A Decision Support System for Advanced Composites Manufacturing Cost Estimation

by

Mark Alan Eaglesham

Dissertation submitted to the Faculty of the
Virginia Polytechnic Institute and State University
in partial fulfillment of the requirements for the degree of
Doctor of Philosophy
in
Industrial and Systems Engineering

Dr. Michael P. Deisenroth, Chair
Dr. Larry N. Killough
Dr. William H. Mason
Dr. William G. Sullivan
Dr. Eileen M. Van Aken

April 10, 1998
Blacksburg, Virginia

Keywords: manufacturing cost, activity costs, design decision support, composites

A Decision Support System for Advanced Composites Manufacturing Cost Estimation

by Mark Eaglesham

Michael P. Deisenroth, Chair

Department of Industrial and Systems Engineering

(ABSTRACT)

The increased use of advanced composites in aerospace manufacturing has led to the development of new production processes and technology. The implementation of advanced composites manufacturing technology is poorly served by traditional cost accounting methods, which distort costs by using inappropriate volume-based allocations of overhead. Activity-based costing has emerged as a methodology which provides more accurate allocation of costs to products or activities by their usage of company resources. Better designs may also be produced if designers could evaluate the cost implications of their choices early in the design process. This research describes a methodology whereby companies can improve product cost estimation at the conceptual design phase, using intelligent searching and arrangement of existing accounting data to enable designers to access the activity cost information more readily. The concept has considerable scope for application in industry because it will allow companies to make better use of information that is already being recorded in their information systems, by providing it in a form which will enable designers to make better informed decisions during the design process. The design decision support framework is illustrated by applying it to a typical problem in aerospace composites manufacturing. Feasibility of the approach is demonstrated using a prototype software model of the Design Decision Support System, implemented using commercially available software.

Acknowledgments

I would like to thank Dr. Michael P. Deisenroth for his support and guidance throughout my studies at Virginia Tech. His support was crucial to my starting, and completing this research. I would also like to express my gratitude and appreciation to Dr. Larry N. Killough, Dr. William H. Mason, Dr. William G. Sullivan, and Dr. Eileen M. Van Aken for serving on my committee. They have each contributed valuable suggestions and advice that have assisted me in completing the research.

I would like to thank the staff of the ISE department for their helpfulness in attending to the many administrative matters that were required while at Virginia Tech. In particular I would like to thank Mrs. Lovedia Cole for her always friendly and helpful assistance, and to Mr. Will Vest for his help in keeping the computers functioning when all else had failed.

I would like to thank my wife, Sue, and son, James for their love and support while I have worked on this research, and to Sue for taking care of all the things I could not. I would also like to thank my family for their support in getting me this far, and for always encouraging me along the way.

Table of Contents

List of Illustrations

List of Tables

Chapter 1: INTRODUCTION

1.1 Background

The growing use of advanced composites in the aerospace industry has led to the development of new methods and equipment for manufacturing these new materials and structures. In this relatively new field of design, the behavior of production costs relative to the different design variables is not as well defined as is the case for more established aircraft manufacturing methods, such as sheet metal forming and fabrication. The weight engineering models traditionally used for aircraft cost estimation may not be valid for composite materials. For example, the cost of graphite composite parts may be more expensive than a similar glass composite part, but substantially lighter in weight, and having enhanced structural properties. The trade-offs between weight, performance and cost are of interest to designers, but are difficult to assess, given the lack of accurate cost information currently available.

This research evolves from integrating work from several knowledge domains related to manufacturing economics. The primary goal of this study is the integration of information from these various domains to provide information to designers on the cost impact of their design choices. The work assumes that computer integrated manufacturing methods will be used in this environment, from computer aided design and drafting, through computer aided process planning and production scheduling, and computer controlled or assisted manufacturing processing. The principles of Design for Manufacturability provide a core philosophy for the achievement of design and manufacturing cost reductions. Existing cost estimation techniques provide some ready tools and models for comparison and evaluation. The shortfalls of these methods provide the impetus for this work.

1.2 Composites in Aerospace

Historical trends have shown an increasing fraction of composite materials in aircraft, from a small fraction in the early 1970's to nearly complete aircraft in the late 1990's

(Walden, 1990; Harmon and Arnold, 1991; Niu, 1992). The high strength to weight ratio of advanced composite materials has encouraged designers to substitute them for metal, to achieve enhanced aircraft performance (Niu, 1992; Middleton, 1990). As the techniques become more widely used, the production cost will tend to decrease, providing even greater incentive to use them.

The justification for increased use of advanced composite materials is well established in the literature and is driven by the demand for improved performance and lower costs in aircraft. The fabrication techniques and processes are covered in detail by researchers in the material sciences. Properties and applications of the materials are covered by research in mechanics of materials, as well as by aerospace research. Although this knowledge exists, it is not always easy for designers to assimilate the new facts and transform them into rules or axioms for design applications. Compared to the designers' accumulated experience in metal part fabrication techniques, the advanced composite processes are relatively unknown. This study is intended to provide a relatively simple means to build up a new design knowledge base, and thereby speed up the assimilation of newly applicable design rules. The high value of aerospace components, and the demand for increased levels of performance, make this an important area for research. Potential benefits of the process are the possibility of integrating components for reduced parts count, lighter structures, and greater operational performance of the aircraft.

1.3 Computer Integrated Manufacturing

Integration of computer information systems into the design and manufacturing process has reached an advanced stage of development. The concept of Computer Integrated Manufacturing (CIM) is defined by the Society of Manufacturing Engineers (SME) as follows:

> **Definition**: CIM is the integration of the total manufacturing enterprise through the use of integrated systems and data communications coupled with new managerial philosophies that improve organizational and personnel efficiency.

Objective: The goal of CIM is the integration of all enterprise operations and activities around common data repositories.
(Computer and Automated Systems Association of SME, 1993)

The enterprise wide integration of activities and operations is difficult to achieve in practice, despite significant efforts towards that goal. It is more difficult to retroactively integrate systems than to build in integration up front. When systems evolve separately, they are more likely to have inherent features and system architectures that are incompatible with other systems. The opportunity to design integrated systems from the bottom up will likely result in greater integration of systems in the future. Already there are systems in use which allow design engineers to create product designs using a combination of computer-aided drawing and computer aided analysis tools. Designs can then be transformed into a set of processing instructions using computer aided process planning. The processing instructions are then translated into machine instructions that are executed by computer numerical controlled (CNC) machines on the factory floor. It may also be possible to coordinate planning and scheduling of production operations using computer networks, and ultimately to control the distribution network and subsequent billing actions. While it is difficult to find industries that have totally integrated all of these components, many companies are using portions of this framework successfully.

The difficulty of integrating the various systems has prevented more widespread implementation, as the implementation cost begins to outweigh the potential benefits that could be achieved. Researchers too, have avoided trying to solve too large a piece of the problem, knowing that this can become an unwieldy task. This study provides a means to integrate accounting information systems with design and production control information systems, in order to provide more accurate cost knowledge to the designers. Because the accounting, engineering and production disciplines have been traditionally separate, the systems each department uses have often evolved in isolation, with no intention to provide information to users outside their own specific domain. In order to achieve some measure of integration, this research assumes that cooperation between the departments is assured, and that each information system is readily accessible for use by the decision support system. In practice, this state is not easily achieved, and requires highly developed management systems, and a fully supportive team environment. Although this may be a limiting assumption, it is not crucial to the research, as this framework limits its intrusiveness by using already captured data, rather than trying to redesign the information flows in the existing systems. As long as the databases from the various information systems can be provided in an accessible form, the Design Decision Support System, DDSS, does not require on-line interaction with the source data, except for updates of the databases. The design and manufacturing environment chosen for the study is highly automated, and significant advances have been made in CAD/CAM modeling of advanced composite products. The DDSS methodology is applicable to both highly automated, and manual processing of composites. The focus of this methodology is on manipulation of cost data to describe the effectiveness of the manufacturing processes, rather than on linking computer aided design systems to computer controlled manufacturing systems.

1.4 Design for Manufacturability

Recent developments in concurrent engineering have led to greater cooperation between traditionally separate teams of design and manufacturing disciplines. Concurrent engineering is a philosophy for product design that relies on the design being simultaneously evaluated by the design engineers, manufacturing engineers and the marketing experts, in order to achieve the greatest level of customer satisfaction (Jo, Parsei & Sullivan, 1993). Further discussion of concurrent engineering is presented in Section 2.2. Concurrent engineering provides the means to Design for Manufacturability, DFM. The philosophy of Design for Manufacturability (Boothroyd & Dewhurst, 1987) promotes the simplification of product design to reduce the total manufacturing cost. It suggests concurrent analysis of the functionality of the product and the manufacturing process specifications, and to avoid specifying design elements that are difficult (and expensive) to produce. It also promotes the reduction of the parts count as being an effective way to reduce total manufacturing and assembly costs. An important need for DFM to be applied is an early estimate of manufacturing cost, to enable the designers to make these decisions during the conceptual design phase. Boothroyd and Dewhurst identified the difficulty in obtaining these early cost estimates from company cost records as being a major problem preventing the implementation of the methodology. Although these methods were initially developed for application to prismatic, machined parts and assemblies, the concepts are also applicable in the area of composites, and may provide the key to more widespread use of these materials.

A criticism of the application of composites in aircraft has been that designers have often merely replaced metal components, without considering possible amalgamation of parts and functions, to take advantage of the unique properties and benefits of composite materials. Sahr et al. (1995) describe the evolution of composite designs in aircraft structures. At first, composites were used as metallic skin reinforcement. Gradually, structural elements such as longerons and shear webs and skins were introduced, assembled much as prior metallic designs had been. More advanced designs are now being developed, which integrate panels and stiffeners into one co-cured part. The Airbus vertical and horizontal stabilizers are examples of massive integrated elements in which most of the structure is laid-up and co-cured simultaneously (Sahr et al., 1995).

The purpose of the DDSS is to provide decision-making information to product designers (or managers) that will enable them to make informed design choices, gaining the most value from their production resources for the least cost. The background outlined above gives reason to believe that this information will be of considerable value to designers in the aerospace industry, enabling them to develop greater knowledge about the impact of their design choices on the product cost. The methodology provided by this research may also be useful to managers, providing a tool for analyzing the value-adding versus non-value-adding processes in the production environment (McCusker & Walleigh, 1993).

1.5 Cost Estimation Techniques in Use

Cost models for estimating the costs of these aircraft production processes have focused on either a global overview of program costs, using design takeoff gross weight as the prime cost driver, or have taken a micro-level view of calculating the time taken for each step in the production process. Examples of the global overview model are the DAPCA IV model developed by Rand Corporation (Hess & Romanoff, 1987), PRICE-H, and Roskam (1985). Roskam provides alternative, but similar models, focused on developing the weight estimate needed for the cost estimate. Examples of the process level cost estimation models are ACCEM (Rohani & Dean, 1996), and COSTADE (Mabson, et al., 1994). There is a significant gap between the two types of model. The manufacturing cost model proposed by Wong et al. (1992) embodied some of the important elements which should be included, but did not provide details of how to implement their "fully integrated cost estimating system."

1.6 Trends in Cost Accounting/Management Accounting

Johnson and Kaplan’s *Relevance Lost* (1987) lamented the failure of the management accounting profession to change methodology in response to major structural changes that have occurred in industry. They argued that the decline of management accounting relevance was due to its reliance on financial reporting procedures, which resulted in information that was collected “too late, too aggregated, and too distracted to be relevant for managers’ planning and control decisions" (Johnson and Kaplan, 1987). One of the foremost factors which distorted information was the use of aggregated cost categories for allocating overhead cost to cost centers. The traditional methods of cost accounting allocated overhead costs to products by volume-based measures such as labor hours, machine hours, or material cost. While these methods of allocation were effective in earlier times when these volume bases were a significant metric of cost consumption, the increasing use of automated machinery, coupled with significantly higher overhead costs, resulted in severe cost distortions. Traditional cost accounting systems have not been able to provide a detailed cost breakdown of non-value adding activities, because these have been aggregated in pools of overhead cost. Production costs have also been aggregated by organizational groupings, rather than by process outputs, making it difficult to analyze the cost of each process or activity. Advances in the field of management accounting have led to the development of activity-based costing (ABC) as a solution to the problems of cost aggregation. By choosing smaller cost pools that capture all of the inputs into a particular process, the cost per unit of output of that process or activity can be determined. Activity-based costing differs from traditional cost accounting in the selection of more numerous, and more appropriate bases for allocation.

