WHY SCHEDULES SLIP:
ACTUAL REASONS FOR SCHEDULE PROBLEMS ACROSS LARGE AIR FORCE SYSTEM DEVELOPMENT EFFORTS

THESIS

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AFIT/GSM/LAP/95S-2

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William M. Cashman

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Abstract

The three main objectives of this research were to identify the actual reasons for schedule problems across large Air Force system development efforts, to quantify the importance of each category of reasons in terms of frequency and severity, and to demonstrate that the reasons for schedule problems are not program unique, but are common across system development efforts.

To this end, this thesis contains a categorization and analysis of 549 reasons for schedule difficulties on 22 large Air Force Engineering and Manufacturing Development (EMD) programs from 1981 to 1994. These aircraft, missile, aircraft equipment, aircraft upgrade, and simulator programs had contract values ranging from $40M to over $10B. All reasons were extracted from narrative explanations of negative schedule variances contained in contractor generated Cost Performance Reports (CPRs).

Reasons for schedule problems were placed into categories, and categories were ranked by frequency of problems, total schedule variance (in dollars), and total schedule variance (in work days). Seven categories (technical problems, late subcontractors, manufacturing problems, design changes, late data, contracting, and staffing) accounted for 49 percent of the frequency, 57 percent of the schedule variance (in dollars), and 49 percent of the schedule variance (in work days).

WHY SCHEDULES SLIP:

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I: Introduction

General Issue

Simply put, large defense systems take too long to develop (Drezner and Smith, 1990:i,1). Following project initiation, a typical system spends between one and six years in a preliminary design and prototype hardware phase. If approved for development, an additional three to ten years will typically pass before the first system is ready for delivery to an operational unit (Drezner and Smith, 1990:8-13). Thus, it can take as many as *sixteen years* before a validated system concept is developed into an operational military capability. In today's environment of advancing technology and changing national security concerns, the current practice of fielding 1979 weapon system concepts in 1995 systems simply does not make sense.

The idea that large defense system development takes too long is further supported by the fact that system development projects are typically late even by their own schedules. Specifically, the average defense system development effort requires one-third more time to complete than was originally scheduled (Augustine, 1983:115; Drezner and Smith, 1990:44).

There are four consequences of overly lengthy system development efforts. First, since a system's design tends to be "locked in" early in development, the longer it takes to field the system, the more likely the system will be based on old -- even obsolete -- technology. Such systems reduce the effectiveness of operational units, which rely on superior weapon systems to provide them with a combat advantage over enemy forces (Drezner and Smith, 1990:I,1). Second, a longer development effort increases the cost of a system in terms of inflation and overhead (Drezner and Smith, 1990:1). Third, a longer development effort provides more opportunities for introducing technical changes into, and new requirements for, the system (Drezner and Smith, 1990:1). These changes further lengthen the project and often lead to technical problems. Fourth, the longer a development effort, the more likely it is to be canceled prior to first system delivery (Augustine, 1983:203-204). One reason this last phenomenon may occur is because managers tend to associate schedule problems with project failure, and projects perceived to be failing are prime candidates for cancellation (Pinto and Mantel, 1990:273). In any case, a canceled development effort often represents a "lose-lose" proposition in which money is wasted and operational needs remain unfulfilled.

Thus, as was stated in the Packard Commission report on defense management, the length of the defense system development process is "a central problem from which most other acquisition problems stem." (The President's Blue Ribbon Commission on Defense Management, 1986:47).

Specific Problem

Clearly, there is a need for improving schedule performance in the development of large defense systems. Logically, such improvement could be realized by first identifying actual reasons for schedule problems on these efforts, then taking appropriate corrective action such as providing supplemental training, changing administrative procedures, or improving techniques. Unfortunately, very little research addresses the actual reasons for schedule problems on defense systems development efforts (i.e., late vendor selection or excessive engineering changes), and the research that does exist categorizes reasons at too high a degree of abstraction to enable the development of appropriate corrective actions. Without knowledge of these reasons, any attempt to improve schedule performance is little more than a "shot in the dark."

Thesis Objectives

The objectives of this thesis are to:

(a) identify the actual reasons for schedule problems across large Air Force system development efforts, describing those reasons at a level of detail that will allow the development of appropriate corrective actions;

(b) quantify the importance of each category of reasons, in terms of frequency and severity, in order to determine the categories of reasons most and least deserving of management attention; and,

(c) demonstrate that the reasons for schedule problems are not program unique, but are common across system development efforts, therefore schedule-related lessons learned from past and present efforts are likely to be relevant to future efforts.

Scope

This thesis examines the reasons for schedule difficulties on 22 Air Force Engineering and Manufacturing Development (EMD) programs from 1981 to 1994. These aircraft, missile, aircraft equipment, aircraft upgrade, and simulator programs had contract values ranging from $40M to over $10B. All reasons were extracted from narrative explanations of negative schedule variances contained in contractor generated Cost Performance Reports (CPRs), a standard deliverable data item on large defense system development contracts. Frequency and severity data for each category of reasons were obtained from the same CPRs. The severity data was based on schedule variances associated with each observed reason for schedule problems. In order to ensure reasons were obtained *across* programs, data for each program were taken from the same number of CPRs as for all other programs.

II: Literature Review

Introduction

The literature contains very little research dealing directly with the actual reasons for schedule problems across large defense system development efforts. The literature does, however, contain two related areas: (1) theorized reasons for schedule problems, and (2) reasons for schedule problems observed on actual projects. These areas will be discussed in order, followed by an explanation of limitations in the current body of knowledge.

Potential Reasons for Schedule Problems

Table 2-1 summarizes some potential reasons for schedule problems. They have been synthesized from a variety of sources including: contract administration and materials management books (Contract Administration, 1975; Riemer, 1968; Ammer, 1974); surveys of project management instructors, practitioners, and headquarters personnel (Ketchum and McKenzie, 1976; Dunbar, 1980); a study of government/industry difficulties (Montgomery, 1978); a literature review and field interviews on reasons for construction project delays (Dawkins, 1987), and an examination of potential trouble areas on ten specific weapon system projects (Drezner and Smith, 1990). Note that these reasons are based on expert opinion, rather than on formal studies of schedule problems occurring on specific programs.

TABLE 2-1: Potential Reasons for Schedule Problems

Planning	Procedures
Poor Support Planning Poor Resource Planning Poor Financial Planning Backlog of Orders Unrealistic Overall Schedule Late Government Furnished Equipment Late Receipt of Materials **Changes** Poor Management of Changes Engineering Change Proposals Design Changes Inadvertent Constructive Changes Government Directed Changes to Work Tempo	Source Selection Poor Quality Control Causing Rework Failure to Inspect in a Timely Manner Failure to Make Timely Progress Payments Joint Service Project Management Paperwork Processing Delays (Reviews/Approvals) Poor Inspection/Acceptance Criteria Poor Management Practices/Lack of Follow Up Failure to Coordinate Multiple Contractors Failure to Obtain Proper Approvals Slow "Ramp Up" of Resources Failure to Understand the Contract Failure to Communicate Inadequate Supervision Micromanaging the Contractor
Execution	**External**
System Integration Contractor Motivation Technical Difficulties Labor Problems Defective Government Furnished Equipment Default of Subcontractors Program Complexity (Coordination Burden) Contractor Performance Program Manager Turnover	Political Influences External Guidance Concept Stability External Event Funding Stability Major Requirements Stability Economic Factors

(Adapted from Ammer, 1974:437; Contract Administration, 1975:161-171; Dawkins, 1987:7-8; Drezner and Smith, 1990:21-22; Dunbar, 1980:40; Ketchum and McKenzie, 1976:23; Montgomery, 1978:30; and Riemer, 1968:553)

There are three main points to note about the data in Table 2-1. First, in spite of the variety of sources, the reasons for schedule problems are fairly consistent. For example, "major requirements stability" is mentioned in four of the eight sources (Contract Administration, 1975; Dawkins, 1987; Drezner and Smith, 1990; Ketchum and McKenzie, 1976), "late/defective government furnished equipment" is mentioned three times (Dawkins, 1987; Dunbar, 1980; Montgomery, 1978), and "poor quality control" is mentioned twice (Dawkins, 1987; Montgomery, 1978). Even though many reasons are only mentioned once, their similarity suggests that the actual reasons for poor schedule performance on large system development projects will resemble those listed in Table 2-1. Second, there are many reasons that could potentially impede schedule performance. Table 2-1 contains forty-three reasons, many of which need to be subdivided into still more reasons before they provide useful information on which to base corrective actions. Third, the literature that deals with theoretical reasons for schedule problems fails to provide any information on the frequency of these reasons or the severity of their consequences. This is significant, because it is impractical to implement corrective actions for all the reasons identified in Table 2-1. Thus, the theoretical literature fails to provide guidance as to which reasons most deserve attention.

Reasons for Schedule Problems Observed on Actual Projects

Guidance as to which reasons deserve the most attention improves somewhat in the literature dealing with observed reasons for schedule problems. Specifically, two studies provide reasons for poor schedule performance, the amount of delay associated with each reason, and roughly how often each reason is encountered. The first study, summarized in Table 2-2, investigates delays in the development of ten major weapon systems and therefore applies well to this thesis. Unlike the theorized reasons for poor schedule performance presented earlier, the significance of the reasons in Table 2-2 has been identified. For example, "technical difficulties" account for more poor schedule performance than "external events."

TABLE 2-2: Significance of Reasons for Schedule Problems on Ten Major Weapon System Development Projects

Reason	Percent of Total Delay[a]	Frequency (max is 10)[b]
Technical Difficulty	29.8%	5
External Guidance	22.5%	5
Unknown (could not identify)	18.5%	1
Funding Stability	16.7%	5
External Event	7.6%	4
Contractor Performance	2.5%	2
Program Complexity	1.8%	1
Concept Stability	1.5%	1
Major Requirements Stability	-1%	2

[a] Total delay attributed to a reason divided by total delay across programs
[b] Reason observed on this number of projects

(Adapted from Drezner and Smith, 1990:32-35)

There are two difficulties associated with applying the results of the study to this thesis. First, the reasons listed in Table 2-2 are too abstract to serve as a basis for choosing corrective actions designed to improve schedule performance. For example, how does one actually go about improving "technical difficulty" or "contractor performance"? Unless these categories can be subdivided into more precise reasons, they are of limited usefulness. Second, there is very little information regarding how often each reason occurs. Although the study indicates whether or not a reason occurs on a development project, and provides the amount of delay associated with the reason, it does not identify how often that reason is observed in the development project (Drezner and Smith, 1990:32-34). Thus, important information for determining appropriate corrective actions to remedy poor schedule performance is missing from the study.

The second study, summarized in Table 2-3, examines the reasons for delay on forty-eight general building (aircraft hangars, military personnel housing, instructional facilities, laboratories, modification/conversion/building addition projects, office buildings, and warehouse facilities) construction contracts (Dawkins, 1987:44-45).

TABLE 2-3: Significance of Reasons for Schedule Problems on Forty-Eight General Building Construction Contracts

Reason	Percent of Total Delay	Number of Changes[a]
Design Error	33.3%	157
Site not as Expected/ Unforeseen Work	27.2%	130
Discretionary Owner Change	18.7%	50
Time Extension	14.3%	27
Mandatory Owner Change	5.4%	21
Claims Settlement	1.1%	1

[a] Total number of contract changes associated with each reason (Adapted from Dawkins, 1987:66,69)

Although there are many differences between building construction and major defense system development, there are also similarities. For example, "design error" in Table 2-3 (construction) could easily refer to "technical difficulty" in Table 2-2 (weapon systems). Likewise, "mandatory owner change" in Table 2-3 (construction) could easily refer to "major requirements stability" in Table 2-2 (weapon systems). Thus both studies are useful in identifying the general categories of reasons for poor schedule performance and in estimating the delays resulting from them.

The construction study, however, has a problem. As in Table 2-2 (weapon systems), the reasons for poor schedule performance in Table 2-3 (construction) are still too abstract to serve as a basis for choosing corrective actions designed to improve schedule performance. The author solved this problem by dividing the reasons listed in Table 2-3 into more specific sub-categories. For example, a "design error" may fall into a subcategory called "electrical" or "internal architecture" (Dawkins, 1987:66). If a large percentage of reasons for poor schedule performance fall into the "design error - electrical" subcategory, electrical designers may need to receive supplemental training in this area. While the subcategories are construction-specific and would not provide appropriate guidance for large defense system development projects, this method seems very useful for providing detailed knowledge about reasons for poor schedule performance in general.

Reasons Why Previous Research on Schedule Problems is Inadequate

As presented earlier, the literature suggests forty-three potential reasons for poor schedule performance (See Table 2-1). It also attempts to identify the consequences associated with fourteen reasons observed on actual projects (See Tables 2-2,2-3). Unfortunately, it neither describes the reasons for schedule problems at a level of detail appropriate for determining corrective actions, nor does it quantify categories of reasons in a manner that allows management to determine which reasons are the most deserving of immediate attention. There are three probable reasons why previous research has not provided this information.

First, there is a prevailing attitude that poor schedule performance only occurs when an effort is completed later than its scheduled date (for example, see Drezner, 1990:17). If this were truly the case, the easiest way to improve schedule performance would be to *lengthen* the schedule. This is, in fact, what various schedule estimating methodologies accomplish (for example, Boyd and Mundt, 1993; Harmon and Ward, 1990; Harmon, Ward, and Palmer, 1989). By basing schedule predictions on historical data, these methodologies assume the mistakes and inefficiencies of the past will continue into the future. When researchers take this stance, they fail to investigate ways to improve project execution. They also fail to look for signposts, such as the reasons for poor schedule performance, that would identify potential areas to improve.

Second, there is a belief that schedule performance on large defense system development projects is controlled primarily by factors external to the contractor and government project office. In fact, the previously mentioned study of ten major weapon system development projects found that five of the projects had between seventy and one-hundred percent of their delays caused by external factors. This result, however, must be viewed with some degree of skepticism, since three of the ten projects had over seventy percent of their delay caused by *internal* factors (Drezner and Smith, 1990:34-37). Further, studies in both the construction industry and in weapon system production found that a majority of poor schedule performance is due to the internal factor of poor management practice (Newmann, 1983:32; Dunbar, 1980:104). Finally, a recent survey of small architecture and engineering firms found that as the use of project management "best practices" increases, projects are more likely to meet or exceed their schedule objectives (Anderson and Tucker, 1994:40). Thus, there is a fair amount of evidence that the government project office and the contractor for a large defense system development project can improve their schedule performance through improving the effectiveness of their operations. Research into the reasons for schedule problems is necessary in order to pinpoint where improvements need to be made.

Third, there is a widespread belief that the reasons for schedule problems on one project will not apply to the next project. Therefore, research into reasons for schedule problems is of little use. This view is understandable given the unique nature of projects. In his project management text, Nicholas states that "a project is a one time activity, never to be exactly repeated again" (Nicholas, 1990:4). Thus, it is not surprising that project managers tend to see the reasons for various project failures, including poor schedule performance, as isolated incidents that are not generalizable across projects (Pinto and Mantel, 1990:269). This perception is perpetuated through a lack of carry-over experience from one project to the next due to factors ranging from the breakup of project teams at the conclusion of a project, to the lack of training designed to preserve lessons previously learned for future projects (Bitner, 1985:73). Only through further research can this perception be altered. Just as Ketchum and McKenzie, in their formulation of fifteen weapon system acquisition case studies, found that "the method of dealing with acquisition management problems may differ, but the problems themselves seem to remain essentially the same," (Ketchum and McKenzie, 1976:31) the study of reasons for schedule problems will most likely reveal similarities in these reasons across weapon systems. These reasons can then be used to determine generally applicable solutions to the problem of poor schedule performance.

Conclusion

The literature does not contain a single study, or collection of studies, that: (a) identifies actual reasons for schedule problems across large Air Force system development efforts, describing those reasons at a level of detail that allows the development of appropriate corrective actions; (b) quantifies the importance of each reason in terms of its frequency, and severity in a manner that allows the determination of the categories of reasons most and least deserving of management attention; and, (c) demonstrates that the actual reasons for schedule problems are not program unique, but are common across system development efforts. This thesis will build upon the related research summarized in this literature review, and expand the existing body of knowledge dealing with the actual reasons for schedule problems in order to satisfy (a), (b), and (c) above.

III: Methodology

Introduction

This research had three main objectives. The first was to identify the actual reasons for schedule problems across large Air Force system development efforts, describing those reasons at a level of detail that will allow the development of appropriate corrective actions. The second was to quantify the importance of each category of reasons, in terms of frequency and severity, in order to determine the categories of reasons most and least deserving of management attention. The third was to demonstrate that the reasons for schedule problems are not program unique, but are common across system development efforts, therefore schedule-related lessons learned from past and present efforts are likely to be relevant to future efforts. This chapter provides a detailed description of the manner in which the research was conducted in order to satisfy the above objectives. It discusses the overall research approach, the appropriateness of the data source, the pilot study conducted to determine the data collection methodology, the specific data to be collected along with the rationale for choosing those particular data, the use of schedule variance in this study, the sampling frame, the sampling process, the data collection process, and the method of data analysis.

Overall Research Approach

Because studies identifying and quantifying the reasons for schedule problems on large defense system development efforts do not currently exist, this research is intended to provide the missing foundation upon which project managers can build schedule problem insight and researchers can base investigations into more specific schedule-related management questions. This research, then, is a descriptive study (Emory and Cooper, 1991:148) in which the goal is to provide information on observed reasons for schedule problems on defense system development efforts that will be useful in preventing those problems in the future.

Although this research is neither focused on determining causal relationships nor on answering specific management questions, it is still a formal study (Emory and Cooper, 1991:140) in that it has well-defined objectives related to identifying and quantifying the reasons for schedule problems.

In order to identify and quantify the reasons for schedule problems in an unbiased manner, this research uses an observational, *ex post facto* approach (Emory and Cooper, 1991:140-141) in which all data are taken from official reports. Because these reports are prepared by people familiar with the schedule problems and are recorded soon after the problems occur, their use helps to ensure that reasons for the problems are neither distorted nor omitted. If this approach were not taken, it would be likely that only reasons associated with the more memorable or more recent schedule problems would be captured (Emory and Cooper, 1991:402).

Another fundamental aspect of this research is that it examines many system development efforts, rather than one or two in depth. This approach helps to ensure that the results of this research reflect the variety of reasons for schedule problems encountered across system development efforts, and that these results will most likely apply to similar development efforts not specifically studied. This approach also satisfies the research objective of demonstrating that the reasons for schedule problems are not program unique, but are common across programs.

Finally, this research is conducted using a longitudinal approach (Emory and Cooper, 1991:141) in that it examines the reasons for schedule problems on defense system development efforts over time. Compared to a cross-sectional study, which considers observations within a "'snapshot' of one point in time," (Emory and Cooper, 1991:141) this approach provides far more potential data. Given that system development efforts may experience different types of problems during various stages of development, this approach most likely also provides a better representation of the reasons for problems experienced within the development phase as a whole.

Appropriateness of the Data Source

The data source for this research is the Cost Performance Report (CPR), a standard deliverable data item typically required on large defense system development contracts. The CPR is an appropriate data source for the following reasons. First, CPRs contain information regarding both the reasons for schedule problems and the severity of those problems. Thus, they contain the type of information needed to satisfy the research objectives. Second, CPRs have been used on large defense system development contracts for many years. Thus, they provide a reasonably consistent source of data on a wide variety of development efforts for the duration of those efforts. Third, CPRs are prepared by the developing contractor at roughly the same time as the schedule problems being reported. This improves the credibility of the data because it is recorded by knowledgable individuals who are not relying heavily on memory to produce the reports. Fourth, CPRs are generated monthly. This helps to ensure the data are at the right resolution to help identify the reasons for schedule problems at a level of detail that allows the formulation of appropriate corrective actions. If the CPR were less frequent, the data may be too aggregated to suggest corrective actions. Regular monthly reports also facilitate the sampling of data across development efforts. Fifth, CPRs for large Air Force system development efforts managed by the Aeronautical Systems Center (ASC) are readily available in the ASC Cost Library. This is significant, because consistently recorded and archived schedule information on defense system development efforts is difficult, if not impossible to find otherwise.

Pilot Study

In order to determine data availability, the most appropriate data to collect, and the most effective method for data collection, a pilot study involving 77 CPRs from the C-17 system development effort was conducted. This study involved obtaining CPRs from the ASC Cost Library, recording narrative and numerical data associated with negative schedule variances (schedule variances will be explained in the next section), and evaluating the data and the data collection process in terms of the above pilot study objectives. The pilot study supported three conclusions. First, it was determined that sufficient data existed in CPRs to support this thesis effort. Second, although CPRs contain a wide range of cost and schedule data presented in a variety of ways, only a small subset of these data were relevant to this research. The specific data subset, described in the next section, was chosen based on insights gained during the pilot study. Third, data collection for the thesis effort had the potential to be extremely time consuming. For this reason, a sampling methodology (described in a later section) would have to be adopted.

Data Selection

Based on the pilot study described in the previous section, specific types of data were selected from the CPRs for use in this thesis. This section both identifies these data, and provides justifications for their use.

Data Identifying Schedule Problems. In a CPR, each time the schedule variance (a concept that will be explained shortly) exceeds a predetermined threshold, the contractor is required to explain that variance in narrative form. Although thresholds vary from contract to contract, and can even vary during the length of a single contract, the threshold used on any given CPR has been chosen to ensure that only significant variances are reported. The fact that the CPR only explains variances significant to the corresponding system development effort increases the relevance of studies using CPRs as a data source. The narratives that accompany negative schedule variances (which correspond to behind schedule conditions) are the sole source of reasons for schedule problems on large defense system development efforts contained in this research.

Measures of Schedule Problems Severity. In addition to the narrative data, which identifies the reason for a given schedule problem, numerical data must also be collected to quantify the severity of that problem. While frequency data is obtained merely by counting the number of observed reasons for schedule problems, the magnitude of the problems associated with the reasons is obtained by collecting the schedule variance and the Budgeted Cost of Work Scheduled (BCWS) for each collected reason (these terms will be explained shortly).

Before explaining what is meant by schedule variance and BCWS, and the appropriateness of these measures to this research, there are two important elements of data selection to be discussed: the use of current month rather than cumulative data, and the use of data associated with Work Breakdown Structure (WBS) elements rather than data associated with functional areas.

Use of Current Month Data. Although CPRs contain both cumulative and current month data, only current month data was collected. Part of the reason for doing this is to avoid double-counting schedule problems when sampling multiple CPRs on a given development effort. Another reason for collecting only current month data is that narratives associated with cumulative schedule variances generally contain many more reasons for the variance than do current month narratives. The more reasons per schedule variance, the more difficult it is to accurately separate and quantify the magnitude of the schedule problems associated with each reason. Also, cumulative data tends to be more sensitive to schedule variances early in an effort, and less sensitive towards the end of an effort. This is because explanations are only generated when schedule variance exceeds a predetermined threshold. This threshold may be in absolute terms (dollars), relative terms (percent), or a combination of both (AFSCP 173-4, 1989: Para. 4-3(c)(3)(a)). If the threshold is defined in relative terms, a given variance early in an effort may be of the same magnitude as a variance late in the effort, but only the early variance will exceed the threshold and be reported. This is because at the time of the earlier variance, less work was scheduled to be completed than at the time of the later variance, and as a proportion, causes the same amount of variance to appear larger.

Use of Data Reported Against WBS Elements. Although CPRs identify schedule problems both by Work Breakdown Structure (WBS) element and by functional area, only data corresponding to WBS elements were collected. This approach was taken because in the C-17 pilot study, the reasons for schedule problems were better separated when reported against WBS elements. Functional area explanations tended to contain many reasons per reported variance, which, as was explained in the discussion of current month versus cumulative data, is an undesirable attribute. Also, as will be explained shortly, schedule variance is measured based on progress towards completing tasks defined by WBS elements. Because the determination of schedule variance is more closely tied to WBS elements than to functional elements, the collection of data organized by WBS element rather than by functional area is appropriate.

