Concurrent Engineering: Effective Deployment Strategies

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ABSTRACT

This paper provides a comprehensive insight into current trends and developments in Concurrent Engineering for integrated development of products and processes with the goal of completing the entire cycle in a shorter time, at lower overall cost and with fewer engineering design changes after product release. The evolution and definition of Concurrent Engineering are addressed first, followed by a concise review of the following elements of the concurrent engineering approach to product development: Concept Development: The Front-End Process, Identifying Customer Needs and Quality Function Deployment, Establishing Product Specifications, Concept Selection, Product Architecture, Design for Manufacturing, Effective Rapid Prototyping, and The Economics of Product Development. An outline of a computer-based tutorial developed by the authors and other graduate students funded by NASA (accessible via the world-wide-web), is provided in this paper. A brief discussion of teamwork for successful concurrent engineering is included. Case histories of concurrent engineering implementation at North American and European companies are outlined with references to textbooks authored by Professor Menon and other writers. A comprehensive bibliography on concurrent engineering is included in the paper.

Introduction

Concurrent Engineering (**CE**) has become the new norm in North American, European and Japanese companies, for organizing and managing all aspects of the product-process design and development activity for new products. Concurrent Engineering is an engineering management approach which enables the integrated development of products and processes with the goal of completing the entire cycle in a shorter time [33], at lower overall cost and with fewer engineering design changes after product release [23]. This approach is also referred to by a number of other synonyms: Integrated Product Development, Simultaneous Engineering, Life Cycle Engineering, Parallel Engineering, and Team Engineering. In this paper we will use Concurrent Engineering and the abbreviation **CE** in referring to this approach. The generally accepted definition of CE as formulated by the Institute for Defense Analysis is as follows: *"Concurrent Engineering is a systematic approach to the integrated, concurrent design of products and their related processes, including manufacture and support. This approach is intended to cause the developers, from the outset to consider all elements of the product life cycle, from conception through disposal, including quality, cost, schedule and user requirements"* [IDA Report R-338, Winner, R.I., Pennell J.P., Bertend H.E. and Slusarczuk M.M.G [28]]. This approach requires a high level of teamwork and simultaneous involvement of all company functional disciplines very early in the product-concept-design process. This will ensure that all necessary modifications are made when it is easy to do so and development teams are empowered with more autonomy to enhance the overall product life cycle. Effective implementation of CE can benefit companies with greater customer satisfaction, lower cost, higher quality and impressive reductions in time-to-market cycles from concept through to full-scale volume production. Many companies now regard CE as being essential to remain competitive and for the Defense industry the DoD now expects all contractors to use this integrated product development approach.

Readers interested in the historical evolution of Concurrent Engineering should refer to the first two pages of the textbook by Carter and Baker[2] which indicates that the formal development of Concurrent Engineering in the United States can be traced back to circa 1982 when DARPA (Defense Advanced Projects Agency) initiated a study to look for ways to improve concurrency in the design process, with the formal research being carried out by IDA (Institute for Defense Analysis) with the results published as IDA Report R-338. This IDA report provides the first formal recommendations for the adoption of Concurrent Engineering by U.S. industry, especially Defense Contractors. It is important to distinguish between the formal evolution of Concurrent Engineering and the informal use of approaches and techniques by many Japanese companies circa 1970 onwards which bear strong resemblance to Concurrent Engineering. In addition many U.S. and European engineering executives attending Concurrent Engineering seminars taught by Professor Menon and others, have indicated that many of the principles of concurrent engineering have in fact been an integral part of the way in which they have lead product and process design projects during their careers dating back to many decades circa 1960 and they do not really regard Concurrent Engineering as being an entirely new engineering philosophy. However, it should be noted that such informal application of Concurrent Engineering tended to prevail in smaller projects in smaller companies rather than in the mega-projects in large multi-national companies. It is in the context of the large corporations where all of the contributing functional departments are distributed far and wide with numerous sub-contractors, where the formal application of Concurrent Engineering becomes a necessity and the development of the necessary managerial and technical infrastructure becomes a major challenge, requiring special expertise and guidance from seasoned consultants.