This DDSS tool uses activity-based cost allocation to determine the relative costs of different design features, by searching out relevant costs of processing activities. By comparing the change in cost behavior versus possible increases in design performance, the methodology supports the creation of strategic value to the company, by increasing the effectiveness of the available production resources.

1.7 Decision Support Systems

Considerable work has been done in the field of decision support for design. Much of the work, however, is focused on presenting design axioms or advice to designers on how to design. These approaches invest a lot of time into capturing the knowledge into forms that can be accessed, to provide the designer with suitable advice. The different approaches provide ready-made platforms on which to structure design information. Some of the published decision support models are reviewed in more detail in Section 2.7, to identify desirable features that were identified for inclusion in this research.

A shortfall in these design decision support systems is that they do not use structures typical of business systems, and they do not take advantage of the data that most companies store about their own operations. It is this information which is most difficult for companies to formalize, and it is usually impossible to buy "off-the-shelf." There appears to be a significant gap between the predominantly (mechanical) design decision support research and the decision support systems research typical of business schools. It is in integrating knowledge from engineering design into the business information systems that this research is useful. Engineers have typically created their own stand-alone systems, just to get things done, rather than having to wait for the management information system (typically 'owned' by financial departments) to provide them with the information they need. This results in expensive 'islands' of information that duplicate efforts elsewhere, and that are difficult to maintain accurately, because they are not integrated with the primary sources of data. The integration of information systems and manufacturing systems is a complex task, but it is crucial to the long-term success of the proposed design decision support system. This concept is discussed further in Chapter 2, but must include the following elements:

- consideration of the aircraft designers' information needs;
- detailed specification of the manufacturing system, and of the advanced process technology;
- activity-based accounting principles for accurate allocation of overhead costs;
- integration of the system into the business information system of the company; and
- the ability to use existing data and information.

1.8 Research Objectives and Purpose

1.8.1 Importance of this Research to Industry

The growing use of advanced composites in the aerospace industry has led to the development of new methods and machinery for manufacturing the new materials and structures. In this relatively new field of design, the behavior of production costs relative to the different design parameters are not as well defined as is the case for more established aircraft manufacturing methods, such as sheet metal forming and fabrication. The weight engineering models traditionally used for aircraft cost estimation may not be valid for composite materials; for example, the cost of graphite composite parts may be more expensive than a similar glass composite part, but substantially lighter in weight, while having enhanced structural properties.

1.8.2 Research Hypothesis

The hypothesis that this research investigates is whether this framework can be constructed in the manner envisaged, and what benefits will be achieved by the proposed design decision support system. This hypothesis can be more formally stated as the research question, research purpose, and research objectives:

I. The **research question** is *what the research intends to answer*, and *how it will expand the academic body of knowledge*. For this study, the research question was: how can product cost estimates be modeled using the existing information sources in an advanced composites manufacturing environment?

II. The **research purpose** answers the question*, what is the overriding reason for doing this research?* The purpose of this research is to provide decision making information to product designers (or managers) that will enable them to make informed design choices, gaining the most value from their production resources for the least cost.

III. The **research objective** answers the question, *what will be the results of this research, or what can be learned from this research?* The desired result of this study is a methodology for a decision support system that actively seeks out costs related to a product or function, by intelligently searching the existing accounting, production and engineering data sources. Sub-objectives were:

- To assess the needs of aircraft designers, by analyzing typical trade studies used during the conceptual design phase for aerospace components, and to satisfy the information needs to Design for Manufacturability (Boothroyd & Dewhurst, 1987).
- To model the interaction of activities and processes in the given manufacturing setting, and the associated information flows, and to measure the costs consumed by these activities and resources.

- To develop a methodology to structure the search process, and to collect and manipulate data into a manageable form for portrayal to decision-makers.
- To create a system that "learns" by capturing information from each iteration of the process, and uses the information gained to speed up or enhance future cost estimates.
- To provide a development framework to design the decision support system.

1.8.3 Scope of the Research

In order to realistically model this manufacturing environment, it is necessary to build sufficient complexity into the system to illustrate the methodology. However, to keep the project manageable, limits must be imposed on the scope of the problem, which tend to reduce the accuracy of the model. In this study, the manufacturing database has been to set up to include some representative composite components, machines and processes, with information flows simulated to represent all of the resources and controls to produce some mixture of these products. This information is modeled as closely as possible on information about aerospace manufacturing companies, notwithstanding their reluctance to release this information to outsiders. These limitations on the scope of the study are defined as follows:

a. Composites Manufacturing Domain

The domain is limited to composite component manufacturing in a mixed batch and custom manufacturing job shop environment, similar to a medium sized sub-contractor to the aircraft industry. The scope of the manufacturing cost estimation process is limited to the immediate manufacturing facility, excluding other sectors of the organization that do not have a direct impact on production costs.

b. Accessible Data

It is assumed that production data is already captured and accessible for computerized searching. The source documentation is assumed to be in typical formats used in industry, working from formats described in the literature. The specific formats used are described in Section 3.4, and in Appendix D. The methodology makes this assumption based on the premise that many of the target production settings have already made considerable progress towards computer integrated manufacturing. Where information is not already in computer accessible form however, the manual forms of data may be captured into electronic form by a manual conversion process.

c. Process Plans Captured in Database Format

As a starting point for the methodology, it is assumed that process plans for the prior product experience of the company are available in database format, and in sufficient detail to link to the job order, process detail, and bill of materials databases. If this capacity is not already available, companies could readily generate database or spreadsheet forms of the process plans, by importing the text or database forms into the desired format. Microsoft Excel offers a number of conversion utilities, to import data from text or database sources, and to re-arrange it by splitting into tabular form.

d. New Designs Based on Variation of Existing Product Designs

The methodology assumes that new designs to be produced are based to some extent on producing parts using similar structures and processes to those already being used by the company. Since the cost estimation process is based on using data from previously made components, there has to be a process detail record of a similar part or process that the new part can be modeled on.

e. Limited Dictionary of Available Products and Processes

This research assumes that there is a limited vocabulary of descriptive words available to the designers, based on existing product descriptions, material descriptions, activity descriptions, and machine names in the manufacturing and accounting databases. This is not an unrealistic assumption, given that each company has a limited set of production resources, and a limited number of generic processing activities.

f. Support for Component-level Design

The methodology addresses component-level manufacturing cost. Extensions to consider the effects of the manufacturing cost on the life-cycle cost of aircraft, and the other factors for aircraft design, are not provided in this research.

g. Security / Privacy Considerations

In the implementation of the DDSS methodology it is assumed that there are no limitations on data security or privileged access to information. In reality, companies may need to restrict access to certain types of information, e.g. employee salary scales, and strategic cost or pricing data.

1.8.4 Measures of Success

The Design Decision Support System aims to satisfy each of the sub-objectives listed in the objectives. It is difficult however, to quantify the level of satisfaction. To adequately measure success, multiple attributes should be considered. Other qualities that are desired of the research are:

- **Explainable**: the methodology should be easily explained to and understood by potential users of the system.
- **Flexibility**: the framework should allow for a flexible approach to configure it for different manufacturing and operating systems, and to allow for subsequent modifications to the system.
- **Cost**: the potential benefit of the system should significantly outweigh the cost to implement it.
- **Portability**: it should be possible to adapt the methodology for use on different software platforms.

1.9 Outline of the Study

The rest of this document follows this outline. In the discussion and literature review (Chapter 2), the various topics relevant to this work are reviewed. In each topic, the specific factors that are used in the theoretical development of the DDSS model are emphasized. In Chapter 3, the specific objectives of this research are presented, and the DDSS methodology is described with explicit references to each of the topics presented in the literature review. The software implementation of the model is also described. In Chapter 4, the validity of the model is tested on a typical aircraft composite part. This is shown by first estimating the cost of the part manually, and then by using the DDSS model. The example is extended to carry out design modifications using the system, and to depict outputs in graphic form. An implementation guide is provided to show how the Design Decision Support System methodology could be introduced in a given manufacturing setting. The conclusions evaluate whether the methodology satisfies the goals set out for the project, and investigates possible avenues for further research, and opportunities to use this methodology for other applications.

Chapter 2: DISCUSSION

2.1 Computer Integrated Manufacturing

2.1.1 Definition of Computer Integrated Manufacturing

In this section, the specific aspects of CIM relevant to this work are discussed. In order to do this, the relationship of this work to the CIM environment must be investigated. The key elements of the SME definition and objectives of Computer Integrated Manufacturing (CIM) are, as stated previously (in Section 1.3):

> **Definition**: CIM is the *integration* of the total manufacturing enterprise through the use of *integrated systems and data communications* coupled *with new managerial philosophies* that *improve organizational and personnel efficiency*.
>
> **Objective**: The goal of CIM is the *integration of all enterprise operations* and activities around *common data repositories*.
>
> (Computer and Automated Systems Association of SME, 1993)

This research work is grounded in the philosophy of sharing common data resources, requiring access to knowledge sources in manufacturing, production control, accounting and design systems. The challenge is to integrate this information in new ways to provide increased value to the design activities of the enterprise, and thereby improve the competitive advantage of the company. The SME's use of *efficiency* as a goal is unfortunate; *effectiveness* would have been a more far-reaching goal. Effectiveness implies that one seeks to improve the position of the company by deciding its activities, rather than just improving the efficiency of whatever activities it is doing.

2.1.2 Objectives of Computer Integrated Manufacturing

In reference to the CASA/SME Manufacturing Enterprise Wheel (see Appendix C), the authors state that the CIM environment should support the following key objectives:

- “The central role of a customer-oriented mission and vision to strive for continuous improvement.
- The importance of teams and human networking in the new manufacturing environment.
- The continuing importance of computer tools, now increasingly distributed and networked (including tools to support networking and concurrent engineering).
- A focus on key processes and best practices throughout the enterprise, from marketing through design, manufacturing, and customer support.
- Recognition of the move away from bureaucratic structures, to leaner and more agile organizations.
- The need to integrate an understanding of the external environment, including customers, competitors, suppliers, and the global manufacturing infrastructure.” (CASA/SME, 1993)

This research attempts to incorporate these objectives into the methodology. The design tool is intended to improve the value of the product by improving performance, or decreasing the cost. It is designed to use distributed databases of the different information systems, thereby providing a means to integrate the knowledge from various departments, and to increase interdisciplinary understanding. By focusing attention on value-adding processes versus non-value adding processes, management can use the system to eliminate unnecessary or wasteful procedures. Greater understanding of the organization’s competitive strengths and weakness can be used to develop strategies to compete more effectively in the global marketplace.

2.1.3 Research Agenda for Integrated Product and Process Design

The Committee to Study Information Technology and Manufacturing was formed by the National Research Council to determine the computer science and engineering research needed to support advanced manufacturing. The Committee, comprising members from the Computer Science and Telecommunications Board (CSTB), Manufacturing Studies Board, and National Research Council, set out an ambitious research agenda for information technology in manufacturing (CSTB, 1995). In the area of integrated product and process design, they identified the following key research questions and outlined their recommendations for research objectives. These are summarized here:

1. "*How should information associated with products be captured and represented?* Development of schemas to represent high level functionality of designs, detailed design information in various domains, interchangeable product data models for use by different parts of the manufacturing operation, and the relationships between high level function abstractions and the physical reality of geometry and materials.
2. *How can manufacturing processes be represented?* Issues relevant to this question are the development of languages for process description and models of specific manufacturing processes, both as they actually exist, and as they might be improved. Process model representation schemes (aggregate and detailed), and on-line data collection.
3. *How should tools be constructed that support product design?* An integral aspect of product design is how to make trade-offs (e.g. among cost, performance, reliability, between space allocations, between making or buying a component, between long term operating costs and initial costs, and so on). Designers would benefit greatly from tools that would help them evaluate these trade-offs in a rigorous and systematic manner. Presentation and display tools for visualizing various design alternatives would also help the designer."(CSTB, 1995)

The third question provides a stimulus for this work. The Design Decision Support System is intended to be one of the tools to satisfy this need, by enabling designers to evaluate the cost implications of their design decisions early in the design process. They will be able to evaluate cost and function trade-offs between different manufacturing methods, and between different materials for the designed components. The methodology also seeks to avoid some of the inaccuracies of traditional cost models, especially in the area of advanced composite materials, which has a relatively small historical knowledge base.