The Use of Schedule Variance in this Study

This study relies on the use of schedule variance to quantify the severity of schedule problems on large defense system development efforts. In order to appreciate the usefulness and limitations of schedule variance as a measure, it is important to understand what schedule variance is, and how it is calculated on a CPR.

Schedule variance measures the difference between progress made over a given period of time (in the case of this research, a month) and progress scheduled to occur during that same period of time (The AFSC Cost Estimating Handbook: Para. 5.4.2). If an effort is exactly on schedule, the schedule variance is zero. A negative schedule variance, however, indicates that the effort is behind schedule.

In order to calculate schedule variance, both the amount of progress scheduled to occur and the amount of progress that actually did occur must be defined. The amount of progress scheduled to occur during a given period is known as the Budgeted Cost of Work Scheduled (BCWS) (Nicholas, 1990:385). The BCWS is typically calculated at the start of an effort by defining the tasks required to complete the effort and estimating the amount of work (in dollars) involved in each task. The amount of work estimated for each task is then distributed over time, based on the schedule for the effort, to form a time-phased budget (Nicholas, 1990:355-356). The amount of work in this time-phased budget that is planned to occur during a given period is that period's BCWS. The current month BCWS, then, represents the amount of work that would occur during that month if the effort were on schedule.

Because large defense system development efforts are rarely, if ever, precisely on schedule, another measure, capturing the actual progress made during the current month, is necessary. This measure, known as the Budgeted Cost of Work Performed (BCWP) or "earned value," only takes credit for actual progress towards completing the effort (The AFSC Cost Estimating Handbook: Para. 5.4.2). The difference between the BCWP and the BCWS in a given month represents the difference between the amount of progress actually made during that month and the amount of progress scheduled to be made during that month. This difference, known as the monthly schedule variance, is negative if less progress occurred than was scheduled (Nicholas, 1990:387-388). By collecting the negative schedule variance associated with a schedule problem, the magnitude of that problem in terms of progress not made can be quantified.

Note, however, that schedule variance is measured in dollars rather than in time. This is because it is a measure of deviation from scheduled progress, and progress is measured against the time-phased estimated *cost* of the tasks comprising the development effort. Although negative schedule variance measured in dollars implies a behind schedule condition, and by itself is a good quantitative indicator of schedule problem severity, it is also useful to view schedule problem severity in terms of time. The method used in this research to calculate schedule variance in terms of time is as follows. Because the current month BCWS represents the total progress scheduled to be made during the month, it can be said to represent one month worth of progress. Likewise, a negative current month schedule variance, which represents the amount of progress scheduled but not made during the month, can be said to represent between zero and one month worth of not making progress. Thus, when the negative schedule variance is compared to the current month BCWS, the resulting ratio (variance/BCWS) can be said to represent the fraction of a month in which progress is not being made (AFSCP 173-4, 1989: Para. 12-1(d)). This fraction of a month is what this research uses to represent schedule variance in terms of time.

Both measures of schedule variance (dollars and time) provide information useful in quantifying the magnitude of schedule problems. Schedule variance measured in dollars tends to characterize schedule problems on large efforts as much greater than problems on smaller efforts. This is because larger efforts tend to spend more money per month than smaller efforts. A month of delay on a large effort may cause a $1M schedule variance, while a month of delay on a smaller effort may only cause a $50K schedule variance. Even though both tasks are a month behind, the task on the larger effort appears to have a much more severe schedule problem. This is consistent with the view that a delay to an effort such as the F-22 is far more significant than a delay to a smaller effort, such as a tactical communication system.

On the other hand, schedule variance measured in time views all task delays as equal, regardless of the size of the development effort. Thus, even though the schedule variance (in dollars) on a large effort may be 20 times the size of the schedule variance (in dollars) on a smaller effort, the schedule variance (in time) for both cases may be the same. This is consistent with the view that all development efforts are equally important, and that a delay to the F-22 is no more or less significant than a delay to a smaller tactical communication system effort. Depending on the reader's purpose and perspective, both this view and the opposing view, as described in the preceding paragraph, may be equally valid. For this reason, this research collects and presents both measures of schedule problem severity.

One final note on the use of schedule variance in this research. Although negative schedule variances, especially those stated in terms of time, may seem to imply that the overall development effort is experiencing a delay equal to the variance, this is usually not the case. In fact, only when tasks are on the critical path of a development effort do their schedule variances indicate delays to the overall effort (Nicholas, 1990:284). When tasks are not on the critical path, task delays indicated by negative schedule variances will generally be absorbed by "slack" in the overall development effort's schedule so as not to cause a delay in the overall effort. However, even if negative schedule variances often do not describe a delay in the development effort's completion date, they are still a valid measure of schedule inefficiency, and therefore pertain directly to this research. Further, the fact that an observed schedule problem is not associated with a task on the critical path of an effort does not mean that a similar problem will not occur on a critical path task in the future.

The Sampling Frame

The following criteria were used to select the system development efforts that are included in this research. First, for ease of access, only system development efforts whose CPRs were available in the ASC Cost Library were considered. This includes most large Air Force system development efforts managed by program offices at ASC.

Second, only efforts with a target price of over $40M were considered. This selection criteria originates from the fact that in general, CPRs are applied to larger efforts, and reports known as Cost Schedule Status Reports (C/SSRs) are applied to smaller efforts (AFSCP 173-4, 1989: Para. 3-4(a)). As explained previously, CPRs are the sole source of data for this research. C/SSRs were not used because although they contain similar information, they require only cumulative, rather than current month reporting. Also, unlike the CPR, where BCWS and BCWP for a task must be calculated by directly summing subtask BCWS and BCWP, C/SSRs do not have a standard approach for calculating these parameters (AFSCP 173-4, 1989: Para. 3-4(b)). Because these parameters are used to calculate schedule variance, variances taken from CPRs should be more able to be consistently compared across development efforts than variances taken from C/SSRs. Also aiding in consistency is the fact that C/SCSC (Cost/Schedule Control Systems Criteria) is required on contracts using the CPR, but is not necessarily applied to contracts using the C/SSR (The AFSC Cost Estimating Handbook: Para. 5.4.2). Because contracts applying C/SCSC have accounting and reporting systems that meet the same criteria, cost and schedule data from these contracts are more consistent than among contracts not applying C/SCSC. In any case, limiting the sampling frame to efforts with a target price of over $40M also controls for the fact that small efforts may have different reasons for schedule problems than large efforts. Eliminating this potential moderating variable (small versus large efforts) increases the credibility of the results of this research.

Third, this research only considers Engineering and Manufacturing Development (EMD), previously known as Full Scale Development (FSD), efforts. The reason for this criteria is to exclude basic research and exploratory development efforts, which tend to be neither planned nor managed with the same emphasis on schedule as EMD efforts.

Fourth, this research only considers development efforts that are ongoing, or that have ended after 1984. This timeframe is based on a compromise between obtaining a wide variety of data on a number of types of development efforts, and ensuring the results are relevant to current and future efforts. With a large timeframe, more efforts are included, providing a wider variety of data. With a smaller but more recent timeframe, fewer efforts are included, however the schedule problems observed are more likely to represent those encountered on efforts operating under today's management practices.

Based on the above criteria, the ASC Cost Library document catalog indicated 39 system development efforts described by 1850 CPRs would comprise the sampling frame. After an examination of several CPRs from each of these efforts, five development efforts were removed for not containing any negative schedule variances, four were removed for not reporting explanations for schedule variances, three were removed because they were not currently available, two were removed for not reporting current month variances, one was removed for a lack of data due to a late contract definitization, one was removed for not presenting data in a format conducive to identifying reasons for schedule problems, and one was removed for reporting variances against functional areas rather than by WBS elements. In addition, the number of usable CPRs on four efforts was less than anticipated because reports early or late in the efforts lacked variance explanations. Table 3-1 displays the final sampling frame of 22 system development efforts described by 973 CPRs.

TABLE 3-1: Description of Sampling Frame

Effort Type	Number of Efforts	Specific Effort Types	Years Covered	Number of CPRs	Contract Value
Aircraft/Missile	7	Fighters (3) Bomber (1) Transport (1) Cruise Missile (1) Trainer (1)	1982 - 1994	316	$ 15,277 M
Aircraft Upgrade	6	Fighters (2) Elec Warfare (2) Bomber (1) Special Msn (1)	1984 - 1994	190	$ 819 M
Aircraft Equipment	5	Recon (2) Engine (1) Launcher (1) Transponder (1)	1981 - 1991	290	$ 580 M
Simulator	4	Elec Warfare (2) Aircrew (2)	1984 - 1994	177	$ 358 M

Note that in Table 3-1 , the actual system development effort (program) names have been replaced with generic program types, and data regarding the development effort duration and cost have been aggregated in order to allow unrestricted dissemination of this research. By omitting clues that tie the data to specific defense programs, sensitive information is properly safeguarded, yet the ability to fully understand and appreciate this research is preserved.

The Sampling Process

Based on the previously mentioned C-17 pilot study, a census of all 973 CPRs in the sampling frame would be too time consuming for a limited scope research effort such as this. In addition, because of the wide variation in the number of CPRs associated with the efforts in the sampling frame, a census would represent efforts unequally. In order to satisfy the research objective of demonstrating that the reasons for schedule problems on large defense system development efforts are common across efforts, it is important to ensure efforts are represented equally. For these reasons, a sampling approach randomly selecting an equal number of CPRs from each effort in the sampling frame for examination was adopted.

Specifically, nine CPRs were randomly selected from each sampling frame system development effort, using random number tables (Kendall and Smith, 1938:147-166) to choose among the CPRs available for each effort. The reason for selecting nine CPRs per development effort is that the effort with the fewest CPRs had only nine CPRs associated with it. Thus, nine was the maximum number of CPRs that could be examined per effort given the intent was to examine an equal number of CPRs per effort. In addition, the resulting number of CPRs (198) was deemed, based on the C-17 pilot study, to represent an ambitious yet reasonable data collection and analysis effort given the scope of this research. The exception to the rule of examining nine CPRs per effort occurred towards the end of the data collection effort, when only eight reports in a usable format were available on one of the fighter aircraft development efforts. In this case, only eight CPRs were examined, however there is no evidence that this discrepancy significantly affects the results of this research.

The Data Collection Process

Data collection for this research was a two-step process. In the first step, relevant data was copied from all sampled CPRs. Specifically, for each sampled CPR, every page containing either schedule variance or narrative related to an explained current month negative schedule variance reported against WBS elements (contained in Format V of the CPR) was copied either with a standard office or microfiche copier. In addition, Format I of each CPR, which contains BCWS values for the WBS elements, was copied in the same manner.

In the second step, the CPR pages copied in step one were examined such that each explained current month negative schedule variance reported against a WBS element generated an entry in a computer database. For each entry, the program name, reason for the schedule variance (extracted from the narrative), schedule variance, BCWS, and CPR date were recorded. In recording this information, the following guidelines were followed. First, only negative schedule variances that represented a true behind schedule condition for a task generated a data entry. Variances resulting from accounting errors or late billing for completed work were not included. Similarly, false negative variances resulting from work completed early or out of planned sequence were not included. An example of how a task actually completed early can generate a false *negative* schedule variance is as follows. Suppose a task is scheduled to occur in the month of May, but instead occurs in April. Because no effort was scheduled for April, the actual progress made during April will cause a positive schedule variance (as expected). However, because the effort was originally scheduled for May, and no progress occurs in May (because the effort is complete), a false negative schedule variance is reported. If only the May report is sampled, the negative variance will appear to indicate a behind schedule condition when in fact it does not. For this reason, data associated with such false variances has been excluded from this research.

Second, the narratives associated with explained negative current month schedule variances were often written in paragraph form. In order to facilitate data collection and analysis, these paragraphs were summarized in one-line descriptions of 75 characters or less. Where possible, explanations were recorded verbatim, although most explanations were paraphrased. In summarizing the explanation, the primary focus was on preserving the actual reason for the schedule variance, while a secondary emphasis was on capturing how the schedule problem impacted the development effort.

Third, in many cases, the explanation associated with a single schedule variance reports multiple reasons for that variance. Although this occurs more often in explanations of cumulative variances and variances reported against functional areas, it occurs often enough in explanations of current month schedule variances reported against

WBS elements that the following rules were adopted for use in this research. First, if more than one reason was associated with a single schedule variance, a data entry was created for each reason. Thus, a single reported schedule variance on a CPR could result in multiple entries in the database supporting this research. This, however, created a problem in deciding how to divide the variance among its associated reasons, hence the second set of rules. On occasion, the narrative will identify, either in dollars or in percent, the amount of variance associated with each included reason. In these cases, variance was divided accordingly. More often, the narrative will state that the variance was caused primarily by one reason, but other reasons contributed. In these cases, the variance was divided in a ratio of 3 to 1 if there were two reasons, and 3 to 1 to 1 if there were three reasons. Most often, the narrative contains no indication of one reason being any more significant than another. In these cases, variance was divided equally among each reason.

The final rule for dividing quantitative information among reasons for schedule problems is that when multiple reasons are associated with a single variance, and hence a single BCWS, on a CPR, the BCWS is *not* divided among the reasons. Instead, the total BCWS associated with the reported variance is applied to each recorded reason. At first, there may appear to be an inconsistency between dividing variance and not dividing BCWS. The reason for the apparent discrepancy is that while variance is fully described by the reasons listed in the narrative, BCWS is based on the completion of tasks that may or may not be listed in the narrative. Recall that BCWS reflects all work that is scheduled to occur on a given WBS element, and schedule variance only reflects work not accomplished. When variance is divided, it merely is an attempt to distribute a known amount of inefficiency, relative to the completion of a WBS element, among known reasons for that inefficiency. If BCWS were to be divided in the same manner, it would imply that each reason for schedule variance was creating a given amount of inefficiency against its very own lower level WBS element. While this is possible, it certainly is not expected. Given the absence of information on how multiple reasons associated with a single reported schedule variance impact lower level WBS elements, this thesis has applied the full BCWS associated with each reported variance to each reason associated with that variance.

Method of Data Analysis

It is necessary to group data associated with similar reasons into categories in order to analyze the collected data in a manner that allows meaningful identification of the reasons for schedule problems across system development efforts, quantification of the severity of the problems associated with those reasons, and demonstration that those reasons are common across efforts. Because this research is descriptive in nature, no attempt was made to force the data into pre-defined categories. Instead, categories were developed to reflect the data. A discussion of the method for categorizing the data is as follows.

The initial categorization of the data into groups having similar reasons for schedule problems was conducted in parallel with the entry of CPR data into the computer database. As each reason for schedule problems and associated quantitative information was extracted from the CPR, the reason was categorized based on its wording and the researcher's five years of experience as an Air Force project manager. This categorization was intended to represent the reason at a high enough level of generality to allow the reduction of hundreds of data entries into a manageable and understandable form, while preserving the descriptive nature of the original reason. For each data entry, if the reason for the schedule problem was similar to an existing category, the reason was placed in that category. In the event that a reason did not fit into any categories, a new category was defined based on the above method.

Once all the data was entered into the computer database and grouped according to initial categories, the researcher conducted two separate reviews to ensure appropriate categorization of the data. The first review was to ensure the reasons for schedule problems truly belonged in their assigned category. This review also was to ensure the categories themselves were at similar levels of detail. Based on this review, several reasons were recategorized, and several categories at too low a level of detail were divided into more detailed categories. As an example of the latter, a category named "development problems" was divided into "technical problems," "technical definition," and "manufacturing problems."

The second review was conducted primarily to ensure that the categories focused on the reason for the schedule problem, and not what the problem impacted (such as integration), or where the problem occurred (such as at the subcontractor's facility versus prime contractor's facility). Based on the review, several categories were eliminated, and their reasons were assigned to other categories. Following this reassignment, the review reexamined whether each reason belonged in its assigned category. This time, only four reasons were recategorized, demonstrating that the categories were now stable enough to allow meaningful analysis.

Following the grouping of reasons for schedule problems on large system development efforts into descriptive categories, the reasons within each category were further grouped into subcategories. These descriptive subcategories were determined in the same manner as the categories. Their purpose is to provide a level of detail between the fairly general categories and the detailed data entries. This additional detail allows greater insight into the reasons for schedule problems by identifying the types of reasons that make up each category. In addition, the subcategories allow for a more orderly grouping of data entries in the full listing of the computer database in the appendix.

After fully categorizing and subcategorizing the data, the data was analyzed by category in terms of the previously discussed schedule problem severity measures of frequency, schedule variance (in dollars), and schedule variance (in time). The data was also analyzed to demonstrate that the reasons for schedule problems are common across system development efforts. The details of these analyses are presented in Chapter 4.

IV: Data Description and Analysis

Introduction

This research had three main objectives. The first was to identify the actual reasons for schedule problems across large Air Force system development efforts, describing those reasons at a level of detail that will allow the development of appropriate corrective actions. The second was to quantify the importance of each category of reasons, in terms of frequency and severity, in order to determine the categories of reasons most and least deserving of management attention. The third was to demonstrate that the reasons for schedule problems are not program unique, but are common across system development efforts, therefore schedule-related lessons learned from past and present efforts are likely to be relevant to future efforts. The following chapter presents a characterization of the data collected in this research, and an analysis of that data with the intent of satisfying the above research objectives.

Specifically, it discusses the number of schedule problem observations obtained from each type of development effort, the number of observations per development effort, the number of observations by year of occurrence, the categories into which the reasons for schedule problems were grouped, and the types of reasons composing each category. The chapter then compares the categories of reasons for schedule problems in terms of frequency, total schedule variance per category (in both dollars and work days), and average schedule variance per category (in both dollars and work days). The chapter concludes with a summary ranking of each category in terms of the above measures, and an analysis demonstrating that the reasons for schedule problems are common across system development efforts.

General Description of Data

Using the methodology addressed in Chapter 3, 549 instances of reasons for schedule problems across 22 system development efforts were observed. In order to provide a context within which to assess the results of this research, the following section broadly characterizes these reasons in terms of where and when the reasons occurred.

Figure 4-1 provides a graphical representation of the proportion of reasons for schedule problems observed on each of the types of system development efforts (programs) defined in Chapter 3, Table 3-1.

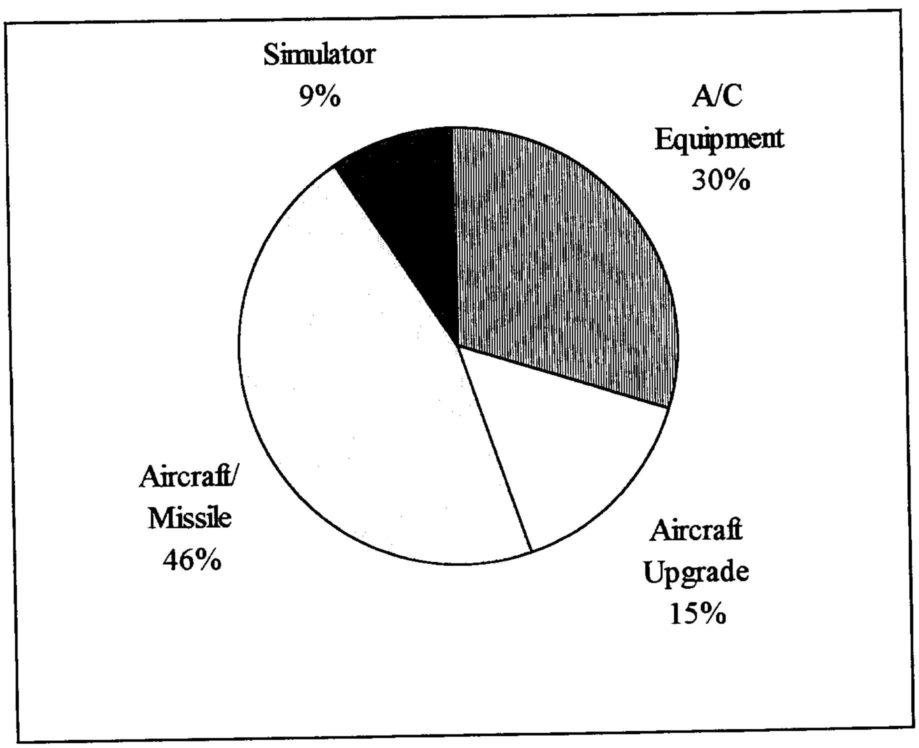

FIGURE 4-1: Proportion of Reasons from Each Development Effort Type

Although Figure 4-1 may appear to imply that schedule problems are more likely to occur on one type of development effort than another, this research neither supports nor refutes that conclusion. As explained in Table 3-1, the number of efforts, size of efforts, and length of efforts is not consistent across development effort types. For this reason, comparisons among the effort types in this research is not appropriate. Instead, the utility of Figure 4-1 is that it assists in understanding the origin of the data underlying this research so that results of this research can be correctly interpreted.

To further assist in understanding the origin of the data, Figure 4-2 presents the number of observed reasons for schedule problems per sampled development effort.

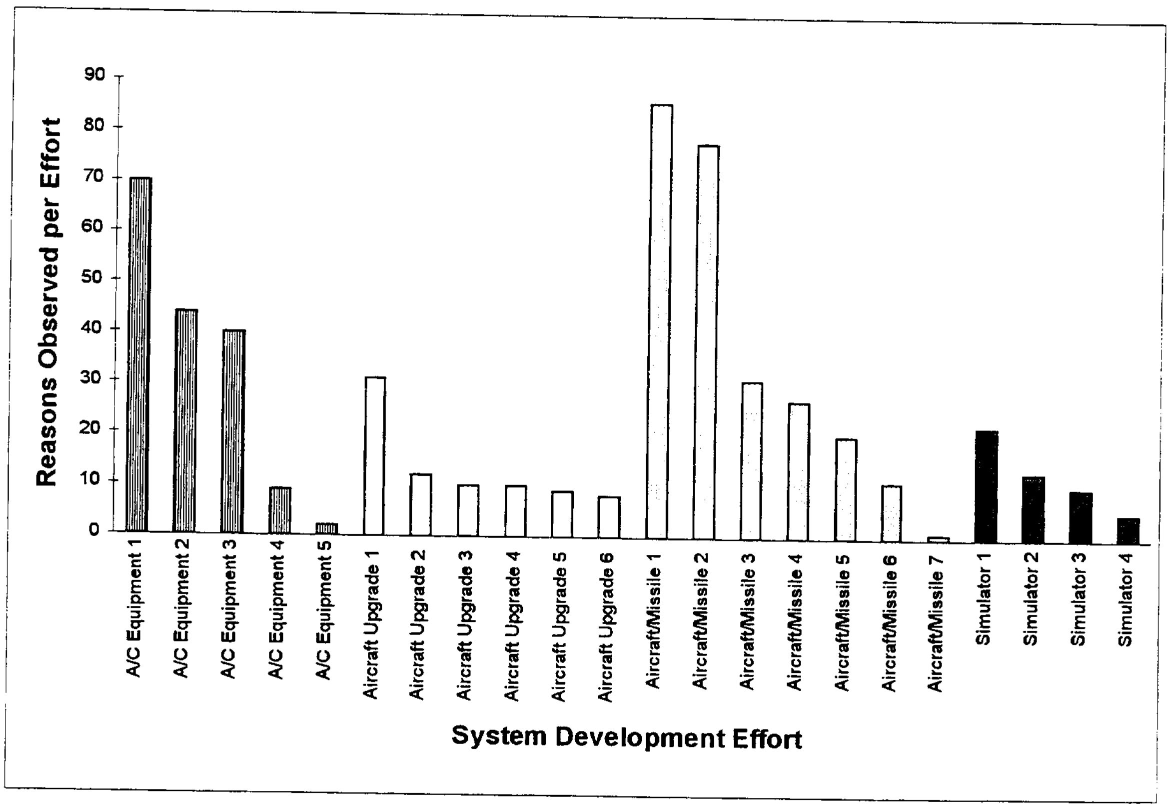

FIGURE 4-2: Reasons Observed per Development Effort

From Figure 4-2, it is clear that not all development efforts provided the same number of reasons for schedule problems. This is despite the fact that, as explained in Chapter 3, the data was collected from an identical number of monthly Cost Performance Reports (CPRs) for each development effort. Although the cause of this variation was not investigated in this research, potential reasons could include varying schedule problem reporting thresholds among programs and varying schedule-related success among programs. In any case, for the purposes of this research, it is important to note that certain development efforts influence the results more than others, but that most efforts provided a reasonable contribution. Overall, the average number of reasons for schedule problems observed per effort was roughly 25, with a standard deviation also of roughly 25.

