

MECHANISMS FOR INTERTEAM INTEGRATION: FINDINGS FROM FIVE CASE STUDIES

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ABSTRACT

Many product development programs consist of multiple integrated product teams (IPTs) and functional groups. Interteam information dependencies greatly affect program success. Program integration has thus become an issue of increasing interest. This paper summarizes findings from five case studies of integrative mechanisms (IMs) in complex system product development projects at Chrysler, General Electric Aircraft Engines, McDonnell Douglas, Sundstrand, and Texas Instruments. Two types of IMs are investigated in this paper: (1) Systems engineering and interface optimization and (2) Improved information and communication technologies. As the appropriateness of a given IM varies as a function of many parameters—such as program stage, size, complexity, risk, etc.—the goal of this research was not to formulate a universal template for IM application. Rather, it is hoped that the lessons learned by these five programs will help others determine the appropriateness of particular IMs in their situations. Also, the continued development of an IM categorization scheme will hopefully prove useful to those developing an integration “tool kit.”

INTRODUCTION

Today, many product development programs consist of multiple integrated product teams (IPTs) and functional groups. Efforts towards concurrent engineering and accompanying new forms of program organization have exposed interteam information dependencies. Program integration has thus become an issue of increasing interest. While more of the contemporary research has focused on the

characteristics and effectiveness of teams in general (Katzenbach, 1993) and IPTs in particular (Cole, 1995; Klein, 1994; Klein, 1995a; Klein, 1995b; Peters, 1995; Sheard, 1995; Susman, 1996a; Susman, 1996b), less has been explicitly addressed in the realms of interteam or program integration and the differences between this and IPT formation. The case for explicitly considering interteam issues and the categorization of nine integrative mechanisms (IMs) was presented in a previous INCOSE paper. (Browning, 1996b) This paper presents findings from case studies of IMs used (or not used) in five complex system product development projects. As the appropriateness of a given IM varies as a function of many parameters—such as program stage, size, complexity, risk, etc.—the goal of this research was not to formulate a universal template for IM application. Rather, it is hoped that the lessons learned by these five programs will help others determine the appropriateness of particular IMs in their situations. Also, the continued development of an IM categorization scheme will hopefully prove useful to those developing an integration “tool kit.”

To uncover a variety of interteam integration issues within ongoing programs and to investigate each program's use of IMs, an exploratory, case study research method was chosen. Five case studies were researched and written. Full details of these efforts and the five programs themselves are available in (Browning, 1996a). The case study programs represent a breadth rather than a depth of the defense aircraft industry. They span a variety of program sizes, stages, and defense aircraft industry sectors—avionics, airframes, and engines. For the sake of comparison and for a wider collection of

potential issues, a commercial aircraft program and a commercial non-aircraft program supplement the defense aircraft programs. Table 1 summarizes the five programs. The purpose of the research includes showing what types of issues might

appear if this study was done at a more focused level by persons intimately familiar with their sector or a given product type. Also, the hope is that the reader will be able to relate at least one of these cases to programs with which she or he is familiar.

Table 1. Summary of Case Study Programs

Company	Sector	Program	Phase	Relative Size of Program
Texas Instruments (TI)	Avionics	GEN-X	pre-production	Small
McDonnell Douglas (MDA)	Airframes	F/A-18E/F	EMD	Large
General Electric Aircraft Engines (GEAE)	Engines	TACOE and F110+	support	Medium
Sundstrand	Commercial Aircraft	737-700 EPGS	development	Small
Chrysler	Commercial (non-aircraft)	Small Car Platform (Neon)	development/production	Large

INTEGRATIVE MECHANISMS

A previous paper outlined and described nine categories of IMs. (Browning, 1996b) To recapitulate, IMs are strategies and tools for effectively coordinating actions across teams and groups within a program. As catalysts, they facilitate information flow across communication barriers, such as a company or program's organizational structure, incentive systems, location, leadership styles, cultural differences, and management traditions (Morelli, 1993, p. 11). They must also regulate information flow such that it does not overwhelm or underwhelm its recipients. Here, the nine IMs studied are broken into two categories: (1) integration enablers—IMs which provide for the establishment of integration; and (2) integration maintainers—IMs which monitor and facilitate integration. Together, they may be thought of as the tools in a program integration “tool kit.”¹

Integration Enablers:

1. Systems engineering and interface optimization

2. Improved information and communication technologies
3. Training
4. Co-location
5. “Town meetings”

Integration Maintainers:

6. Manager mediation
 - A. Management hierarchy (“up-over-down”)
 - B. Heavyweight Product Managers (HPMs) or Integrators
7. Participant mediation
 - A. Conflict Resolution Engineers (CREs)
 - B. Liaisons
 - C. Engineering Liaisons (ELs)
8. Interface “management” groups
 - A. Predetermined
 - B. Impromptu
9. Interface contracts and scorecards

This paper will summarize findings regarding the first two IMs in the above list. Due to space constraints, the remaining seven IMs will have to be left for discussion elsewhere.²

FINDINGS REGARDING INTEGRATIVE MECHANISMS

When is one IM more appropriate than another? How should they be applied? While these questions will be addressed

¹ Other typologies of integration and coordination approaches have been developed. This list expands upon some categories in (McCord and Eppinger). Coordination mechanisms useful in DFM contexts are discussed by Adler in “Managing DFM: Learning to Coordinate Product and Process Design” in (Susman, 1992, pp. 140-156).

