- Each program has a development effort that is modeled using an ETVX (entry, task, validation, and exit criteria) model.
- Each program has a process for schedule management about the work performed on the program in order to have an up-to-date view of the status.
- The integration project expects certain input from each of the development programs as indicated by the arrows in the diagram. The integration project also has a process that performs the function of schedule management.

It was also stated that there was some concern about meeting the schedule event for the integration effort shown in Figure 3. In particular, there was concern voiced that the input from Programs 1 and 2 would not be ready for the integration effort to proceed.

Following the presentation of the preceding information, the members of the red team were invited to express their concerns. That discussion, largely couched in the form of questions, is presented in the following section.

3.2 RED TEAM QUESTIONS

A number of questions were asked regarding the information shown in Figures 3 and 4. The various questions can be grouped in the following categories:

- basic information
- organizations and dependencies
- shared information
- approval
- risks
- dealing with change

The questions were posed to a program manager (PM), the integrator (Integrator), or all organizations (All).

3.2.1 Basic Information

A number of questions arose simply regarding the interpretation of the material shown in Figure 3, including

- (All) What is the meaning of the triangles shown in this figure? Are they formal milestones, reviews, or what?
- (All) From a higher level perspective, what drove the choice of dates for the schedule events? How did these choices fit the overall contracting strategy?
- (PMs) How did you pick the date for the schedule events? What are the chances you'll meet those dates? Do you have metrics or past performance information to support the confidence in your estimates?
- (Integrator) How did you pick the date for when PMs had to provide you with things for the integration? What was the role of the PMs in deciding this? What confidence do you have that the PMs will meet their dates?
- (All) Please describe the process called schedule management.
- (All) What is the critical path?

3.2.2 Organizations and Dependencies

A number of organizations participate in the integration effort. It is natural, therefore, to seek to understand their roles and interdependencies. The following questions were asked:

- (All) What organizations can influence your schedule or your ability to meet any dates?
- (All) Describe the nature of any dependencies with other programs or organizations that can affect a schedule event. How are these dependencies managed (e.g., on a one-to-one or a collective basis)?

- (All) What is the nature of the ongoing interactions between the PMs and the integrator with respect to schedule? Is there a description of this process? Are there practices? MOUs?[5] How formal are they?
- (All) Who makes sure the process is performed according to its intended plan? Where's the belly-button?
- (All) Who is the arbitrator for decisions if there are disagreements; how are disagreements resolved? Is there an overarching authority?
- (All) Are there dependencies on external entities (a legacy system, an organization, or a commercial off-the-shelf [COTS] product) that cannot be changed? How is a case such as this handled?

3.2.3 Shared Information

Because the context of this exercise deals with the integration of work products (or services) provided by different PMs to an integrator, it is natural that there would be questions about the information shared. The following questions were asked:

- (PMs) What is it that you are expected to provide to the integrator? Is there a written agreement regarding this information? Who signed off on it? When was it signed? How often has it been modified and why?
- (Integrator) Do you routinely monitor the progress of the PMs for their ability not only to meet the integration date but also to provide quality products[6] to you? How would you know if this were not the case?
- (PMs) What are the exit criteria for products of relevance? Who developed them? Were they approved by the integrator?
- (Integrator) Is there a way you can verify the exit criteria are satisfied for the products provided to you? Are the exit criteria from the PMs the same as your entrance criteria to the integration effort? If not, what differences are there?
- (All) How harmonious are the exit criteria among the participants? Here are two examples:
  - Are the exit criteria for the PMs **weaker** than the entrance criteria defined by the integrator?
  - Could the entrance criteria defined by the integrator be **stronger** than the exit criteria defined by the PMs?

  Who monitors situations like these for potential mismatches? While the two cases appear to be similar (and will have similar consequences), their rationale is different. How are conflicts identified and resolved? And who **pays** to make the products conform to the entrance and exit criteria assessments when there is a disagreement?
- (PMs) If you want to change an exit criterion, is the change agreed to by the integrator? Who pays?

5. An MOU is a Memorandum of Understanding. For a listing of acronyms and initialisms used in this technical note, see the Acronyms and Initialisms section.

6. Here and hereafter, we will use the term *product* to mean either a product or a service.

- (Integrator) If you want to change an entrance criterion, is the change agreed to by an affected PM? Who pays?
- (All) Is there any proprietary information? How is it handled?
- (All) Are there intermediate points where you share information to get an idea on progress?
- (PMs) Are there any dependencies between the products you are creating, independent of the integrator? How are conflicts identified and managed?

3.2.4 Approval

Schedule events can be of various types, from formal reviews with other organizations to events that are localized to a project. There may also be requirements related to the approval of a schedule event. The following questions arose:

- (All) Does the schedule event require approval? If so, why is this not shown as a milestone on the slide?
- (All) Who approves the schedule events?
- (All) What is the current status of the schedule event(s) with regard to it being approved?
- (All) What are the consequences to the schedule event if is not approved when expected? Is there another round of approval? What are the implications of another round of approval to the overall process?
- (All) What are the criteria associated with the approval process? Who decides them?
- (All) Are there artifacts that must be provided as part of the approval process? What are they? Are these artifacts shared with others? If so, how are they used?
- (All) Are there dependencies among the approval processes and if so, how are they managed (e.g., is it possible that the schedule event for the integrator could be approved **prior** to the approval of the schedule events for the PMs)? Who manages the dependency of approvals?
- (All) Can the approval for a previously approved schedule event be withdrawn? By whom? What happens? Has this ever happened?

3.2.5 Risks

It is accepted that programs should manage risk. Thus, it was not surprising that questions were generated around this topic, including

- (PMs) What are the risks to your meeting the schedule event? What is the basis of risk and how was it determined? Are the risks shared, and managed, among all PMs and the integrator?
- (Integrator) What are your risks, apart from those directly related to a PM, to meet the integration schedule event? How were they determined?
- (All) How much sharing of risk management information is performed? What is the process? Is it routinely practiced? How are decisions made about risk mitigation planning; in particular, who pays? What is the level of authority of partici-

pants? Do they have the ability to authorize change? What is the scope of their authority and knowledge to make decisions?

- (Integrator) What happens if the PMs do not meet their schedule? How and when will you know? What is your fallback position? Do you have any contingency plans?
- (All) What are the risks to your schedule that are outside the scope of your control (e.g., COTS)? How do you deal with these risks?

3.2.6 Dealing with Change

Dealing with change is normal for acquisition programs. The ability to deal with and manage change becomes more important when multiple acquisition programs are involved. It was natural that the red team would probe this point; the questions asked included

- (PMs) What is the impact on you if the integrator has to move the schedule event to the left? To the right?
- (PMs) How do you make the integrator aware of changes to your schedule events? What is the severity of change? How do you assess impact of change to schedule? How does the integrator participate in this process?
- (All) How do you find out about potential schedule changes from other organizations, like contractors or other programs?
- (Integrator) How do you communicate the need for possible schedule changes to the integration schedule event to the PMs?
- (All) What is the time-dependence of the entrance and exit criteria? Do those criteria change often? Why? We are interested in the volatility of these criteria.
- (All) Is there slack built into your schedule? How is it determined? Is it visible to others?
- (All) Do you foresee the need to make any contractual modifications? If so, how will cost be managed? What happens to the schedule? Has this been done in the past? What happened?

3.3 SUMMARY

Approaching the question of schedule by considering a *Gedanken* red team has proven to be interesting. It is worth stepping back and noting some observations about the results.

- The questions cover many topics, typical of a red team. We believe this reflects two things. First, schedule events are a focal point for entrée into a discussion of many related topics. Second, the inherent importance of schedule events makes them prime candidates for discussion.
- Schedule has interest beyond some milestone. There is a lot of information reflected by a schedule, and it didn't take long to uncover questions demonstrating a much larger scope than simply a milestone.