Elsewhere in the agenda, the CSTB identify some other tools to be developed, which are also relevant to this research. In the area of the information infrastructure to support enterprise integration, they note that incompatible representations of knowledge and information are common in computer-aided design, computer-augmented process planning, and computer aided manufacturing. These incompatibilities are a major obstacle to enterprise-wide integration. They also regard as essential the development of tools and capabilities needed for human and machine-based information and resource searching (CSTB, 1995).

2.2 Concurrent Engineering

2.2.1 Cost Models to Support Concurrent Engineering

Concurrent engineering is a philosophy for product design that relies on the design being simultaneously evaluated by the design engineers, manufacturing engineers and the marketing experts, in order to achieve the greatest level of customer satisfaction (Jo, Parsei & Sullivan, 1993). Consideration is given to design for manufacturability, design for assembly, and design for reliability and maintainability. Jo, et al.(1993), provide several references to the importance of design in determining manufacturing costs as well as life cycle costs for products. Concurrent engineering relies on computer integrated manufacturing as one of the tools necessary to succeed. Product cost estimation at an early stage is important, for decision-makers to assess the impact of the design choices they have to make. Jo, et al. reinforce this view, with a description of how the cost estimation model for concurrent engineering should function. They emphasize that the cost estimator should construct cost models that can derive meaningful manufacturing cost estimates based on the collected data. This data should include the predicted costs of material, machining, overhead, testing, assembly and other related drivers. They acknowledge that traditional cost estimating models are not structured adequately to support concurrent engineering. The uncertainty of information at the early stage of process planning hinders the accuracy of the estimates, which limits the accuracy of the early design cost.

2.2.2 Concurrent Engineering in the Aerospace Industry

Funke (1997) reviews the implementation of various concurrent engineering techniques and their objectives in the aerospace industry. The following list of techniques are cited as the tools falling under the umbrella of concurrent engineering, and that are being used by the major aircraft manufacturers:

Integrated Product Teams (IPT)
Digital Product Definition (DPD)
Digital Pre-assembly/Mock-up (DPA)
Computer Integrated Manufacturing (CIM)
Lean Manufacturing (LM)
Design for X-ability (DFX)
Total Quality Management (TQM)
Quality Function Deployment (QFD)
Supplier Involvement on Product Team (SI)
Customer Involvement on Product Team (CI)

He provides significant references from industry sources to illustrate the benefits of concurrent engineering to the aerospace industry. Examples of these are:

- Boeing 777 Commercial Airliner: A 50% reduction in engineering changes due to engineering errors was achieved. Techniques used: IPT, CI, SI, DPD, DPA, DFX, CIM.
- McDonnell Douglas C-17 Transport: Saved $68M due to common automatic test equipment, and reduced the number of parts and fasteners on the cargo door assembly. Techniques used: IPT, CI, SI, DFX, TQM, LM, QFD.
- British Aerospace: BAE Airbus 146 Wings: Development time was reduced from 36 to 18 months. Techniques used: IPT, SI, QFD, TQM, LM.

These examples serve to illustrate that the aerospace industry has taken up the challenge of concurrent engineering as an important part of their strategy to maintain competitive in the global market. Evidence shows that each of the major aircraft manufacturers is utilizing some of the techniques described here.

2.2.3 Integrated Product Teams (IPT)

A common thread in the examples of improvement due to concurrent engineering is the use of Integrated Product Teams or their equivalent. Funke (1997) describes how the Boeing company approach has evolved from Design Build Teams (DBT) to Integrated Product Teams (IPT). The Evolution of Product Development Teams at Boeing started with separate functional groups working sequentially. The next stage was Design/Build Teams that worked functionally to develop airplane structural sections or systems. The DBTs evolved into Integrated Product Teams, which were cross-functional teams that had responsibility to integrate all airplane structures within a product such as a wing or fuselage section. IPTs also have the responsibility of ensuring integration between products such as the wing to body join. The desired future path is for these IPTs to take on the characteristics of high performance teams (Funke, 1997).

Fallon and Garbo (1995) describe how Boeing-Sikorsky Helicopters used Integrated Product Teams to achieve higher mission goals on the RAH-66 Comanche helicopter. The improved mission performance was achieved by using advanced composite materials to replace parts that were previously made using sheet metal. The advantage of the IPT approach was to integrate the design requirements with manufacturability requirements at an early stage of the program.

Iden and Pham (1995), review the process of fabricating the Boeing 777 composite empennage. Boeing used integrated Design-Build Teams that included representatives from engineering, tooling, operations technology, manufacturing engineering, quality assurance and other departments. Their common goal was to design and build a cost effective and high quality product. They point out the advantages of this team-working environment in resolving many potential problems early in the program, resulting in a smooth transition from design to production.

Funke (1997) described the critical success factors for the IPT approach as follows:

- building inter-team integration into the organization,

- management support for the culture change,
- empowerment of the teams,
- functional diversity of the team, including inputs from vendors/suppliers and operators/customers,
- rewards/compensation should recognize the evolution of employee development in the team,
- teams should have budget authority,
- costs should be collected by product and by function, in order to let the team know whether they are on track or not,
- team leaders should be selected for their team and technical skills, as well as administrative ability,
- work teams should be product oriented, have cross functional membership, be co-located, and membership must be stable over time,
- team processes should be tasked using a work breakdown structure or integrated master plan, and
- teams should have access to all the information they require.

Relevant to this work are the factors related to product and function cost tracking, work breakdown structure, and access to information. The DDSS methodology serves to fulfill each of these requirements, by searching for costs related to each product using a work breakdown structure (driven by the process, or activity plan), thereby providing the design team with the information they need.

2.3 Design for Manufacturability

2.3.1 Definition of Design for Manufacturability (DFM)

Design for manufacturability is an approach to design practice that encourages designers to consider the consequences of every specification on the manufacturing process to make the product. The philosophy calls for design engineers to work closely with manufacturing engineers and production planners, to gain a better understanding of the impact of their designs. There has been considerable work in this field, with several authors providing methodologies to simplify designs, and thereby make them easier to produce. Boothroyd and Dewhurst (1987) promote a Design For Assembly (DFA) philosophy that components should be simplified by making them easier to assemble, or by reducing the parts count. Their two step procedure is first to apply specific criteria to each part to determine whether it needs to be separate from all other parts in the assembly, and then to estimate the handling and assembly costs for each part. They differentiate between component- or part-DFM, versus product-DFM. Part-DFM is focused on making a part easier to make, once the component form and functions have been decided. Product-DFM looks at the more basic design problem, to determine what changes could be made to the product structure to reduce the manufacturing cost of the whole product (Boothroyd & Dewhurst, 1991).

McCusker and Walleigh provide a review of some guidelines applied to achieve cost reductions in manufacturing; these are summarized as follows (McCusker & Walleigh 1993):

- **Reduce the number of parts:** each part represents another opportunity for a quality defect in fabrication and assembly. The chances of producing a perfect product decreases geometrically with increasing numbers of parts. Reducing parts count has a direct effect on the number of inventory items carried. Savings can be achieved in reduction of inventory, and on the cost of purchase transactions.
- **Reduce the supplier count:** rather than using multiple vendors to get discounts, work closely with a few well qualified vendors who get to know and understand your quality needs.
- **Mistake-proof the Assembly Design:** the Japanese technique of *poke-a-yoke* involves designing products so that they can only be produced the right way. If it is possible to assemble it wrong, at some stage it *will* be made wrong. Obvious quality benefits are the defects that are prevented; costs can be reduced because there is less need to document assembly procedures and inspect for defects. It is also easier to train production workers, and it makes their jobs easier.

- **Simplify and automate the assembly process:** robots have less than human capability to adjust and correct for mistakes in assembly. Automated production processes must be designed to consist of simple movements.
- **Facilitate ease of testing:** most products require some form of verification or quality inspection. Build this into the design up-front, not as an expensive afterthought.
- **Use common components and processes:** using existing parts and known methods is cheaper than designing and making new parts.
- **Avoid excessively tight tolerances:** in general, it is more expensive to make something with a small tolerance than with a larger tolerance. Set the tolerances according to the functionality required, and if it possible to change the design to allow greater tolerances, then do it.
- **Use modular designs for flexibility:** market demands for a greater number of products should be balanced against the cost to make special options. Modular design enables components to be replaced later without changing the rest of the design.

2.3.2 Design for Manufacturability in the Aerospace Industry

The principles of DFM are widely generalizable; the aerospace industry has applied them to achieve major cost savings, especially by reducing parts count. Mietrach (1991) noted the case of a large transverse nose frame in a Boeing YC-14 aircraft. The original design consisted of 400 detail parts and 2000 fasteners. They were able to replace it with a single-piece aluminum casting using an improved design. Other DFM successes are given by Sahr, et al.(1997), and Herrera (1997).

Herrera (1997) describes how the Design For Manufacturing and Assembly (DFMA) approach achieved significant cost and weight savings in several redesigned areas of the Longbow Apache Helicopter. The DFMA method was applied using Boothroyd Dewhurst, Inc.'s proprietary DFMA analysis software program. This software analyzes the design, manufacturing, assembly process, and the materials used. It then produces recommendations to improve the design using DFMA principles. For the system considered (the instrument panel of the pilot and co-pilot), the parts count was reduced by 87%, fabrication time reduced by 93%, assembly time was reduced by 94%, weight was reduced by 10%, and the cost was reduced by 74%. They point out that for the DFMA process to be successful, it is essential to use the concurrent engineering philosophy of using integrated teams having knowledge of engineering, manufacturing, suppliers, product support, and quality to develop the product design. Herrera states that:

> "to maximize the benefits of DFMA the designer must have a good knowledge of the manufacturing processes available, and process capabilities to produce the part. The design and manufacturing elements must work closely to determine the best manufacturing approach, which then heavily influences the design approach." (Herrera, 1997)

Data requirements to carry out this study were onerous. Producibility analyses, design concept descriptions and lists, weight data analysis, schedules of the design and manufacturing plans, cost estimates and detailed DFMA plans on at least four different assemblies were used to assess the impact of DFMA on the process. The article also refers to the benefits of high speed machining (HSM), composite design, and superplastic forming in reducing parts count by rapidly creating complex geometrical parts usually designed with many mechanically fastened sheet metal parts. Herrera (1997) points out the significance of reducing parts count:

> "Reducing parts count cascades into savings in other areas. For example, it reduces part cost, fabrication and assembly time, and reduces tool design and fabrication cost. The tooling manufacturing process can be eliminated (for HSM) since the designs are transferred directly from the CAD system to the high speed NC machines."

Scoville (1997) identified the following areas where savings are achieved through parts count reduction. In this case, Boeing reduced the number of parts by using complex aluminum castings instead of multiple-part sheet metal assemblies. These benefits could apply equally for composite parts in the aircraft industry:

<u>Recurring costs</u>
raw material
labor (manufacturing & inspection)
rework
scrap
inventory (cycle time reduction)

<u>Non-recurring costs</u>
design
tooling
structural testing
part qualification
manufacturing planning (detail, assembly, installation)

These are broken down into recurring costs and non-recurring costs to show the significance of non-recurring costs to reducing engineering, development, and tooling costs. There are obviously some cost trade-offs to consider, as the design of complex integrated structures also requires considerable effort. Not mentioned here, but a significant saving in the lifetime operating cost of the aircraft, is the saving in reduced numbers of spare parts necessary to be carried. Logistics support for maintenance is a major part of the life cycle cost of an aircraft.