² All nine IMs are discussed in (Browning, 1996a).

below, indirectly, the difficulty of reaching any universal conclusions should be evident. IMs are tools, and different tasks can require varied tools. Integrators should be aware of the strengths and weaknesses of IMs and complement this with a broad knowledge of the system product and the organization's culture and traditions. No two programs are alike, so it is impossible to find a set template of IMs that are *always* most appropriate. Some uses are better than others, however. The following sections summarize findings regarding two types of IMs for the purpose of better understanding and more appropriate application.

Systems Engineering and Interface Optimization

Designing the organization to mirror the product architecture makes common sense. If a system is well partitioned into subsystems and elements, it will have a minimal number of architectural interfaces. Likewise, the teams developing these subsystems and elements will usually require the minimal amount of interaction with other teams. Rechtin sums up this concept with a heuristic akin to that of minimum communications: "Design the elements to make their performance as insensitive to unknown or uncontrollable external influences as practical." (Rechtin, 1991, p. 42) This is also appropriate for IPTs, where organization designers should maximize the ability to communicate while minimizing the need to do so.

When organizational integration of a cross-functional, upstream/downstream, customer, and supplier nature is the goal, making the organization mirror the architecture becomes especially challenging. At what level should the assimilation of these disparate views occur? within the IPTs? This is not always possible. Perhaps some resources are only available at the program level. Constraints will often dictate the best level (position, not amount) of cross-perspective integration. However, an understanding of which constraints are the most limiting can help systems engineers and managers decide where to apply the resources that will gradually relax the constraints. Organizational inertia will perhaps be the biggest constraint of all: drastic change is seldom met with enthusiasm from those holding power.

Systemic approaches to organization have a good chance of leveraging improvements in cost, schedule, and performance. Getting everyone to buy in to the use of system models can integrate decision makers and lead to more enlightened choices of organizational structures and more appropriate applications of IMs. For example, quality function deployment (QFD) and approaches such as the requirements allocation matrices (RAMs) and derived allocation matrices (DRAMs) used at MDA (Kepchar, 1994), deserve consideration for their ability to systematically flow down requirements and responsibilities through a system architecture and an organization. Systems engineering, applied to the *organization* that develops the system, is a primary, *a priori* integration enabler.

Improved Information and Communication Technologies

A broad category of technologies have the potential to enable integration. We will look at several of them in turn—first, **electronic mail**. Today, employees on most programs have access to e-mail, at least internally. While many attribute the reduction of hard copy memos to the advent of e-mail, others see e-mail as a hindrance to integration. In some programs, people copy their messages to everyone else. It is just as easy to send the message to the whole program as it is to send it to a single person; besides, one thinks it better to provide the information to everyone, lest some critical recipient be omitted and take offense. Hence, some find themselves inundated with information, much of it nominally relevant. While such messages are an excellent way to keep abreast of the program's activities, most people do not have the time to assimilate them all. Instead, they sometimes do not look at *any* of the messages, figuring that any really important notice will come to them through another channel. Soon, with others not able to count on these individuals to read their e-mail, senders do have to resort to other channels, and the availability of e-mail is relegated to little more than a novelty. Individuals and teams should realize who really needs to know something: i.e., they should be aware of their interfaces. Understandably, on a multi-disciplined IPT, the amount of information to assimilate—because of the additional perspectives considered—will be

greater. Eliminating superfluous information becomes even more important here. E-mail messages coming from outside a team could be filtered, perhaps by that team's liaison. Finally, some effort should be made to archive messages, both centrally and individually. Sometimes e-mail documents important decisions. Thus, it would behoove programs to establish guidelines for the use of e-mail if they are going to rely on it as an IM.