- There is a gradation of visibility about information derived from a discussion of schedule. Some information might be public and can be shared with others; other information might be kept private with little willingness to share (e.g., due to loss of a possible competitive advantage). The issue of the degree of sharing appears often in the preceding discussion and is no doubt a general consideration for any system of systems.
- The questions seem to apply to an acquisition of a single system as well as acquisition in the context of a system of systems. It is necessary, however, to consider dependencies, due to the presence of multiple participants in an acquisition in the context of a system of systems. There may be differences in management of control and authority and processes. Significant differences in these aspects might indicate areas of concern. When multiple organizations are present, a holistic picture must emerge—not the view of a single program or organization.

Considerations such as the preceding ones warrant a more detailed look at the elements that are associated with a schedule. This material will be discussed in the following section.

4 Schedule

In this section, we examine the subject of schedule from the perspective of interoperable acquisition; in it, we assume that the reader has some familiarity with DoD acquisition.[7] We focus on milestones, including certain requirements imposed by the legal and regulatory environment, and consider interoperability aspects related to a schedule. While it is oriented toward schedule events more often considered in the context of an acquisition, our discussion in this section can also apply to the development and operational aspects of an acquisition.

4.1 BACKGROUND

The term *schedule* can have various interpretations, depending on the context in which it is used. In the simplest case, a schedule is a sequence of temporal events or activities. For example, in the DoD a schedule is associated with an acquisition life cycle. The life cycle is divided into acquisition **phases**, and there may be **milestones** associated with each phase. A simple rendition of an acquisition life cycle is shown in Figure 5. The life cycle shown is sequential, but other choices are possible, such as an evolutionary acquisition.

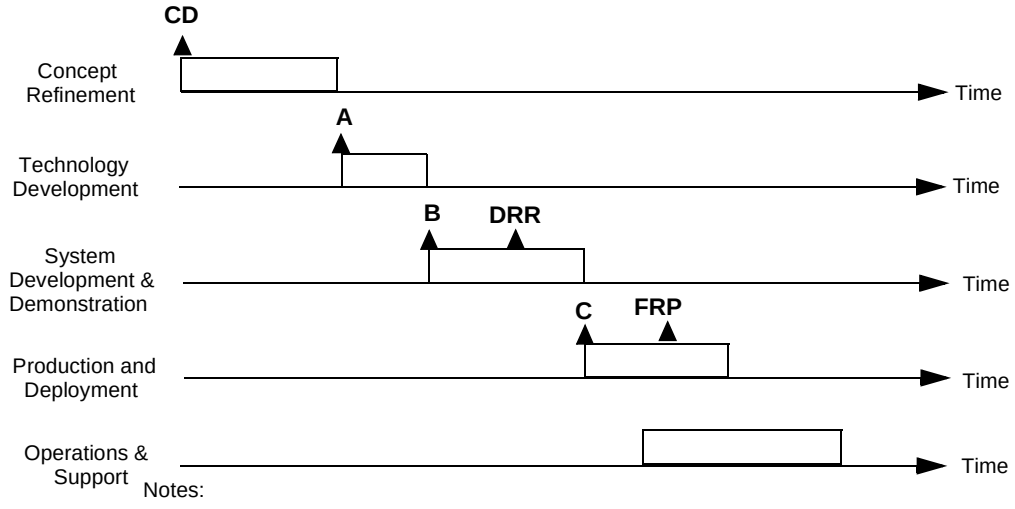

Figure 5: Typical Phases in an Acquisition Life Cycle

To deal with the specifics of a schedule, we represent an abstraction of the concept of a schedule in Figure 6. The representation shown includes information typically presented in a schedule traditionally associated with an acquisition program.

7. The *Introduction to Defense Acquisition Management* from the Defense Acquisition University provides background on DoD acquisition [DAU 05b].

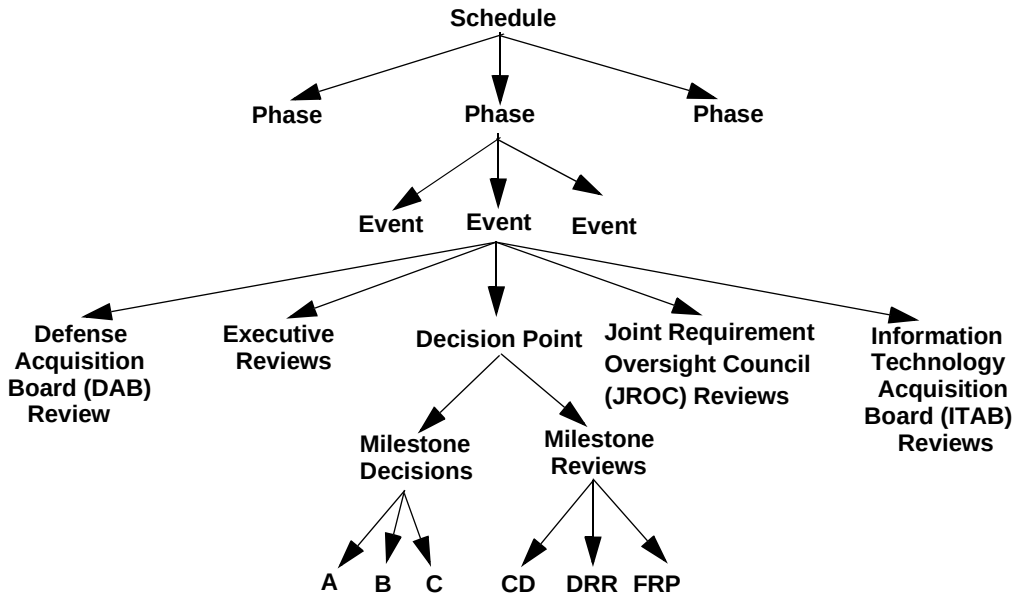

Figure 6: Abstraction of a Schedule

The information shown in Figure 6 suggests that a **schedule** can also be viewed as a collection of **phases** and that **events** are associated with a phase. An event can be of different types, including a **decision point** and others indicated in the figure. A group of decision points is subdivided further into **milestone decisions** and **milestone reviews**. Among the group of milestone decisions are those denoted A, B, and C; milestone reviews include Concept Decision (CD), Design Readiness Review (DRR), and Full Rate Production (FRP). Each event, such as Milestone A, has a name, a meaning (semantic content), and some temporal representation (most often shown as a triangle on a Gantt chart). Notice that the group of events shown in Figure 6 contains other reviews of various types as well as milestone reviews. The simple taxonomy shown in Figure 6 applies to the schedule shown in Figure 5.

4.2 EVENTS

A major element of a schedule is an event, and several events are listed in Figure 6, including decision points. In the following sections, we consider characteristics and supplementary information that could be associated with decision points.

4.2.1 Milestone Decisions

Consider first the milestone decision point, which authorizes entry of an acquisition program into some acquisition phase, such as program initiation. The source of information about a milestone decision can be statutes[8] or agency regulations, such as the *The Defense Acquisition System* (DoD Directive 5000.1) [DoD 05a] and the Federal

8. Most often, a statute (e.g., Title 10) specifies **what** must be done, not **when** it must be done. In some cases, (e.g., specification of Low Rate Initial Production [LRIP] quantities as per 10 USC § 2400), there is direct reference to a temporal event. If a statute does not define when a particular item must be provided, the date is determined through regulations set forth by the acquiring agency [USC 04].