2.3.3 Cost Information to Support Design for Manufacturability

Boothroyd and Dewhurst identified the need for early product cost estimates, in order to make better decisions early in the design process. Once the design configuration has been "locked in" it is more difficult and expensive to make changes. They also identified the failure of most companies' costing systems to get *early* cost estimates. Difficulty in getting early cost estimates is often due to the manner in which costs are handled by standard cost systems. It is only possible to get cost information once a product has been designed, detailed, and a prototype built. By this time, it is too late for "product design for manufacturability;" all that is left is "fine tuning" of the production process to make the part, albeit more efficiently. Boothroyd and Dewhurst criticize some other cost estimating efforts as being misdirected; stating that:

> "...there is much interest in having product DFM and DFA techniques available on CAD/CAM systems. By the time a proposed design has been sufficiently detailed to enter it into the CAD/CAM system, however, it is too late to make radical changes. …A conflict thus exists. On the one hand, the designer needs cost estimates as a basis for making sound decisions; on the other hand, the product design is not sufficiently firm to allow estimates to be made using currently available techniques. The means of overcoming this dilemma is another key to successful product DFM - namely early cost estimating." (Boothroyd & Dewhurst, 1991).

They suggested a simple activity-based costing approach, which was made available in their proprietary software product. The methodology was to capture the main features of a given design, and use a simplified process plan. The product costs were then calculated using known costs for the given processes. The model relies on the basic models of each process being known to the system, in the form of a machine tool database and a material database. These would include processing rates, cost rate for using a machine, and costs of materials. This would be a very good solution for simple items, with well-developed models for the relationship between design parameters and cost. In many industrial-manufacturing environments, there is a significant gap in this knowledge. Unless the company is able to isolate all direct and indirect costs associated with a production process, they are unlikely to have accurate cost data about products coming out of that process. The lack of knowledge in this area has been well documented in the cost management literature. This is one of the motivations to use activity-based costing instead of standard costing, that is, to provide more accurate allocations of overhead costs, and thereby improve the accuracy of product costing. The activity-based costing method seems to be the best way to isolate costs for a particular activity or process. The problem may be that not all companies have the resources, or the necessity, for a complete activity-based accounting system.

Design for manufacturability is a major motivation for this research; a clear need for better manufacturing cost information exists, and it is not satisfied by traditional cost estimating methods.

2.4 Cost Accounting Practices

2.4.1 Changes in Management Accounting Methods

In their book, *Relevance Lost: The Rise and Fall of Management Accounting*, Johnson and Kaplan (1987) described the historical development of management accounting methods, and the failure of the profession to change methodology in response to major structural changes that occurred in industry. They showed that traditional cost accounting systems have failed to accurately report product costs, because they were designed to report inventory costs, and they had not been modified to account for changes in production methods from labor intensive, to capital intensive methods. Furthermore, the information collected for financial reporting procedures, was “too late, too aggregated, and too distracted to be relevant for managers’ planning and control decisions."

A major cause of cost distortion was the use of aggregated categories to allocate overhead cost to cost centers. The traditional methods of cost accounting use volume-based measures such as labor hours, machine hours, or material cost to allocate overhead costs to products. While these volume bases were effective when these were significant measures of cost consumption, the increased use of automated machinery, and significantly higher overhead costs, resulted in severe cost distortions.

Traditional cost accounting systems are often unable to identify costs of non-value adding activities, because these are hidden in pools of general overhead cost. Production costs are most often aggregated by functional groupings of the organization, rather than by process outputs, making it difficult to analyze the cost of each process or activity.

Activity-based costing (ABC) methods were developed as an alternative solution to the problems of cost aggregation. Activity-based costing differs from traditional cost accounting in selecting more numerous, and more appropriate bases for cost allocation. By using smaller cost pools to capture all of the inputs into a particular process, the cost per unit of output of that process or activity can be found. The use of smaller cost pools, and multiple cost drivers to allocate these costs, is shown to be more accurate for product costing.

H. Thomas Johnson uses a powerful analogy drawn from Plato's Allegory of the Cave (Johnson, 1991) to illustrate the extent of the cost distortion. In his analogy, Johnson compares the relationship between post 1950's financial management (using standard costing) and activity-based management, to the condition of prisoners who have lived all of their lives in an underground cave. The only images the prisoners in the cave see are the distorted shadows of people on the other side of a barrier, projected onto the roof of the cave by the light of a flickering candle. The first time these people are allowed out of the cave into sunlight, they see objects and each other clearly for the first time.

Johnson likens the standard costing figures to the distorted shadows on the wall, projected there by people (management accountants) working behind a barrier, manipulating objects and resources to create the shadows. For the people living in the cave, say financial accountants and managers, these figures represent the only reality they have ever experienced. Only when they have attained a true state of enlightenment, by being exposed to the light of the real world outside, are these people able to see the actual objects and resources that were manipulated to cast the shadows on the wall. Johnson infers that activity-based management allows managers to observe the actual activities and resources consumed, and to make decisions based on a new vision of reality, which was not previously available to them.

This analogy emphasizes the necessity for the paradigm shift required in management accounting thinking. As long as managers were using the distorted figures to make decisions on the activities of the business, their decisions were likely to be flawed, and result only in improvements in the distorted figures. Only by using an accurate vision of the enterprises activities can they hope to make good business decisions.

It was alleged that using financial accounting information to plan and control business activities contributed to declining competitiveness of U.S. manufacturing businesses. This resulted from a tendency to focus on short term profits, rather than pursuing long term strategies of investment and research into more effective and efficient manufacturing systems (Hayes & Abernathy, 1980). This has been used to justify the importance of *activity-based management*, which seeks to extend the use of activity costs by decision-makers in the company. By using activity costs to measure each business process, decision-makers can focus their efforts for continuous improvement on the areas that need it most. Improving product cost accuracy helps an organization to compete more effectively in the marketplace. Strategic cost management is offered as the logical next step from activity-based costing/ activity-based management (Shank & Govindjaran, 1993). They argue that limiting the method to only the internal processes of the company, is to miss opportunities to position the company with respect to its competitors.

2.4.2 Definitions / Terminology

In order to describe more completely the techniques and objectives of activity-based management, the following operational definitions are useful. They are taken from the Glossary of Activity-Based Management (Raffish & Turney, 1991):

Activity-based costing: A methodology that measures the cost and performance of activities, resources, and cost objects. Resources are allocated to activities, then activities are assigned to cost objects based on their use. Activity-based costing recognizes the causal relationship of cost drivers to activities.

Activity-based management: A discipline that focuses on the management of activities as the route to improving the value received by the customer and the profit achieved by this value. This discipline includes cost driver analysis, activity analysis, and performance measurement. Activity-based management draws on activity-based costing as its major source of information.

Target Cost: A cost calculated by subtracting a desired profit margin from an estimated (or a market-based) price to arrive at a desired production, engineering, or marketing cost. The target cost may not be the expected initial production cost. Instead, it may be the cost that is expected to be achieved during the mature production stage.

Target Costing: A method used in analyzing product and process design that involves estimating a target cost and designing the product to meet that cost.

Value analysis: A cost reduction and process-improvement tool that utilizes information collected about business processes and examines various attributes of the processes (e.g. diversity, capacity, and complexity) to identify candidates for improvement efforts.

Value-added activity: An activity that is judged to contribute to customer value or satisfy an organizational need. The attribute "value-added" reflects a belief that the activity cannot be eliminated without reducing the quantity, responsiveness, or quality of output required by a customer or organization.

Non-value-added activity: An activity that is considered not to contribute to customer value or to the organization's needs. The designation "non-value-added" reflects a belief that the activity can be redesigned, reduced or eliminated without reducing the quantity, responsiveness, or quality of output required by a customer or organization.

2.4.3 Activity-Based Costing vs. Activity-Based Management

Brimson (1991) describes more completely the methodology of *activity accounting* in the following steps:

1. "Determine enterprise activities.
2. Determine activity cost and performance. Performance is measured as the cost per output, time to perform the activity, and the quality of the output.
3. Determine the output of the activity. An activity measure (output) is the factor by which the cost of the process varies most directly.
4. Trace activity cost to cost objectives. Activity costs are traced to cost objectives such as products, processes, and orders based on the usage of the activity.
5. Determine corporate short-range and long-term goals (critical success factors). This requires an understanding of the current cost structure, which indicates how effectively operating activities deliver value to the customer.
6. Evaluate activity effectiveness and efficiency. Knowing the critical success factors (step 5) enables a company to examine what it is now doing (step 4) and the relationship of that action to achieving those goals (Brimson, 1991)".

Steps 1 through 4 could considered to be the *activity-based costing* method, while the expansion of these methods through steps 5 and 6 describes the broader scope *activity-based management* methodology, whereby management uses the information gained from the activity-based costing system to make better strategic decisions. Brimson (1991), also provides guidance on how to structure the activity accounting systems, and how to gain the most effective use of the information coming out of the systems. Activity accounting is a relatively simple methodology to apply, and helps companies in their efforts to continuously improve their operations. In Section 4.6, an implementation guide is provided to show how the Design Decision Support System methodology could be introduced in a given manufacturing setting.

The methods of ABC and ABM have been shown to be successful in more accurately allocating costs to products, and are also valuable for analyzing the effectiveness of activities performed by companies. There is a considerable amount of quality literature in the field. The *Journal of Cost Management* is a primary source for articles, which have covered almost every aspect of targeting systems for improvement, designing, developing, and implementing ABM systems in industry. Other references which are essential readings in activity-based cost/management topics are *The Handbook of Cost Management* (ed. Brinker, 1995), and *The Design of Cost Management Systems* (Cooper and Kaplan, 1991). The justification for the activity-based methods has been established. Successful applications of the methods have been shown. Some expansions of the ABC/ABM topics include design-for-manufacturability (Boothroyd & Dewhurst, 1987 and 1991; McCusker & Walleigh, 1993), target costing (Aalbrechtse, 1993), value analysis (Dieter, 1983), and strategic cost management (Shank & Govindjaran, 1993). There have been some articles which detail the shortfalls in some ABC/ABM implementations. These are indicative of the difficulties faced by smaller companies faced with the high threshold cost to implement the method, and provide justification for the development of systems which can provide some of the same advantages as an ABM system, at reduced cost.

Each of the topics outlined above are expanded in the following sections, together with the application of these techniques in industry, and problems faced by practitioners implementing the techniques.

2.4.4 Target Costing

Aalbrechtse (1993), provides an alternate description of the target costing concept as "the maximum manufactured cost for a given product; a cost that will allow an expected return to be earned within a given market niche and also allow the product to gain market share." The benefits of adopting target costing are to reduce product costs, to get products to market faster, and to reduce uncertainty about new product launches (Aalbrechtse, 1993). The means for achieving this goal are to first assess the customer requirements, and how much they are prepared to pay for the product. Next, define the expected cost structure for producing the design, i.e. the desired profit margin, the organization's overhead costs, production process costs, and resources that will likely be consumed. The next step is to identify major cost drivers in the design itself, i.e. the effect of changes in various design parameters on the cost. Lastly, the method relies on feedback from the process to foster continuous improvement in the process. The benefits of target costing are in focusing efforts to achieve improvements in the areas that will have the most effect on the process.

The Consortium for Advanced Manufacturing International (CAM-I) has identified target costing as a key area for improving the effectiveness of manufacturing enterprises. In a recent CAM-I study of how major US-based companies are using target costing (Answari et al., 1997), they emphasized the "voice of the customer" as a key input to the product development cycle. Boeing, as one of the consortium members, provided specific examples of product innovations that were incorporated in the Boeing 777 airliner using feedback from airlines (intermediate customers) and passengers (ultimate customers). CAM-I defines *value* as the difference between the benefits received and the costs incurred by the customers in getting those benefits.