Improving **common databases** involves embellishing the breadth and depth of the data stored, increasing accessibility while decreasing access time, establishing standardized formats, and training an ever-greater amount of the workforce in their use. Ideally, an IPT member could access all databases easily and routinely from a single terminal, such as a personal computer on his or her desk. Engineering, manufacturing, schedule, cost, test, and other data of many types should be archived and made readily available. Critical parameters should be tracked regularly for elements, subsystems, and the system as whole; and these data should be easily accessible. To be shared, data must be represented in a common language of mutually understood terms. Sometimes different teams and functional groups use terms differently—either using the same name for different data or giving the same data different names. In these cases, the information receiver often goes to great lengths to extract the desired information. Boeing Commercial Airplane Group found this to be a major barrier in their commercial aircraft division. A truly common database overcomes these obstacles. Sometimes this means team-wide training in a new vocabulary. Sometimes this means establishing a new data language altogether. Another option is to provide special translator tools in software that make the interface appear seamless (i.e., pre- and post-processors). An excellent practice for accessing common databases in a standardized format is MDA's utilization of the Netscape³ browser on their intranet. CD ROMs also provide a good means of storing easily distributable archives.

Standardizing hardware and software presents a constant dilemma. While

³ Netscape is a trademark of Netscape Communications Corp.

increased standardization facilitates IPT integration in the short term, its long term effects are less definite. The global optimum consists of a software policy that provides good interoperability in the short term while maintaining flexibility—by providing alternatives and by fostering innovation—in the long term. This includes recognizing that the ideal software of today may not be the best choice for the future. Software companies change. So do the companies one works with: the new partner company of the future may have standardized on something else. Moreover, mature products can become slow and inefficient. New technologies leap ahead. Without consideration of the need to maintain flexibility (because one realizes that all of the variables that will influence the choice may not be accounted for), the tendency is to converge on and optimize the nearest suboptimal point. Optimizing at the incorrect point actually places one farther away from the global optimum (because of the reluctance to sacrifice the sunk cost investment). Similarly, the choice of a single software suite that has limited interface and translation capabilities may be fine for a given program, but it may not translate easily to future programs or teams. The trade between standardization and the risks thereof must be considered. Decisions must consider when it is best to foster innovation through a variety of tools versus when it is best to channel innovation through one tool, even if towards a local optimum.

Electronic file transfer is essential to interteam integration. Local area networks (LANs) and wide area networks (WANs) are good, fast options. Some form of network or intranet should exist to tie everyone's workstations and terminals together. E-mail can also be used to transfer files, although the coding of files in binary (uu-encoding) or binary-hexadecimal (BinHex) formats, unless performed seamlessly by the mail software, can be a barrier in some cases. Some are wary of using e-mail for intersite file transmission because of the lack of privacy. This barrier can be overcome in some cases by using encryption software. Again, this process is best performed automatically by the e-mail software, although few commercialized systems offer this capability.

CAD/CAM/CAE systems are a critical IM, facilitating file transfers and standardized formats—aiding in design conversations and

providing “a flexible and unambiguous design representation.” (Robertson, 1991, p. 6) With the common point of reference these tools bring, fewer interdisciplinary misunderstandings occur and conversations are more effective. Research by Robertson and Allen has shown that an increase in performance due to CAD use is most strongly realized when it is explicitly used to enable cross-functional communication.⁴ (Robertson, 1991, p. 23) Israel provides an example where CAD was used as an IM to enable concurrent engineering in the Convair Division of General Dynamics in the development of an advanced cruise missile:

The participating engineering functions included structural analysis, human factors, maintenance, and flight dynamics. The primary communication mechanism between these functions was a Mechanical Engineering CAD system. Proposed designs were file transferred from one engineering group to another. Analysis was conducted and the results returned with commentary. The commentaries in this case identified structure over-designs. By using this information early on, a redesigned bulkhead was generated with a significant weight savings. Additional commentary identified a maintenance issue which required the removal of another bulkhead in order to service one of the electronics packages. This removal process would have required two men and a special support dolly. Use of the CAD system helped to incorporate a hinged supporting member, thus eliminating the need for the special dolly and one of the two support personnel. The General Dynamics example is illustrative of the use of a CAD system as a communications enabler which supported information flow and problem identification by overcoming distance and language barriers which typically arise between functional engineering disciplines. (Israel, 1992, p. 24)

Rosenbaum and Postula single out the three-dimensional capabilities of CAD tools as their chief integrative characteristic:

We live in a three-dimensional world. Most people cannot quickly and easily visualize well from two-dimensional views. The result is that designs represented by

drawings are frequently the private domain of designers and drafters. It is not surprising then that drawings often yield designs that cannot be manufactured, cannot be maintained, and do not meet customer expectations. ...

In fact, solid modeling is the key to successful team (concurrent) design. Through solid modeling of parts in extreme detail, very small clearances can be verified (including tolerances) electronically. In similar fashion, electronic mockup of tubing and harnesses can eliminate the need for physical mockups. Companies that have instituted such programs have shown savings in excess of 40 percent.