Acquisition Regulations (FARs). The rationale for including statutory information in this report is that we are interested in the effect of statutes, in particular Title 10, on acquisition in a system-of-systems environment.[9] In general, to the extent that statutes refer to particular temporal events, they affect an acquisition, especially an acquisition in a system-of-systems environment.

Table 1 indicates the required information, its source, and the milestone decision (designated as MS A, MS B, and MS C) to which it is applicable. The information in the table was taken from *Operation of the Defense Acquisition System* (DoD Instruction 5000.2) [DoD 04].[10]

Table 1: Supplementary Information for Milestone Decisions

Required Information	Source	MS A	MS B	MS C
Acquisition Program Baseline	10 USC § 2435		✓	✓
Benefit Analysis and Determination	15 USC 644 (e)		✓	✓
Clinger-Cohen Act Compliance	40 USC Subtitle III Pub. L. 107-248, § 8088	✓	✓	✓
Certification of compliance with the Financial Management Enterprise Architecture	Pub. L. 107-248 § 8088	✓	✓	✓
Competition Analysis	10 USC § 2469		✓	✓
Consideration of Technology Issues	10 USC § 2364	✓	✓	✓
Cooperative Opportunities	10 USC § 2350a		✓	✓
Core Logistics Analysis/Source of Repair Analysis	10 USC § 2460 10 USC § 2464 10 USC § 2466		✓	✓
Independent Cost Estimates	10 USC § 2434		✓	✓
Industrial Capabilities	10 USC § 2440		✓	✓
Live Fire Waiver and Alternate Live Fire Testing and Evaluation (LFT&E) plan	10 USC § 2366		✓	
LRIP quantities	10 USC § 2400		✓	
Market Research	10 USC § 2377 15 USC § 2644(e)	✓	✓	
Program Deviation Report	10 USC § 2435	Immediately upon a program deviation		
Programmatic Environment Safety and Occupational Health Evaluation	40 USC § 4321		✓	✓
Registration of mission-critical and mission-essential information systems	Pub. L. 107-248 Pub. L. 106-398 § 811		✓	✓
Selected Acquisition Report (SAR)	10 USC § 2432		✓	✓
Spectrum Certification Compliance	47 USC § 305 47 USC § 901-904		✓	✓
Unit Cost Report	10 USC § 2433	Quarterly		
Technology Development Strategy	Pub. L. 107-314 § 803	✓	✓	✓

The information shown in Table 1 lists only the statutes that apply to a particular milestone. Beyond statutory considerations, the DoD has developed regulatory requirements. The *Operation of the Defense Acquisition System* (DoD Instruction

9. Results of an analysis of Title 10's effect on acquisition in a system-of-systems context will be reported in the future.

10. Some details associated with the data taken from *Operation of the Defense Acquisition System* are not reported in Table 1. For instance, requirements might vary for different types of acquisition categories.

5000.2) [DoD 04] specifies that exit criteria be provided for milestones A, B, and C, for instance; other DoD regulations require an Initial Capabilities Document (ICD) and Capability Development Document (CDD).

4.2.2 Milestone Reviews

Next, consider the case of milestone reviews. The purpose of such reviews is to assess progress in a program and authorize further activity. The type of information required for a milestone review is shown in Table 2.

Table 2: Supplementary Information for Milestone Reviews

Required Information	Source	CR	DRR	FRP
Acquisition Program Baseline	10 USC § 2434			✓
Beyond LRIP Report	10 USC § 2399			✓
Certification of compliance with the Financial Management Enterprise Architecture	Pub. L. 107-248 § 8088			✓
Clinger-Cohen Act Compliance	40 USC Subtitle III Pub. L. 107-248 § 8088			✓
Independent Cost Estimate and Manpower Estimate	10 USC § 2434			✓
LFT&E report	10 USC § 2366			✓
Post-Deployment Performance Review	5 USC § 306, 40 USC § 1131			✓
Programmatic Environment Safety and Occupational Health Evaluation	41 USC § 4321			✓
Registration of mission-critical and mission-essential information systems	Pub. L. 107-248 § 8088 Pub. L. 106-398 § 811			✓
Selected Acquisition Report (SAR)	10 USC § 2432			✓

The information shown in Table 2 is required by statute, in particular by Title 10. The *Operation of the Defense Acquisition System* (DoD Instruction 5000.2) [DoD 04] does not include references for statutes regarding the Concept Review (CR) and DRR events. However, DoD regulations may place requirements on these reviews. For example, the *Operation of the Defense Acquisition System* (DoD Instruction 5000.2) requires an Analysis of Alternatives (AoA) plan as part of the CD review.

Other requirements specified in *Operation of the Defense Acquisition System* (DoD Instruction 5000.2) [DoD 04] and other regulations apply to milestones A, B, and C, such as

- Acquisition Strategy
- Command, Control, Communications, Computers, and Intelligence (C4I) Supportability Certification
- Economic Analysis
- Component Cost Analysis
- Cost Analysis Cost Description
- Test and Evaluation Master Plan
- Operational Test Agency Report of Operational Test and Evaluation Results

4.2.3 Other Events

Thus far, we have considered information required by statute, in particular by Title 10. There are other schedule events called out in regulatory documents (and shown in Figure 6 on page 20), including the following:

- DAB review
- executive reviews
- JROC reviews
- ITAB reviews

In addition, other events conducted for a particular program are often shown in the details of the schedule of the program. Some possible events of this type are

- risk management reviews
- cost reviews including independent cost estimates
- evaluation of a COTS product
- product status reviews, including obsolete or unattainable products

The preceding events might become part of some other event that is required to be reported and reviewed. For example, a program might perform internal cost reviews; the results of these reviews might be included later in a SAR.

4.2.4 Summary

A myriad of information is required to be reported with a schedule. Some of this information is based on statute; some, on regulations. The amount of information required demonstrates the importance of a schedule to a particular program. Hence, it is natural to assume the same importance is present when one considers multiple programs participating in an acquisition (i.e., in a system-of-systems environment).

4.3 INTEROPERABILITY CONSIDERATIONS

It is relevant now to look at the questions developed by the *Gedanken* red team (see Section 3) in terms of interoperable acquisition. In the following sections, we focus on the three main aspects of interoperability: (1) communicating entities, (2) information shared, and (3) behaviors.

4.3.1 Communicating Entities

A natural approach to identifying entities that seek to communicate schedule information can be determined from our discussion of events. Restricting our attention to the case of milestone reviews, we suggest that the entities would include the following:

- Program Management Office (PMO)
  This PMO has acquisition authority and responsibility for the schedule elements (in this case, events). Note that a PMO is almost always tied to a particular system.
- PMOs with which the system is expected to interoperate
  For example, there may be a need to perform integration testing of the systems.

- Program Executive Office (PEO)
  A PEO provides some form of oversight to programs and often has interest in the progress of the program.
- Milestone Decision Authority (MDA)
  The MDA must approve milestone decision points.
- JROC
  The JROC represents the operational community and is interested in the progress of a program.