The CAM-I study also links target costing to other elements of effective management strategy. They identify value analysis, quality function deployment, design for manufacture and assembly, benchmarking, process costing, component costing, and value chain management as core tools of target costing. Others may not agree on target costing as the umbrella term that covers all of these techniques, target costing is more often seen as one of the techniques in the arsenal available to managers in the quest for continuous improvement.

In a broader sense, target costing should form part of a company's product design strategy, where the designers start out with the expected cost for the product, and work backwards to fit the production processes to meet that goal. The military aircraft programs in this country are examples of this approach, where the military has an idea of the functions they want in an aircraft, and also of how much they can spend. The aerospace manufacturers have to attempt to meet those requirements, imposing cost targets on each portion of the design program. Target costing is often associated with value analysis and other techniques for achieving continuous improvement in organizations. CAM-I (Answari et al., 1997) identified the main sources of information needed for target costing as: the competitive intelligence data base, the marketing data base, the cost data base, the engineering data base, and the procurement data base. They defined further the information for each of these categories, summarized here:

- Competitive intelligence: competitive price and feature information and competitor cost structure information.
- Customer/Marketing data: product life cycles, feature vs. price data, attribute vs. price data, and improvement ideas from customers.
- Cost data: feature (customer focussed) vs. cost data, attribute (engineering properties/characteristics) vs. cost data, and function vs. cost data. To provide this cost information, the costing system must be able to separate out costs for different parts of the product, different manufacturing processes, and the various features of a product (CAM-I notes here that activity-based costing methods are best suited to filling this need).
- Engineering data: technology life cycle data, component/subsystem interaction data, value engineering case studies, and artificial intelligence driven design rules.
- Procurement data: suppliers' cost structure, margins and performance data.

Each of these categories is relevant to the objectives of the DDSS methodology. Companies need their information systems to collect this information and to present it to decision-makers. Not all current information systems were designed with this capability; a supplementary methodology to seek out the relevant information and present it to users in the desired form may be useful to many companies looking to improve their competitive position.

2.4.5 Value Analysis

Value analysis originated as an engineering design method to evaluate the functionality of products with respect to the cost to make them. It considered functions defined from the customer/ user perspective, as opposed to the designers' perspective (Dieter, 1983). The fundamental questions asked during value analysis could be rephrased for manufacturing organizations:

- How can a given requirement of the customer be satisfied at the minimum cost?
- What is the value of each process or activity of the organization to satisfying the customer's requirements?

Further analysis of processes could then be achieved by further questions:

- Can one do without this process/activity?
- Does the process do more than is required?
- Does the process cost more than it is worth to the customer?
- Is there some other way to do the job better?
- Is there a less costly way to satisfy the customer?
- Can one outsource the process or function to the benefit of the customer, as well as the organization?
- Is this process one which this company should be doing, or can someone else do it better?

Quality Function Deployment (QFD) is a recent implementation of the value analysis principles. QFD maps the customer requirements to design attributes, and attempts to quantify how much the customer requirement is satisfied by each design requirement. Analysis of the costs of satisfying each design requirement should also be linked to the customer requirements, and whether the customer perceives value in that process step. This is the key to determining if a process is value-adding or non-value-adding. The question that should be asked is; *If the customer doesn't need it, and it adds to expenses, then why do it?* Answering this question, and executing the value analysis outlined above, requires a decision support system that is capable of providing the cost of each process, and some measure of the value added for the customer.

Johnson and Sapp (1992) write of "process-based information" as a means for management to maintain competitive advantage. They identify this tie-in of activity-costing and process-based information with value analysis and QFD:

- "For each product sold, identify the processes that must be performed to satisfy the customer. Be sure to perform those processes. This is the key concept in QFD.
- In all processes, identify all sources of delay, excess, and variation that cause waste and impede continuous flow.
- Embark on programs to cut lead time and improve flow.
- Track indicators of time and waste to confirm the success of these programs and to motivate people to do more. ‘Chart on the wall’/ visual display of performance indicators.
- Calculate product costs by adding up the costs of activities it takes to design, engineer, make, distribute, sell and service each product. To do this, use the full arsenal of techniques associated with the concept of activity-based costing."

The DDSS methodology could be used as an extension of current systems to provide this information, by tapping into the existing resources of the company, and restructuring the information in a useful form.

2.4.6 Strategic Cost Management

Shank and Govindjaran (1993) criticized ABC/ABM and the value analysis techniques used by ABC/ABM as “starting too late, and stopping too early,” in that they only focus on activities within the company, and do not address upstream and downstream systems. They argued the fundamental importance of the *value chain*, which was proposed by Porter (1985), as a tool to enable companies to develop strategy for competitive advantage. Porter describes the value chain as an analytic tool which “disaggregates a firm into its strategically relevant activities in order to understand the behavior of costs and the existing and potential sources of differentiation.”

Shank and Govindarajan (1993), describe the methodology to construct and use a value chain in three steps:

1. Identify the industry's value chain and assign costs, revenues and assets to value activities.
2. Diagnose the cost drivers regulating each activity.
3. Develop sustainable competitive advantage, either through controlling cost drivers better than competitors or by reconfiguring the value chain.

The value chain displays total value of a product or service, and consists of *value activities* and *margin*. To describe the value chain, the firm must first define the main activities carried out by the firm. These are separated into primary activities directly concerned with the provision of the product or service and its distribution to the customer, and support activities which enable the primary activities to take place. The margin is the difference between total value and the cost of performing all of the value activities (Porter, 1985). A firm gains competitive advantage by performing the strategically important activities more cheaply or better than its competitors. From the customers' perspective, value is created when a firm creates competitive advantage by either lowering the customers' cost for the service, or by increasing the performance of the product from the customer's perspective. By careful analysis of both the value chain and the company's strengths, management should be able to better decide where they can best exploit their strengths for competitive advantage (Porter, 1985). They may also develop strategic partnerships with other suppliers, their distribution channels, and their customers, to create linkages that will ultimately create value for the customer.

Johnson and Sapp (1992) suggest that the management information system for the future should enable management to analyze the value chain:

> "Focus management attention on the underlying causes of cost and profits. It comprises any relevant information about the processes across the entire chain of value – design, engineering, sourcing, production, distribution, marketing and

after-sale service. Identify activities that consume resources but do not add value to the customer."

Relative to the current research, the strategic positioning of companies is strengthened by creating better products than their competitors, for the same or less cost. It is in this area that early design cost estimating can produce a competitive edge, by optimizing the value-to-cost ratio for the customer.

2.4.7 How Companies Use Information from ABC/ABM

There are numerous articles and case studies outlining the benefits of implementing ABC/ABM in manufacturing and service operations. Maisel and Morrissey (1993) summarize some key expectations from implementing an ABC system. Brimson (1991) lists ways that activity accounting can be used to help a company. The following list is compiled from these sources as the key areas for improvement to be gained from ABM techniques, and where the information is most frequently used by companies:

- To identify which products make the most profit or loss.
- To identify which activities support complexity of the product line or customized products for specific customers.
- To identify which activities can be performed more economically or restructured to create greater value for the customer.
- To identify performance measures to achieve manufacturing excellence, which can be used to spur the continuous improvement of business processes.
- To provide feedback on the effects of actions that are implemented, that is, “Were the anticipated results obtained?”
- To identify the costs of quality (including costs for prevention, inspection, and costs of product failures).
- To identify the non-value adding portion of procurement costs.
- To identify costs of support operations included in the cost of getting the product to the customer (material handling, maintenance, marketing, engineering).

- Use information to improve “make/buy” decisions, and more accurate assessment of product life cycle costs.
- Use information for strategic product decisions, and link these to the analysis of operational activities.

2.4.8 Difficulties in Implementing ABC/ABM

Consultants have had mixed success in implementing ABC/ABM projects. There are many accounts of successful implementations, but relatively few on the failures. This is possibly to avoid embarrassment of either the consultants, or of the “bad” clients. There are several articles detailing “war stories” of typical problems experienced. This section summarizes a series of articles by Player and Keys (1995a, 1995b, & 1996) which provide a thorough review of the warning signs, hazards, and recommendations to achieve success. These sets of pitfalls were identified from interviews with fifty practitioners who were implementing ABM, users of ABM information, ABM consultants, and managers who had rejected ABM. The first set of warnings relate to the overview of the project, and share some common failings of improvement projects in organizations (Player and Keys, 1995a):

- Lack of Management buy-in: this results in little commitment to the project at any level, with a resulting lack of resources made available for the project.
- Failure to understand the three views of costs: companies need to understand the different needs and uses of information (namely: *Financial:* Financial accounting, Inventory valuation; *Operational:* e.g. performance indicators, value/non value added, process improvement; and *Strategic:* e.g. target costs, investment justification, life cycle cost, make/buy decisions).
- Lack of clear objectives: similar to lack of buy-in, if the client is not sure why they need the system, maybe they don’t need a new system.
- Lack of ownership: typically a financial person heads the ABM project, which leads to lack of buy-in by users. Cross-functional teams should be used to accurately model the organization/system, and promote wider involvement in the project.

- Lack of resources: adequate resources must be available for employee involvement; monetary support; a substantial investment in software; expertise; and training for users of the system.
- Don't try to sell a ready made solution: each case is different. The ABM system must reflect the goals of the company management, not just the consultants.
- Lack of Cost Management Expertise: the project needs an in-house expert on ABM to guide the process.
- No link to or other management initiatives: where the ABM system can support other improvement efforts e.g. JIT, TQM, BPR, they should be designed to do so.

There are problems associated more specifically with the design of the system itself. These are useful guidelines for system designers, and provide key pointers on why some systems have failed (Player and Keys, 1995b, 1996):

- Failure to begin with a pilot project: start with a target system which is ripe for ABM; build success, identify and correct mistakes faster, get a small system working.
- Too much detail: work on how much detail is necessary, rather than on how much can be obtained. The more detail included, the greater the cost to implement and maintain the system.
- Too little detail: company changes from old cost system to a multiple pool, multiple driver cost system which is much better than the old system, but still does not provide enough information to manage activities in the company.
- Problems collecting data: activity definitions not well defined, data reliability in question, expensive and time consuming methods of data collection (e.g. surveys).
- Inaccurate assignment of costs of activities to products: costs are allocated to cost objects using drivers which do not seem rational to users.
- Unavailability of detailed data: task level data is not maintained, and summary detail does not allow item-by-item cost tracing.
- Costs assigned to the wrong year: need to use life cycle product costing, which conflicts with financial accounting treatment (recognizes costs in the period incurred).

- Software problems: difficulties integrating ABC software with other systems.
- System is too costly to maintain: ABC/ABM systems are expensive to maintain, requiring revisions to reflect continual changes to the organization. Compared to traditional standard costing procedures, these systems have a high overhead cost, and require considerable more data inputs.
- Poor project management: results in project running over budget, not being delivered on time, and not performing to expectations. There are a number of important factors affecting project management, which are common to improvement efforts requiring major changes in an organizational system. Examples are individual and group resistance to change, lack of a clearly defined implementation plan, and lack of resources available for the project.

2.4.9 High Cost of ABC/ABM Systems

There is a danger for ABC systems to be prescribed as the solution to all problems. H. Thomas Johnson complained that ABC has been oversold (Johnson, 1992), and that companies should be more aware of the cost to benefit ratio of these systems. The potential benefit of ABC/ABM techniques should be weighed against the cost of obtaining the information. A recurring theme in the potential pitfalls for activity-based management systems is the high cost of designing, installing and maintaining these systems. Allied to this are the problems with getting and keeping human resources assigned to the project, and top level commitment to the project. An overriding concern for companies considering the implementation of such systems should be the cost benefit of collecting all of this information. The key question to be asked is “How much is enough?” or “Do the potential benefits exceed the cost of getting this information?” Systems need to be tailored to suit the needs of the organization. The high threshold cost of implementing ABM techniques is a barrier to many of the smaller companies that cannot afford the expense of these systems, but would benefit greatly from using the techniques. This DDSS research is directed at this sector of the industry. These companies need the ability to get accurate early design cost estimates, but may not have the resources to implement large scale organizational ABM.