Finally, Figure 4-3 presents the number of reasons for schedule problems observed in all CPRs sampled in a given year.

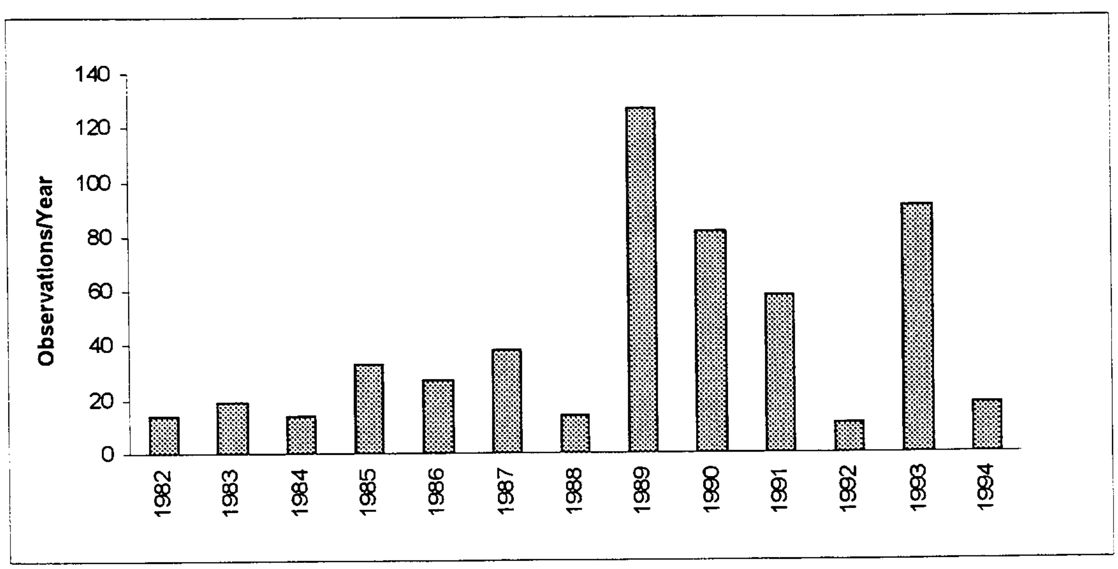

FIGURE 4-3: Reasons Observed by Year of Occurrence

Although Figure 4-3 may appear to imply that schedule problems are more likely to occur on recent efforts than on efforts prior to 1989, this research neither supports nor refutes that conclusion. In the research, there was no attempt to sample data equally across years, and as such, conclusions regarding the prevalence of schedule problems by year are not appropriate. Instead, the utility of Figure 4-3 is that it assists in understanding the origin of the data underlying this research in order that results of this research can be correctly interpreted. For example, based on Figure 4-3, it is clear that a significant proportion of the data underlying this research reflects recent schedule problems (experienced since 1989), which should provide managers with added confidence that the results of this research will apply well to current efforts, and to efforts in the near future.

Categorization of Reasons for Schedule Problems

In order to make sense of the 549 reasons for schedule problems observed in this research, these reasons have been grouped into descriptive categories according to the methodology specified in Chapter 3. Because these categories are intended to reflect the descriptive nature of the original reasons, albeit at a lower level of detail, the best way to describe these categories is through examples of the actual reasons they summarize. In this manner, Table 4-1 provides a brief description of each of the 20 categories used in this research.

TABLE 4-1: Categories of Reasons for Schedule Problems

Category	Examples
Contracting	Contract not yet signed with vendor for wing slat package
	Late source selections delaying H/W & S/W design
Changed Plans	Minor changes in several functional responsibilities
	Rescheduled design effort
Design Changes	Design changes due to weight reduction activities
	Tech manuals delayed due to frequently changing tech data
Estimating	Number of detail parts to be custom designed more than planned
	Overly aggressive material plan could not be met
Facility Problems	Facility design behind schedule
	Design mods/layouts behind due to late test area completion
Gov't Added Work	Gov't directed more detailed specifications than anticipated
	Support for VIP demo flights impacting test effort
Gov't Not Supportive	Delay in obtaining source data from Gov't for tech manuals
	Late final test plan due to delayed customer comments
Gov't Stopped Work	Gov't directed work stoppage impacting other areas
	Stop work order slowed vendor tasks
Inventory Mgt	Delays in recognition of receipt of vendor deliveries
	Parts shortages impacting test article fabrication
Late Data	Lack of imagery data to validate algorithms
	Late engineering drawing releases
Late Reviews	Delayed fabrication due to slip of CDR
	Additional effort required to close out CDR
Miscellaneous Delays	Delay in shipment overseas impacts test
	Site activation meeting delayed
Manufacturing Probs	Delays in fabrication of major assembly tooling fixtures
	Delay in defining/releasing production bill of materials
Quality	Vendor testing not satisfactory for acceptance
	Flight station shipped in an incomplete condition by subktr
Req'ments Changes	Changing specifications impacting effort
	Change in harness board requirements
Staffing	Inadequate systems engineering staffing delaying specifications
	Reassignment of personnel to more critical areas
Subcontractor Late	Late material deliveries delaying STE effort
	Subcontractor delays in reaching development milestones
Test Problems	Unplanned instrumentation modification delaying flight test
	Component difficulties during qual testing
Technical Definition	Delay in specification generation
	Incorrect envelope definition to sub delayed CDR
Technical Problems	Difficulties in analyses and monte carlo simulation
	Technical difficulties associated with H/W algorithms

The categories listed in Table 4-1 identify the reasons for schedule problems across Air Force system development efforts at fairly general level. It is at this level that comparisons of reasons in terms of frequency of observation and severity of associated problems have been made. These categories have also been used to demonstrate the commonality of reasons across development efforts. Prior to making these comparisons and demonstrations, however, it is essential that the above categories are fully understood. In the following subsections, each category listed in Table 4-1 is described based on subcategories (as explained in Chapter 3) of reasons assigned to each category. By understanding the categories in these more detailed terms, the likelihood of formulating appropriate corrective actions for schedule problems based on the results of this research is increased.

"Contracting" Category. This category includes reasons related to contractual actions and the process of awarding subcontracts. In the assignment of reasons to this category, most did not contain sufficient information to determine whether or not the associated schedule problems were caused by contracting functional procedures and staff. Consequently, this category includes contracting-related reasons for schedule problems that were likely caused not only by the contracting department, but by other departments failing to provide information or generate requests in a timely manner, and by management actions resulting in lengthy contracting-related approval cycles. Specific subcategories of reasons for schedule problems within the "contracting" category are as follows:

(1) source selection of subcontractors and vendors (including request for proposal (RFP) preparation and proposal receipt),

(2) placing subcontractors and vendors on contract,

(3) processing purchase orders, and

(4) terminating subcontractors.

Figure 4-4 presents the relative contribution of reasons (in terms of number observed) within the above subcategories to the "contracting" category.

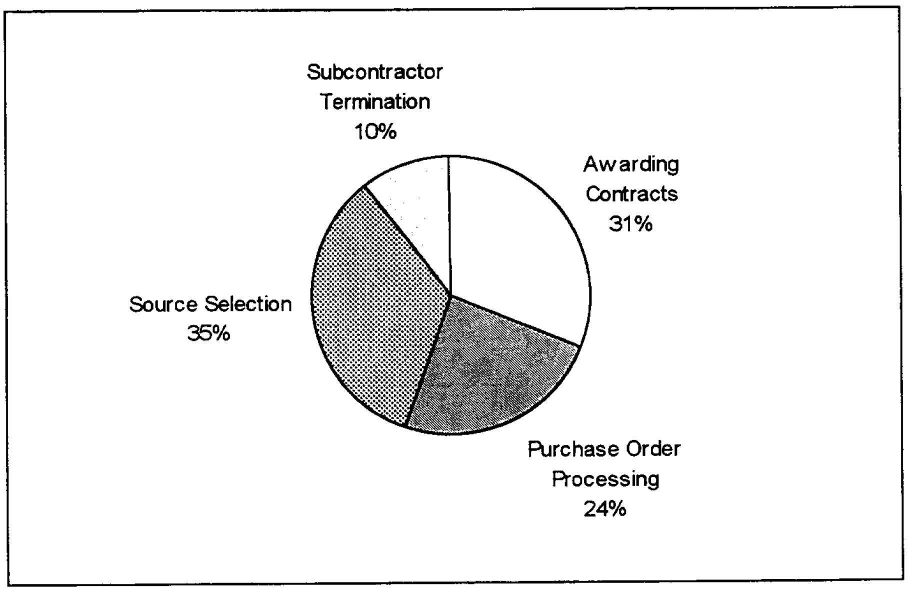

FIGURE 4-4: "Contracting" Subcategories

"Changed Plans" Category. This category includes reasons related to revised schedules and work plans. Specific subcategories of reasons for schedule problems within the "changed plans" category are as follows:

(1) new design schedules,

(2) new delivery schedules, and

(3) changes in work responsibilities among functional departments.

Figure 4-5 presents the relative contribution of reasons (in terms of number observed) within the above subcategories to the "changed plans" category.

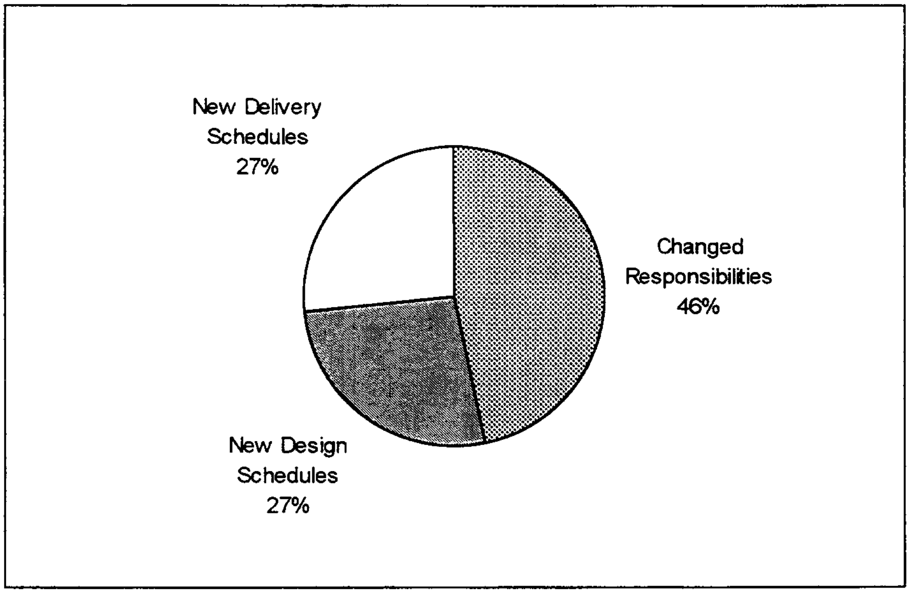

FIGURE 4-5: "Changed Plans" Subcategories

"Design Changes" Category. This category includes reasons related to changes in system or component designs, typically undertaken to fix problems or to improve performance. Quite often, in addition to requiring time to implement, these changes also impact other, related tasks that depend on stable, defined designs for their continued progress. Specific subcategories of reasons for schedule problems within the "design changes" category are as follows:

(1) changes affecting generation of data, such as that needed for engineering drawings or technical manual preparation;

(2) changes affecting manufacturing activities, such as mockup construction, component fabrication, and system assembly;

(3) changes affecting subcontractor deliveries (deliveries delayed due to the need to incorporate changes);

(4) changes affecting testing (tests that must wait for redesigned components);

(5) general delay, including changes limited to affecting design efforts, or changes whose affect is unspecified; and,

(6) changes to reduce the weight of the system.

Figure 4-6 presents the relative contribution of reasons (in terms of number observed) within the above subcategories to the "design changes" category.

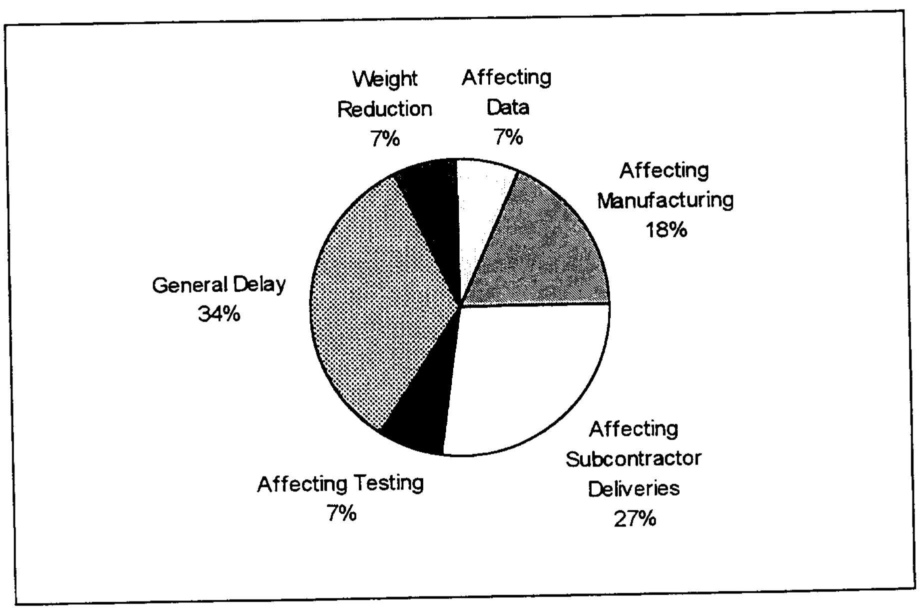

FIGURE 4-6: "Design Changes" Subcategories

"Estimating" Category. This category includes reasons related to the underestimation of time or effort required to complete tasks on schedule. Although many of the 549 observed reasons for schedule problems may indeed have been caused by poor schedule estimating, the reasons included in this category are only those that mention, either directly or indirectly, a problem in schedule planning or estimating. Specific subcategories of reasons for schedule problems within the "estimating" category are as follows:

(1) overly ambitious schedules,

(2) optimistic material budgets (based either on using more material during the observed month because the effort was planned to be further towards completion, or on overly optimistic supply predictions),

(3) planning to an incorrect schedule,

(4) underestimating the time required to order materials,

(5) lack of integrated schedules resulting in disconnects among tasks,

(6) misplanning (poor planning) of tasks,

(7) underestimating the time needed to complete tasks, and

(8) underestimating the amount of work required to complete tasks.

Figure 4-7 presents the relative contribution of reasons (in terms of number observed) within the above subcategories to the "estimating" category.

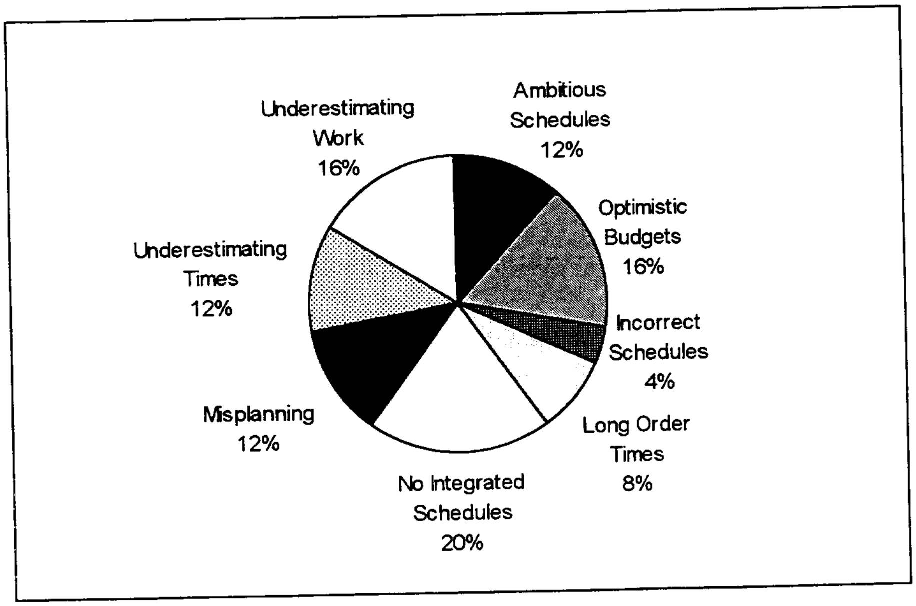

FIGURE 4-7: "Estimating" Subcategories

"Facility Problems" Category. This category includes reasons related to the design, fabrication, and renovation of facilities required for development effort completion. Because only three reasons have been included in this category, two of which are included in Table 4-1, no further description of this category is necessary.

"Government Added Work" Category. This category includes reasons related to government direction that resulted in additional, unplanned effort for the contractor. Specific subcategories of reasons for schedule problems within the "government added work" category are as follows:

(1) additional unplanned government review of contractor efforts,

(2) government directed changes in design and documentation,

(3) government comments at reviews generating contractor action items,

(4) government requested marketing support to help "sell" the development effort to higher-ups, and

(5) government rescheduling of reviews causing inefficiencies in the work schedules of those supporting the reviews.

Figure 4-8 presents the relative contribution of reasons (in terms of number observed) within the above subcategories to the "government added work" category.

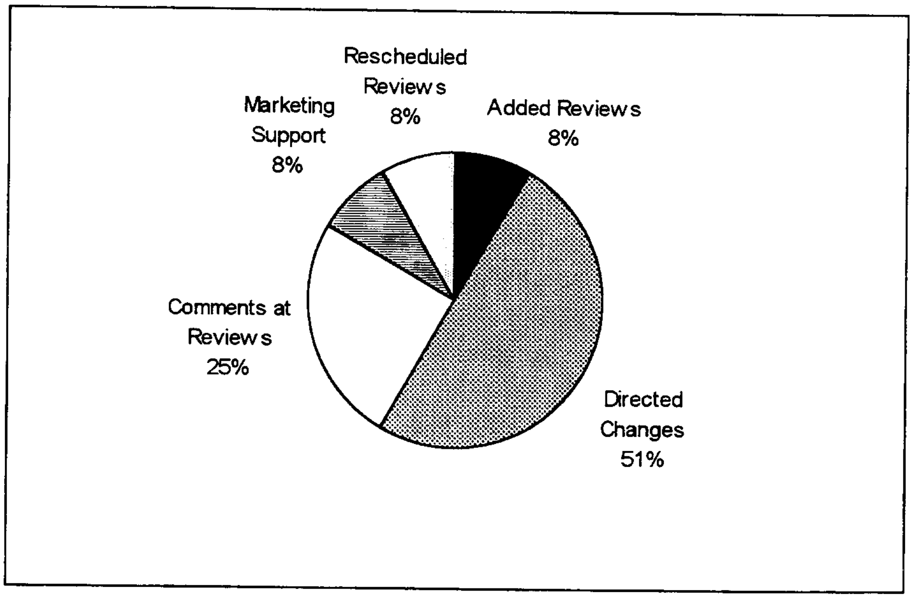

FIGURE 4-8: "Government Added Work" Subcategories

"Government Not Supportive" Category. This category includes reasons related to a government failure to provide an appropriate level of support to the contractor. Specific subcategories of reasons for schedule problems within the "government not supportive" category are as follows:

(1) late data item approval (government was late in approving submitted data items),

(2) failure of the government to provide required data to the contractor (includes classified and unclassified operational, threat, and design-related data that requires government collection or release),

(3) government funding shortfalls impacting contractor task completion,

(4) incomplete or late government furnished equipment or property, and

(5) late direction from the government (including comments, approvals, inputs, and decisions).

Figure 4-9 presents the relative contribution of reasons (in terms of number observed) within the above subcategories to the "government not supportive" category.

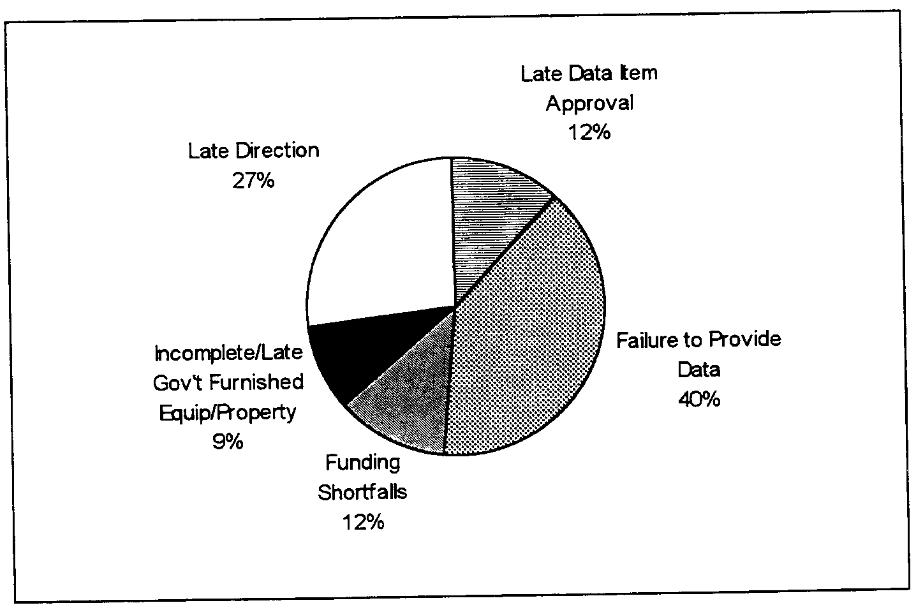

FIGURE 4-9: "Government Not Supportive" Subcategories

"Government Stopped Work" Category. This category includes reasons related to a government-directed stop work order. Reasons in this category reflect schedule variances both in stopped tasks, and in tasks related to the stopped tasks. Because the reasons included in this category are very similar, Table 4-1 is sufficiently descriptive of this category that no further elaboration is required.

"Inventory Management" Category. This category includes reasons related to inventory problems. Specific subcategories of reasons for schedule problems within the "inventory management" category are as follows:

(1) ineffective controls for materials being ordered, delivered, or stored, such as being unaware of delivered material, or having parts in stock that do not match the bill of materials; and,

(2) parts shortages.

Figure 4-10 presents the relative contribution of reasons (in terms of number observed) within the above subcategories to the "inventory management" category.

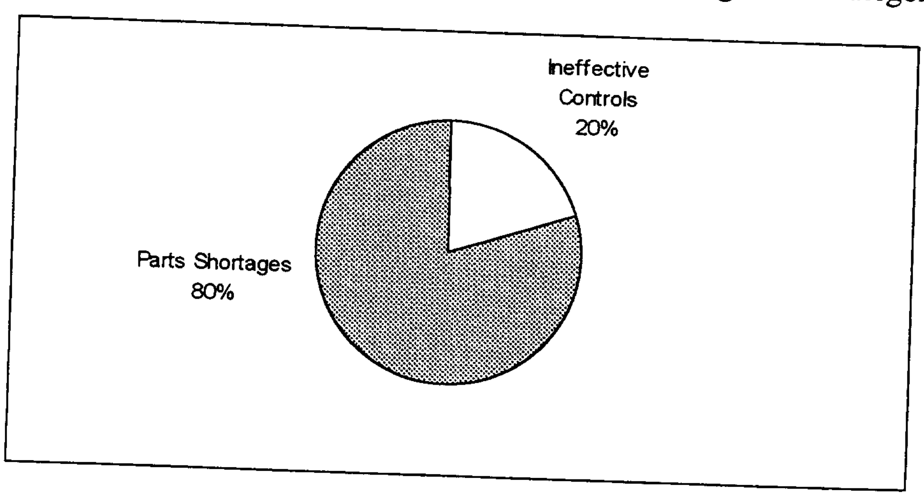

FIGURE 4-10: "Inventory Management" Subcategories

"Late Data" Category. This category includes reasons related to the late receipt or generation of required information either within the contractor's organization, or between contractor and subcontractor. Specific subcategories of reasons for schedule problems within the "late data" category are as follows:

(1) incomplete data items (late completion of specifications and other documents required for delivery to the government);

(2) late engineering release of drawings and other design data required for manufacturing and other activities; and,

(3) late or incomplete information (such as specifications, reports, and data) impacting areas such as design, manufacturing, training, provisioning, technical publications, test, facilities, and material orders.