Possibly, other organizations can be included, too. Thus, we extend the preceding list to include these entities:

- contractor management
- user representatives
- sustainment agency
- training agency
- test and evaluation
- deployment agency
- oversight agency[11]

4.3.2 Information Shared

One key aspect of interoperability is the information that must be shared among entities. Figures 5 and 6 (on pages 19 and 20) illustrate the concepts that need to be identified with regard to a schedule. However, what information is associated with each of these items? For a schedule event, we suggest that the following are relevant:

- **the name of the particular schedule event**
  The name must be unique across all instances of relevant schedule events.
- **the semantics (meaning) of the particular event**
  In the case of Milestone A, one choice for the semantics is "the point at which a recommendation is made and approval sought regarding starting or continuing an acquisition program, i.e., proceeding to the next phase. Milestone A approves entry into the Technology Development (TD) phase" [DAU 05a].
- **contact**
  There may be a need to obtain information about a particular schedule event, particularly in a system-of-systems context. The means of contact may be by telephone, email, or Web page. (Note that the contact need not be a person.)
- **date and milestone probability distribution function**
  Traditionally, a milestone has been represented as a point in time. However, as we all know, that is a bit unrealistic. In the general case, the "date" for a mile-

11. The role of an oversight agency always causes contention. For example, in a recent review of a NOAA satellite program, it was stated that "inadequate management oversight, in effect, postponed critical evaluations and decisions needed to replan the program's faltering elements and contain cost and schedule overruns.... Time and money were thus wasted" (*Federal Computer Week*, May 15, 2006, available at http://www.fcw.com/article94525-05-15-06-Web).

stone can be regarded as a probability distribution function (pdf). Several example representations are shown in Figure 7.

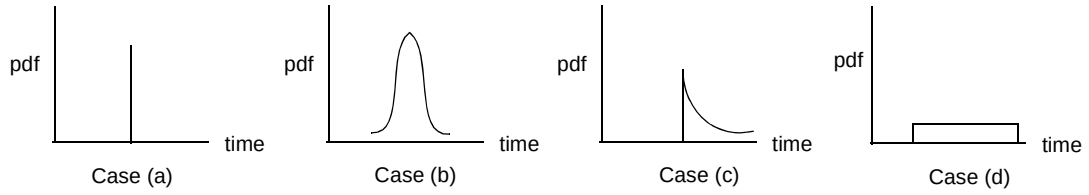

Figure 7: Some Different Representations of a Milestone

- Case (a) shows the traditional approach—a milestone represented as a single point in time. Case (b) represents a milestone as a Gaussian (normal) distribution that has some mean and standard deviation. Another choice is shown in Case (c), which is a skewed distribution; the typical interpretation for a skewed distribution is that the milestone cannot come before some date and is most likely to occur after a specified date. Finally, Case (d) shows an equal probability over some interval. In any case, inclusion of a pdf reflects the possible risk to achieving a particular date.
- A date associated with a milestone should not be considered as a single point in time. Instead, we must recognize the inherent possibility of variation whenever a date is specified. Furthermore, we need to be interested in not only one pdf, but also in joint distributions that must account for dependencies among the participants. For example, if a program has a schedule indicating when it is supposed to deliver something to an integration effort (which also has a schedule), it is the joint distribution that is more reflective of the collaboration of the two organizations.

- **the status of the schedule event**
  The event status indication might be limited to values such as *Pending*, *In_Progress*, and *Complete*.
- **approval information**
  Most milestones have some information associated with event approval. For example, a milestone decision review requires approval by the MDA. As a minimum, we would suggest that the following information is relevant regarding approval:
  - approval status
    An indication of the state associated with the approval process, such as the values *Unapproved*, *In_Progress*, and *Approved*.
  - approving office
    This office has authority to approve the schedule event.

- approving individual
  This individual has authority to approve the event.
- approval date[12]
  This date is when approval was granted.

The tuple of name, meaning, contact, milestone pdf, status, and approval information applies to all decision reviews and to other events (although not all other events apply to the concept of a phase). We recognize that there are two types of decision points, milestone decisions and milestone reviews, and find that different supplementary data is associated with each type (due to statutory or regulatory considerations). The differences were noted in the discussion of Tables 1 and 2 on pages 21 and 22.

Each item associated with a schedule has an associated syntax and semantics. The broader the scope of the participants (e.g., from a bounded environment to an unbounded environment), the more important developing and sharing of a common vocabulary will be.

4.3.3 Operations

The final aspect of interoperability relates to the operations that communicating entities might perform on the data of relevance—in this case, data related to a schedule. Consideration of operations leads to a consideration of the **behaviors** of the communicating entities. The operations act on some state data, such as those elements described in Section 4.3.2.

What are the behaviors that communicating entities might perform with regard to schedule? Let us assume for the moment that a schedule event, such as a milestone review, has a designated owner. We further assume the owner is the organization that is principally responsible for the event, recognizing that other organizations may have interest in the schedule event.

From the perspective of the event owner, we suggest that the following behaviors apply:

- **assume sole responsibility and authority for making changes** to data associated with a schedule event
  These changes could include, for example, creating and modifying the date for some schedule event.
- **notify other entities of any change** to a schedule event
  There should be a deadline when notifications should be provided to entities that require such schedule information.
- **maintain a history of changes** to schedule events
  Historical data can be useful when multiple programs are involved. For example, analysis of such data could be used to indicate the presence of possible problems. This kind of analysis is analogous to the use of past performance information;

12. In fact, it is also possible to include an approval date itself as an event on some schedule. In this case there is a dependency between the schedule that contains approval information and the schedule that includes an event for which approval is being sought. There are also variations in what is being approved. It could be the choice of a particular date, or the information that will be provided on that date, such as the result of an exit criteria.

however, for an *ongoing* multiproject acquisition, we would introduce a new term—***present* performance information!**

- **mediate negotiation about possible changes** to a schedule event

Given our assumption that the schedule event has a single owner, the first two behaviors are obvious. The reason to maintain a history of changes to a schedule event is that analysis of those changes might provide insight into the overall management process.[13] Finally, we have assumed that the owner of a schedule event is responsible for managing (mediating negotiation about) changes to a schedule event because the owner is most likely the entity with the greatest interest in the event.

4.4 SUMMARY

A simple summary of the concepts associated with a schedule is presented as a semantic net and shown in Figure 8.

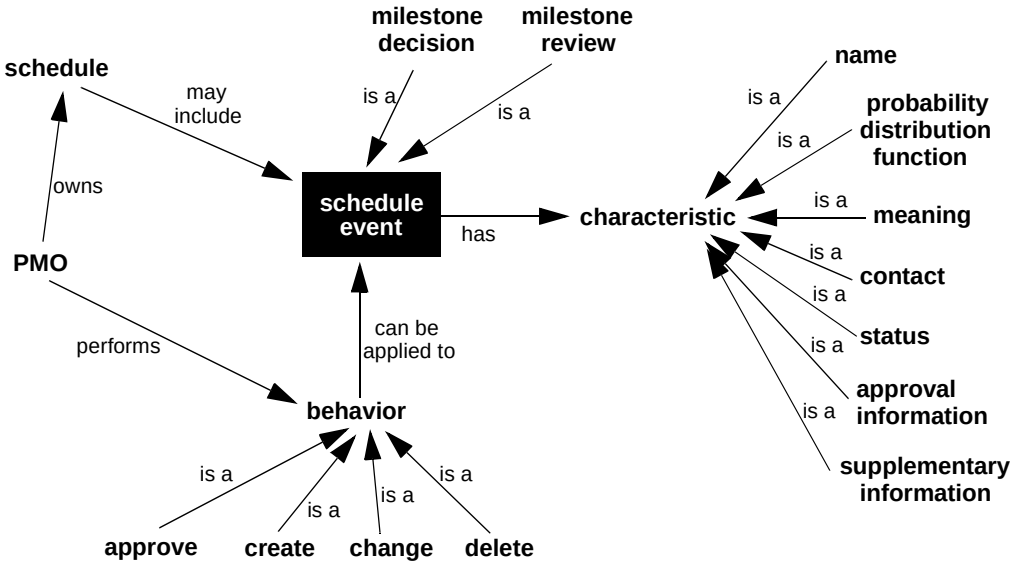

Figure 8: Semantic Net for Schedule Information

The primary focus of Figure 8 is to show some types of schedule events, their characteristics, and the behaviors that organizations may perform. No doubt a diagram such as this can be developed in greater detail.