2.Traditional Design Paradigms and New Transitions

If CE is the new and preferred approach, what then is the old approach which we are seeking to replace and what was wrong with it? In comparative discussions, the "traditional approach to Engineering Design" has been assigned the following self-descriptive labels: Serial Engineering, Over-the-wall Engineering, Sequential Engineering, etc. It is assumed that in the old approach a designer translated his perception of customer requirements into a concept design and final detail design which was tossed "over-the-wall" to Manufacturing Engineering and other functional disciplines who were required to overcome any obstacles in translating the design to a satisfactory product, which conforms to all customer specifications and expectations. The metric for this phenomenon in product development is the "Engineering Change Order - ECO". which is a documentation of "imperfections in the design process". Of course there are many reasons for originating an ECO. but a very substantial majority of ECO's are attributable to poor design decisions which in most cases could have been avoided, if there had been more discussions during the formative periods of the preliminary design, between the designer and other "downstream functional disciplines". In many cases where highly innovative concepts and processes are part of the product design, even such dialogue among the product development team would be insufficient and iterative cycles of "prototyping" may be necessary to lead to a "right-first-time product design".

This arguably simplistic premise of the "old approach to design" assumes that many designers do not consult all "requisite downstream functional disciplines" and/or do not "prototype-totrouble-shoot" the design concept. Hence we find the consequence that the number of ECO's that became necessary, are at a much higher level than is justifiable. The comparative metric for this premise is that if we compare our industry to Japan, we find the following contrasts:

* Japan has much shorter concept-to-market development cycles.

* Japanese products have fewer ECO's issued after product launch.

* The frequency distribution of ECO's over time is left-skewed for Japanese products and right-skewed for U.S. products which indicates that their higher level of teamwork and early prototyping contrasts with our "over-the-wall" discover-problems-late in the product cycle and hence we suffer higher costs per ECO.

U.S. industry has recognized that we have to change our approach to product development and we must find ways to compress the time-to-market, if we are to remain competitive in global markets. Thus, we are beginning to see significant changes in industry and the emergence of new paradigms for organizing the product development process which reflects a Concurrent Engineering approach with teamwork and greater emphasis on prototyping to identify design modifications.

3.Literature Review

Readers unfamiliar with Concurrent Engineering concepts, may wish to consult any of the following textbooks: [Prasad [16]] or [Syan and Menon [23]] or [Ulrich and Eppinger [24]] for general insights into the fundamentals of this approach to product development. We have limited our Concurrent Engineering oriented literature review to those publications which are in accord with the above definition. While there is unanimity among the authors on what Concurrent Engineering is all about, there is diversity in viewpoint and perspective with respect to the "organizational level" addressing the spectrum of Concurrent Engineering issues, from the high-level macro view through to micro-level considerations. Some authors have taken a very high level, strategic approach to Concurrent Engineering, while others focused on the implementation aspects Concurrent Engineering. A brief outline of this diverse perspective is reviewed here to provide the global viewpoints on Concurrent Engineering.

Revolutionizing Product Development [Wheelwright and Clark, [27]] is an excellent textbook for senior executives, which takes a case study approach to covering the topic, using instances of effective and ineffective product development to emphasize the success of Concurrent Engineering. The authors stress that a company's ability to bring a variety of superior products to market quicker than its competitors will make it successful and ensure corporate survival in today's highly competitive global market where only the robust and adaptive companies will survive. "Product Design and Development" [Ulrich and Eppinger. [24]]