2.4.10 Application of ABM Techniques for this Research

The methods of Activity-Based Costing, Activity-Based Management, and some of the associated techniques, have been shown to overcome some of the failings of traditional cost accounting approaches. ABC/ABM provide more accurate methods of allocating costs to products, using smaller cost pools, and using more numerous and appropriate bases for measuring the costs of activities.

McNair suggests the following design features for matching accounting to the production process (summarized from McNair, 1993):

Regularity: Whether the same products are made on a consistent basis. If so, the costing problem is simplified.

Complexity: The level of interdependence between production of various component parts, and the final product. The number of parts and products being made. Each of these adds considerably to the difficulty of tracking costs for each

Linearity: Is product flow from the plant is smooth, yielding predictable output of good units? Stable flow makes it easier to assign costs accurately.

Flow characteristics: Are products made singly, in batches, or continuously? This determines the types of cost incurred, which should be reflected in the cost accounting system.

Variability: How does variation in activity volume affect the use of resources? This guides the types of estimates and cost accounting assumptions used in the system.

Capacity: What is the effective versus utilized capacity of the equipment? The impact of bottleneck resources should be factored into the cost estimating system.

Controllability: To what degree is the cost controllable or affected by decisions at that level? Costs that are unavoidable (at a certain level) should be clearly indicated as such.

Capability: The system needs to reflect not just the current resources being utilized, but should recognize in some manner the degree of idle resources in the plant, and their cost.

Type and proliferation of automation: New forms of technology radically influence change the manufacturing process and the cost structure of the company. Increased automation results in increased fixed costs; this may create significant costing distortions if incorrectly allocated.

Structure of the support systems: What is the support structure of the firm? Cost system must determine how this affects the cost and value of these services to internal and external customers.

Target costing, value analysis and Design for Manufacturability provide useful extensions of the methods into the engineering design activities of companies. By using these techniques to guide product design, companies can set goals to provide greater value to their customers. Design for Manufacturability identified the difficulty in obtaining early cost estimates as a major obstacle to implementing the methodology. It is this need that provides the justification for this research. This cost estimation methodology is intended to provide aircraft designers with a better understanding of the impact of their decisions on the manufacturing cost of the aircraft.

Strategic Cost Management identified the need to look beyond the company's internal systems when applying the methods of ABM and value analysis. Companies can use this approach to make better strategic positioning decisions, including the upstream and downstream systems in the *value chain* from supplier through to the ultimate consumer of the product or service. The emphasis of the customer perspective is an important consideration when configuring the value chain; an activity is only valuable to the customer if the product value is increased, or if the cost of the product is reduced.

In the area of composite manufacturing cost estimation, activity-based costing could be applied to all of the activities involved in producing a part. These activities include design and engineering, production planning, through to procurement of materials, and all subsequent process activities involved in fabricating the part, and getting it to the customer, or assembling it to the aircraft. Analysis of the activities would determine the value-adding processes and non-value-adding processes. These could be mapped to the functional requirements set by the customer, in order to optimize the design choices.

The advantages of using ABC/ABM methods were shown, together with some of the typical uses of the information. Some of the difficulties of implementing ABC/ABM systems in industry were described. Two main obstacles to implement the methods are the high threshold cost and difficulties getting commitment of resources to design, implement, and maintain the systems. When considering the value of an ABC/ABM system, the key question to be answered is whether the consumer of the product or service will gain from the implementation of the techniques. The benefit of the system must outweigh the cost to implement it, or provide the potential to achieve greater benefits in the future. The DDSS methodology used here overcomes these obstacles of high cost and resistance to major change by limiting the intrusiveness of the system. The method seeks out cost information in organizational databases without changing the underlying accounting information system or production information databases.

2.5 Manufacturing Cost Models

2.5.1 Parametric Cost Models

The Rand Corporation model for the Development and Procurement Costs for Aircraft (DAPCA IV model, Hess & Romanoff, 1987) is the standard for weight-based cost estimating relationships. This model uses the historical database for 34 previous military aircraft program costs, and derives a series of exponential curves from multiple least-squares linear regression analysis of the data. These are fitted to the data to extrapolate the costs for some given aircraft configuration. Program costs are subdivided into separate cost estimating relationships for engineering, tooling, manufacturing labor, manufacturing material, development support, flight testing, and quality control. The hours estimated by these are multiplied by average hourly rates for the various labor skills. For consideration of materials other than aluminum, cost can be adjusted using modifying factors for the new technology materials. The developers point out their own limitations in estimating costs of future aircraft, due to the influence of rapid changes in technology. They make specific note of the following:

> “airframes are changing dramatically with respect to materials (e.g., more extensive use of composites), design concepts (e.g., concepts to increase fuel efficiency and

to reduce radar cross section), and manufacturing techniques (e.g., use of computers and robots). We believe that the material and design changes will act to increase unit costs but we are uncertain about the net impact of capital equipment changes." (Hess & Romanoff, 1987)

This is a critical issue in the consideration of composite materials for aerospace applications. The fundamental assumption of these models has been that increasing weight of aircraft results in increasing cost. Even the modifying factors are just multipliers of the existing cost estimating relationships. These assumptions are at odds with the concepts of design for manufacturability, which promotes reducing the parts count and careful consideration of manufacturing process tolerances, as a key strategy to reducing the cost of the design.

There are examples of where the relationship between cost and weight may not be a smooth function, but one that has significant step increments moving from one type of production process to another. Factors such as the size constraints of a manufacturing system, and the company's investment in advanced machinery are factors that are not considered by the model, except as a multiplying factor for complexity, or for implementing new technology. In recent research work carried out by the author (Tyll, Eaglesham, Schetz, Deisenroth & Mook, 1996), the DAPCA IV cost model was applied to the multi-disciplinary design optimization of MAGLEV vehicles. Aerodynamic performance variables were traded off versus geometric shape and form parameters in order to optimize acquisition cost and life cycle cost to operate the vehicles. The shortfalls of the cost model were clearly shown, being largely insensitive to changes in shape/form factors, and being dominated by cost-to-weight relationships.

In an extension to the DAPCA IV model, Resetar et al. (1991) modified some of the cost indices to accommodate the use of new materials and technology. Their report describes some of the manufacturing processes and aircraft structures using advanced composite materials they expected to be incorporated into aircraft during the 1990s, and evaluates the expected cost effects of the new technology.

The report presents data obtained from surveys of airframe builders, reflecting their combined experience and cost projections using the new materials and manufacturing methods. They carried out the survey in two parts, once for the industry in the late 1980s, and then again for the mid-1990s. The results of the report are presented as modified indices to be used with the DAPCA IV model. For example, the baseline aluminum aircraft for the mid 1980s has an index of 1.0 for each of the cost categories. Using graphite/epoxy composite materials has resulting indices varying from 1.4 to 4.9. These indices are applied to a slightly modified DAPCA IV model. The model was modified first by splitting the original categories for engineering and tooling into separate recurring and non-recurring components. Manufacturing material, development support and flight test CERs were also updated from FY77 dollars to FY90 dollars. The revised model is available as an on-line calculator at the NASA cost estimating web-site (NASA, 1996a). Users are able to enter the standard parameters for the model, and a cost and weight estimate is calculated.

The model is a substantial improvement over the original for several reasons. The authors attempted to differentiate between a number of different advanced material combinations, and used more recent survey data than the original model. By splitting the engineering and development costs into recurring and non-recurring costs, they were able to include feedback from airframe builders on the amount of non-recurring engineering effort for components made of a particular material relative to the amount of effort for the same component to be made using the late-1980s aluminum baseline. They reported that on average, the non-recurring engineering hours for composites would be 40 to 70 % higher than for metals. It is interesting to note the qualitative feedback from industry sources on the expected trends for each of these categories. For non-recurring engineering hours, they expected them to be significantly higher for these reasons:

- Additional design effort is required to manage the individual composite plies, to account for the number of plies, thickness, and fiber-orientation to achieve desired properties.
- Engineers have little experience designing with the new materials, and will have to develop new analytic tools to model and test them.
- New material standards have to be developed since many properties of these materials are unknown, or unproven. Additional modeling of material properties and behavior under load conditions will be necessary.

(summarized from Resetar et al., 1991).

They also observed that the main argument for reduction of engineering hours is the anticipated reduction of parts-count, thereby simplifying the design process.

Tooling hours were also expected to increase substantially:

- higher temperatures experienced in the autoclaves require more expensive materials for tools, and greater tool design effort to ensure the desired part shapes are obtained.
- parts cannot be reworked after autoclaving; tools must be made more accurately than for metal.
- more tools may be required, because of the long processing times in the autoclave, and also the need to make (mold) tools to produce the production tools (if the tools are made from composites themselves).

(summarized from Resetar et al., 1991).

The main drawback to using this modified DAPCA IV model is that the cost estimating relationships (CERs) are still based at the program level, and are based on the cost experience of military aircraft procured over a period of 28 years. Given the political changes (with respect to military procurement programs), and economic/structural changes (with respect to manufacturing organizations and advances in manufacturing methods) experienced over that period, it would be difficult to extrapolate specific cost figures for different parts of an airframe with any confidence that the cost obtained would be accurate in today's factory. The historical costs obtained for the various aircraft programs are all based in the standard costing paradigm, and can reasonably be expected to suffer from all of the cost distortions and inaccuracies discussed in Section 2.4.1 (Changes in Management Accounting Methods). Specifically, the model could not be applied to calculate the cost of any given aircraft component, as is the intended purpose of the current research study.

2.5.2 Manufacturing Process Cost Models

The Manufacturing Process Cost Models (MPCM) include Northrop's Advanced Composite Cost Estimating Model, ACCEM (Le Blanc et al., 1976) and Manufacturing Cost Model for Composites, MCMC (Ramkumar et al., 1991), and the joint MIT and Boeing developed Composite Optimization Software for Transport Aircraft Design Evaluation, COSTADE (Mabson et al., 1994).

These models have common methodology of analyzing cost drivers in the manufacturing process level in such a way as to capture all of the costs associated with a given process, including materials, labor, overhead costs, recurring and non-recurring costs of production. These models provide more accurate cost estimates for manufacturing composites, but require detailed knowledge of processing times.

ACCEM uses three estimating modules: a factory labor standards module, a support function module, and a cost projection module. The labor standards module use industrial engineering standard time equations to calculate the times for each fabrication process. The support function module calculates the cost of engineering, tooling, quality and other services. The cost projection module uses standard costs for labor hours, machine hours and variances to multiply the process times to get product cost.

COSTADE uses much the same approach (Mabson, et al., 1994), extending the research by Gutowski, et al., (1994), and incorporating a structural optimization program. This is regarded by the developers as the “finite elements method” of product cost estimating, and requires similar levels of complexity to program and use. There have been a number of papers published to show the application of the method to different 'pieces' of the aircraft such as fuselage crown panels, fuselage side panels, fuselage keel panels, wing design, fuselage door cutouts, and fuselage splices.

A major problem with the Manufacturing Process Cost Models (MPCM) is that the programs are owned by the large aerospace companies, and the cost database contains proprietary information which they do not wish to share with their competitors, or potential competitors. From the strategic cost management literature, it is clear that accurate product costs can be used to great benefit by companies wishing to make strategic positioning decisions (Porter, 1985; Shank & Govindjaran, 1993). The same argument holds in reverse: companies do not want to give away hard-earned product cost information at any price. This creates a significant barrier to competition, in that smaller companies do not have the resources to develop these accurate process cost models, or sufficient skilled people even to utilize these highly complex models.