Consider what happens as we turn our attention to a system of systems. How does the information shown in Figure 8 change? We suggest it can be represented as shown in Figure 9. It is assumed in that figure that two PMOs (PMO and PMO') have a schedule dependency, with one of them providing information to an integration activity.

13. The expression *overall management process* does not imply a centrally managed process; peer-to-peer management process applies as well.

There are a number of points we would make about Figure 9, centering on the PMOs' dependency on some schedule events. In particular, we suggest this dependency implies a need to share

- characteristics (such as those shown in Figure 8)
  For example, if the schedule event for one program changes, it is incumbent on that program to provide an update to the other program(s).
- behaviors that can cause a change to a characteristic of a schedule event resulting in a change to the schedule event
  For example, if a schedule event is approved in the context of one program, this information should be provided to the other program (because it may then be viewed as a constraint to that program). Of course, one would hope that the approval processes are negotiated in view of the fact that there is a dependency relation.

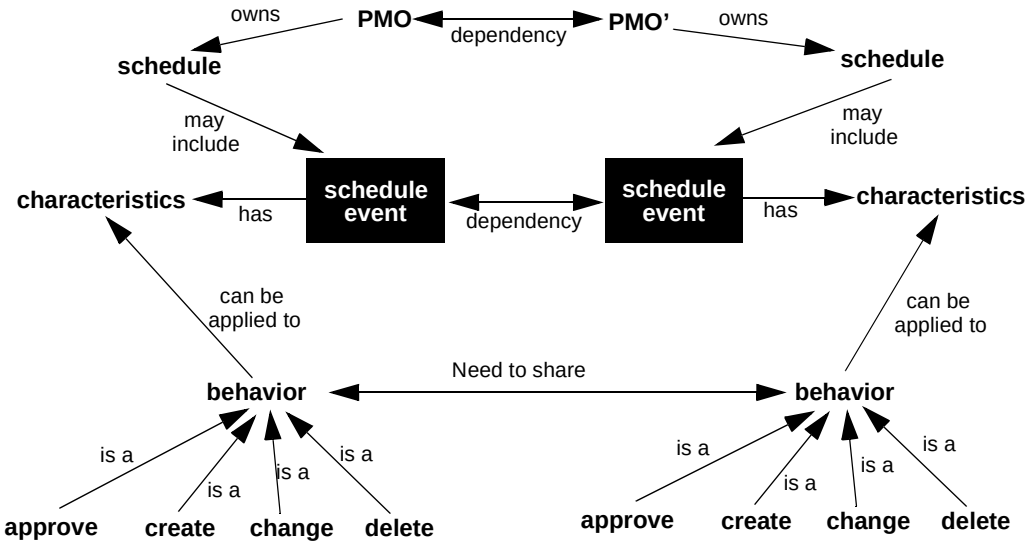

Figure 9: Semantic Net for Interactions Regarding Scheduling

The dependency on schedule events between programs implies a dependency between the programs. That connection is obvious, but realizing that the dependencies are negotiated is less obvious! Figure 9 reflects the behaviors that PMOs would have to change when considering the context for acquisition in a system-of-systems environment. One example of a such a dependency is when there is a change to an event by one program that should involve resolution of any dependencies with other programs. This type of behavior occurs in a system-of-systems context but may be absent in a system-specific acquisition.

5 Reflection

Based on the discussion in Section 4 about schedule from the perspective of interoperable acquisition, we can take a larger perspective to provide some observations and identify a number of research issues appropriate to this area.

5.1 SOME OBSERVATIONS

Dealing with schedule is like the tip of the proverbial iceberg. One simple approach is to treat a schedule as a temporal sequence of events, recognizing that there can be different types of events. This approach was taken in Figure 6 on page 20. However, another equally valid approach is to consider a schedule as a set of temporal activities that includes goals, resources, constraints, and events. This approach encompasses a much broader scope.

Overall, it is not enough to define schedule; rather, it is essential to determine what is needed to achieve interoperability between entities that participate in an acquisition—the factors that, like the submerged 90% of an iceberg, are critical. Put another way, *a schedule is a window into a program*.

The information to be shared regarding schedule is problematic. One result of the discussion in Section 4 is the view of schedule (using the particular case of an event) in terms of its associated information. Our abstract example of this approach is shown in Figure 6 on page 20. In Figure 10, we drill into the structure of data for a schedule event to describe **core** (elements) and **supplementary** (elements and details) data. The type of the event—a decision point or an executive review, for example—is important, of course.

- The core data consists of those elements deemed most relevant: a name, the name's meaning, a date and probability distribution function, a contact, a status, and information about the approval of the schedule event. Those elements were discussed in Section 4.3.2 on page 24.
- Depending on the type of a core data element, there may be various supplementary data items required by statute or regulation. For instance, there is a requirement to demonstrate compliance with the Clinger-Cohen Act for Milestones A and B. Milestones B and C also have a requirement to provide SARs. We detailed the supplementary information required for milestone decisions and reviews in Section 4.2 on page 20.
    - Should such information be made available to others? From the perspective of a milestone as a date in time, some might argue that such additional data is not of particular relevance. But others would argue that achieving interoperable acquisition is about sharing information and allowing others to gain benefit from it. Hence, share everything! We believe that supplementary data belongs in the basic information category, because it relates to the approval of a milestone. Consequently, it assumes greater importance.

The scope and extent of information (core and supplementary) regarding schedule is possibly larger than one might like. A schedule event might be thought of as a milestone with a name and some representation for its temporal character, at first. We have represented the temporal character as a probability distribution function rather than a single point in time. We then expanded the boundary of core schedule information to include data relating to the approval of a schedule event. Some of the approval data might be relevant and should be shared (see Section 4.3.2). Further, there may be supplementary data artifacts for some schedule event, required by statute or regulation as we have described.

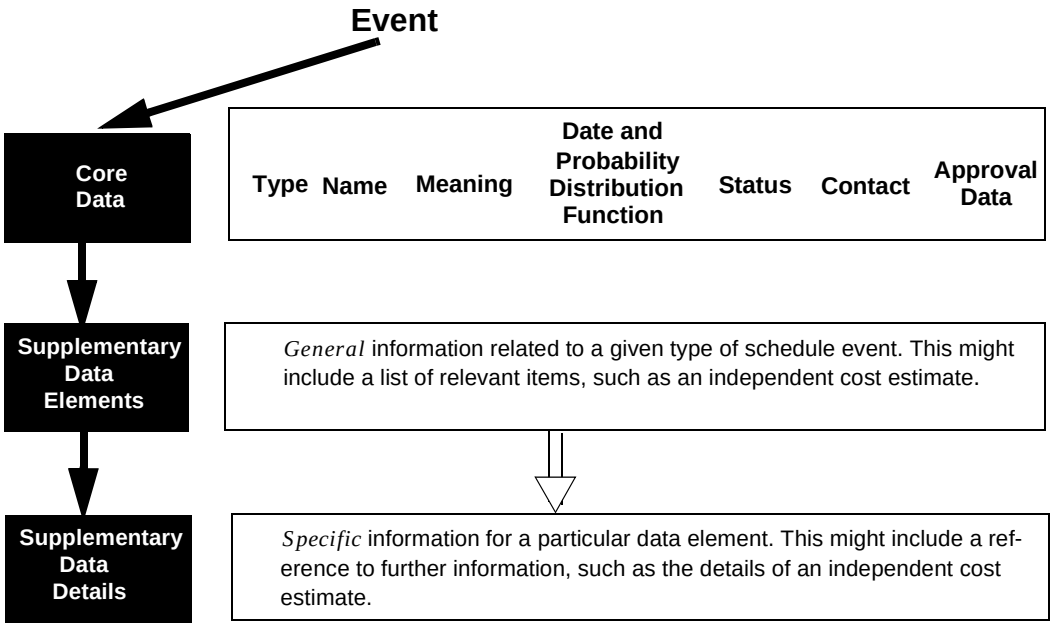

Figure 10: Structure of Data for an Event

The scope of the data could even extend beyond the artifacts required by regulatory processes. Consider the case of risk management. It is quite likely that some entity would inquire about the risks that could adversely impact some schedule event. Should such information be provided by the owner of the schedule event? Moreover, there is the very real possibility that there may be **shared** risks about some schedule event; how should they be treated in this context?