Probably the most important attribute of the solid modeling approach is that all functions, from design to analysis to manufacturing to estimating to management, have simultaneous access to an unambiguous description of the product—in real time. (Rosenbaum, 1991, p. D.3.5)

Today, most complex development programs in the defense aircraft industry use CAD/CAM/CAE packages to some extent. As Sundstrand found, however, transitioning to new CAE tools can slow a project down. Such transitions should be avoided midstream whenever possible. In fact, many companies have a software tools functional group that explores new CAE tools and makes recommendations for future directions. These groups are hopefully aware of the integrative aspects of the tools. Many programs, notably the F/A-18E/F program and some Boeing commercial programs, have attributed vast improvements in the development cycle to the use of CAE tools such as CATIA and Unigraphics and CAM tools such as Variation Simulation Analysis (VSA). Two- and three-dimensional models have provided for the early recognition of problems (in some cases) and the ability to do rapid, virtual prototyping. Use of the same tools by the subcontractors has also facilitated integration between these groups.

Scheduling and process modeling software can also contribute to integration. A standardized schedule is a good place to highlight critical issues that could cause delays. The previous section already mentioned the integrative effects of having a common modeling tool from which to analyze and ask questions about the program. Some of the five case study programs are

⁴ They also recommend each CAD system have a text message template to standardize annotations.

experimenting with the use of tools such as RDD-100™ (Ascent Logic Corp.) for process modeling. RDD-100 is an example of a systems engineering tool with the potential to integrate program decisions. However, the steep learning curves associated with many of these function-packed software packages may inhibit integrative overtures.

Many non-software tools and methodologies were also used as successful IMs in the case study companies. MDA's IPD data sheets and GEAE's electronic worksheets serve to standardize the format of data characterization both within and between teams. MDA's use of the Geometric Dimensioning and Tolerancing (GD&T) language establishes a common vocabulary for multi-discipline interactions. In addition to common reference terms, archives of lessons learned that can be saved and shared not only provide an IM but also foster a policy of learning within the organization. GEAE's Design Record Book and Chrysler's "Book of Knowledge" are excellent examples of these types of efforts. (Some programs are expanding to software enabled, knowledge based tools.) On a broader scale, well-organized process guides—used *and* provided with training in their interpretation and use—can allow more of the product development process to proceed on an integrated basis. Excellent examples of good practices along these lines include GEAE's *Engine Development Cycle Process Guide* and TI's *RF/Microwave Business Unit Teaming Handbook*. While these particular guides could be expanded by explicitly outlining additional approaches and tools, they provide a common framework for an entire program to approach the design process. Such handbooks probably should include guidelines on the appropriate uses of IMs as well. Finally, one of the most effective, non-software IMs—bulletin boards—has been used for a long time. One should not underestimate their importance, even in an electronic age. Often an entire conference room will have walls filled with activity and status reports and schedules. These provide opportunities for employees to discuss aspects of the program in a casual sense and get a better feel for its breadth and depth.

Note that the approaches included in this category of improved information and

communication technologies represent several information tasks: transfer (dissemination), access, and assimilation. Technologies facilitating any one of these areas may not necessarily further them all. For example, some technologies, such as teleconferencing, make information exchange so expedient that the propensity to not document that exchange increases. One must consider such factors if record keeping is a priority. Taking CAD as another example, researchers have looked at the different roles tools like CAD can play in an organization: as physical capital, as support for human capital, or as enablers for improvements in social capital (i.e., as an IM). (Robertson, 1991, pp. 4-7) The existence of three (or more) ways of viewing these types of tools implies that not everyone recognizes them as an IM and that their mere presence does not guarantee superior integration. In fact, some research shows CAD can have a negative effect on integration. (Jakiela, 1990) Certainly, the ease of making changes in CAD does not encourage documentation in the form of annotations. While no one likes excessive documentation, and "improved communication" is seen as the way around it, some amount of design history is necessary for future access. Hauptman and Allen highlight some of the major literature on information and communication technologies in their 1987 paper, which discusses the capabilities, drawbacks, and perceptions of these new approaches. (Hauptman, 1987) Also, much more has been said in other places about the roles many of these technologies need to play *within* IPTs.⁵

This section has focused on interteam integration aspects of improved information and communication technologies. While the IMs in this category possess great potential to enable integration, they will not work best alone as a bandage for an improperly organized program. As Wheelwright and Clark point out, only organizations that have broken down interteam barriers, integrated functional activities, developed structured design processes, and provided appropriate organization and leadership can expect to realize the full benefits of technological solutions. (Wheelwright, 1992, p. 242)

CONCLUSIONS

⁵ See (Hartley, 1992)

This paper has summarized the general findings on two IMs from five case studies of complex system product development programs. While universal guidelines for IM use cannot be derived from such a study, increased understanding of appropriate IM applications was achieved. Above all, the realization that interteam integration, when addressed explicitly and handled appropriately, has the potential to greatly reduce cost, schedule, and system performance risks should spur greater integrative efforts.

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BIOGRAPHICAL NOTE

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