Figure 4-11 presents the relative contribution of reasons (in terms of number observed) within the above subcategories to the "late data" category.

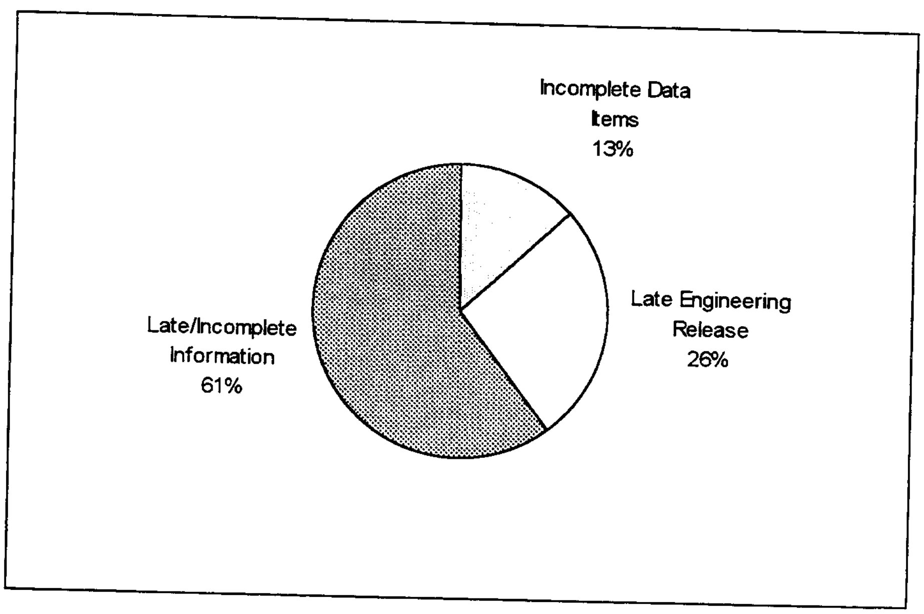

FIGURE 4-11: "Late Data" Subcategories

"Late Review" Category. This category includes reasons related to technical or management reviews that have been either lengthened or postponed by the contractor or subcontractor. Specific subcategories of reasons for schedule problems within the "late review" category are as follows:

(1) review completion (more than the anticipated amount of time was required to conduct the review and address issues that surfaced during the review); and

(2) late start ("slip") of scheduled requirements or design reviews, often impacting activities such as design, fabrication, and test.

Figure 4-12 presents the relative contribution of reasons (in terms of number observed) within the above subcategories to the "late review" category.

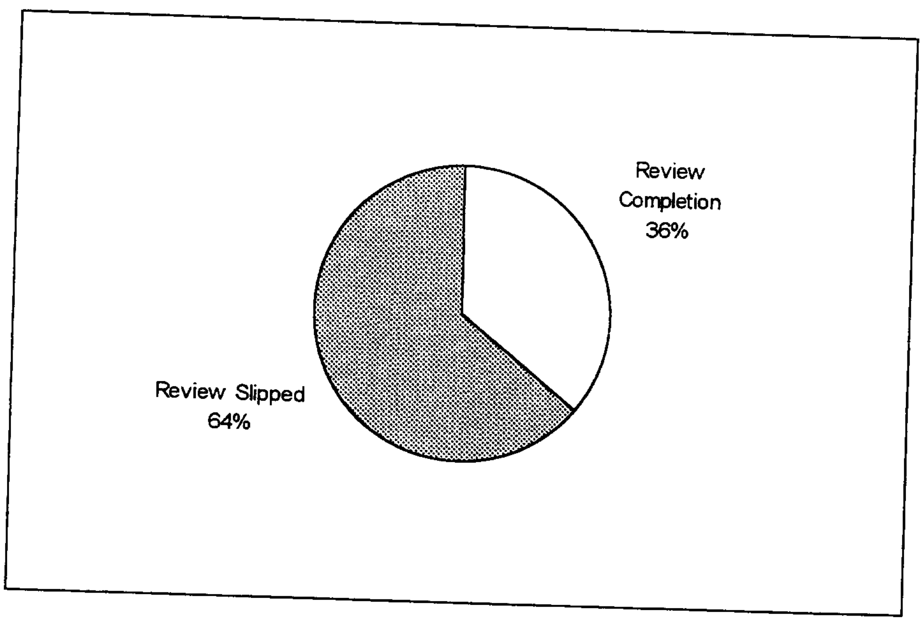

FIGURE 4-12: "Late Review" Subcategories

"Miscellaneous Delays" Category. This category includes schedule variance explanations that failed to state the reason for a particular schedule problem, and reasons that did not fall neatly into another category. The explanations include various schedule problems whose reason was unspecified, impacting activities such as design, logistics, deployment, test, and manufacturing. The reasons in this category include delays in overseas shipments and an inefficient management process. Because of the diverse nature of the reasons and explanations in this category, subcategorization is not particularly useful in this case, and as such, has not been conducted.

"Manufacturing Problems" Category. This category includes reasons related to problems building hardware, both in the development and preparation for production of a system. These problems, described below, are those encountered in translating an engineering design into developmental and production hardware. Specific subcategories of reasons for schedule problems within the "manufacturing problems" category are as follows:

(1) miscellaneous problems, such as late requisitioning of inventory, a slowdown due to a new computer system, and design problems discovered during fabrication;

(2) fabrication problems on breadboards, system components, tooling, and test equipment;

(3) late receipt of material impacting fabrication and assembly;

(4) late start of tooling;

(5) manufacturing design problems in developing the bill of materials, releasing tooling, and providing articles required for development;

(6) machine proofing problems and delays impacting fabrication and assembly; and,

(7) manufacturing process problems, such as a fabrication process that produces system components that do not meet the specification.

Figure 4-13 presents the relative contribution of reasons (in terms of number observed) within the above subcategories to the "manufacturing problems" category.

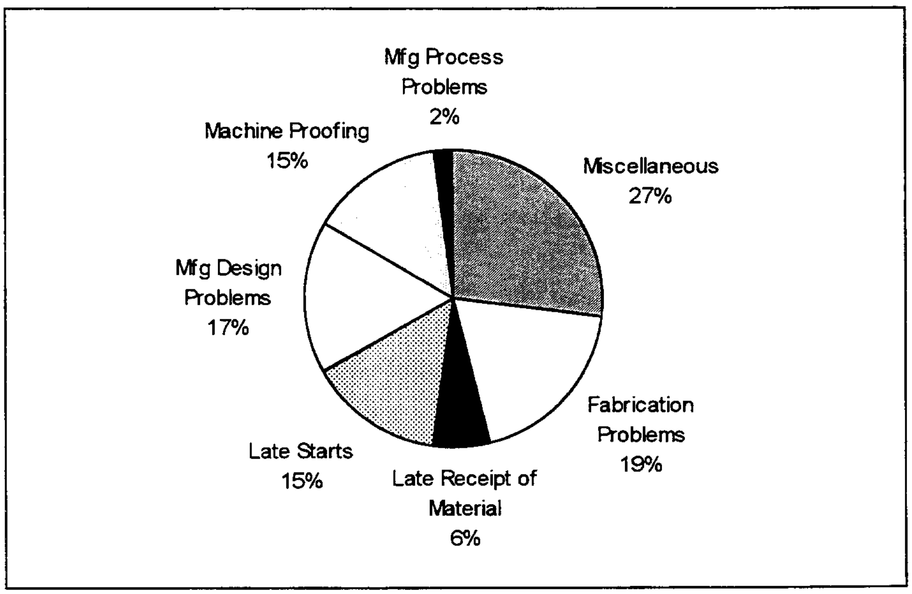

FIGURE 4-13: "Manufacturing Problems" Subcategories

"Quality" Category. This category includes reasons related to either a lack of quality (in terms of defective equipment/components, inadequate testing, and substandard personnel performance), or delays caused by quality assurance activities. Most of these reasons deal with subcontractor or vendor problems. Specific subcategories of reasons for schedule problems within the "quality" category are as follows:

(1) miscellaneous problems, such as poor subcontractor performance or inadequate preparation for testing;

(2) inadequate testing, such as when vendor in-house testing is insufficient to determine whether or not a product is acceptable;

(3) unacceptable items, that were either delivered with missing components or did not meet specifications; and,

(4) acceptance procedures, such as inspections or approvals by the prime contractor, delaying subcontractor deliveries.

Figure 4-14 presents the relative contribution of reasons (in terms of number observed) within the above subcategories to the "quality" category.

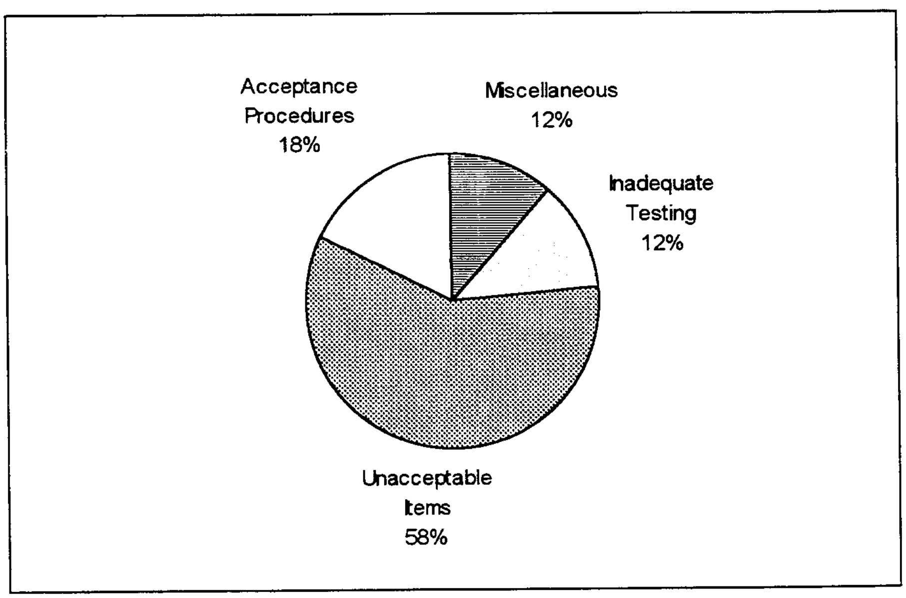

FIGURE 4-14: "Quality" Subcategories

"Requirements Changes" Category. This category includes reasons related to changes in security, test, and system component requirements, as reflected in specifications or otherwise. This category is different from the "design changes" category in that design changes are made in order to reach an objective, whereas requirements changes alter the objective. Although more of the 549 reasons for schedule problems may indeed belong in this category, only those reasons in which changing requirements were either directly or indirectly mentioned were included. Because "requirements changes" adequately captures the essence of all reasons included in this category, further subcategorization is of little value, and hence was not conducted.

"Staffing" Category. This category includes reasons related to having insufficient personnel assigned to tasks. Specific subcategories of reasons for schedule problems within the "staffing" category are as follows:

(1) hiring delays, either during the initial ramp-up of personnel to conduct the effort, or in replacing personnel later in the effort;

(2) inadequate staffing for the timely completion of tasks either at contractor or subcontractor facilities, impacting such activities as design, manufacturing, test, and technical publications;

(3) receipt of security clearances taking longer than expected, causing delays until sufficient numbers of cleared personnel are available to work on the effort;

(4) reassignment of personnel to higher priority or nearer term tasks, resulting in delays on the original tasks; and,

(5) wrong people assigned to a task, such as when subcontractors with either a lack of required expertise or with an inappropriate mix of personnel are working on a task.

Figure 4-15 presents the relative contribution of reasons (in terms of number observed) within the above subcategories to the "staffing" category.

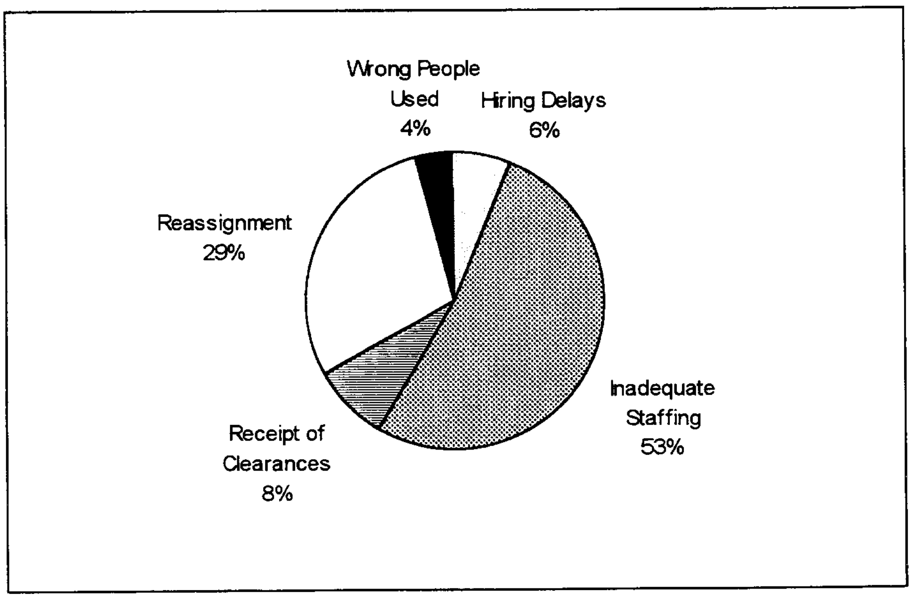

FIGURE 4-15: "Staffing" Subcategories

"Subcontractor/Vendor Late" Category. This category includes reasons related to late deliveries or slow progress by subcontractors or vendors. Specific subcategories of reasons for schedule problems within the "subcontractor/vendor late" category are as follows:

(1) late deliveries of software, hardware (including anything from connectors to entire radar or head-up display units), and other miscellaneous products impacting prime contractor activities such as design, manufacturing, and test;

(2) late deliveries by a subcontractor's subcontractor (essentially the same type of reasons as in (1) above, however delivery is late to subcontractor rather than to prime contractor); and

(3) slow progress of a subcontractor toward meeting its planned schedule.

Figure 4-16 presents the relative contribution of reasons (in terms of number observed) within the above subcategories to the "subcontractor/vendor late" category.

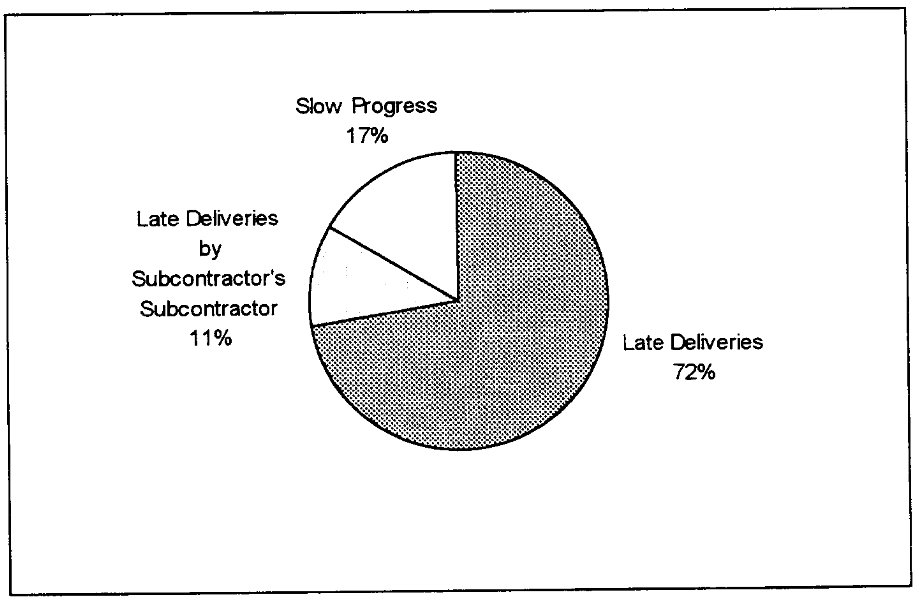

FIGURE 4-16: "Subcontractor/Vendor Late" Subcategories

"Test Problems" Category. This category includes reasons related to problems encountered in preparing for or conducting component or system ground or flight testing.

Included reasons are associated with schedule problems in simulation, instrument modification, and test asset receipt, as well as those encountered in environmental, transportation, qualification, component, and flight testing. Because the reasons in this category are adequately described as "test problems," and because the varied specifics of each reason makes grouping below the category level extremely difficult, further subcategorization was not conducted.

"Technical Definition" Category. This category includes reasons related to defining requirements, interfaces, designs, and tasks to a level where work can proceed without being hampered by a lack of appropriate technical direction. Specific subcategories of reasons for schedule problems within the "technical definition" category are as follows:

(1) finalizing requirements (ongoing definition of requirements and decision making causing delays to tasks awaiting technical direction); and,

(2) poor requirements definition (incorrect or incomplete definition of requirements, interfaces, designs, and tasks).

Figure 4-17 presents the relative contribution of reasons (in terms of number observed) within the above subcategories to the "technical definition" category.

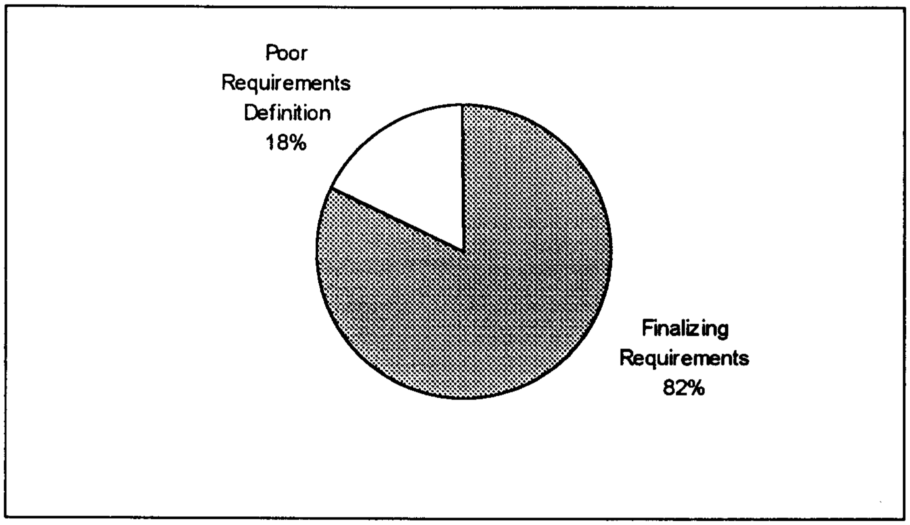

FIGURE 4-17: "Technical Definition" Subcategories

"Technical Problems" Category. This category includes reasons related to difficulties encountered in the design and development of components and systems. Specific subcategories of reasons for schedule problems within the "technical problems" category are as follows:

(1) analysis problems (difficulties and delays conducting analyses or studies);

(2) coordination and integration between system and related systems;

(3) design problems (such as unresolved design issues, design errors, and design activities being more challenging than expected);

(4) development problems (problems with acquiring or creating, and integrating both hardware and software into the system); and,

(5) task growth (additional effort expended due to unexpected problems or the need for required improvements).

Figure 4-18 presents the relative contribution of reasons (in terms of number observed) within the above subcategories to the "technical problems" category.

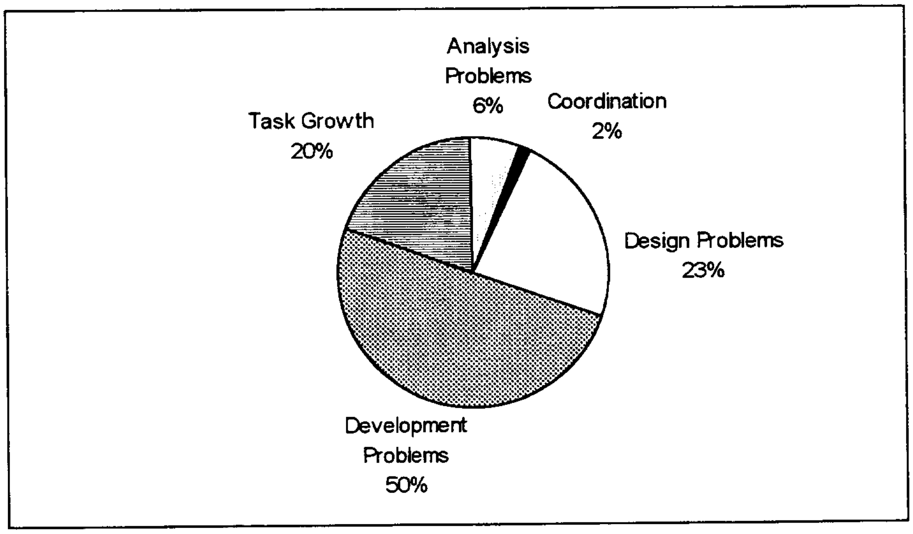

FIGURE 4-18: "Technical Problems" Subcategories

A Final Word on Categorization of Reasons. The above categories are useful for understanding and making comparisons among the major classes of reasons for schedule problems on system development efforts. In order to provide further detail, all 549 observed reasons for schedule problems have been listed in the appendix, where they are grouped in categories and subcategories identical to those described above. By identifying these categories, subcategories, and individual reasons, this research satisfies its objective of identifying the actual reasons for schedule problems across large Air Force system development efforts, describing those reasons at a level of detail (in this case, three levels of detail) that will allow the development of appropriate corrective actions.

In meeting this objective, it is important to note that there is no single "correct" manner in which to classify reasons into categories and subcategories. Certainly, other schemes for defining categories and assigning reasons to those categories may be equally valid. What the above portion of the analysis provides is merely the data presented in a reasonable, consistent framework that allows the above research objective to be satisfied.

Comparison (by category) of Reasons for Schedule Problems

The second objective of this research is to quantify the importance of each category of reasons, in terms of frequency and severity, in order to determine the categories of reasons most and least deserving of management attention. To this end, the following subsections quantify and compare the significance of the reasons for schedule problems in terms of frequency of occurrence, total schedule variance (in dollars and in work days), and average schedule variance (in dollars and in work days).

Frequency of Reasons by Category. Figure 4-19 presents the total number of observed reasons for schedule problems that fall within each category. Based on this data, it appears that on system development efforts, certain types of reasons are likely to occur far more often than others. Although frequency is only one of several measures of reason significance, the below figure provides important information for determining the types of reasons for which corrective action would provide the greatest benefit.