One can go even further. It is possible that a program should share information about the products it is using, or has selected, such as vendor (and license) information. The reason to share product information is that another program might find it valuable. Thus, sharing of this information could prove useful to another program.

The question of authority is problematic. Recall the discussion concerning behaviors regarding schedule events in Section 4.3.3. There, it was assumed that a single entity had the responsibility and sole authority to make changes to a schedule event. Is this the right model, or does it go against the grain of network-centric operations regarding collective behavior? In this area, we are closing in on the problem of

centralized versus distributed control. There must be a clear understanding of the concepts of ownership and authority, as well as their areas of control. In fact, one might choose to also consider a hierarchy of authority.[14]

Dealing with the unbounded case raises new questions. The subject of an unbounded environment was discussed in Section 2.2; in particular, see the discussion regarding Figure 2 on page 6**.** In the unbounded case, there may be entities, data, and behaviors that are only known at runtime, characteristic of a dynamic environment. It is not possible, *a priori*, to negotiate agreements concerning communication among entities, the data they share, and the behaviors they are expected to perform. How are dependencies managed in an unbounded environment, recognizing that they might have implications for other agreements?

5.2 RESEARCH QUESTIONS

There are a number of research questions that arise from addressing schedule in the context of interoperable acquisition, in addition to those mentioned in the preceding section. Schedule is but one aspect of interoperable acquisition; a related topic is interoperable risk management. A number of research questions for interoperable risk management are discussed in *Risk Management Considerations for Interoperable Acquisition* [Meyers 06b]. The questions we would raise here are similar to those.

How do considerations for schedule in the context of a system-centric acquisition differ from such considerations in the context of interoperable acquisition?

One approach to identifying the role of a schedule is the use of a checklist, and it has been previously addressed [Park 95]. Park's work addressed topics such as objectives of estimates, estimation factors, integrity of the estimating process, historical evidence, and changes. These same topics apply to the context of interoperable acquisition.

Given that general similarity, what are the differences when one moves from a system-centric to an interoperable-acquisition context? It is an oversimplification to say that a system-centric perspective just needs to consider the larger context of interoperable acquisition. To answer the question adequately, we need to return to the approach to interoperability and address the communicating entities, information shared, and behaviors performed. All of these are different for interoperable acquisition when compared to system-centric acquisition. In the area of behaviors alone, there is a greater need to share information, negotiate agreements, and communicate status among entities engaged in the broader context. Many of the following questions probe the contextual differences.

14. However, we remind the reader of the tension between a rigid hierarchal structure and the structure espoused for network-centric operations. In the latter case, decisions are made at lower levels (or at the edge, if you like), subject to intent provided by some higher level authority.

What are the entities that need to participate in a discussion of schedule in an interoperable acquisition?

We identified a number of possible entities, such as a PMO and an MDA. But as a the scope of interest in a schedule enlarges, what other organizations are affected and what are their roles in discussions regarding schedule? In an unbounded environment, all the entities that have an interest in schedule information might not be known.

What information regarding schedule needs to be shared?

The topic of schedule information was discussed in Section 4.3.2. There, it was suggested that, as a minimum, the following items warrant consideration for sharing about a schedule event of a given type:

- name
- meaning
- contact
- date and pdf
- status
- approval information

Yet, despite the apparent simplicity of that suggestion, there are questions about these items. Consider the information regarding the approval of a schedule event. Some questions that come to mind are these:

- What is the appropriate state model for the approval status? Are the values *Unapproved*, *In_Progress*, and *Approved* sufficient? Or, should a more elaborate state model be employed that might include states for *Complete* or *Pending*? These questions are particularly relevant for interoperability: If a different project uses different values, a conflict in interpretation is possible.[15]
- Should the possibility that the individual having decision authority may delegate this authority to someone else be included?
- Is the concept of joint approval relevant?
- What is the proper choice for a contact? Should it be a set of individuals? Should there be contacts for different aspects of a schedule? Each event could have a different contact.
- Should approval information be considered part of the core information about a schedule?

Another way to approach these issues is to apply the concept of an **ontology** for a schedule in a multiprogram context.

What is the distinction, if any, between owner and authority?

Most would assume that an owner of some schedule event has authority over the event and may therefore make changes. However, this is not true even for the case of

15. The status of a schedule event is not defined in any specifications we are aware of.

a particular program (think of the role of an MDA in approving milestone decisions for a program). In the context of a traditional system-centric acquisition the relation between owner and authority is specified. However, in the case of interoperable acquisition, these lines of demarcation may not be so clear. Ownership and authority may need to be viewed as a shared responsibility.

What are the processes for schedule management in interoperable acquisition?

The role of process in regard to various aspects of software engineering is well known.[16] But what are the process implications with regard to schedule management? For example, if an acquisition organization uses a process for schedule management, must other organizations involved in the interoperable acquisition use that same process? Or, instead, must there be a way for the inputs and outputs of those processes to be understood?

What are the behaviors necessary to be performed by entities regarding schedule management in an interoperable acquisition context?

This interesting question goes to the heart of achieving interoperable acquisition. What set of requirements would describe the expected behavior of entities collaborating with regard to schedule information? For example, consider the candidate requirements shown in Figure 11.

3.4.1: Exchange of Schedule Information

An organization participating in exchange of information regarding schedule shall conform to the following requirements:

1. It shall permit exchange of information regarding *milestones* that includes the name of the milestone, semantics, date and probability distribution function, and a point of contact.
2. Organizations shall be capable of exchanging information regarding the approval status of a specified milestone.
3. There shall be a means to determine the confidence in elements of a schedule. The confidence information shall be made available to others.
4. Upon receipt of a request for information, the organization responsible for managing a schedule item (e.g., milestone) shall provide such information within one day.
5. The requestor, nature of the requested information, and the time interval between request and response for schedule information shall be recorded.

Figure 11: Sample Requirements for Exchange of Schedule Information

At first sight, these requirements appear to be innocuous, but they illustrate some points raised earlier:

- The sample requirements presume the semantics of terms such as schedule item and probability distribution are understood.

16. See for instance *CMMI: Guidelines for Process Integration and Product Improvement* [Chrissis 03] and *Adapting CMMI for Acquisition Organizations: A Preliminary Report* [Dodson 06].

- The syntactic representation of the basic schedule items must be shared. Are they represented as a sequence of characters (e.g., ASCII or Unicode) or in another way?
- There is a requirement for a one-day response. Suppose this were changed to a response in five minutes? If so, we are moving into a domain of autonomous agents that participate in the process.
- How might the information maintained about the request and response be used in a larger context? This question alludes to the use of metrics to assess the collective process.
- What about the trustworthiness of the data provided?

What is the role of an integrated master schedule in a system-of-systems acquisition environment?