2.5.3 Examples of Manufacturing Cost Estimating Models in the Literature

There are numerous books and articles in the field of cost estimating for manufacturing; useful references works are: *Cost Estimators Reference Manual* (Stewart, et al., 1995) and *Cost Estimating* (Ostwald, 1984), which provide thorough reviews of cost estimating methodologies in use. These references are used in the development of the cost estimation module of this study. Recent examples of cost estimating models in the literature follow:

a. A Totally Integrated Manufacturing Cost Estimating System (TIMCES) (Wong, et al., 1992)

This article reviews some of the computerized cost estimating packages, and then provides a framework for a proposed computer integrated manufacturing cost estimating system. This system incorporates automated generation of a cost estimated using design inputs. The methodology consists of the following major steps:

- Material cost estimating: Measure shape and volume of material using inputs from design drawings and bills of material; Identify the material prices from accounting records, vendors and surveys; Find value of salvaged material; Choose material cost policy (LIFO/FIFO); and tabulate total cost of material.
- Labor cost estimating: Identify operation from production plan, machine selection, process sequence, and material requirements; Determine labor time from motion and time studies, work standards, and man-hour reports; Identify hourly reports from accounting records, personnel data; Get overhead costs; Tabulate total labor costs.
- Cost of machinery and tools: Determine investment necessary for tools; Evaluate tooling combinations and choose one with least cost.
- Cost of operations: Use part design, production plans, material specifications, tooling specifications, and standard time sheets to calculate the setup-, cycle-, and maintenance times for each operation in each of the categories labor, material and tooling.
- Overhead cost: allocated using standard labor hours, labor dollars or prime cost ratio.
- Cost of Product is calculated as the sum of all the above elements.

This model proposes to use much of the detailed costing methodology common to manufacturing cost models. It is a well structured approach, except for the retention of standard costing methods for allocation of overhead costs. The model hopes to integrate information from the following databases: CAD, planning, material costs, labor costs, operation costs, overhead costs, and product costs. In this, it has a lot in common with the area of interest of this research proposal. At this time, there has been no published work suggesting any further developments on this framework.

Their model still falls short of detailing how they propose to integrate all of these databases, and whether they will be able to use existing databases (as opposed to data structured specifically for the system). They do not provide a specific manufacturing domain for the system, but the limited descriptions of the manufacturing system imply conventional machining operations. Another limitation of the paper is that they do not provide any detail of how the search process for information will be carried out. They do make note that they intend to use dBase IV database management software, and C language for programming.

b. <u>Development of a theoretical cost model for advanced composite fabrication</u> (Gutowski et al, 1994)

The theoretical cost model seeks to estimate time for human and machine activities in fabrication processes in three steps: (1) the development of simple dynamic models for primitive steps; (2) simplification and summation of the steps; and (3) application of a complexity factor to account for part complexity. Gutowski et al. derive a first order model to fit each process parameter, of the form:

$rate = rate_0 [1-e^{-t/\tau}]$, where rate has dimensions λ/time, and λ is the appropriate extensive variable for the task (often length, area, volume or weight). These power laws are integrated to derive a relationship between time and the extensive variable, using only two physically based parameters, $rate_0$ and a time constant τ . τ represents the delay in getting to full speed, taking account of setups and the complexity of the part. The time constant includes terms for setup delays, repetitive delays, and rate related to volume/length/area.

They introduce the idea of a complexity factor based on an earlier communications model, which was in turn based on an entropy description from statistical thermodynamics. This complexity factor modifies the time constant by defining a relationship between process time and bend angle (fiber orientation). Their model is then compared to the ACCEM model (Advanced Composites Cost Estimating Model) for hand lay-up processing of some 200 parts. ACCEM is a detailed process model which estimates each process step, and then sums these to get a time estimate for part fabrication time. They showed similar times were obtained using ACCEM and their model.

The model is based on a concept of using engineering dynamics terms to describe cost behavior: modeling cost behavior using a Hooke's Law analogy; it also uses the entropy concept from statistical thermodynamics. It is very much an engineering approach to cost modeling, but neglects the accounting basis of the information, and the need for understanding by people using the model. They are essentially modeling micro-level step process times and fitting these according to the integrated first order equations which parameterize the process variables. Ultimately they get a time for each process, which has been scaled using a power law derived from ACCEM tables, and a complexity factor related to fiber bend radius.

The model allows for input of setup delays, but is unlikely to capture the actual delay times which may be incurred in the factory, since their model takes little account of the non-value adding processes and idle time during production. The model still requires definition of each sub-process step, and considerable analysis is required to modify the model for each type of process. This would be difficult to carry out in practice, making this an extremely expensive method of cost estimating, requiring a large overhead to install and maintain. This model forms the basis of the COSTADE software, an advanced cost modeling package developed for estimating the cost to produce composite airframes.

c. Review of Current Cost Estimation Models for Aircraft (Rohani & Dean, 1996)

This article reviews the current state of the art in aircraft cost estimating techniques. It introduces the main factors affecting cost as: the cost of raw materials; the cost of tooling of individual components; the costs associated with a particular fabrication process or technique; the costs of jigging and assembly of the final structure; scrap rates; damage tolerance considerations and repair rates; environmental factors (with respect to toxicity of the materials used); and certification issues. Rohani and Dean emphasize the influence of early design stages on cost, with evidence that 70-80 percent of an aircraft's cost is fixed at the end of the conceptual design phase. They also refer to the work carried out in the design for assembly, and design for manufacturability (Boothroyd et al., 1994). They estimate that for a composite military aircraft, airframe manufacturing cost accounts for approximately 50 percent of the manufacturing "flyaway" cost and about 30 percent of the life cycle cost. This provides the justification for increased attention on manufacturability as a major factor influencing quality and cost. A multidisciplinary design optimization (MDO) procedure is described which incorporates modules for the calculation of the following key attributes: cost, materials, structures, manufacturing, performance, aerodynamics, propulsion, and control. These modules submit sensitivity coefficients to a gradient-based optimizer program that solves for optimized designs by iteration through the design space. The success of the model rests on the ability of the mathematical relations established to quantify the effect of changes in the aircraft design on its manufacturing cost. The authors state that "the establishment of proper cost models that accurately link product design variables to process constraints and vice versa is the key to successful inclusion of cost factors in MDO."

The article points to the importance of integrated product and process development in a concurrent engineering environment as a necessary framework to address manufacturing, operations, service, cost, and other requirements early in the design process. This leads to the identification of the following cost drivers for advanced composites manufacturing as part size, number of plies, orientation of plies, automatic versus manual lamination, and tooling concept. Two main methods of aircraft manufacturing cost modeling approaches are identified: parametric cost models and manufacturing process cost models. The form of parametric cost models is:

Cost = X (x_i) Y (y_i) where X is the complexity estimating relationship, the x_I 's are the complexity determining relationships of the product, Y is the cost estimating relationship (CER), and the y_i 's are the cost determining parameters of the product. This is the basis of the weight engineering cost models described previously. The authors note that weight-based CER's do not accurately represent manufacturing cost.

A model which takes the CER approach one step further is the PRICE-H model (see NASA, 1996b). This model includes the following factors to represent manufacturing complexity: a specification complexity which includes quality and reliability levels, number of parts, an assembly complexity index, a machining complexity index, and a material complexity index (machinability). The effect of these factors as cost drivers, is to promote the following measures to reduce manufacturing cost: reduce parts count, relax assembly tolerance requirements, relax component machining requirements, use more machinable materials, relax surface finish requirements, and use near net shape raw stock to reduce machining requirements. Again, one could argue that these directives ignore the benefits of trading off material cost performance versus enhanced design performance, and would tend to bias against using new technologies. The method is easily formulated, but depends strongly on an a pre-existing database of process cost knowledge.

The review also covers the Manufacturing Process Cost Models (MPCM) discussed in Section 2.5.2. Explanations of each of these models have been published, but not all of the references listed by the authors are available in the public domain.

d. ***COSTADE*** (Mabson, et al., 1994)

COSTADE uses much the same approach as described for ACCEM, but including the complexity function CER approach (from the research by Gutowski, et al., 1994), and incorporating a structural optimization program. This is regarded by the developers as the "finite elements method" of product cost estimating, and requires similar levels of complexity to program and use. A number of papers have been published to show the application of the method to different 'pieces' of the aircraft. The NASA / DoD Advanced Composites Technology Conference (ed. Davis et al., 1995) devoted a significant portion of the time to COSTADE-related work. There are articles on cost modeling of each of: fuselage crown panels; fuselage side panels; a fuselage keel panels; wing design; fuselage door cutouts; and fuselage splices. It should be noted that if the analysis requires three or more highly skilled academics to develop it for each case, then it will be a very costly method to develop and use in practice. The method will need to be redefined for changes in the configuration of the design. This then requires the company to retain these advanced skill levels to modify the cost model each time. The model also contains proprietary information about the company's costs, and so cannot be generalized for use by other manufacturers, even if it were made available to them.

d. Commercial Systems

The NASA Parametric Cost Estimating Handbook (NASA, 1996 b), published as a collection of web pages, briefly describes a number of commercial cost estimating systems. These web pages provide internet links to the various commercial sites, as well as reviews of some of the more prominent systems. Details of each program are proprietary, and are generally copyright protected. Some of the programs are commercial spin-offs of software developed in-house by major aerospace manufacturers and defense contractors. Examples of programs that are applicable to the area of aircraft program cost estimation are PRICE-H, ACEIT, and SEER-H. Each of these are parametric cost estimation programs that work from a work breakdown structure of the program cost. The NASA Parametric Cost Estimating Handbook provides links to the various internet websites of software vendors. Descriptions of the methods for obtaining the Cost Estimating Relationships (CERs) are available from the vendors.

The parametric cost estimation methods differ in a fundamental way from the objectives of the current study. They use CERs statistically developed from data or calculated using algorithms based on the expert knowledge base for the system. In contrast, the DDSS attempts to generate new knowledge about the system by actively seeking out cost information from a company's own databases, using the activity costs obtained directly from the company's own production system. This knowledge is then compiled on-the-fly to develop the cost estimate. Another significant characteristic of the parametric cost estimation software is its reliance on the traditional methods of cost collection and aggregation. The DDSS methodology, in contrast, uses activity-based costing principles, which should result in more accurate allocation of overhead costs to various processes, and hence to the individual products.

2.6 Aircraft Design Decision Support

2.6.1 Growing Use of Composites in Aerospace

Historical trends have shown an increasing fraction of composite materials in aircraft, from a small fraction in the early 1970's to nearly complete aircraft in the late 1990's. There are a number of references to this trend in the literature. Examples of these are articles by Walden (1990), Harmon and Arnold (1991), and in academic texts by Niu (1992), and Middleton (1990).

Turner (1995) provides specific examples of composite structures in commercial aircraft, with brief descriptions of the construction method, and the improvement achieved over the original designs. In the Airbus A310:

- Composite rudder: three carbon / epoxy skinned honeycomb sandwich panels are assembled as a hollow triangle. Weight savings of 22% were achieved over the original metal structure. Parts count was reduced by half (to 335), and a reduction of details from 17000 to 4800 was achieved mainly by the eliminating rivets.
- Composite vertical stabilizer: aluminum modules are wrapped in prepreg to form integral skin stiffeners, which are then positioned by a robot on the already laid up skin, with UD strips placed on top of modules to form spar caps. The entire assembly is co-cured in an autoclave.
- Composite horizontal stabilizers and elevators for A320. Weight savings of approximately 20% were achieved, and parts count and detail count were substantially reduced.
- Empennage of all Airbus A320, 330, and 340 models. An overall weight saving of 20% has allowed substantial gains in aircraft range and/or payload.

In the ATR 42/72 twin turboprop regional airliners

- The ATR 42 has nearly 2200lb of composite secondary structure.

- All control surfaces are carbon or aramid sandwich, except for monolithic carbon/epoxy ailerons.
- Engine nacelles are made primarily of carbon or Kevlar/nomex sandwich.
- Large fairings for wing-to-fuselage, and to landing gear are made of aramid/honeycomb panels.
- Propeller blades and brakes are carbon composite.
- Interior floor, door and wall panels are made of composite materials.
- Outer wing sections on ATR 72 are largely composite.