provides a sound Concurrent Engineering methodology to implement a strong-customer-focused approach for product design and development to ensure manufacturability and success in the market. The tools and methods they describe, are applied to actual product development examples, making them easy to understand."Design and Marketing of New Products" [Urban and Hauser,[25]] takes a managerial approach to the development of new products from a marketing-viewpoint, emphasizing an understanding of the issues and problem solving techniques. This book also draws on real-world examples to convey the idea that integrating the core functions in the development process is the path to success. " Concurrent Engineering: The Product Development Environment for the 1990's" [Carter and Baker,[2]] stresses implementation issues and they discuss the five forces of change that firms must contend with in competitive product design and the ways that these forces can be effectively managed. This includes implementation of multi-functional teams to ensure that product designs are plausible and to reduce the time-to-market cycle. "Total Design: Integrated Methods for Successful Product Engineering" [Pugh,[19]] stresses the importance of design to the manufacturing process. Pugh[19] presents a sound framework for IPPD with a focus on the creation of innovative products that satisfy customer needs. Several tools including the "needs-metrics matrix" and the related "House of Quality" are outlined. Another noteworthy viewpoint is presented in "Research to Product: A Major U.S. Challenge" [Spencer,[22]] describes the need for American firms to become stronger for competition in a global market. This article proposes a parallel approach to new product development to develop products quickly. It also compares the old, serial design process to the new parallel design process pointing out available tools to implement it. "Architecture and Process: The Role of Integrated Systems in Concurrent Engineering Introduction" [Izuchukwu,[9]] discusses the need to switch to a concurrent engineering system due to the acceleration of product development that can be achieved. Along with this is a discussion of lost-profit-opportunity, when firms get to market late with products. "Meet the New Competitors: They Think in Terms of Speed-to-Market" [Vesey,[26]] looks at the effect time-to-market has on the profitability of new products. The article stresses the "need for speed" as a critical success factor for firms in the 1990's. "Accelerating the Development of Technology-Based New Products" [Gupta and Wilemon,[7]] discusses the need to accelerate the product development process listing several factors pertinent to today's marketplace. In addition to this, the article lists several reasons for product delays that are based on field interviews and mail surveys of product development managers. Readers with a specific interest in developing engineering education tutorials using the world-wide-web as the media will find excellent examples developed by the NASA-AMDAF researchers at Georgia Tech under the direction of Professor Mistree [3, 29].

4. The Major Elements of Concurrent Engineering

The way in which Concurrent Engineering is implemented varies a great deal from company to company and there is no universal protocol on any standard model for concurrent engineering (see Carter and Baker [2] for guidelines on determining the specific Concurrent Engineering Framework for a given organization). However, in general we would expect to find some elements from the following phases of Concurrent Engineering in any implementation:

Concept Development: The Front-End Process
Identifying Customer Needs
Establishing Product Specifications
Concept Selection
Product Architecture
Design for Manufacturing
Effective Prototyping
The Economics of Product Development

There is a great deal of material on each one of the above topics and conference proceedings size limitations do not permit comprehensive descriptions of each one of the above topics in this paper. Therefore a brief outline of the above phases are included below in section 5 of this paper, with a much more comprehensive treatment of the above topics in a NASA funded world-wide-web tutorial (Integrated Product Development), developed by the authors of this paper at California Polytechnic State University, which is accessible via the Internet worldwide. This Integrated Product Development Tutorial which uses the aircraft industry as the illustrative model for concurrent engineering, can be accessed via the world-wide-web at **http://www.calpoly.edu/~ime400p1/nasa/nasa.html/**.

The issues covered in the Concurrent Engineering web site are those that were felt to be most important in implementing this integrated product and process development philosophy. Some of the topics are covered at a very high level with the method of implementation left up to the user. Other topics are covered in a very step-by-step fashion, spelling out how to implement the technique. It is hoped that users who are exposed to these topics and keep them in mind when designing a new system will find that their new product is well-aligned with customer needs. Access to topics in the Concurrent Engineering web site is very flexible. There is an outline page which details the topics covered allowing users to jump to any topic of interest. Additionally, users can easily get out of sections by clicking on a home-button common to the whole site. The use of buttons to go forward and backwards and jump out of a topic were deployed to make the modules more easy to use.

5. Outline of Tutorial

We recommend that readers of this paper who have access to the world-wide-web with a good browser like Netscape or

Mosaic may wish to login and connect to the current version of our web pages (e.g. Figures 1-3) by invoking the following world-wide-web URL:

http://www.calpoly.edu/~ime400p1/nasa/nasa.html

which will enable you to "actually see" what we describe below and explore interactively any aspect of our perceptions of "Integrated Product Development of Commercial Aircraft". For other readers who do not have access to the world-wide-web at this time, we provide a brief hardcopy view of the opening few pages (Figures 1-3) for simple illustration and hope that you will be motivated to seek online access to our web site in the future.

The Concurrent Engineering/IPD web site begins with a home page (Figure 1) outlining the content of the site and reasons for its development. The major contributors are discussed here and links to their web sites are incorporated. In addition to this, there are links to other related sites and a mail function so that users can submit comments. If a user chooses to do so, they may enter the tutorial by clicking a Cal Poly/NASA button common to all pages .The first page of the actual tutorial is an outline of the site with buttons allowing users to immediately jump to topics of interest (Figure 2). By including this page users can bypass sections that they are either not interested in or have already viewed. This increases the flexibility of use.