An integrated master schedule (IMS) is a well-known concept and is frequently called out on a contract. An IMS shows tasks and their timing; it typically contains contract milestones, accomplishments, tasks, and, thus, the relation among activities and events in some organization. The data item description[17] for an IMS defines it as "an integrated schedule containing the networks, detailed tasks necessary to ensure successful program execution" [DoD 05b]. The information about IMS is typically in the context of a particular program. How do things change when one considers interoperable acquisition? Can the concept of a system-centric IMS be extended to the larger context?

How does the concept of schedule viability apply in the context of interoperable acquisition?

Loosely speaking, a schedule is viable if the dates and their associated requirements can be achieved. How does this concept extend to the scope of interoperable acquisition where the number of participating organizations may become quite large? Individual schedules might be viable but their composition not viable, because dependencies between the schedules must be accounted for. Who is responsible for determining the viability of that larger schedule?

What are the metrics to assess interoperability with regard to schedule?

The goal of an organization that professes to be a high-maturity organization is to perform in an optimal, quantitatively managed manner. When one considers a system of systems, the question of optimality becomes problematic: optimal for a particular organization may be suboptimal for the system of systems. However, the question of quantitative measures to assess the overall management is still relevant. One approach to this question is through the use of metrics.

17. In general, a DoD data item description (DID) spells out the deliverable data required of a contractor.

It is interesting to examine this question from two perspectives. First, consider the entity responsible for managing a schedule in some acquisition context. Some possible metrics in this case might include

- creation of any new schedule events
- changes to an attribute associated with any existing schedule event, including the date of the schedule event

Now, consider the perspective that addresses those other entities with interest in or knowledge of some schedule event. Here metrics could measure the

- number of schedule events that occur within bounds defined by the associated pdf
- number of requests for information about basic schedule attributes
- interval of time between the request for schedule information and its response
- number of requests to change some schedule attribute
- number of requests for changes in some schedule attribute that were granted. This latter case raises the question about the ripple effects that can impact other participants.

Potentially, a wealth of information can be captured regarding schedule information. For example, consider the hypothetical data shown in Figure 12.

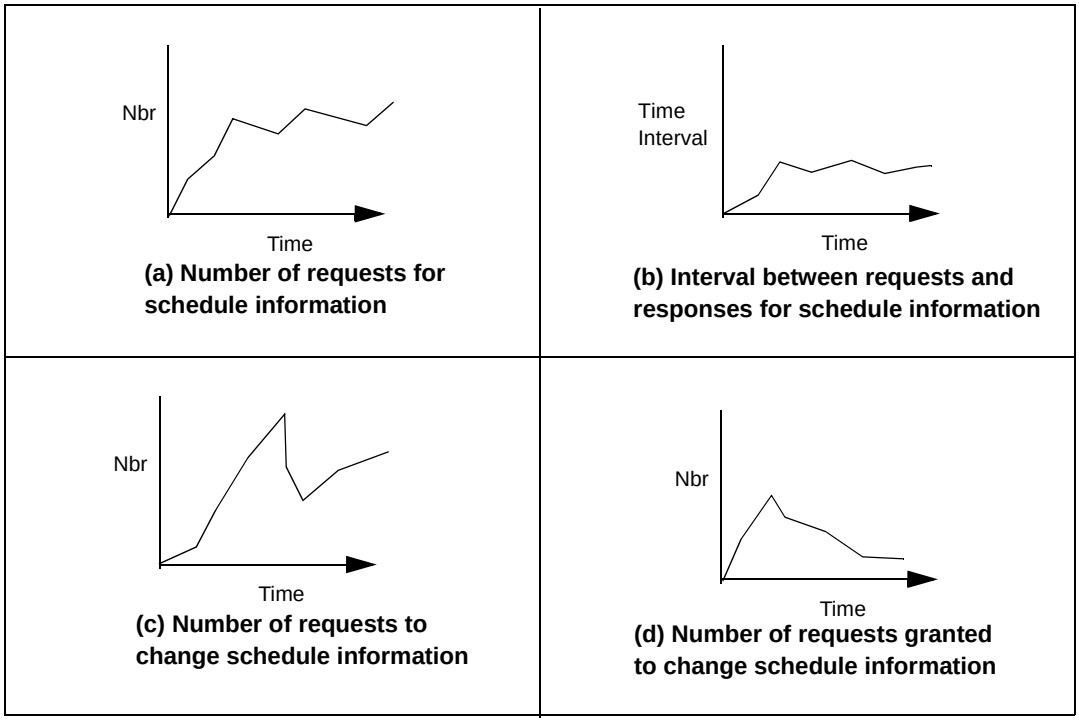

Figure 12: Hypothetical Schedule Metrics

In part (a) of the figure, we show that the number of requests made for information regarding schedule is relatively large and constant. The high and consistent volume might indicate the desire of communicating entities to be aware of schedule informa-

tion. Part (b) shows the time interval between schedule information requests and the response. This largely constant function indicates that the process of responding to requests is well managed. In part (c), the number of requests to change schedule information is shown; this function, although it fluctuates, remains relatively high. Finally, in part (d), the number of changes to schedule information is shown. Notice that this function decreases with time—indicative, perhaps, of a need to stabilize the (collective) process by not granting changes to a schedule.

Although examples of information, such as those in Figure 12, are interesting, the collective perspective is of greater interest. In regard to the hypothetical data, one might conclude that "The interaction between entities for schedule information is relatively high, the responses are good, but there were a lot of requests for changes that were denied. This analysis indicates the individual entities were seeking (too much) schedule relief and that there are problems at the local management level."

That conclusion illustrates one inference about the sharing of information regarding schedule among organizations—an inference based on the data shared and reflecting the behaviors of communicating entities engaged in acquisition in a system-of-systems environment. In that sense, the **appropriate** metrics can be quite valuable in helping to gain insight into the overall acquisition. We say "appropriate" metrics because the wrong metrics could contribute to unintended interpretations of performance.

We find discussions of metrics and their use to be of special importance to a system of systems. The discussion of metrics regarding schedule might form part of a more general question about metrics for the collaboration of organizations. For example, the hypothetical metrics shown for schedule in Figure 9 on page 28 could also be presented for topics such as cost considerations or risk sharing. In each case, the metrics would reflect the collective behaviors regarding these topics. Our discussion of metrics goes beyond the traditional scope (i.e., in the context of a particular organization) of metrics to emphasize a sharing of information and management opportunities. Thus, the use of metrics is but another aspect of the different characteristic of a system-of-systems environment.

How can the sharing of history data be used to advantage when multiple organizations are engaged in an acquisition?

This question arose in the discussion of behaviors in Section 4.3.3. There, we introduced the concept of **present performance information** to allude to a possible advantage of sharing information—namely, that such sharing would benefit the entities that collaborate in an acquisition. Note also the close relation of sharing history data to the role of metrics. If it were possible to maintain and share history information about acquisition programs engaged in interoperable acquisition, it might be possible to make corrections to an acquisition(s) during the course of a program execution.

How much automated support can be provided for schedule considerations in the context of interoperable acquisition?

We view this question as extremely important. To the extent possible, there is no need for a person to intervene in managing schedule information in an interoperable acquisition context. For example, if some entity is interested in schedule information, this should be provided without involvement by a person.

However, there are questions about the utility of autonomous agents.

- Do they have enough knowledge to identify and carry out a particular task?
- Do they have access (and rights) to relevant information?
- Would a decision-making capability be embedded in an agent?
- How is an agent notified of changes to the environment?
- How can agents be kept current in a dynamically changing environment?
- What happens in an unbounded environment?

We also would enlarge the discussion of where autonomous agents can play an active role in managing schedule information. For example, consider an autonomous process that is invoked whenever a change to some schedule event occurs. This process assesses the potential impact of the change on some program and may take actions. Perhaps for a small change, no action is likely required. (Of course, many small changes can have an adverse cumulative effect.) However, if the change affects the entity in a serious way, the action performed by the autonomous agent is commensurate with the nature of the change. As systems become more intertwined and need to support greater interoperability, the process of managing and using schedule information should be made as automated as possible. There are also concerns about areas such as bandwidth and security.