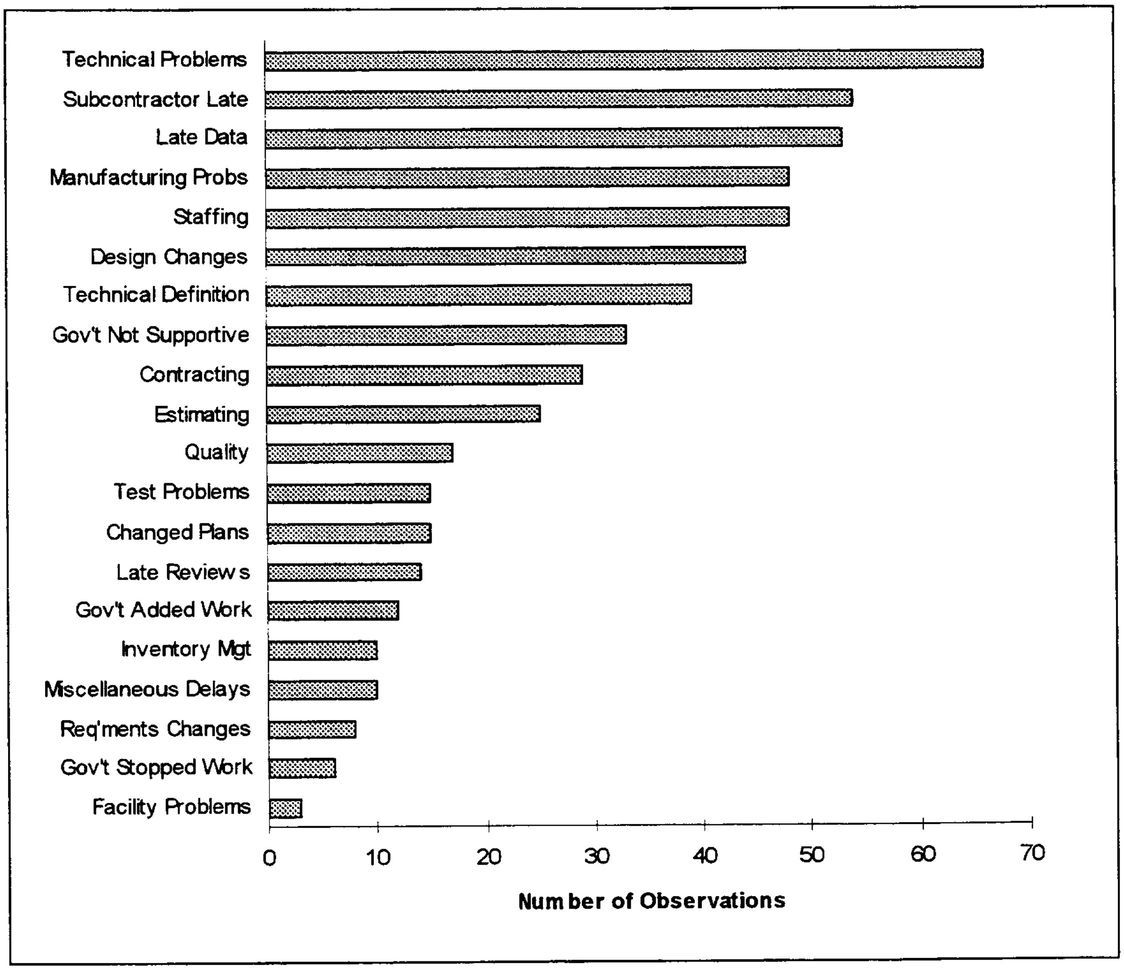

FIGURE 4-19: Frequency of Reasons by Category

Total Schedule Variance (in dollars) by Category. Figure 4-20 presents, for each category, the sum of the negative schedule variances associated with the reasons assigned to that category. This provides a measure of the total impact of the observed reasons on the development efforts. Because the below schedule variances are measured in dollars, they tend to bias the results towards reasons that occur on larger efforts, which tend to experience larger dollar schedule variances. For a more complete discussion of this topic, please refer to Chapter 3.

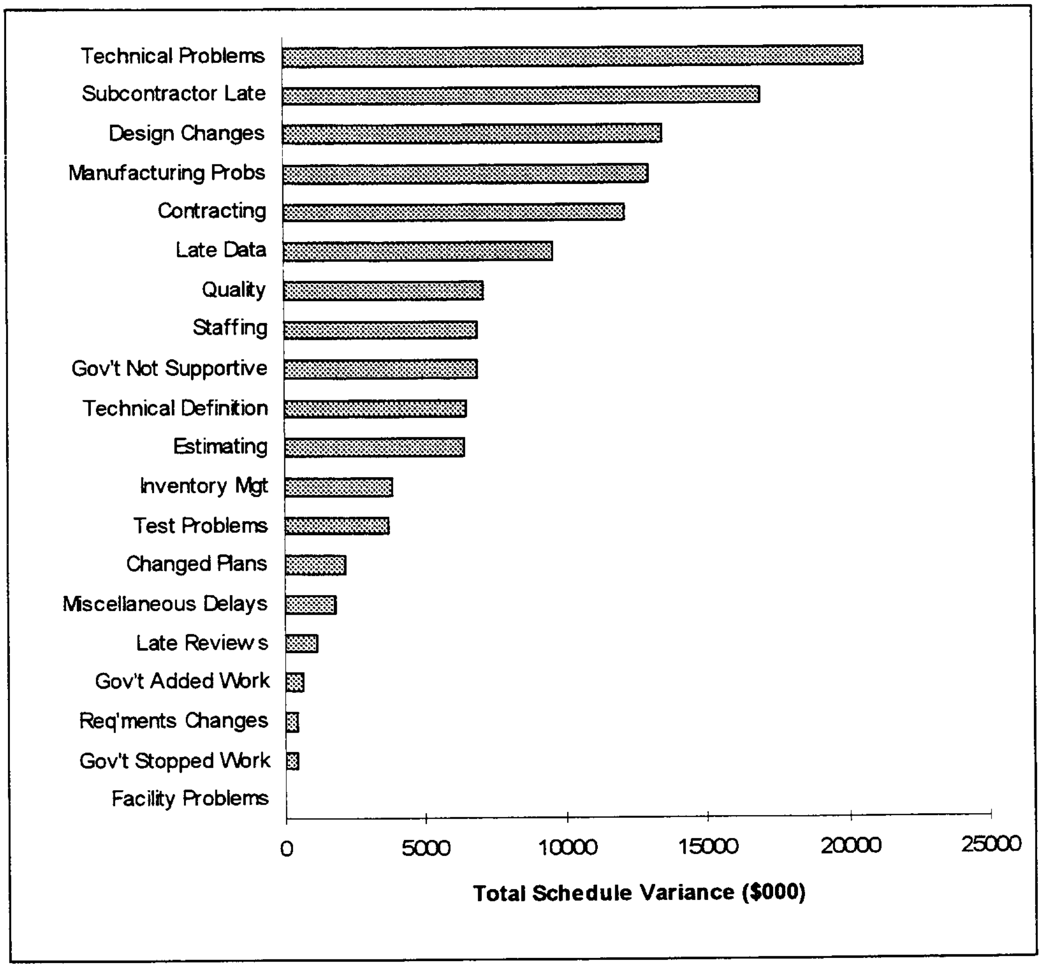

FIGURE 4-20: Total Schedule Variance (in dollars) by Category

Total Schedule Variance (in work days) by Category. Figure 4-21 presents, for each category, the sum of the negative schedule variances (in work days) associated with the reasons assigned to that category. Chapter 3 discusses the method used to convert schedule variances from dollar amounts to fractions of a month. Within each category, then, each reason's month fraction was converted to work days (assuming an average of 22 work days per month), then summed to provide the totals in the below figure.

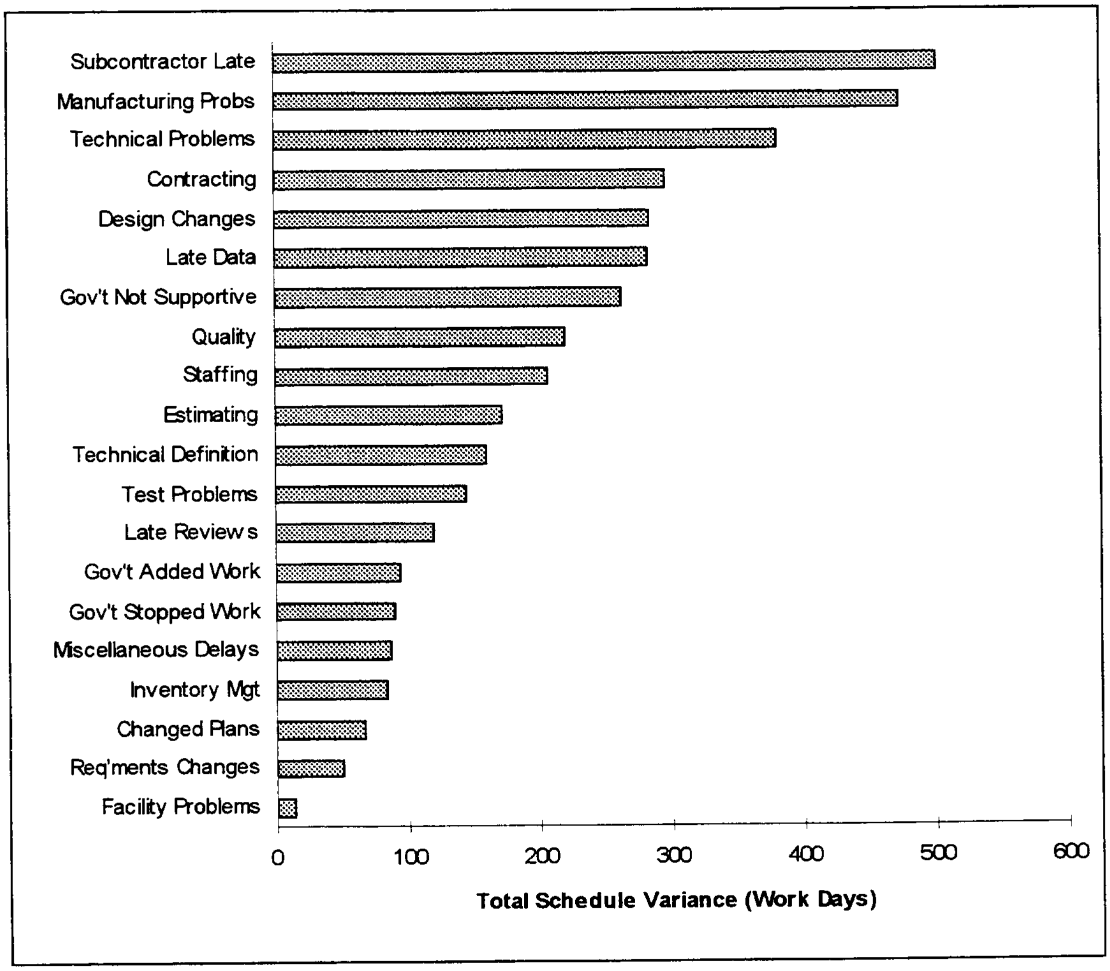

FIGURE 4-21: Total Schedule Variance (in work days) by Category

Like total schedule variance (in dollars), total schedule variance (in work days) provides a measure of the total impact of the observed reasons on the development efforts. As discussed in Chapter 3, however, schedule variance (in work days) represents a month of delay on small efforts the same as it represents a month of delay on large efforts. This tends to bias the results towards reasons found on smaller efforts, which would tend to get less attention under normal circumstances. Thus, both types of schedule variances (in dollars and in work days) provide information useful in quantifying the severity of problems associated with various reasons.

Average Schedule Variance (in dollars) by Category. Figures 4-20 and 4-21 quantify the severity of schedule problems associated with categories of reasons for those problems. When using total schedule variances, however, there is an underlying assumption that the frequency distribution of reasons that occurred in the past will not change in the future. In the event that the frequency distribution of reasons is expected to change, the measures of problem severity should not be based on the observed (past) frequency distribution. Average schedule variance per category provides the required separation from the observed frequency distribution.

Figure 4-22 presents the average negative schedule variance (in dollars) for reasons within each category. In interpreting this figure, it should be noted that within each category there is a wide statistical variance among the observed schedule variances. In fact, across categories, the standard deviation of schedule variances observed within a category exceeded the mean value of the category's schedule variances by an average of 59 percent.

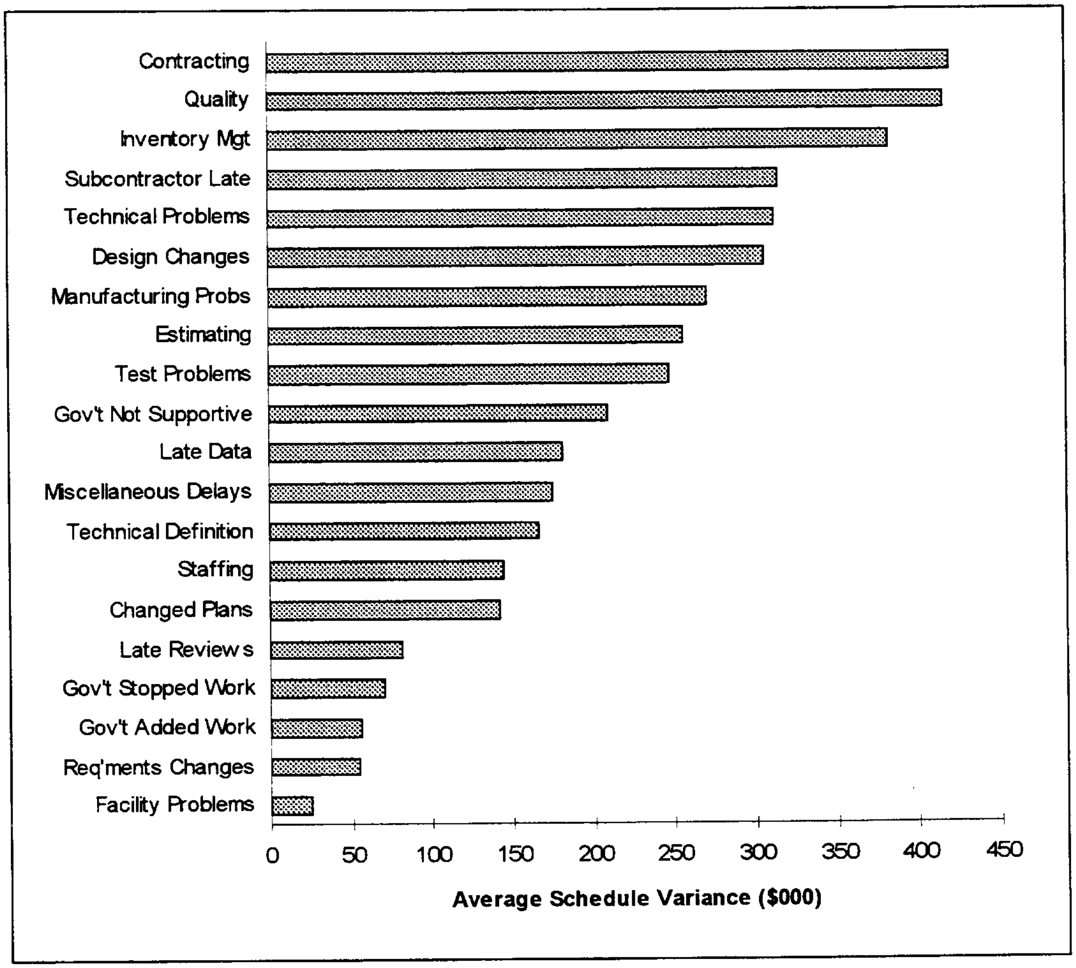

FIGURE 4-22: Average Schedule Variance (in dollars) by Category

Average Schedule Variance (in work days) by Category. As in Figure 4-22, Figure 4-23 presents the average negative schedule variance for reasons within each category. Figure 4-23, however, presents schedule variance in terms of work days rather than in terms of dollars. The conversion of individual schedule variances in dollars to schedule variance in work days, as well as the pertinent attributes of each of the two variance measures was explained in the above "Total Schedule Variance" subsections. Just as with average schedule variance (in dollars), there is a wide statistical variance among the observed schedule variances (in work days) within each category. In fact, across categories, the standard deviation of schedule variances observed within a category exceeded the mean value of the category's schedule variances by an average of 2 percent.

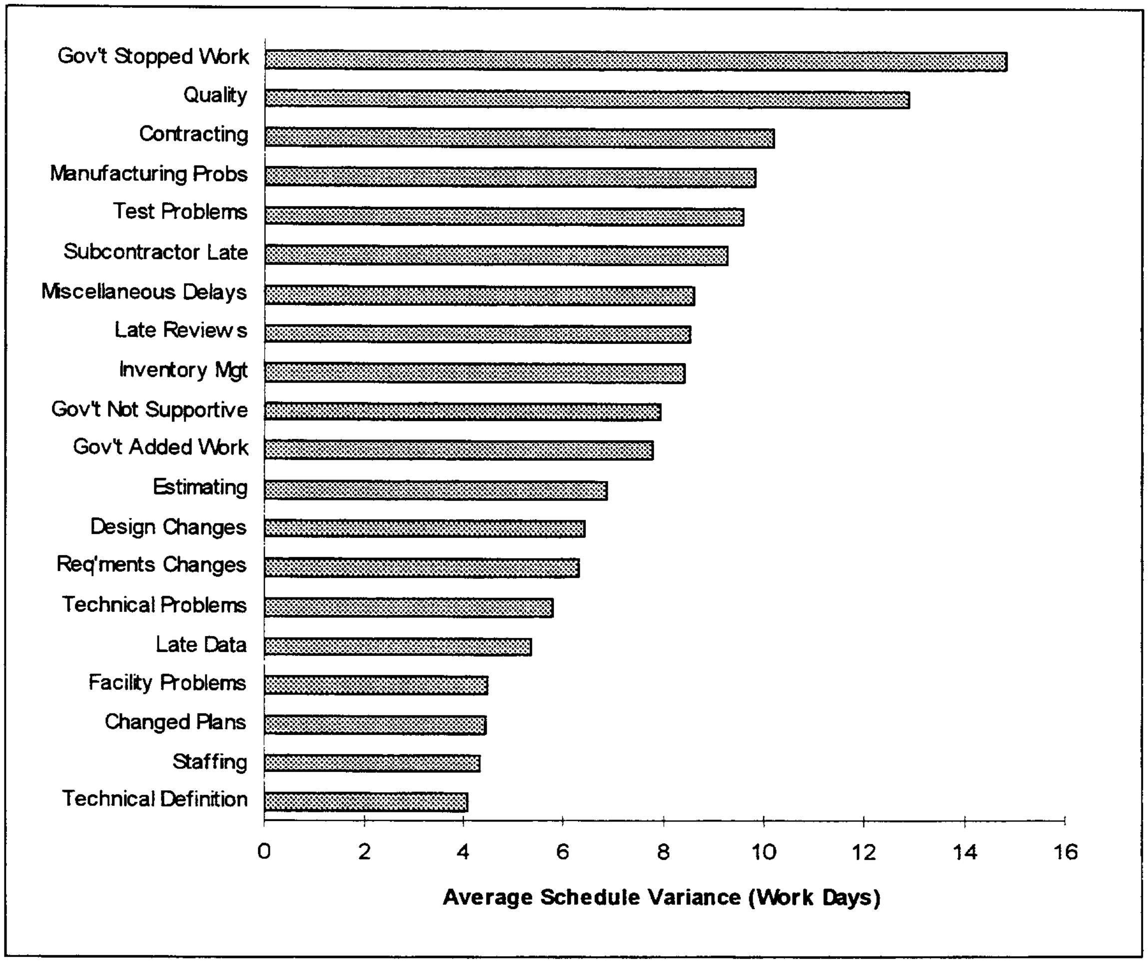

FIGURE 4-23: Average Schedule Variance (in work days) by Category

Summary of Category Rankings by Comparative Measures. Although the above subsections provide information about how each category of reasons for schedule problems compares to other categories for each of the five comparative measures (frequency, total schedule variance in dollars, total schedule variance in work days, average schedule variance in dollars, and average schedule variance in work days) individually, Table 4-2 presents the ranking of each category of reasons in terms of all five comparative measures simultaneously.

TABLE 4-2: Summary Ranking of Categories

Category	Frequency	Total Variance ($)	Total Variance (Days)	Average Variance ($)	Average Variance (Days)
Technical Problems	1	1	3	5	15
Subcontractor Late	2	2	1	4	6
Manufacturing Probs	4	4	2	7	4
Design Changes	6	3	5	6	13
Late Data	3	6	6	11	16
Contracting	9	5	4	1	3
Staffing	4	8	9	14	19
Gov't Not Supportive	8	9	7	10	10
Quality	11	7	8	2	2
Technical Definition	7	10	11	13	20
Estimating	10	11	10	8	12
Test Problems	12	13	12	9	5
Late Reviews	14	16	13	16	8
Changed Plans	12	14	18	15	18
Inventory Mgt	16	12	17	3	9
Gov't Added Work	15	17	14	18	11
Miscellaneous Delays	16	15	16	12	7
Gov't Stopped Work	19	19	15	17	1
Req'ments Changes	18	18	19	19	14
Facility Problems	20	20	20	20	17

In Table 4-2, categories have been ranked from one to twenty for each measure of schedule problem significance, with lower numbers indicating the more significant categories (categories having the same number within a column are "tied" for a given rank). The categories have been presented in order of significance, based on a simple aggregate ranking scheme, where the three rankings to the left of the double line have been summed. Again, the lower the sum of the category's ranks, the more significant the category. Note that this ordering scheme is merely a useful tool for presenting the data, and does not imply that this scheme is the "correct" way to interpret category significance in all cases. Rankings to the left of the double line are those that should be considered if the frequency distribution of reasons is not expected to change from that observed in the data. If another frequency distribution of reasons is expected to occur in the future, rankings to the right of the double line should be considered, along with the expected future distribution. In any case, the rankings in Table 4-2 enable informed decisions to be made regarding the categories of reasons for which corrective action would provide the greatest benefit.

Commonality of Reasons Across System Development Efforts

The third and final objective of this research was to demonstrate that the reasons for schedule problems are not program unique, but are common across system development efforts. The achievement of this objective enables schedule-related lessons learned from past and present efforts to influence schedule performance in future efforts. Figure 4-24 demonstrates this commonality of reasons by presenting the number of efforts on which reasons within each given category occurred.

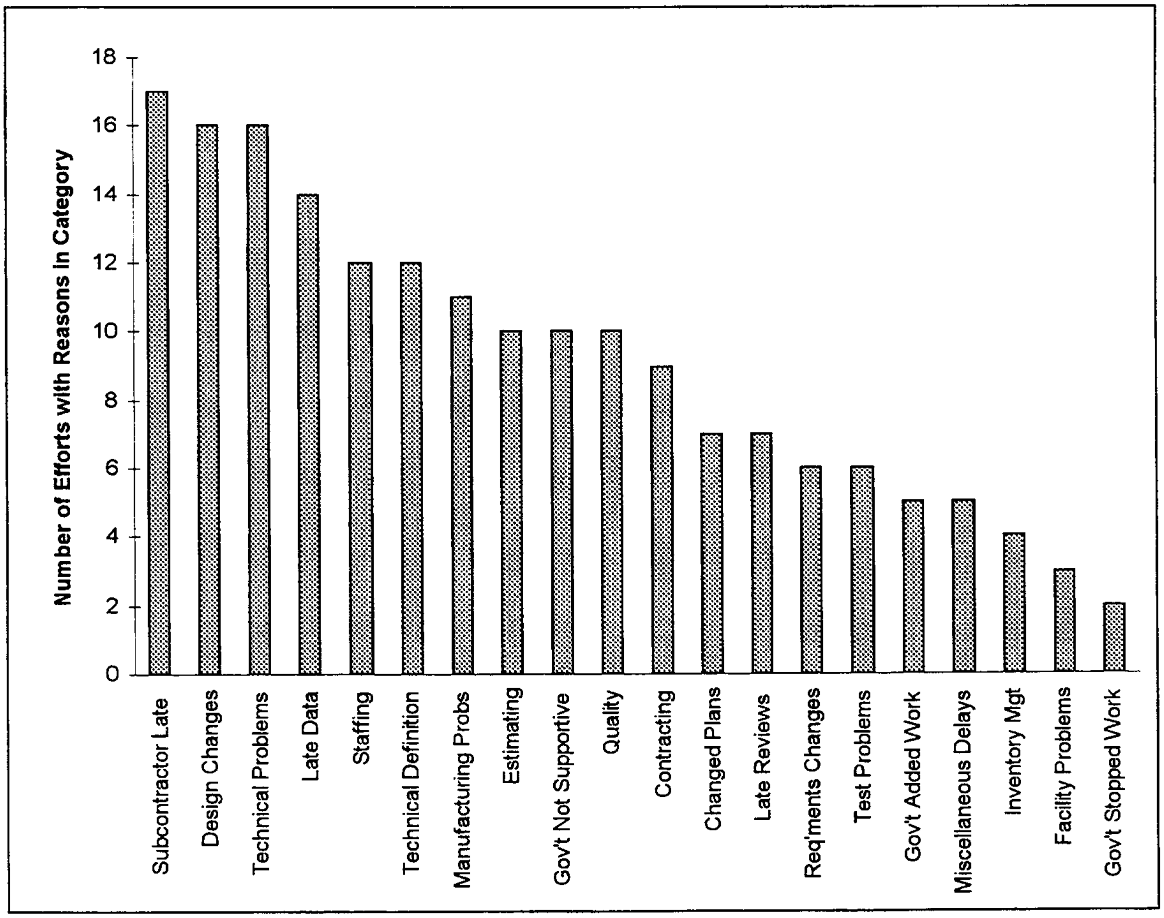

FIGURE 4-24: Commonality of Reasons Across Development Efforts

From Figure 4-24, it is clear that in general, reasons for schedule problems on system development efforts are not unique to a given effort. While all 22 development efforts did not experience all 20 categories of reasons for schedule problems, no category appeared only on one effort, and on average, categories appeared on 9.1 efforts. Certainly, this is compelling evidence supporting the further study of lessons learned from past schedule problems so that these problems (which *will* recur without intervention) can be avoided in the future.