The first section concerning Concurrent Engineering/IPD is called "What is Integrated Product Development?" This section describes the Concurrent Engineering/IPD philosophy and contrasts it to traditional product development methodologies. This is a high level discussion of what is required to implement Concurrent Engineering/IPD successfully within a development team. Topics covered in this section include the four dimensions of product development. In the "communication" portion of this discussion, the user will have the opportunity to view an MPEG that details the importance of establishing proper channels of communication in product development. The "Why is Integrated Product Development Important?" (Figure 3) section points out the importance of implementing Concurrent Engineering/IPD. It discusses the effect today's market is having on the development of new products and the failure of traditional design processes to meet the requirements of the market. The need to accelerate the product development process is stressed here. The next section, "Concept Development: The Front-end Process," lays the foundation for topics such as customer needs identification and product specification development. This is the first section of the tutorial that describes methods to be used in Concurrent Engineering/IPD implementation. After completing this section, users can understand the issues involved in product concept development and needs identification.

In the "Identifying Customer Needs" section a methodology is presented that will enable users to perform a step-by-step process to properly identify customer needs. Real world examples are used here to help explain how to implement this needs identification process. In addition to this, product development tools are described in this section that will be useful later in the development process. Next, in the "Establishing Product Specification" section of the Concurrent Engineering/IPD tutorial, the proper procedure for developing product specifications based on customer needs is described. Included in this section is a description of competitive benchmarking which can be an important source of development input. For a more comprehensive treatment on the important Concurrent Engineering topic of Establishing the correct Product Specifications, the reader is referred to Pugh [19] (1996 edition and the earlier 1990 edition on TOTAL DESIGN for more details of a good methodology for developing engineering specifications).

The next section of the Concurrent Engineering/IPD tutorial provides insight into "Quality Function Deployment : QFD " which provides a structured approach to establishing customer requirements and the compromises needed to formulate the product specifications and subsequent product/process stages of the development cycle. For a more comprehensive insight into QFD the reader is advised to refer to Syan & Menon [23] (Chapter 5, pp91-99), Pugh [19] (Chapter 16, pp 183-200, 1996 edition), and Prasad [16] (Chapter 2, pp82-89). The description of Quality Function Deployment in this section centers mainly on the development of the "House of Quality." This tool compiles information gathered in previous sections of the product development process ensuring that the design process remains customer-focused.

The web-based tutorial includes a good introduction to important topic of "Effective Prototyping" which covers the basic principles of the technologies for building physical prototypes. We have also set up hypertext-pointers within the Prototyping tutorial which will take the user to many other web pages set up by rapid prototyping groups in industry and at other universities. In addition readers seeking more comprehensive details on all aspects of rapid prototyping are advised to see Syan and Menon [23] (Chapters 8 and 9, pp 137-159) or Menon [34]. The tutorial includes a good introduction to the topic of Design for Manufacture, however this is a very broad topic which cannot be covered comprehensively within a web-tutorial module. Readers should consult additional supplements on the various aspects of Design for X (i.e. all the factors that are affected by design) using the following as a starting point for such elaborate study of DFX: Syan & Menon [23] (Chapters 6 & 7, pp 101-136), Corbett et al [35] and Pugh [19] (1996 edition, Chapter on Design for X, pp 389-448). The other modules in this tutorial address important Concurrent Engineering considerations covering each of the following activities: Concept Selection, Product Architecture, and finally The Economics of Product Development.

6. Importance of Teaming and Teamwork

In addition to the material outlined above, a very important aspect of Concurrent Engineering which merits close attention is TEAMING and the processes to be deployed which will engender effective teamwork, to produce "high-functioning teams" which seems to be evident in most successful product developments. Formulating guidelines for teamwork is difficult because they have to be customized to the specific cultural and national characteristics of a given team. Thus, teamwork is a very natural part of the way in which Japanese companies have operated for many decades, whereas in most western countries individualism is the norm and developing teamwork requires substantial effort and dedication, to create truly high-functioning teams. Readers interested in more details of these organizational issues should review material presented by Pawar in the textbook by Syan and Menon [23] (Chapter 3, pp49-74) and Pugh [19] (1996 edition, Chapter 25, pp 325-341).