However, increased information exchange by machine (perhaps even in the case of autonomous agents) raises new issues. In particular, there needs to be agreement on a communication protocol. The protocol must address, at a minimum, the syntax and semantics of the information exchanged. We established the importance of semantics by suggesting that it is one of the basic attributes of a schedule event (see Section 4.3.2). However, we did not view, in that context, the syntax of that information to be of equal importance. But when machine communication is applied, the syntax of schedule information must be addressed.

The use of an autonomous agent can be viewed as but one example of a decision aid that can assist in schedule management in an interoperable acquisition context. There are other decision aids that can also be applied. For example, a decision aid that can assist in tracking and maintaining the state of multiple acquisitions would be useful (as opposed to an individual making changes to a large wall-sized Gantt chart).

What are the practical implications of this work?

One aspect of interoperability is the sharing of information about items of interest. In that sense, it is natural to speculate about how various types of organizations would respond to requests for information sharing—or, more to the point, about the degree of information they would share. On the one hand, communicating entities need to develop a common understanding of certain key concepts, such as information about schedule. On the other hand, an organization might not enter into an agreement about sharing schedule information, to avoid losing a competitive advantage. For example, some organization may believe it has a robust and accurate cost estimating process that gives it a competitive advantage. It is one thing to share the results of that process (such as the variance of a schedule event) but quite another to expose the details of the process.

One approach to this question would be to survey organizations of various types to see what information they would share and why they would share it. No doubt, an organization's answers would depend on its type (e.g., PMO or contractor). Perhaps the extent to which organizations are willing to compromise in the best interest of a system of systems will influence their answers, too.

Questions related to schedule concerns (such as those listed in Section 3.2) can be useful. Those questions can be used for assessment, as indicated earlier. They represent a starting point for eliciting material about multiple organizations that must interoperate. In fact, questions in this section also apply in that context. A caution is needed here, though: There may be parameters (e.g., should the type of contract, or the domain of application, be considered as a parameter?) that can influence many possible results.

How can cultural concerns be accounted for?

This question is closely related to the practical implications of this work. For example, it is necessary to consider what behaviors should be rewarded and what possible changes to the reward system would foster success in interoperable acquisition. One would expect that the culture of acquisition in a system-of-systems environment must encourage the sharing of information as well as the collective behaviors that are oriented toward goals reflecting a system of systems, rather than one particular system.

To what degree can the information about schedule be applied to other areas, such as cost?

In Section 3, we listed a number of questions that shed light on various aspects of a schedule. Two questions were these: "What are the risks to your meeting the schedule event? Are the risks shared, and managed, among all PMs and the integrator?" What if *schedule event* were replaced with the word *cost*? We suggest that the questions posed in Section 3 can be adapted to other items of interest to acquisition in a system-of-systems context. The **portability** of the those questions means that they can serve as a model that could be applied to other domains.

Does the concept of a dependency framework apply to this and other work regarding a system of systems?

We introduce the concept of a **dependency framework** as a contextual means to understand dependencies (and influence relations). Such dependencies need to be defined and their implications understood. Defining and understanding them involves consideration of data and behaviors, among other things. In the simplest case, an organization may have a dependency on some other organization, reflected in a schedule.

We believe that much can be done in dependency management and that it is of special relevance to interoperable acquisition. For example, consider the notation *Depends_On (A, B)* to denote that A depends on B. If there is another dependency *Depends_On (B, C)*, one may be tempted to assume that it follows that *Depends_On (A, C)* is also true. Understanding, expressing, and managing dependency relations is expected to be important where one is concerned with interoperable acquisition.

6 Summary

This report examined the role of schedule in the context of interoperable acquisition. The importance of schedule to the acquisition of an individual system is multiplied—considerably—as one considers a system-of-systems environment. This report has taken a step in the direction of examining how to deal with schedule in interoperable acquisition.

We believe there are several interesting aspects of this work with regard to schedule in a system-of-systems acquisition environment, including the following:

- A change from a system-centric environment to a system-of-systems environment motivates the need to share data and engage in collective behavior. This point was illustrated in our discussion of Figure 9 on page 28 that shows dependencies must be understood and managed.
- The connection between sharing of schedule information and risk management could be exploited to advantage. For example, knowledge of possible risks and their implication on schedule is desirable. This coupling of risks and their schedule implications is necessary to gain a more realistic picture of acquisition.
- The question of metrics is very interesting. The discussion concerning Figure 12 on page 35 illustrates possible metrics for schedule in the broader context. Of greater interest are the inferences of collective behaviors that may shed light on the progress of an interoperable acquisition.

There are several opportunities for follow-on work identified here. Among them, we would note the following:

- How can the research questions posed in Section 5 regarding communicating entities, information shared, processes, the role of automating schedule management, and other topics be pursued to meet the goal of more effective acquisitions in a system-of-systems context?
- To what extent can this work, focused on schedule, be applied to other areas? How much of the approach used here can be reused in another context? What about the concept of **cost**, for instance? What is the interaction between cost and schedule, and how should that connection be addressed?
- Can an assessment process be developed that addresses schedule events when there are multiple organizations involved? The example of a *Gedanken* red team, presented in Section 3, is a start in this direction. However, a more general approach is warranted, so that it can be applied to other areas.

It is worth noting that we have considered schedule in the context of acquisition, but the importance of a schedule extends to other areas, significantly in the construction and operation of systems. This recognition highlights the need to understand and exchange information about schedule across those areas (which we termed aspects of interoperability in Section 2.2) to achieve interoperability. Hence, we believe that much of this work can be applied to areas other than acquisition.

We anticipate the work outlined here, as well as further work related to the concept of schedule management in a system-of-systems environment, will be pursued.

Appendix A Acronyms and Initialisms

AoA
Analysis of Alternatives

C4I
Command, Control, Communications, Computers, and Intelligence

CD
Concept Decision

CR
Concept Review

CDD
Capability Development Document

CMMI
Capability Maturity Model Integration

COTS
Commercial off-the-shelf

DAB
Defense Acquisition Board

DAU
Defense Acquisition University

DID
Data Item Description

DoD
Department of Defense

DRR
Design Readiness Review

ETVX
Entry, Task, Validation, Exit

FAR
Federal Acquisition Regulation

FRP
Full Rate Production

ICD
Initial Capabilities Document

IMS
Integrated Master Schedule

IR&D
Independent Research and Development

ITAB
Information Technology Acquisition Board

JROC
Joint Requirements Oversight Council

LFT&E
Live Fire Testing and Evaluation

LRIP
Low Rate Initial Production

MDA
Milestone Decision Authority

MOU
Memorandum of Understanding

pdf
probability distribution function

PEO
Program Executive Office

PPBES
Planning, Programming, Budgeting, and Execution System

PM
Program Manager

PMO
Program Management Office

Pub. L.
Public Law

SEI
Software Engineering Institute

SAR
Selected Acquisition Report

SOSI
System-of-Systems Interoperability

TD
Technology Development

USC
United States Code

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13. **ABSTRACT** (maximum 200 words)

The role of schedule is fundamental to the acquisition of a particular system. This topic is of even more importance to acquisition in a system-of-systems environment. This report examines the issue of schedule considerations for interoperable acquisition. First, a *Gedanken* red team project is used to explore concerns about schedule in interoperable acquisition. Then, those concerns are examined in light of current requirements regarding schedule. From that examination, several research questions are proposed.

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