The evidence for commonality of reasons for schedule problems across system development efforts would most likely be even stronger if reasons were classified under fewer categories. This approach, however, was not taken because in order to satisfy the first two objectives of this research, reasons needed to be explained in sufficient detail (hence the need for a greater, not a fewer number of categories) to allow the development of appropriate corrective actions.

V: Findings and Conclusions

Introduction

This research had three main objectives. The first was to identify the actual reasons for schedule problems across large Air Force system development efforts, describing those reasons at a level of detail that will allow the development of appropriate corrective actions. The second was to quantify the importance of each category of reasons, in terms of frequency and severity, in order to determine the categories of reasons most and least deserving of management attention. The third was to demonstrate that the reasons for schedule problems are not program unique, but are common across system development efforts, therefore schedule-related lessons learned from past and present efforts are likely to be relevant to future efforts. The following chapter summarizes the findings of this research related to these three objectives, comments on the differences between the results of this research and results found in the literature, provides observations regarding the collection of meaningful schedule-related data from system development efforts, and suggests areas in which future related research would be appropriate.

Findings Related to the Research Objectives

Identified Reasons for Schedule Problems. In order to satisfy the first objective of this research, the reasons for schedule problems on large Air Force system development efforts were identified. All 549 observed reasons (see Appendix) were categorized (see Table 4-1) and subcategorized (see pages 43-61) in order to facilitate understanding and comparing those reasons at a level of detail that allows the development of appropriate corrective actions.

Although the categories and subcategories are useful in understanding classes of reasons and for making comparisons among reason classes, the 549 unsummarized reasons contained in the appendix may be of equal or greater value to managers. These reasons, grouped by category and subcategory, are essentially a database of lessons learned from 22 past and present system development efforts. The mere act of skimming through these actual reasons for schedule problems may provide managers with the "heads-up" reminder of things that have gone wrong before that will allow them to avoid these problems in the future.

Relative Importance of Categories of Reasons. In order to satisfy the second objective of this research, the identified reasons for schedule problems were compared in terms of frequency of occurrence and schedule variance (in dollars and in work days). The complete set of comparisons may be found in Figures 4-19 to 4-23, and in Table 4-2. Table 5-1 presents the top five and bottom five categories of reasons in terms of frequency, and total schedule variance (both in dollars and in work days). Although Chapter 4 also presented average schedule variance, in addition to the measures presented in Table 5-1, total schedule variance better describes the significance of the reasons in terms of the impact they actually had across the 22 sampled development efforts.

TABLE 5-1: Most and Least Significant Categories of Reasons for Schedule Problems

Top Five Categories (Rank Ordered)		
Frequency	Total Schedule Variance ($)	Total Schedule Variance (Work Days)
Technical Problems	Technical Problems	Subcontractor Late
Subcontractor Late	Subcontractor Late	Manufacturing Probs
Late Data	Design Changes	Technical Problems
Manufacturing Probs	Manufacturing Probs	Contracting
Staffing	Contracting	Design Changes
Bottom Five Categories (Rank Ordered)		
Frequency	Total Schedule Variance ($)	Total Schedule Variance (Work Days)
Miscellaneous Delays	Late Reviews	Miscellaneous Delays
Inventory Mgt	Gov't Added Work	Inventory Mgt
Req'ments Changes	Req'ments Changes	Changed Plans
Gov't Stopped Work	Gov't Stopped Work	Req'ments Changes
Facility Problems	Facility Problems	Facility Problems

The seven categories listed in Table 5-1 comprising the "top five," or most significant, categories of reasons for schedule problems account for 49 percent of the observed reasons (frequency), 57 percent of the schedule variance (in dollars), and 49 percent of the schedule variance (in work days). Clearly, these categories represent reasons more deserving of management attention than the eight categories listed in Table 5-1 comprising the "bottom five," or least significant, categories of reasons for schedule problems, which account for only 7 percent of the observed reasons (frequency), 2 percent of the schedule variance (in dollars), and 8 percent of the schedule variance (in days).

Where Management Attention Should Focus. Based on the results of this research, management should focus its attention on the seven categories of reasons for schedule problems comprising the "top five" portion of Table 5-1. To this end, this subsection presents additional detail on the reasons in these categories and provides suggestions for improvement.

First, the "technical problems" category includes reasons related to difficulties encountered in the design and development of components and systems. These difficulties include: difficulties and delays conducting analyses or studies; coordination and integration between the system and related systems; unresolved design issues; design errors; design activities being more challenging than expected; problems with acquiring or creating, and integrating both hardware and software into the system; and, additional effort expended due to unexpected problems or the need for required improvements. In order to reduce the number of "technical problems" encountered, managers should ensure that adequate technical planning is conducted prior to the start of a project. In this planning, the integration of components and systems should be given high priority, because this aspect of planning is often neglected. By taking a methodical, systems engineering approach to project planning, many (though not all) "technical problems" can be eliminated.

Second, the "subcontractor late" category includes reasons related to late deliveries or slow progress by subcontractors or vendors. These difficulties include: late deliveries of software, hardware, and other miscellaneous products; late deliveries by a subcontractor's subcontractor; and, slow progress of a subcontractor toward meeting its planned schedule. By being one of the top two categories of reasons for schedule problems in all three of the Table 5-1 measures of problem significance, subcontracting has been shown to be extremely important to the schedule success of defense system development efforts. In order to improve schedule performance in this area, managers need to increase visibility into subcontractor plans and procedures. In addition, better "early warning systems" are needed to allow managers to predict subcontractor delays in time to implement alternate work plans.

Third, the "manufacturing problems" category includes reasons related to problems building hardware, both in the development and preparation for production of a system. These problems, encountered in translating an engineering design into developmental and production hardware, include: late requisitioning of inventory; slowdowns due to new computer systems; design problems discovered during fabrication; fabrication problems on breadboards, system components, tooling, and test equipment; late receipt of material impacting fabrication and assembly; late start of tooling; manufacturing design problems in developing the bill of materials, releasing tooling, and providing articles required for development; machine proofing problems and delays impacting fabrication and assembly; and, manufacturing process problems, such as fabrication processes that produce system components that do not meet the specification. Just as in the "technical problems" category, much improvement could occur in the "manufacturing problems" area if management required a methodical, integrated, systems engineering approach to planning these activities.

Fourth, the "design changes" category includes reasons related to changes in system or component designs, typically undertaken to fix problems or to improve performance. Quite often, in addition to requiring time to implement, these changes also impact other, related tasks that depend on stable, defined designs for their continued progress. The key to mitigating problems in this area is for management to be aware that design changes often have a "ripple effect" throughout the system. Before permitting a design change, managers should insist on a thorough analysis of the potential impacts on the entire system.

Fifth, the "late data" category includes reasons related to the late receipt or generation of required information either within the contractor's organization, or between contractor and subcontractor. These difficulties include: late completion of specifications and other documents required for delivery to the government; late engineering release of drawings and other design data required for manufacturing and other activities; and, late or incomplete information (such as specifications, reports, and data) impacting areas such as design, manufacturing, training, provisioning, technical publications, test, facilities, and material orders. The lesson of this category is that system development is a data intensive activity, and that efforts to speed the generation and flow of data will speed the overall development effort. Plans that incorporate the need for data generation and sharing, procedures that facilitate these actions, and computer based tools that enable these actions can all have a significant positive impact on development effort schedule performance.

Sixth, the "contracting" category includes reasons related to contractual actions and the process of awarding subcontracts. These difficulties include: source selection of subcontractors and vendors (including request for proposal (RFP) preparation and proposal receipt); placing subcontractors and vendors on contract; processing purchase orders; and, terminating subcontractors. Improvements in this area could be realized by thoroughly planning subcontracting activities at the beginning of the development effort, and by further streamlining source selection procedures.

Seventh, the "staffing" category includes reasons related to having insufficient personnel assigned to tasks. These difficulties include: hiring delays, either during the initial ramp-up of personnel to conduct the effort, or in replacing personnel later in the effort; inadequate staffing for the timely completion of tasks either at contractor or subcontractor facilities; receipt of security clearances taking longer than expected, causing delays until sufficient numbers of cleared personnel are available to work on the effort; reassignment of personnel to higher priority or nearer term tasks, resulting in delays on the original tasks; and, having the wrong people assigned to a task, such as when subcontractors with either a lack of required expertise or with an inappropriate mix of personnel are working on a task. Improvements in this area could be realized by locating appropriate personnel prior to contract award, planning for an adequate number of personnel to meet the schedule demands of the effort, ensuring that the qualifications of personnel are matched to the tasks they are to perform, and allowing adequate time to both locate replacement personnel and to process security clearances.

The preceding suggestions for improvement only "scratch the surface" of potential corrective actions that could be applied to improve schedule performance on defense system development efforts. Indeed, a thorough investigation to identify corrective actions based on the reasons for schedule problems identified in this thesis would be a significant research effort in and of itself. Hopefully, this research, by providing a starting point in terms of identifying the reasons for schedule problems and suggesting which categories of reasons most require management attention, will enable both researchers and practitioners to develop appropriate corrective actions to mitigate schedule problems in the future.

Commonality of Reasons Across Development Efforts. In order to satisfy the third and final research objective, the number of development efforts on which each category of reasons for schedule problems had been observed was analyzed to demonstrate that reasons were not unique to a given effort. According to this analysis, as presented in Figure 4-24, although all 22 development efforts did not experience all 20 categories of reasons for schedule problems, no category appeared only on one effort, and on average, categories appeared on 9.1 efforts. Certainly, this is compelling evidence supporting the further study of lessons learned from past schedule problems so that these problems (which *will* recur without intervention) can be mitigated in the future.

Differences Between the Results of this Research and Results in the Literature

Overall, there is a remarkable similarity between the reasons for schedule problems found in the literature (see Tables 2-1, 2-2, and 2-3), and those observed in the course of this research (see Table 4-1, pages 43-61, and Appendix). The few exceptions are as follows.

First, several reasons for schedule problems mentioned in the literature were not observed in the data. One explanation for these discrepancies is that the data source (Cost

Performance Reports, or CPRs) is written from a contractor perspective, whereas some of the reasons found in the literature are stated from a government perspective. For example, poor management practices, a lack of "follow-up," inadequate supervision, and a lack of motivation are all things that a contractor is unlikely to admit on a report being sent to the government (CPR). Similarly, there would be a tendency to downplay the effects of program manager turnover, and not to address political influences or economic factors on a CPR. In addition, there would be a tendency to not be too critical of the government, avoiding references to micromanagement, constructive changes, and problems with joint service project management. Finally, Engineering Change Proposals (ECPs) would probably not be listed as a reason for schedule problems on a contractor report because when ECPs modify the work to be accomplished, they also modify the baseline schedule against which progress on the development effort is measured. Thus, although the ECP may lengthen the development effort, it doesn't typically cause a schedule variance (and thus is not reported) unless delays occur in conducting the work associated with the ECP.

Another explanation for reasons not appearing in the data is that some reasons in the literature may be reasonably rare, and therefore were not observed in the limited sample of development effort reports used in this research. Reasons such as labor problems, concept stability, and external events may fall into this category.

Second, several reasons for schedule problems observed in the data were not mentioned in the literature. These reasons, such as contractual actions, changed plans, facilities problems, late direction, technical definition, manufacturing problems, and test problems, tend to be more specific than many of the reasons in the literature. This is to be expected in an initial descriptive study such as this one, where the desired outcome is to identify reasons not already expressed and to provide added detail such that the identified reasons are useful to managers for developing appropriate corrective actions.

Third and finally, unlike the reasons provided in the literature, the reasons for schedule problems identified in this research have been quantified in terms of the significance of their associated schedule problems so that managers can determine the categories of reasons most and least deserving of their attention.

Obtaining Meaningful Schedule-Related Data from System Development Efforts

Three observations regarding obtaining meaningful schedule-related data from large Air Force system development efforts are worthy of mention. First, it is difficult to find a usable source of this type of data. In the Air Force, and in the DoD in general, schedule has been of significantly less interest than cost. This is reflected in the fact that although there are numerous functional organizations throughout the DoD that focus on cost, there are few if any that focus primarily on schedule. The result is that unlike cost information, schedule information is rarely archived and seldom studied. Fortunately, due to the interest of the cost community, the Cost Performance Reports (which also *happen* to include schedule information) were a readily available source of data for this research. In order to properly preserve the schedule-related lessons of the past so that mistakes are not continually repeated, more schedule-related information needs to be archived and studied in the future.

Second, in general, the format of Cost Performance Report (CPR) has not been optimized for identifying and quantifying the reasons for schedule problems. This is partly because the format of the CPR varies from contract to contract. Of the 22 development efforts examined, many had CPRs formatted such that reasons were easy to identify and quantify, however others made identification and quantification more difficult by presenting poorly organized, rambling narratives, and by grouping many reasons in a narrative without identifying the schedule variance associated with each reason. To remedy this problem, guidelines could be modified to call for contractors to explain variances in a way such that the root reasons for schedule problems are clearly and succinctly identified, followed by whatever narrative is necessary to understand the nature of the problems and associated consequences. Also, if a reportable schedule variance has several reasons, contractors should identify the amount of variance associated with each reason (as some contractors already do).

Third and finally, there needs to be a better measure than schedule variance for quantifying the severity of schedule problems. As explained in Chapter 3, negative schedule variance is based on a deviation from a time-phased budget, and while it is a reasonable indicator of schedule inefficiency, it does not usually equate with delay to the development effort. Any measure that more directly describes the delay to the overall effort, or at least the loss of "slack time" on tasks would be an improvement over the current schedule variance measure because it would better describe the real world management concern of project delay.

Suggested Areas for Future Research

Based on the experience gained and the results provided in this research, the following three areas are suggested for future exploration. First, as was stated earlier in this chapter, the data source used in this research (the Cost Performance Report) is written from a contractor perspective. In order to gain additional insight into the reasons for schedule problems on system development efforts, it is highly desirable to also use a data source written from a government perspective. The Defense Acquisition Executive Summary (DAES) report is such a data source, which is similar to the CPR, yet is written by the government manager of the system development effort. The DAES reports are centrally archived by the Performance Management Branch of the Office of the Undersecretary of Defense for Acquisition and Technology in the Pentagon. The only complication with using the DAES as a data source is that portions of the DAES are classified. Although the data required to support further research into the reasons for schedule problems on system development efforts are generally *not* classified, the data would still have to be extracted from the classified reports. Once extracted, however, the data would allow a future effort to balance the contractor perspective contained in this research with a much needed government perspective.

Second, this research has provided a great deal of information about the reasons for schedule problems on past and present large Air Force system development efforts that can be used to help avoid these types of problems in the future. This information represents a host of lessons learned from previous efforts that provide managers with valuable insight into the types of problems that actually occur across development efforts. Given the value of these insights, it is important that this research approach not be limited to schedule-related problems. In fact, a very valuable contribution would be to apply the general approach of this research to the *cost* data contained in Cost Performance Reports.

This would allow managers a better understanding of the reasons for *cost* problems on system development efforts, which in general tend to be even more significant than schedule problems.

Third and finally, because of the lack of existing information regarding the reasons for schedule problems on system development efforts, this research necessarily focused on describing the reasons, rather than on determining causal relationships for explaining why reasons occurred as they did. Now that this research provides some insight into the reasons for schedule problems, future research can focus on specific management questions. For example, it may be interesting to investigate how reasons vary from one development effort type (such as fighter aircraft, or simulators) to another. Perhaps certain types of reasons are more likely to appear on certain types of development efforts. Also, it may be useful to investigate how reasons vary from one timeframe to another. Perhaps changed management practices, such as total quality management (TQM) or acquisition reform, impact the types and quantities of reasons for schedule problems that are experienced from one year to the next. In such future research efforts, great care would have to be taken to control for differences in potential moderating variables such as development effort size, type and level of completion (for example, it is important to avoid comparing efforts early in development with those late in development). Also, if reasons are being compared among timeframes, it is important to ensure that data is sampled equivalently among those timeframes. Given the need for careful, tailored data collection on these types of future research efforts, the more general research contained in this thesis will most likely not *directly* apply, although it will certainly provide a source of future research questions and a context within which to assess future research results.

Conclusion

This research has filled a gap in the existing management body of knowledge regarding the reasons for schedule problems on system development efforts. By capturing the schedule-related lessons of past and present development efforts, and presenting them in a coherent framework, these lessons of yesterday can be used by the managers of today to solve the schedule problems of tomorrow. This research is not only valuable by itself, but provides a starting point from which more specific schedule-related management questions can be addressed in the future.

Appendix

549 Reasons for Schedule Problems

Observed on 22 Large Air Force System Development Efforts

Category	Reason for Schedule Variance	Variance ($000)	Variance (Days)	Program	Year
Contracting					
Awarding Contracts	Late simulator installation - not yet on contract	45	3.85	A/C Equipment 3	1989
	Delays in placing subcontract for tooling effort	2388	5.31	Aircraft/Missile 1	1986
	Late subcontract awards impacting support equipment efforts	361	4.72	Aircraft/Missile 1	1986
	Delay in placing subcontract for static testing	178	20.19	Aircraft/Missile 1	1986
	Delay in placing subcontract for durability testing	183	19.08	Aircraft/Missile 1	1986
	Contract not yet signed with vendor for wing slat package	49	0.21	Aircraft/Missile 1	1989
	Delays in awarding subcontract	146	1.64	Aircraft/Missile 1	1987
	Delayed contractual finalization	217	0.63	Aircraft/Missile 2	1993
	Late placing of vendor subcontract	217	0.63	Aircraft/Missile 2	1993
PO Processing	Delays in processing purchase orders	35	1.48	A/C Equipment 1	1989
	Delays in processing purchase orders delayed consultant support	30	1.39	A/C Equipment 1	1989
	Delays in purchasing required S/W	21	2.31	A/C Equipment 1	1990
	Delays in purchasing engineering materials	21	2.31	A/C Equipment 1	1990
	Late selection of supplier impacting H/W & S/W design	225	11.00	Aircraft/Missile 1	1986
	Prolonged procurement cycles	1065	3.28	Aircraft/Missile 1	1989
	Delays in placing purchase orders	77	18.02	Aircraft/Missile 3	1991
	Behind schedule piece part purchase order placements	967	8.92	Simulator 1	1991
Source Selection	Delays in vendor response to RF Engineering RFQ's	6	16.50	Aircraft Upgrade 1	1985
	Late receipt of vendor responses to RFQs	34	2.54	Aircraft Upgrade 1	1985
	Delays in vendor responses to RFQs	6	18.86	Aircraft Upgrade 1	1985
	Delays in receiving responses to vendor RFQs (changing from make to buy)	4	17.60	Aircraft Upgrade 1	1985
	RFP to subcontractor delayed due to inadequate RFP	54	1.63	Aircraft Upgrade 6	1993
	Late source selections impacting subsystem design	343	22.00	Aircraft/Missile 1	1986
	Potential supplier non-responsive to RFP	225	11.00	Aircraft/Missile 1	1986
	Delay in source selection impacting integration facility build-up	2023	13.52	Aircraft/Missile 1	1986
	Late source selections delaying H/W & S/W design	1445	22.00	Aircraft/Missile 1	1986
Subktr Termination	Sub terminated	81	22.00	Aircraft Upgrade 5	1991
	Sub terminated	56	22.00	Aircraft Upgrade 5	1991
	Sub terminated for failure to perform	1650	21.53	Aircraft/Missile 1	1989

Category	Reason for Schedule Variance	Variance ($000)	Variance (Days)	Program	Year
Changed Plans					
Changed Responsibilities	Change in mgt office for component to get downstream efficiency	59	9.01	A/C Equipment 2	1983
	Minor changes in several functional responsibilities	24	0.26	Aircraft Upgrade 2	1993
	Minor changes in several functional responsibilities	63	0.77	Aircraft Upgrade 2	1993
	Minor changes in several functional responsibilities	23	0.15	Aircraft Upgrade 2	1994
	Minor changes in several functional responsibilities	171	5.87	Aircraft Upgrade 3	1989
	Minor changes in several functional responsibilities	76	1.09	Aircraft Upgrade 3	1991
	Minor changes in several functional responsibilities	34	1.46	Aircraft Upgrade 3	1992
New Design Schedules	Rescheduling of large scale integration prototypes by sub	134	0.27	Aircraft/Missile 2	1993
	Rescheduled design effort	29	1.62	Aircraft/Missile 5	1983
	Revised drawing schedules	30	0.41	Aircraft/Missile 5	1983
	Rescheduling of missile analysis task	19	1.53	Simulator 1	1989
New Delivery Schedules	New subcontractor delivery schedule for better inventory management	113	0.71	Aircraft Upgrade 2	1994
	Rescheduled hardware delivery	1034	21.92	Aircraft/Missile 4	1989
	Rescheduled hardware delivery	39	10.21	Aircraft/Missile 4	1989
	Rescheduling of hardware delivery	276	10.92	Aircraft/Missile 4	1989
Design Changes					
Affecting Data	Tech manuals delayed due to frequently changing tech data	92	10.02	A/C Equipment 3	1991
	Increased drawing changes leading to late drawing release	150	2.04	Aircraft/Missile 2	1993
	Sub drawings behind schedule due to design changes	62	0.93	Aircraft/Missile 2	1993
Affecting Manufacturing	Significant rework due to engr request to relocate strain gauges	82	0.71	Aircraft/Missile 1	1990
	Late engr design/changes delay horiz/vert stabilizer build up	459	2.71	Aircraft/Missile 1	1989
	Engineering redefinition of mockups	40	8.38	Aircraft/Missile 1	1987
	Manufacturing experiencing heavy change traffic from Engrs	40	8.38	Aircraft/Missile 1	1987
	Delays in mockup construction due to engineering changes/late releases	83	16.16	Aircraft/Missile 1	1986
	Late receipt of material, tooling, and engr changes impacting integration	1015	0.95	Aircraft/Missile 1	1989
	Design changes and redefinitions of mockups	83	14.85	Aircraft/Missile 1	1987
	Engineering changes to cabinet caused installation delays	61	1.74	Simulator 2	1994