7. Words of Wisdom for Successful Implementation of CE

Studies conducted by the Institute of Defense Analysis as well as many other researchers (e.g. Shina [30]) point to a number of strategies which seem to have been deployed by companies who have demonstrated successful implementation of Concurrent Engineering in their organization. The list of factors typically include the following:

Elements of Deployment Strategy

Ø Support from senior management.

Ø Changes made are variations from previous company practices, not radically different.

Ø There needs to be a common perception within key areas of the organization that there is a high-priority need for organizational change to remain competitive and survive, with concurrent engineering being a well proven option.

Ø Organizational culture conducive to successful formation of multi-disciplinary high- functioning teams for product and process development.

Ø Modifying any prior policies or company practices which may have been obstacles to early design changes.

Ø Sufficient empowerment of responsibility and authority, for members of product- process design and development teams to enable them to become innovative problem-solvers able to address unprecedented chlallenges.

There is consensus among researchers who have examined concurrent engineering that the following are essential elements for the successful implementation of concurrent engineering:

Essential Strategic Elements

Ø Multi-disciplinary teams that have teaming effectiveness at a high-functioning level.

Ø Sustained communication and co-ordination across different disciplines and organizations involved with the product.

Ø Deployment of Total-Quality-Management methods and principles.

Ø Organization culture which empowers employees for continuous improvement.

Ø Use of systems simulation and various forms of rapid prototyping for iterative-design.

Ø Framework for seamless integration of information systems, applications and user-i nterfaces at every key level of the organization.

Ø Strong, timely and effective training program for employees at all levels.

Ø Employee attitude of ownership towards key processes they are involved in and strong loyalty towards the organization to ensure high-quality performance.

The following general guidelines for achieving success with Concurrent Engineering are based on feedback from several successful implementations:

Guidelines from Sucessful Implementations

Ø Do not undertake Concurrent Engineering until the company is truly ready for this.

Ø The deployment of Concurrent Engineering is just as difficult and challenging as the I mplementation of a new complex product line in the company.

Ø Concurrent Engineering is a methodology and it involves cultural change at every levelof the organization, which must be receptive to such drastic change of approach.

Ø Concurrent Engineering tools and techniques without a strong Concurrent Engineering culture will not yield the full potential of possible benefits.

Ø There should be strong senior executive who is the champion for Concurrent Engineering with a strong commitment to making sure that this will be a sucessful initiative with measurable benefits that are monitored and made known to employees.

Readers interested in more information on strategies for successful implementation should refer to material in the textbooks by Shina [30], Prasad [16] and Syan and Menon [23] which elaborate on the above recommendations with case examples, frameworks and Concurrent Engineering techniques. It should be stressed that while the basic principles are the same whether Concurrent Engineering is being applied in a small company or a large corporation, the technological challenges are far more difficult in the larger organizations.

8. Case Histories on Concurrent Engineering (U.S.A. & EUROPE)

A very good set of concise case histories on Concurrent Engineering lessons from Ford Motor Company in UK,as outlined by Professor Chelsom (ex-Ford executive), can be found in Syan and Menon[23]. Another good source of U.S. case histories on the successful implementation of Concurrent Engineering can be found in a text book edited by Shina [30], which documents the actual experience of several companies covering different types of U.S. companies including many well known companies such as: Raychem Corporation, Hewlett-Packard, Sun Microsystems, Northern Telecom, Polaroid., Digital Equipment Company, and many others, adding up to a set of thirteen case examples which provide a good basis for formulating winning strategies based on the lessons learned by proficient companies. One common conclusion that can be drawn from these case experiences, is that implementing Concurrent Engineering is a very challenging task which requires substantial commitment at all levels of the organization and strong leadership by the CEO and senior executives of the company. It is fair to say that this managerial leadership and organizational commitment to make Concurrent Engineering work effectively for the company, is far more important, than any of the tools that are needed for Concurrent Engineering. In addition to the above mentioned textbooks, there are numerous case histories on concurrent engineering published as papers in many conference proceedings (e.g. Annual CALS/CE Conference, Washington D.C., IIE Annual Conferences in U.S.A., FAIM Conference series co-hosted by Virginia Tech and University of Limerick, and publications from European Community research initiatives like the PACE project at the University of Nottingham with many EC partners).