Category	Reason for Schedule Variance	Variance ($000)	Variance (Days)	Program	Year
Affecting Subktr Delivs	Slowed sub effort due to potential design changes from PDR	55	10.00	A/C Equipment 1	1990
	Sub effort slowed pending design changes discussed at PDR	79	14.61	A/C Equipment 1	1990
	Sub slowdown due to PDR design/requirements changes	56	6.96	A/C Equipment 1	1990
	Delays in subcontractor deliveries due to design changes	351	3.31	Aircraft Upgrade 4	1994
	Changes to test loading fixture design impacts parts deliveries	346	1.50	Aircraft/Missile 1	1989
	Design changes delaying material procurement by sub	147	0.60	Aircraft/Missile 2	1993
	Material specification updates delaying material deliveries	530	5.00	Aircraft/Missile 2	1993
	Radar array design by sub slipped due to changes for vibe, ECCM, etc	335	0.74	Aircraft/Missile 2	1993
	Design changes delay subcontractor deliveries	3237	22.00	Aircraft/Missile 4	1989
	Revised design delayed subcontractor delivery	2756	22.00	Aircraft/Missile 4	1989
	Late vendor deliveries due to design changes	39	11.00	Aircraft/Missile 4	1989
	Revised data impacts subktr ability to deliver	222	22.00	Aircraft/Missile 4	1989
Affecting Testing	Changes to development aircraft delayed test station fabrication	27	0.33	Aircraft Upgrade 2	1993
	Test fixture orders not placed by sub until designs stable	191	0.34	Aircraft/Missile 2	1993
	Development of new fuel bladder delaying testing	50	6.43	Aircraft/Missile 3	1991
General Delay	Incorporation of H/W changes	6	22.00	A/C Equipment 2	1982
	Delay in card design - design instability	26	4.50	A/C Equipment 3	1989
	Component design changes	107	8.20	A/C Equipment 5	1986
	Change in design approach to improve efficiency downstream	16	1.15	Aircraft Upgrade 1	1985
	Changes to loading system concepts on winglets	49	0.21	Aircraft/Missile 1	1989
	Redesign of production winglet due to rejected previous design	82	0.71	Aircraft/Missile 1	1990
	Decision to integrate two systems into one	272	0.48	Aircraft/Missile 1	1987
	Changes to LRU design delayed systems engineering tasks	96	4.31	Aircraft/Missile 2	1993
	Additional analysis required due to changed loads	150	2.04	Aircraft/Missile 2	1993
	Incorporation of config change at sub delays electrical H/W development	603	13.55	Aircraft/Missile 2	1993
	Incorp of electrical power system design changes by sub	316	7.12	Aircraft/Missile 2	1993
	Changes in bus design by sub	226	0.40	Aircraft/Missile 2	1993
	Oper flight S/W updates delaying completion of S/W development	115	5.58	Aircraft/Missile 6	1987
	Unexpected design changes due to size of circuitry	33	6.37	Simulator 1	1989
	Component redesign due to dev probs and perf improvement	59	9.01	Simulator 4	1986

Category	Reason for Schedule Variance	Variance ($000)	Variance (Days)	Program	Year
Weight Reduction	Changes required for weight reduction	146	1.64	Aircraft/Missile 1	1987
	Design changes due to weight reduction activities	561	1.00	Aircraft/Missile 1	1987
	Design concept changes to avoid increased aircraft weight	40	0.82	Aircraft/Missile 5	1982
Estimating					
Ambitious Schedules	Overly aggressive material plan could not be met	31	4.04	A/C Equipment 1	1990
	Delay in drawing completion - ambitious schedule	48	6.00	A/C Equipment 3	1989
	Aggressive schedule by sub led to delayed test equip design documents	149	0.82	Aircraft/Missile 2	1993
Optimistic Budgets	Slower than expected demand for engineering materials	35	4.50	A/C Equipment 1	1989
	Original material budgets too optimistic	42	7.39	A/C Equipment 1	1989
	Material receipt scheduled too early	511	6.45	A/C Equipment 3	1989
	Material receipts not occurring as originally planned	82	0.71	Aircraft/Missile 1	1990
Incorrect Schedules	Task baselined to incorrect schedule	23	0.43	Aircraft Upgrade 2	1992
Long Order Times	Poor planning of purchased items that required more time to order	128	13.74	A/C Equipment 1	1989
	Longer than sub planned lead times on radome material	53	0.89	Aircraft/Missile 2	1993
No Integrated Schedules	Sub effort scheduled in parallel when should have been sequential	110	9.03	A/C Equipment 1	1990
	Planning based on non-integrated schedule (tasks out of sequence)	58	17.72	A/C Equipment 1	1989
	Parts late due to buy schedule out of synch with build schedule	1055	18.73	A/C Equipment 4	1984
	Parts late due to buy schedule out of synch with build schedule	868	20.00	A/C Equipment 4	1984
	Schedule phasing mismatch between engineering & tooling	2388	5.31	Aircraft/Missile 1	1986
Misplanning	Poor material planning	43	5.80	A/C Equipment 1	1989
	Misplanning of several design engineering test support tasks	13	1.67	A/C Equipment 1	1990
	Misplanning of several design engineering test support tasks	38	3.54	A/C Equipment 1	1990
Underestimating Times	Integration schedule significantly underestimated	476	13.34	A/C Equipment 3	1991
	Design time underestimated	17	0.92	Aircraft Upgrade 1	1985
	Development slower than anticipated	40	0.74	Aircraft Upgrade 2	1992

Category	Reason for Schedule Variance	Variance ($000)	Variance (Days)	Program	Year
Underestimating Work	Greater than anticipated effort for special test equipment	44	2.49	Aircraft Upgrade 6	1994
	Component SRR work significantly more than anticipated	27	2.79	Aircraft/Missile 3	1991
	Number of detail parts to be custom designed more than planned	70	20.53	Aircraft/Missile 3	1991
	Underestimation of required effort	35	3.76	Simulator 3	1990
Facility Problems					
	Maintenance test slipped pending completion of building renovation	3	8.25	A/C Equipment 2	1982
	Facility design behind schedule	70	4.81	A/C Equipment 3	1990
	Design mods/layouts behind due to late test area completion	2	0.40	Aircraft Upgrade 1	1987
Gov't Added Work					
Added Reviews	Gov't review of RFP not in original plan	54	1.63	Aircraft Upgrade 6	1993
Directed Changes	Gov't directed tempest design changes	24	2.54	A/C Equipment 1	1990
	Gov't directed tempest design changes	17	2.05	A/C Equipment 1	1990
	Gov't directed tempest design changes	26	3.14	A/C Equipment 1	1990
	Gov't directed more detailed specifications than anticipated	56	13.84	Aircraft/Missile 3	1991
	Sub implementation of Gov't-directed HUD symbology changes	136	22.00	Aircraft/Missile 4	1989
	Sub implementing Gov't-directed HUD symbology changes	142	22.00	Aircraft/Missile 4	1989
Comments @ Reviews	Specification work more than anticipated due to Gov't SRR comments	23	2.44	Aircraft/Missile 3	1991
	Additional specification work due to Gov't comments at SRR	25	2.24	Aircraft/Missile 3	1991
	Increased specification work due to Gov't comments at SRR	19	2.21	Aircraft/Missile 3	1991
Marketing Support	Support for VIP demo flights impacting test effort	80	5.37	Aircraft/Missile 6	1988
Rescheduled Reviews	PDR rescheduled by customer	68	13.98	Aircraft/Missile 3	1991

Category	Reason for Schedule Variance	Variance ($000)	Variance (Days)	Program	Year
Gov't Not Supportive					
Late Data Item Approval	Awaiting Gov't review of system test plan	44	8.42	A/C Equipment 2	1987
	Gov't delay in approving qualification test plan	125	8.57	A/C Equipment 4	1984
	Gov't approval of data item delaying structural analysis	4	0.22	Aircraft Upgrade 1	1985
	Specifications on hold pending Air Force review/comment	22	2.33	Simulator 1	1989
Failure to Provide Data	Sub non-receipt of classified documents	17	1.70	A/C Equipment 1	1990
	Non-receipt of USAFE data base information	34	6.13	A/C Equipment 2	1982
	Delay in obtaining source data from Gov't for tech manuals	76	5.11	A/C Equipment 3	1993
	Contractor waiting for Gov't data	47	2.81	Aircraft Upgrade 1	1986
	ALC waiting for SPO authorization to release data to subcontractor	98	10.57	Aircraft Upgrade 5	1990
	Lack of Gov't classified data / subcontractor access delayed RFP	54	1.63	Aircraft Upgrade 6	1993
	Late customer data causing design changes delaying H/W deliveries	77	22.00	Aircraft/Missile 4	1989
	Late receipt of customer design data	71	8.40	Aircraft/Missile 4	1989
	Late customer data causing design changes impacting H/W delivery	77	22.00	Aircraft/Missile 4	1989
	Late interface data from customer	1010	21.93	Aircraft/Missile 4	1989
	Late customer data causes design changes impacting H/W deliveries	1252	22.00	Aircraft/Missile 4	1989
	Late receipt of customer interface data impacts H/W delivery	1837	8.66	Aircraft/Missile 4	1989
	Analysis delayed due to lack of intelligence data from customer	11	1.34	Simulator 1	1989
Funding Shortfalls	Lack of funding delays study	50	6.51	Aircraft/Missile 3	1991
	Gov't funding shortfalls impacting piece part purchases	139	14.36	Simulator 1	1991
	Subcontractor failure to deliver simulator due to funding shortfall	967	8.92	Simulator 1	1991
	Manpower shortage due to funding shortfalls	105	12.69	Simulator 1	1990
Incomplete/Late GFE	Awaiting GFP design packages supporting facilities design	33	4.43	A/C Equipment 2	1988
	Late GFE	51	4.30	A/C Equipment 3	1993
	Incomplete Gov't furnished test equipment	47	2.81	Aircraft Upgrade 1	1986
Late Direction	Late final test plan due to delayed customer comments	13	1.67	A/C Equipment 1	1990
	Delayed NATO mtgs/lack of comments on draft docs	35	3.44	A/C Equipment 1	1990
	Delayed customer comments delay final test plan	38	3.54	A/C Equipment 1	1990
	Test requirements delayed due to non-receipt of Test SOW	16	1.15	Aircraft Upgrade 1	1985
	Awaiting Gov't decisions on flight test instrumentation	47	2.81	Aircraft Upgrade 1	1986

Category	Reason for Schedule Variance	Variance ($000)	Variance (Days)	Program	Year
	Sub H/W on hold pending Gov't approval of accept tests/nonstandard parts	40	10.48	Aircraft/Missile 4	1989
	Late customer approval of component causes reconfiguration	152	19.00	Aircraft/Missile 4	1989
	H/W deliv on hold pending Gov't approval of acceptance tests	276	10.92	Aircraft/Missile 4	1989
	Delay in inputs from Air Force to aircraft analysis task	19	1.53	Simulator 1	1989
Gov't Stopped Work					
	Gov't directed work stoppage impacting other areas	219	13.20	A/C Equipment 3	1991
	ILS effort slowing due to stop work and program restructure	57	19.00	A/C Equipment 3	1991
	Gov't stop work	41	8.93	A/C Equipment 3	1991
	Stop work order slowed vendor tasks	11	14.24	Aircraft Upgrade 5	1990
	Reduced sub activity due to partial stop work	67	22.00	Aircraft Upgrade 5	1991
	Stop work order	26	11.44	Aircraft Upgrade 5	1990
Inventory Mgt					
Ineffective Controls	Parts received in stock do not concur with original Bill of Material	24	22.96	Aircraft Upgrade 1	1986
	Delays in recognition of receipt of vendor deliveries	901	12.93	Aircraft Upgrade 3	1991
Parts Shortages	Parts shortages / delay in card assembly delaying integration	37	7.61	A/C Equipment 2	1983
	Delinquent parts	20	11.89	Aircraft Upgrade 1	1986
	Material shortages impacting manufacturing	2	0.40	Aircraft Upgrade 1	1987
	Delinquent parts impacting test, STE, and modifications	311	9.72	Aircraft Upgrade 1	1986
	Late availability of standard parts	49	0.21	Aircraft/Missile 1	1989
	Parts shortages	645	0.60	Aircraft/Missile 1	1989
	Parts shortages impacting test article fabrication	1027	10.73	Aircraft/Missile 1	1990
	Part/material shortages for static test assembly	805	7.01	Aircraft/Missile 1	1990
Late Data					
Incomplete Data Items	Delays in SSDD and Interface Specifications	21	6.24	A/C Equipment 1	1989
	Data items not yet approved or submitted	49	0.35	Aircraft Upgrade 4	1991
	Late S/W data items	116	6.81	Aircraft Upgrade 4	1994

Category	Reason for Schedule Variance	Variance ($000)	Variance (Days)	Program	Year
	Sub interface control document not completed	147	0.60	Aircraft/Missile 2	1993
	Non completion of data item	761	9.72	Aircraft/Missile 6	1986
	Awaiting document inputs	19	1.53	Simulator 1	1989
	Late delivery of review copies of SRS and IRS delayed prelim design	125	22.00	Simulator 3	1989
Late Engineering Release	Late release of engineering data	338	4.16	A/C Equipment 2	1987
	Delayed drafting efforts	48	5.62	A/C Equipment 2	1988
	Late engineering release impacting manufacturing start-up	510	6.44	A/C Equipment 3	1989
	Late STE design releases impacting manufacturing	2	0.40	Aircraft Upgrade 1	1987
	Delayed releases from Electrical Engineering	32	1.87	Aircraft Upgrade 1	1985
	Delays in engineering release of components	12	0.65	Aircraft Upgrade 1	1985
	Engineering release not fast enough to support analysis	18	0.43	Aircraft Upgrade 2	1992
	Late engineering delaying subcontractors	272	0.48	Aircraft/Missile 1	1987
	Late engineering drawing releases	263	22.00	Aircraft/Missile 1	1986
	Late engineering impacting tooling activities	598	1.07	Aircraft/Missile 1	1987
	Delays in engr design/drawing release	610	4.39	Aircraft/Missile 1	1989
	Drawing release delaying test equipment development	50	6.43	Aircraft/Missile 3	1991
	Late engineering releases	47	1.42	Aircraft/Missile 5	1984
	Late engineering releases	135	1.87	Aircraft/Missile 5	1983
Late/Incomplete Info	Unavail of spec information delayed CSCI requirements analysis	14	4.22	A/C Equipment 1	1989
	Specifications not complete	35	4.50	A/C Equipment 1	1989
	Classified specifications impacting effort	30	5.69	A/C Equipment 1	1990
	Lack of required information to begin drafting efforts	21	2.31	A/C Equipment 1	1990
	Sub unable to proceed without interface control docs / specs	110	9.03	A/C Equipment 1	1990
	S/W requirements analysis delayed by lack of SSDD and I/F specs	12	3.26	A/C Equipment 1	1989
	Facilities design efforts delayed due to lack of drawings	15	1.78	A/C Equipment 2	1987
	Lack of imagery data to validate algorithms	338	4.16	A/C Equipment 2	1987
	Lack of adequate vendor data to support ILS efforts	132	7.17	A/C Equipment 2	1987
	Delays in data impacting provisioning effort	12	4.80	A/C Equipment 2	1983
	Delay in specification completion	10	11.58	A/C Equipment 2	1982
	Lack of related system spec delays test planning (integration problem)	2	11.00	A/C Equipment 2	1982
	Lack of sufficient data to complete tech manuals	22	1.57	A/C Equipment 3	1990
	Training impacted by unavail of data and system access	42	9.15	A/C Equipment 3	1991
	Lack of preliminary layouts delaying thermal analysis	4	0.22	Aircraft Upgrade 1	1985

Category	Reason for Schedule Variance	Variance ($000)	Variance (Days)	Program	Year
	Subcontractor S/W development data items late	347	17.31	Aircraft Upgrade 4	1992
	Delays in R&M engineering receiving FMECA data	146	1.64	Aircraft/Missile 1	1987
	Late drawings and data	33	0.36	Aircraft/Missile 1	1985
	Lack of resource info delays raw material/purchase parts deliveries	346	1.50	Aircraft/Missile 1	1989
	Late loads info from engineering delayed deliveries	347	2.05	Aircraft/Missile 1	1989
	Tech pubs behind schedule due to lack of source data	191	9.13	Aircraft/Missile 1	1989
	Unavailability of source data for tech pubs	153	4.22	Aircraft/Missile 1	1990
	Late R&M analysis data for power plant	623	22.00	Aircraft/Missile 1	1985
	Late loads info causes parts delivery delays impacting testing	510	4.27	Aircraft/Missile 1	1989
	Brassboard fab/assy delayed at sub due to late completion of studies	370	2.45	Aircraft/Missile 2	1993
	Delays in receipt of drawings	96	4.31	Aircraft/Missile 2	1993
	Sub delay in detailed design data delayed acceptance tests	442	1.80	Aircraft/Missile 2	1993
	Sub drawings not meeting release schedule delayed H/W orders	413	4.63	Aircraft/Missile 2	1993
	Late drawings by sub	431	4.52	Aircraft/Missile 2	1993
	Design data for printed circuit boards not received on schedule	39	5.72	Simulator 1	1989
	Late design data for printed circuit boards slipping PDR	45	6.11	Simulator 1	1989
	Delays in sub obtaining final system data to freeze courseware design	68	5.50	Simulator 2	1991
Late Reviews					
Review Completion	Additional effort required to close out CDR	204	10.84	A/C Equipment 2	1988
	End of non-recurring effort pending engineering validation	147	2.01	Aircraft Upgrade 3	1992
	Awaiting closure of component CDR action items by sub	413	4.63	Aircraft/Missile 2	1993
	Detailed design task awaiting PDR completion	14	4.46	Simulator 1	1989
	Delay in completing S/W review	24	2.20	Simulator 3	1991

Category	Reason for Schedule Variance	Variance ($000)	Variance (Days)	Program	Year
Review Slipped	Delay in S/W design & test due to late SSR	41	12.36	A/C Equipment 1	1989
	Delayed SSR delaying S/W design and test	35	9.51	A/C Equipment 1	1989
	Delay in S/W Specification Review	21	6.24	A/C Equipment 1	1989
	Delayed PDR impacts auxillary equipment effort	7	9.63	A/C Equipment 2	1982
	PDR slippage	35	6.31	A/C Equipment 2	1982
	Delayed fabrication due to slip of CDR	96	4.31	Aircraft/Missile 2	1993
	Slip of component SRR/PDR	56	22.00	Aircraft/Missile 3	1991
	Slipped PDR impacting detailed design tasks	19	11.00	Simulator 1	1989
	Slipped PDR delaying S/W detailed design tasks	24	13.89	Simulator 1	1989
Miscellaneous Delays	Late start of trade studies	33	5.58	A/C Equipment 1	1989
	Delays in common supt equipment effort	49	14.57	A/C Equipment 2	1983
	Delay in shipment overseas impacts test	174	10.94	A/C Equipment 2	1985
	Delay in shipment overseas impacts project mgt	47	4.72	A/C Equipment 2	1985
	Delay in shipment overseas impacts site activation	32	22.00	A/C Equipment 2	1985
	Other schedule slips impacting system testing	22	10.30	A/C Equipment 2	1983
	Site activation meeting delayed	42	10.87	A/C Equipment 3	1990
	Availability of test article delayed	82	0.71	Aircraft/Missile 1	1990
	Tooling falling behind due to outside manufacturing delays	1197	0.86	Aircraft/Missile 1	1988
	Inefficiencies created by a multi-site development process by subktr	68	5.50	Simulator 2	1991
Manufacturing Probs	Behind schedule requisitioning from inventory of equip, H/W, material	942	16.90	Aircraft Upgrade 3	1990
	Behind schedule requisitioning of H/W from inventory	115	4.53	Aircraft Upgrade 3	1990
	H/W interface problem discovered during build	54	2.67	Aircraft/Missile 3	1991
	Delayed manufacturing activities impacting quality assurance	24	0.73	Aircraft/Missile 5	1984
	Material not being used as quickly as anticipated	144	64.65	Simulator 2	1994
	Slowed material movement due to new manufacturing computer system	60	38.82	Simulator 2	1994
	New manufacturing planning computer slowed material usage	175	101.32	Simulator 2	1994

Category	Reason for Schedule Variance	Variance ($000)	Variance (Days)	Program	Year
Fabrication Problems	Difficulty with breadboard fabrication	2	0.11	Aircraft Upgrade 1	1985
	Delays in fabrication of major assembly tooling fixtures	80	4.07	Aircraft/Missile 3	1991
	Delays in fabricating major assembly tooling fixtures	46	3.71	Aircraft/Missile 3	1991
	Mfg mock-up problems delayed fabrication of fuel sys test equipment	71	7.04	Aircraft/Missile 3	1991
	Delayed workstation integration & checkout efforts	26	1.43	A/C Equipment 3	1990
	Delays in structural test specimen fabrication	33	0.36	Aircraft/Missile 1	1985
	Delays in building test fixtures	217	0.63	Aircraft/Missile 2	1993
	Late fab of fixture by sub slips instrument landing system	60	0.11	Aircraft/Missile 2	1993
	Delays by sub in completion of RF test benches	689	1.38	Aircraft/Missile 2	1993
	Detail parts not being built as quickly as expected	163	8.06	Aircraft/Missile 3	1991
	Assembly tools taking longer than planned to manufacture	36	2.34	Aircraft/Missile 3	1991
	Sub having difficulty fabricating fuel system bladders	71	7.04	Aircraft/Missile 3	1991
	Problems with board fabrication / final installation	61	1.74	Simulator 2	1994
Late Receipt of Material	Cables not ordered because parts lists behind schedule	42	20.09	A/C Equipment 2	1983
	Late receipt of breadboard parts	2	0.11	Aircraft Upgrade 1	1985
	Late tools/material for proof of production impacts test article assembly	393	3.29	Aircraft/Missile 1	1989
	Lack of adequate tooling availability to support assembly	584	0.54	Aircraft/Missile 1	1989
	Late tools/materials for proof of production impacts test article fab	2022	8.75	Aircraft/Missile 1	1989
	Parts shortages due to engr changes, lack of raw material, capacity probs	584	0.54	Aircraft/Missile 1	1989
	Late tools/material for proof of production impact test article fab	1426	8.43	Aircraft/Missile 1	1989
	Delayed engineering and late receipt of tools impacts fabrication	60	1.82	Aircraft/Missile 5	1984
	Delay in assembly of test article due to late main frame receipt	57	1.72	Aircraft/Missile 5	1984
Late Starts	Late start of sheet metal and machine detail tools	145	2.01	Aircraft/Missile 5	1983
	Late start of canopy tooling	13	0.53	Aircraft/Missile 5	1984
	Late start of conventional machine tool designs	62	0.86	Aircraft/Missile 5	1983

Category	Reason for Schedule Variance	Variance ($000)	Variance (Days)	Program	Year
Mfg Design Problems	Delay in defining/releasing production bill of materials	57	17.66	A/C Equipment 1	1990
	Production bill of materials not yet defined/released	54	17.22	A/C Equipment 1	1990
	Critical process tooling not released as planned	76	21.16	A/C Equipment 4	1985
	Tooling not released as planned	185	20.87	A/C Equipment 4	1985
	Late tool completion due to late releases, engr changes, and rework	2042	1.91	Aircraft/Missile 1	1989
	Delays in sub completing range mock-up for elec warfare testing	238	0.54	Aircraft/Missile 2	1993
	Subcontractor slower than planned mfg process / tooling development	707	1.29	Aircraft/Missile 2	1993
	Delays in proof of concept article by sub	226	0.40	Aircraft/Missile 2	1993
Machine Proofing	Time required to revise data between proofing runs causing delays	138	11.12	Aircraft/Missile 3	1991
	Proofing delays impacting parts fabrication delaying assembly	180	12.38	Aircraft/Missile 3	1991
	Delayed machine proofing delayed fab of parts required for assembly	103	10.44	Aircraft/Missile 3	1991
	Mfg mock-up not yet started due to unanticipated machine proofing problems	36	2.34	Aircraft/Missile 3	1991
	Delays due to time required to revise data between proofing runs	240	12.22	Aircraft/Missile 3	1991
	Proofing delays impact parts fabrication delaying assembly	132	12.25	Aircraft/Missile 3	1991
	Assembly drawings late due to unanticipated level of support for proofing	16	1.76	Aircraft/Missile 3	1991
Mfg Process Problems	Problem in curing process delayed receipt of bladder	109	12.62	Aircraft/Missile 3	1991
Quality					
	Sub test start delay due to insufficient parts/cables	80	10.35	Aircraft Upgrade 4	1994
	Poor subcontractor performance	1065	3.28	Aircraft/Missile 1	1989
Inadequate Testing	Vendor testing not satisfactory for acceptance	108	13.35	Aircraft/Missile 4	1989
	Seller in-house testing not adequate	598	20.27	Aircraft/Missile 4	1989
Unacceptable Items	Speed problems with sub's vendor's computer chips	104	6.07	Aircraft Upgrade 1	1986
	Subcontractor data items rejected	98	10.57	Aircraft Upgrade 5	1990
	Rescheduling of major forgings due to quality problems	272	0.48	Aircraft/Missile 1	1987
	Air data computer sys failure to pass test (sub)	1285	15.45	Aircraft/Missile 1	1990
	Mechanical fit problem at sub discovered after PDR	55	0.22	Aircraft/Missile 2	1993
	Rejected H/W delivery due to excessive test time on components	98	22.00	Aircraft/Missile 4	1989
	Rejection of subcontractor hardware	178	39.96	Aircraft/Missile 4	1989
	Subcontractor components required additional debug & integration	61	1.74	Simulator 2	1994