9. Concluding Comments

Concurrent Engineering and its synonyms are now an integral part of the engineering management approach to the development of new products and processes in U.S., European and Japanese companies. For most U.S. companies, especially major contractors to the U.S. Department of Defense, Concurrent Engineering is no longer an option; it is a necessity for survival in the highly cost-quality-schedule oriented competitive environment which now prevails in the United States and worldwide. In this paper we have explored the origins of Concurrent

Engineering, outlined the definition and elaborated on the tools and processes deployed to attain Concurrent Engineering, including references to a world-wide-web-based tutorial developed by the authors with support from NASA, which provides insights into all aspects of concurrent engineering. We hope that our advocacy of Concurrent Engineering will result in more widespread adoption of Concurrent Engineering worldwide given the inter-dependencies on the global supply-chain for most modern new product developments.

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Cal Poly, SLO
AMDAF

Integrated Product Development of Commercial Aircraft

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This is an on-line tutorial designed to teach aeronautical engineering students the principles of Integrated Product Development (IPD). It is being done as part of the Aeronáutics Multi-disciplinary Design and Analysis Fellowship (AMDAF) coalition at California Polytechnic State University, San Luis Obispo. By exposing undergraduate engineering students to the multi-disciplinary design approach that IPD assumes, the coalition hopes to develop better engineers for the commercial aircraft industry. This project is made possible through funding by NASA and support from Boeing, Northrop Grumman, and McDonnell Douglas.

The topics covered in this tutorial include:

- Concept Development: The Front-End Process
- Identifying Customer Needs
- Establishing Product Specifications
- Concept Selection
- Product Architecture
- Design for Manufacturing
- Effective Prototyping
- The Economics of Product Development

To begin the tutorial.

Figure 1: Home Page for Cal Poly NASA-AMDAF

Integrated Product Development of Commercial Aircraft

The contents of the tutorial are described in this outline. By clicking on the arrow next to a section's heading, you can go to that section. Clicking on the small NASA/Cal Poly logo anywhere in the document will take you back to this page. Please be patient because some of the sections are still under development. Those sections marked with an asterisk are currently empty.

> I. What is Integrated Product Development?

> II. Why is the Integrated Product Development Process Important?

> III. Effective Team Building

> IV. Concept Development: The Front-End Process

> V. Identifying Customer Needs

> VI. Establishing Product Specifications

> VII. Quality Function Deployment

> VIII. Concept Selection

> IX. Product Architecture

> X. Design for Manufacturing

> XI. Effective Prototyping

> XII. The Economics of Product Development

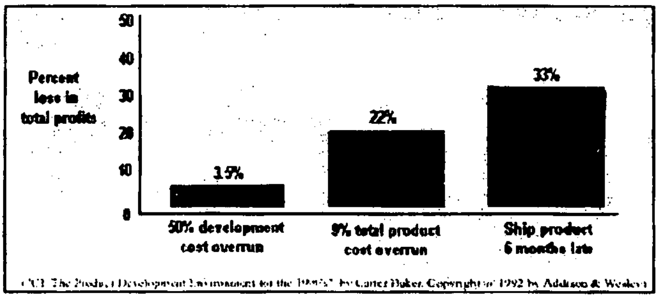
Figure 2: Tutorial homepage within Cal Poly NASA-AMDAF

Why is the Integrated Product Development Process Important?

There are three major factors that make adoption of the integrated product development process important:

- Increasing intensity of international competition
- Increasing market fragmentation
- Rapid changes in technology

Due to the rise of the global marketplace, firms no longer have the luxury of exclusive rights to their home markets. American companies are competing against firms from all over the world. These firms are producing a variety of products to meet the increasingly diverse needs of customers. This has forced companies to reduce the total cycle time of the product development process to remain competitive. Quickly implementing technological changes into a firms core competencies to facilitate this agile manufacturing requirement can only be accomplished through the cross-functional interaction of the four product development functions. Slow downs in the development of new products will mean late market entry. As shown in the graph below this has a serious effect on the profitability of a firm's new products.



Products that have a fifty percent development cost overrun have a reduction in profits of only 3.5% while products that have a nine percent total product cost overrun have a reduction in profits of 22%. Products that get to market six months late, however, lose 33% of the profits they would have earned had they gotten to market on time. When one considers this and the three factors discussed above it is easily seen that companies need to exercise speed, efficiency, and quality in the development of new products.

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Figure 3: Example tutorial page within Cal Poly NASA-AMDAF