Category	Reason for Schedule Variance	Variance ($000)	Variance (Days)	Program	Year
	Flight station shipped in an incomplete condition by subktr	2105	21.43	Simulator 4	1986
	Sub shipped H/W missing a component	59	9.01	Simulator 4	1986
Acceptance Procedures	Vendor components awaiting MRB approval	106	8.13	A/C Equipment 5	1986
	Quality inspection delays in hardware deliveries	545	23.33	Aircraft Upgrade 3	1992
	Sub components awaiting Prime quality assurance approval	257	13.59	Aircraft Upgrade 4	1994
Req'ments Changes					
	Potential spec changes have delayed sub component design	58	14.84	A/C Equipment 1	1990
	Changing specifications impacting effort	30	5.69	A/C Equipment 1	1990
	Late sub definition/changes in requirements	17	1.70	A/C Equipment 1	1990
	S/W requirements changes	16	2.21	A/C Equipment 3	1989
	Increased structural test complexity	33	0.36	Aircraft/Missile 1	1985
	Expanded test requirements	54	4.70	Aircraft/Missile 3	1991
	Change in harness board requirements	13	0.53	Aircraft/Missile 5	1984
	Changes to SCIF requirements	209	20.53	Simulator 3	1990
Staffing					
Hiring Delays	Subcontractor has slower staffing than planned	98	10.57	Aircraft Upgrade 5	1990
	Slow manpower buildup by sub	1663	16.55	Aircraft/Missile 1	1987
	Delays in hiring/replacing engineers	217	0.63	Aircraft/Missile 2	1993
Inadequate Staffing	Manpower shortages in design areas	21	2.31	A/C Equipment 1	1990
	Lack of initial staffing for trade studies	33	5.58	A/C Equipment 1	1989
	Inadequate staffing for specification design	46	2.13	A/C Equipment 1	1989
	Manpower shortage at sub delayed test article fabrication	74	2.36	A/C Equipment 1	1990
	Inadequate systems engineering staffing delaying specifications	107	4.54	A/C Equipment 1	1989
	Understaffing in test engineering design area	31	5.25	A/C Equipment 1	1989
	Shortage of manpower in shelter design	6	8.25	A/C Equipment 2	1982
	Staffing shortages in H/W and S/W engineering	237	3.32	A/C Equipment 2	1987
	Manpower shortages	266	4.71	A/C Equipment 2	1988
	Loss of software engineers	16	3.12	A/C Equipment 3	1989

Category	Reason for Schedule Variance	Variance ($000)	Variance (Days)	Program	Year
	Shortage of illustrators and writers impacting tech manuals	67	4.79	A/C Equipment 3	1990
	S/W development understaffed	16	2.21	A/C Equipment 3	1989
	Engineering resources not available to conduct study	32	2.75	A/C Equipment 3	1990
	Sub late in supplying engr support	80	17.60	Aircraft/Missile 1	1987
	Shortage of personnel for structural test	33	0.36	Aircraft/Missile 1	1985
	Inadequate staffing to support assembly	584	0.54	Aircraft/Missile 1	1989
	Loss of experienced design team personnel	561	1.00	Aircraft/Missile 1	1987
	Lack of personnel support to accomplish test	215	2.25	Aircraft/Missile 1	1990
	Low experience levels of newly hired personnel	82	0.71	Aircraft/Missile 1	1990
	Lack of staffing for technical publications	126	8.56	Aircraft/Missile 1	1988
	Insufficient tech pubs staffing	153	4.22	Aircraft/Missile 1	1990
	Manpower shortages	645	0.60	Aircraft/Missile 1	1989
	Manpower shortages	294	2.25	Aircraft/Missile 2	1993
	Inadequate staffing for design and stress analysis tasks	146	1.32	Aircraft/Missile 2	1993
	Test vehicle design activities delayed due to manpower constraints	48	5.28	Aircraft/Missile 3	1991
Receipt of Clearances	Delayed clearances/staffing problems	38	3.54	A/C Equipment 1	1990
	Staffing problems/slow receipt of clearances	24	4.22	A/C Equipment 1	1989
	Slow design engineering startup due to understaffing/clearance delays	56	9.78	A/C Equipment 1	1990
	Delayed clearances/staffing problems	13	1.67	A/C Equipment 1	1990
Reassignment	Assignment of personnel by sub	17	1.70	A/C Equipment 1	1990
	Diversion of software resources to system engineering	82	8.05	A/C Equipment 2	1982
	Reassignment of personnel to more critical areas	61	4.97	A/C Equipment 3	1991
	Labor redirected from planned S/W activities to system CDR prep	59	2.94	Aircraft Upgrade 4	1992
	Development startup diverted designers from mockups	40	8.38	Aircraft/Missile 1	1987
	Reassignment of T&E personnel to higher priority tasks	82	0.71	Aircraft/Missile 1	1990
	Personnel reassignments	238	0.54	Aircraft/Missile 2	1993
	Diversion of manpower from one analysis to another	19	0.83	Aircraft/Missile 5	1984
	Manpower diversion	37	2.07	Aircraft/Missile 5	1983
	Manpower diversions	26	0.36	Aircraft/Missile 5	1983
	Analysis delayed to focus on SRS update and PDR	11	1.34	Simulator 1	1989
	Redirection of principal designer to an Ada study	33	6.37	Simulator 1	1989
	Design personnel required to support non-design tasks	14	2.37	Simulator 1	1989
	Test support effort reassigned from one group to another	72	8.61	Simulator 4	1985

Category	Reason for Schedule Variance	Variance ($000)	Variance (Days)	Program	Year
Wrong People Used	Subcontractor had wrong mix of technical personnel assigned	25	8.46	A/C Equipment 2	1983
	Subcontractor lack of critical subject matter expertise	68	5.50	Simulator 2	1991
Subcontractor Late					
Late Deliveries	Delays in vendor shipments of engineering materials	38	3.54	A/C Equipment 1	1990
	Delays in vendor shipments of engineering materials	13	1.67	A/C Equipment 1	1990
	Delays in major H/W procurements	52	2.40	A/C Equipment 2	1983
	S/W delivery delays	39	11.75	A/C Equipment 3	1991
	Late delivery of H/W delays S/W and H/W integration	77	9.68	A/C Equipment 3	1990
	Hardware not delivered	73	12.26	A/C Equipment 3	1989
	Fuel controls not received as planned	84	19.45	A/C Equipment 4	1985
	Late receipt of material for DT&E flight test	57	10.81	Aircraft Upgrade 1	1987
	Late material deliveries delaying STE effort	10	1.98	Aircraft Upgrade 1	1987
	Late hardware deliveries	673	8.18	Aircraft Upgrade 2	1993
	Delays in receipt of sub high speed memory units	449	4.91	Aircraft Upgrade 4	1993
	Delays in RF synthesizer receipt from sub resulted in design issues	449	4.91	Aircraft Upgrade 4	1993
	Late receipt of satellite simulator for GPS related modification	450	14.37	Aircraft Upgrade 6	1994
	Late delivery of computer test units	1110	18.89	Aircraft/Missile 1	1988
	Late receipt of parts from vendor for hydraulic system simulator	98	0.86	Aircraft/Missile 1	1989
	Late deliveries from subcontracts supporting airframe static testing	145	12.91	Aircraft/Missile 1	1987
	Electronic flight control sys not delivered as scheduled (sub)	1706	17.30	Aircraft/Missile 1	1989
	Behind schedule receipt of materials for test station	146	1.29	Aircraft/Missile 2	1993
	Material not received from vendor	505	1.17	Aircraft/Missile 2	1993
	Late delivery of connectors from sub delays brassboard fabrication	437	3.87	Aircraft/Missile 2	1993
	Schedule slip on material	134	0.27	Aircraft/Missile 2	1993
	Late delivery of test equipment by sub	134	0.27	Aircraft/Missile 2	1993
	Materials for sub endurance test not delivered as planned	62	0.93	Aircraft/Missile 2	1993
	Delays in sub transporting panels to test facility	53	0.89	Aircraft/Missile 2	1993
	Continued timing variances by sub on purchased H/W	110	1.20	Aircraft/Missile 2	1993
	Late receipt of models needed for electrical simulation design by sub	55	0.22	Aircraft/Missile 2	1993
	Radar array material deliveries slipped	335	0.74	Aircraft/Missile 2	1993
	Late delivery of sensors from vendor	841	25.04	Aircraft/Missile 3	1991

Category	Reason for Schedule Variance	Variance ($000)	Variance (Days)	Program	Year
	Late hardware deliveries (electrical system)	1947	22.00	Aircraft/Missile 4	1989
	Late H/W delivery	92	22.00	Aircraft/Missile 4	1989
	Late delivery of radar hardware	237	115.87	Aircraft/Missile 4	1989
	Delayed delivery of HUD units	232	10.05	Aircraft/Missile 6	1987
	Delays in equipment receipt and system req'mnts defn from sub	90	5.64	Aircraft/Missile 6	1987
	Late delivery of equipment	51	8.63	Simulator 1	1989
	Late delivery of equipment items	64	14.22	Simulator 1	1989
	Late delivery of H/W items	76	8.89	Simulator 1	1989
	Did not receive S/W & H/W from vendor	60	38.82	Simulator 2	1994
	Late receipt of materials	34	1.81	Simulator 3	1991
	Late receipt of vendor H/W	636	21.93	Simulator 4	1985
Late Deliv by Sub's Sub	Late delivery of connectors to subcontractor	126	0.83	Aircraft/Missile 2	1993
	Late receipt of carriers/sockets/cable material at sub	570	1.04	Aircraft/Missile 2	1993
	Subcontractor material late	1743	4.61	Aircraft/Missile 2	1993
	Test station material not received at sub	370	2.45	Aircraft/Missile 2	1993
	Late receipt of materials at subcontractor	399	0.73	Aircraft/Missile 2	1993
	Late receipt of procured tooling at sub	216	2.26	Aircraft/Missile 2	1993
Slow Progress	Slower than planned sub start up	17	2.05	A/C Equipment 1	1990
	Slower than planned sub start up	26	3.14	A/C Equipment 1	1990
	Slower than planned sub start up	24	2.54	A/C Equipment 1	1990
	Disk storage subcontractor not maintaining schedule	237	3.32	A/C Equipment 2	1987
	Vendor delay in bench qualifying fuel control unit	125	8.57	A/C Equipment 4	1984
	Subcontractor behind schedule in computer H/W delivery	223	1.41	Aircraft Upgrade 2	1994
	Delayed milestone achievements by S/W vendor	316	4.37	Aircraft/Missile 2	1993
	Supplier material delays on alternate film selection	53	0.89	Aircraft/Missile 2	1993
	Subcontractor delays in reaching development milestones	707	1.29	Aircraft/Missile 2	1993
Test Problems					
	CI testing delays tech pub procurements	48	3.85	A/C Equipment 3	1989
	S/W testing difficulties	16	3.12	A/C Equipment 3	1989
	Test delays in hot/cold mission sim, hot endurance, vibe/shock tests	149	17.16	A/C Equipment 4	1986
	Failure of elastomers/suspension system of system container	95	19.35	A/C Equipment 4	1985

Category	Reason for Schedule Variance	Variance ($000)	Variance (Days)	Program	Year
	Sub simulation testing delays	110	1.20	Aircraft/Missile 2	1993
	L-band variances caused test time to slip for sub	119	0.21	Aircraft/Missile 2	1993
	Slips in special testing	238	0.54	Aircraft/Missile 2	1993
	Delays in dielectric testing by sub	53	0.89	Aircraft/Missile 2	1993
	DT&E problems	68	2.54	Aircraft/Missile 5	1984
	Delay in receipt of test assets	13	0.53	Aircraft/Missile 5	1984
	Schedule delays in canopy jettison test	31	1.26	Aircraft/Missile 5	1984
	Unplanned instrumentation modification delaying flight test	80	5.37	Aircraft/Missile 6	1988
	S/W problems during flight test	259	57.56	Aircraft/Missile 6	1988
	Non-completion of qual test line items	761	9.72	Aircraft/Missile 6	1986
	Component difficulties during qual testing	1675	21.01	Aircraft/Missile 7	1989
Technical Definition					
Finalizing Requirements	Delays in requirement/specification generation	21	2.31	A/C Equipment 1	1990
	Late definition of effort to sub	74	2.36	A/C Equipment 1	1990
	Late definition of sub requirements	35	3.44	A/C Equipment 1	1990
	Unavailability of specs delaying S/W requirements analysis	39	9.98	A/C Equipment 1	1990
	Delay in specification generation	88	16.69	A/C Equipment 1	1990
	Delay in final design specifications	54	8.08	A/C Equipment 1	1989
	Delay in requirements/specs	31	4.04	A/C Equipment 1	1990
	S/W delays due to late microprocessor selection	14	4.22	A/C Equipment 1	1989
	Lag in microprocessor and design methodology selections	21	6.24	A/C Equipment 1	1989
	Delay in microprocessor/design methodology selection	12	3.26	A/C Equipment 1	1989
	Consolidating digital imagery operations concept	237	3.32	A/C Equipment 2	1987
	Rework of requirements test allocations and methods	48	11.00	A/C Equipment 2	1987
	Interface specs not approved by associate ktrs or Gov't	33	4.43	A/C Equipment 2	1988
	Interface specification development delays	15	1.78	A/C Equipment 2	1987
	Late design definition	266	4.71	A/C Equipment 2	1988
	Simulator not complete - must resolve interfaces	45	3.85	A/C Equipment 3	1989
	S/W requirements not finalized	16	2.21	A/C Equipment 3	1989
	Subktr delays with top level design	28	2.21	Aircraft Upgrade 1	1985
	Lack of flight test instrumentation definition	13	1.75	Aircraft Upgrade 1	1987
	Vendor negotiations on spec control dwg defining antenna footprint	16	0.42	Aircraft Upgrade 2	1992

Category	Reason for Schedule Variance	Variance ($000)	Variance (Days)	Program	Year
	Late identification/complexity of requirements	45	2.55	Aircraft Upgrade 6	1994
	Late design definitization	645	0.60	Aircraft/Missile 1	1989
	Product definition changes causing parts shortages	644	6.73	Aircraft/Missile 1	1990
	Continuing product definition changes causing parts/material shortage	862	7.50	Aircraft/Missile 1	1990
	Late engineering designs impacting test and evaluation	1065	3.28	Aircraft/Missile 1	1989
	Late design definition impacting material orders	252	3.03	Aircraft/Missile 1	1990
	Delayed receipt of test technical requirements	82	0.71	Aircraft/Missile 1	1990
	Slip in spec/requirements definitization for RF systems	238	0.54	Aircraft/Missile 2	1993
	Security issues related to elec warfare aperture fabrication	238	0.54	Aircraft/Missile 2	1993
	Test effort suspension awaiting resolution of SOW issues	20	2.80	Aircraft/Missile 5	1982
	Delay in system hardware requirements definition	183	3.47	Simulator 2	1991
	Design issue resolution delaying effort	34	1.81	Simulator 3	1991
Poor Req'mnts Definition	Lack of line replaceable unit definition	30	5.69	A/C Equipment 1	1990
	Incomplete specifications	43	5.80	A/C Equipment 1	1989
	Design reqmnts for LRU block diagrams / computer interface more than plan	6	0.45	Aircraft Upgrade 1	1985
	Incorrect envelope definition to sub delayed CDR	347	3.45	Aircraft Upgrade 2	1992
	Changes in structural config due to systems integration	146	1.32	Aircraft/Missile 2	1993
	Unplanned effort by sub to mount displays impacting analysis and test	446	2.45	Aircraft/Missile 2	1993
	Slip of Specs/PDR due to gov't needing more detailed specs than envisioned	54	9.74	Aircraft/Missile 3	1991
Technical Problems					
Analysis Problems	Delays in system engineering products	61	2.39	Aircraft Upgrade 6	1993
	Difficulties in analyses and monte carlo simulation	87	5.23	Aircraft Upgrade 6	1993
	Sub trade study and simulation for ejection seat behind schedule	339	7.82	Aircraft/Missile 2	1993
	Unexpected materials study by sub slips instrument landing system	60	0.11	Aircraft/Missile 2	1993
Coordination	Delay in related system's spec delayed S/W spec approval (integration prob)	26	8.80	A/C Equipment 2	1983

Category	Reason for Schedule Variance	Variance ($000)	Variance (Days)	Program	Year
Design Problems	Open microprocessor spec/design issues	59	18.54	A/C Equipment 1	1989
	Design errors delaying integration effort	338	4.16	A/C Equipment 2	1987
	Digital design tasks more complex than originally envisioned	14	0.82	Aircraft Upgrade 1	1985
	Delayed vendor deliveries resulting from design problems	442	6.06	Aircraft Upgrade 3	1992
	Test equipment design not completed	1273	9.04	Aircraft Upgrade 4	1991
	Delays in power supply design activity	217	0.63	Aircraft/Missile 2	1993
	Power supply spec more challenging than anticipated	505	1.17	Aircraft/Missile 2	1993
	Sub design delays in GPS chip slipped test schedule	540	0.96	Aircraft/Missile 2	1993
	Late sub display H/W design delaying ordering of material	149	0.82	Aircraft/Missile 2	1993
	Delays in completion of electrical and packaging design by sub	689	1.38	Aircraft/Missile 2	1993
	Sub Radome design effort behind schedule	53	0.89	Aircraft/Missile 2	1993
	Delays in printed circuit board layouts by sub	335	0.74	Aircraft/Missile 2	1993
	Late engineering design	39	11.00	Aircraft/Missile 4	1989
	Vendor design problems delay autopilot task start	86	14.67	Aircraft/Missile 6	1987
	Effort on other component delays this component's detailed design	34	3.12	Simulator 3	1991
					1900
Development Problems	S/W management tasks not complete	14	0.65	A/C Equipment 1	1989
	Delays in man-machine interface and graphics S/W	41	8.59	A/C Equipment 2	1983
	S/W problems	5	13.75	A/C Equipment 2	1982
	Subcontractor S/W coding difficulties	16	0.82	A/C Equipment 2	1983
	S/W code and test delays	34	1.75	A/C Equipment 2	1983
	Problems with calibration and geopositioning S/W and data bases	25	21.15	A/C Equipment 2	1988
	H/W & S/W slips delayed QA activity	65	2.92	A/C Equipment 3	1989
	Late completion of printed circuit boards - Engr probs	128	7.91	A/C Equipment 3	1989
	Difficulties with S/W to S/W integration	16	3.12	A/C Equipment 3	1989
	H/W & S/W slips delay system integration	89	6.12	A/C Equipment 3	1990
	Delayed S/W development impacts computer security task	32	2.75	A/C Equipment 3	1990
	S/W development problems delay integration	57	3.14	A/C Equipment 3	1990
	Tech manuals lagging due to late system development	91	9.91	A/C Equipment 3	1991
	Late CI Completion	51	6.27	A/C Equipment 3	1989
	S/W development delays	16	1.15	Aircraft Upgrade 1	1985
	Sub behind in component development	5066	16.20	Aircraft Upgrade 3	1989

Category	Reason for Schedule Variance	Variance ($000)	Variance (Days)	Program	Year
	Delayed detailed development of subsystem algorithms by subcontractor	18	0.79	Aircraft Upgrade 5	1990
	Avionics simulation effort suspended due to mission computer delays	293	2.57	Aircraft/Missile 1	1989
	Mission computer development problems (sub)	1800	19.01	Aircraft/Missile 1	1989
	Late mission computer H/W and S/W development by sub	2046	17.50	Aircraft/Missile 1	1989
	Delay in electronic flight control units to support auto test equip develop	935	13.45	Aircraft/Missile 1	1989
	Mission computer effort falling behind schedule	1952	21.68	Aircraft/Missile 1	1988
	Slips in sub evaluating integrated circuits	335	0.74	Aircraft/Missile 2	1993
	Sub delays in developing electrical components	394	11.75	Aircraft/Missile 2	1993
	Delays in component development by sub	303	0.55	Aircraft/Missile 2	1993
	Sub power system development delays	110	1.20	Aircraft/Missile 2	1993
	Delays in computer development by sub	111	0.20	Aircraft/Missile 2	1993
	Not starting terrain following development as scheduled	82	4.67	Aircraft/Missile 6	1985
	Documentation more difficult than anticipated	14	4.46	Simulator 1	1989
	Progress on S/W code and test less than anticipated	61	1.74	Simulator 2	1994
	S/W code and unit test taking longer than expected - impacting integration	29	1.54	Simulator 3	1991
	Delay in obtain, modify, and validate S/W	57	6.12	Simulator 3	1990
	Difficulty finding parts to meet EMI and pulse shape specs	24	2.20	Simulator 3	1991
					1900
Task Growth	Increase in sub component complexity to meet system spec	88	10.19	A/C Equipment 1	1990
	Technical difficulties associated with H/W algorithms	13	6.09	A/C Equipment 2	1982
	Problems with S/W automated test tool and code growth	16	3.12	A/C Equipment 3	1989
	S/W Code Growth significantly increased integration effort	36	13.20	A/C Equipment 3	1991
	Unplanned redesign due to tech problems	92	5.37	Aircraft Upgrade 1	1985
	Unplanned software development	49	0.21	Aircraft/Missile 1	1989
	Unplanned beam fabrication	49	0.21	Aircraft/Missile 1	1989
	Prep/support for weight reduction issues	146	1.32	Aircraft/Missile 2	1993
	Complexities in loads, durability, and damage tolerance analyses	146	1.32	Aircraft/Missile 2	1993
	Mockup/aircraft inconsistencies caused redesign (integration problem)	71	8.40	Aircraft/Missile 4	1989
	Weight avoidance efforts delaying drawing release	69	1.42	Aircraft/Missile 5	1982
	Non completion of operational flight program S/W recode effort	94	9.53	Aircraft/Missile 6	1987
	Unanticipated rework of graphics	68	5.50	Simulator 2	1991

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Vita

Captain William M. Cashman was born on 10 August 1967 in Boston, Massachusetts. In 1989, as a brand new Second Lieutenant commissioned through Air Force R.O.T.C., he graduated from Cornell University with a Bachelor of Science degree in Electrical Engineering. His first assignment was to Wright-Patterson AFB, where he joined the Joint Tactical Weapons System Program Office (SPO), first as a trainee in program control, then as the day-to-day project manager for the Tacit Rainbow anti-radar air-to-ground standoff missile Full Scale Development program. In 1992, he moved to the Electronic Combat SPO to become a project manager for the Joint Modeling and Simulation System (J-MASS), a software system designed to provide a common way to build, use, and reuse models and simulations throughout the DoD. In 1994, after completing Squadron Officer School in residence, he entered the Graduate Systems Management program of the School of Logistics and Acquisition Management, Air Force Institute of Technology (AFIT). In 1995, after completing his Master of Science degree in Systems Management at AFIT, he moved to Los Angeles AFB, where he is currently working as a project manager on advanced space systems.

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13. ABSTRACT *(Maximum 200 words)*

The three main objectives of this research were to identify the actual reasons for schedule problems across large Air Force system development efforts, to quantify the importance of each category of reasons in terms of frequency and severity, and to demonstrate that the reasons for schedule problems are not program unique, but are common across system development efforts. To this end, this thesis contains a categorization and analysis of 549 reasons for schedule difficulties on 22 large Air Force Engineering and Manufacturing Development (EMD) programs from 1981 to 1994. These aircraft, missile, aircraft equipment, aircraft upgrade, and simulator programs had contract values ranging from $40M to over $10B. All reasons were extracted from narrative explanations of negative schedule variances contained in contractor generated Cost Performance Reports (CPRs). Reasons for schedule problems were placed into categories, and categories were ranked by frequency of problems, total schedule variance (in dollars), and total schedule variance (in work days). Seven categories (technical problems, late subcontractors, manufacturing problems, design changes, late data, contracting, and staffing) accounted for 49 percent of the frequency, 57 percent of the schedule variance (in dollars), and 49 percent of the schedule variance (in work days).

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