The high strength to weight ratio of advanced composite materials has encouraged designers to substitute them for metal, to achieve enhanced aircraft performance. As the techniques become more widely used, the production cost will tend to decrease, providing even greater incentive to use them. These references provide the background for justification of this research. There is a need for more comprehensive understanding of how these new materials can be used in aircraft, and their effectiveness over the service life of the aircraft.

There is also growing concern from airlines at the cost of aircraft to own and operate (Velocci, (1996). The cost of ownership is estimated at between 33% (Long range aircraft) and 42% (Short range aircraft) of direct operating costs, according to a NASA Baseline Metallic Aircraft Cost Model (Humphrey, et al., 1995). Airframe structural costs are approximately 37% of total aircraft cost. Within the airframe structure, the fuselage accounts for 54%, the wing for 39%, and empennage for 7% of the cost. There is some resistance from airlines to increase the cost of ownership, without significant benefits to direct operating costs. This resistance works against the introduction of new technology into airframes, as aircraft manufacturers are reluctant to invest large amounts into automated composite manufacturing equipment. It is important that manufacturers should be able to assess the impact of new technology on their production processes. Within the framework of the DDSS, it may be possible to create "virtual machine cost trials", by inputting dummy records using a new type of automated equipment and comparing the cost of typical jobs though it, versus their current methods. This could be used as an additional tool for evaluation of investment decisions for manufacturing equipment.

2.6.2 Advanced Composites Process Technology

In the areas of materials science and engineering mechanics there is a wealth of information on developments in advanced composites processing technology. This area has been extensively researched, and includes studies which model the effect of design parameters on the structural performance of composites, and the optimization of processes to choose the best set of design parameters for a given performance requirement. Hoskin and Baker (1986), Schwartz (1992), and Lubin (1982), provide detailed information on composites manufacturing processes for aircraft.

There are also some cost optimizing models which use cost as the objective function to optimize the structural parameters for a given part. An example of the parameters which are of interest in these models are: the orientation of plies being laid-up, size and geometry definitions, and spacing of stiffeners, and the choice of materials for their strength and chemical properties.

The DDSS should support the ability to conduct trade studies for these special properties of advanced composite materials, as well as the manufacturability/cost trade-offs necessary to achieve these properties. These materials science topics are not the focus of this research, but do provide some inputs to manufacturing cost models. As new materials and processing methods are developed, and absorbed for use in industry, cost models must be modified to reflect the new technology.

2.6.3 Aircraft Conceptual Design

In order to gain an understanding of how aircraft are designed, it was important to review some of the literature on the fundamentals of aircraft design in this study. *Aircraft Design: A Conceptual Approach* by Raymer(1989), provides sufficiently detailed information on the important aircraft design parameters, use of trade studies, and the fundamental measures of aircraft performance. Summary information from this text is provided as an introduction to other more specific topics in aircraft design. Two papers are reviewed here: one focused more specifically on trade studies (Jensen, 1979) and the other on the use of alternative figures of merit in aircraft design (Johnson, 1990).

2.6.4 Aircraft Design Parameters

Some of the main determinants of aircraft design performance used in industry are: lift-to-drag ratio (L/D), thrust-to weight ratio (T/W), design takeoff gross weight, empty weight fraction, the fuel fraction, payload, mission range capability, cruise speed, climb rate, and takeoff distance, amongst others. According to Raymer (1989), the two most important factors affecting aircraft performance are the thrust-to weight ratio (T/W) and the wing loading (W/S). Design variables which have a major impact on the structural design configurations are the size dimensions, e.g. wingspan, fuselage length, tail area, surface wetted area, and volumes of the various components. Weights of structure are highly correlated with these inputs. Weights of engines and landing gear are more strongly correlated with the gross weight of the aircraft. Design takeoff gross weight has been the principal design variable in the industry, with weight engineering methods being the standard means to project the weight and cost of the aircraft. Roskam (1985) provides details of several of these methods; Raymer (1989) provides a summary of these weight-estimating relationships.

In general, these cost estimating relationships (CERs) were formulated by the following method: historical data from previous aircraft programs was collected, and multiple least-squares regression analysis was used to derive a series of exponential curves that are used to calculate the group weights of different parts of the aircraft. These were described more completely in Section 2.5.1 (Parametric Cost Models).

2.6.5 Trade Studies and Figures of Merit

Raymer (1989), describes trade studies as the answer to “what if” design questions. Designers must optimize the combination of design performance variables, often giving away performance in one aspect to gain performance in some other design variable.

The carpet plot of thrust-to-weight ratio (T/W) versus wing loading (W/S) for some figure of merit (usually weight) is the basis of initial sizing analysis in aircraft design. Examples of other trade studies that are considered are:

> *design trades*, which trade off weight and cost of an aircraft to meet a given set of mission and performance requirements;
>
> *requirements trades*, which determine the sensitivity of the aircraft to the various mission requirements; and
>
> *growth sensitivity trades* which determine how the weight would change (grow) if some performance parameter were changed.

<u>Role of Figures of Merit in Design Optimization and Technology Assessment.</u> (Jensen, et al., 1979).

This article provides examples of how trade studies are used to optimize designs for military and commercial cargo transports. A design synthesis program was created which took multiple data inputs and developed multiple aircraft configurations to satisfy the given mission requirements. The approach used multiple regression techniques to develop simple second order relationships between design parameter inputs and the performance / cost outputs for design selection. The model used seven independent design variables, which were bounded using values from previous aircraft design experience. The model then ran multiple iterations of the procedure, and captured design configurations for minimum gross weight, minimum life cycle cost, minimum acquisition cost, minimum flyaway cost, minimum LCC/productivity, minimum direct operating cost, and minimum fuel. These different design performance characteristics were plotted on design and requirement trade diagrams. The concepts of trade boundaries, and off-design penalties were explained. By trading off different design variables, it was shown that there are significant opportunities to keep the design penalty on each figure of merit to a small part of the full penalty.

This concept is useful for application to Design for Manufacturability of aircraft, where ‘extreme’ design requirements may be traded off to achieve significant savings in the overall cost. The cost models used here are based on the weight engineering paradigm for aircraft design, and their accuracy for advanced composite designs is untested, given that the design relationships used in the model are all based on mostly aluminum aircraft, built in the past 40 years.

Choice of a figure of merit for aircraft design has a major influence on the direction of the design process. The aircraft is configured to optimize the figure of merit; trade studies are used to determine the effect of major design parameters on the figure of merit. Understanding of these concepts is important for this research, in order to understand the information needs of aircraft designers, and to adopt methods that fit into their design paradigm. The Design Decision Support System is intended to provide cost information that will support these trade studies, by providing the relative costs of aircraft components as key design parameters are changed. In the next section, the effects of using different figures of merit are investigated.

Minimizing Life Cycle Cost for Subsonic Commercial Aircraft. (Johnson, 1990).
This article provides an overview of a multi-disciplinary design optimization program that produced aircraft designs for different figures of merit. The paper introduced a methodology to choose a conceptual aircraft design using an existing aircraft conceptual and preliminary design program, using different figures of merit as the objective function. The Flight Optimization System (FLOPS), is a program that uses basic inputs to the system of a baseline aircraft mission, minimal aircraft geometry and propulsion data, and economic assumptions relevant to the study. The model uses several models to calculate Life Cycle Cost (LCC). The LCC module sums all of the elements to calculate RDT&E (research, development, testing, and evaluation) cost, production cost, DOC (direct operating cost), and IOC (indirect operating cost). Acquisition costs (RDT&E, ACQ) are split for Airframe (AF), and Engine (ENG) acquisition costs.

LCC = AF RDT&E + AF ACQ + ENG RDT&E + ENG ACQ + DOC + IOC

The airframe cost model uses a weight model which uses performance parameters and weight to estimate the cost of production, and a separate model which includes cost estimating relationships for the engineering, tooling, production, materials, support and testing phases of aircraft program costs. The engine costs use the Rand Corp. model, which uses weight and thrust requirements to size engines, and to correlate these with commercial engine costs. Direct operating costs were determined using an Air Transport Association model that relates aircraft design parameters to the DOC. The indirect operating cost model used airline-operating experience to estimate costs for a certain class of operation. These contained no reference to other design parameters used in the other cost models, so did not have much effect on the final outcomes. In order to limit the complexity of the model, the scope of calculations was limited to subsonic commercial aircraft with turbofan or turbo jet engines. Initial inputs were the basic aircraft geometry, propulsion data, mission characteristics, and aerodynamic data.

The optimization program was configured to optimize the aircraft for minimum life cycle cost, minimum direct operating cost, minimum acquisition cost, minimum takeoff gross weight (TOGW), or minimum fuel burned. Outputs of the model were the wing planforms for the various figures of merit, and the design performance parameters: TOGW, empty weight, fuel, thrust, thrust-to-weight(T/W), LCC, DOC, ACQ, Cost/engine, and total engine cost. The model was then used to produce aircraft variants for three range classes (short, medium, and medium-to-long range). The results were compared for the different figures of merit. This showed that the aircraft configured to optimize the various figures of merit had different wing shapes, and considerable differences in the cost figures of merit were obtained.

The paper was useful in showing the application of a multiple disciplinary design method which could be configured for different objective functions of cost performance. The important trade-offs between optimizing performance for different figures of merit were clearly illustrated. Important to the DDSS research was the difference between designs optimized for life cycle cost versus designs for minimum acquisition cost. Acquisition cost is strongly related to the manufacturing cost for airframe, where the composites cost estimating function is most relevant. Operating cost, and hence life cycle cost, are more strongly dependent on the aircraft performance variables such as lift/drag ratio, thrust/weight ratio, and fuel efficiency. Life cycle cost includes the cost of owning and operating the aircraft, and can be considered the most important figure of merit, as this will determine the ultimate success of the aircraft for the user. This reinforces the concept of system design that 80 percent of the cost of a design are committed during the conceptual and preliminary design phases. It is important to be aware of the impact of these early design choices.

This article makes provision in the methodology for sensitivities to advanced technologies to be included, by specifying incremental factors for cost and performance to determine their effect on the design configuration's figures of merit. For example, it projects that aerodynamic performance could be increased using a high technology airfoil design, with an associated cost penalty of 0%, 20%, or 40%. The resulting effect on TOGW, LCC and DOC can then be assessed. Results show that advanced technology can be worthwhile, even if it results in higher manufacturing costs. This is similar to the use of "fudge factors" used to modify the weight-to-cost ratios for composite materials in aircraft. The model is useful as a guide to direct design, but is limited by the use of existing weight engineering models to estimate weight and cost, and hence all of the main figures of merit.

These models do not account for the complexities of manufacturing, and have not been modified to be accurate for the mostly composite aircraft expected in the near future. There is a developing need to provide more accurate models of the complex relationships between manufacturing costs and the main design variables. The DDSS methodology provides a tool to explore this area, and to capture knowledge about these relationships. This expanded knowledge can then be used to more accurately predict costs in a given manufacturing environment.

2.6.6 Life Cycle Cost of Aircraft

The life cycle cost of a given system can be modeled using a work breakdown structure (WBS), as described by Blanchard and Fabrycky (1990). The life cycle cost captures all of the cost elements of the system, from conceptual design phase, through detailed design and planning phases, to manufacturing, distribution, operation of the system, logistic support and maintenance of the system, and finally disposal or retirement. Tyll et al. (1996) used a simplified version of this work breakdown structure to demonstrate the use of a Multi-Disciplinary Optimization (MDO) methodology for the concurrent optimization of aerodynamic performance versus the life cycle cost. In research work carried out by the author (Tyll et al., 1996), the DAPCA IV cost estimating model was modified to provide the acquisition cost of a MAGLEV vehicle structure, using a sizing model for aircraft fuselage.

The acquisition cost is but one component of the life cycle cost of an aircraft; other important elements of the work breakdown structure may include: the distribution cost, logistic support and maintenance costs, operating costs and finally disposal cost at retirement. In the design of aerospace components, the post-manufacturing costs of a given part may be significant, given that repairs, inspection and replacement of that part may be a scheduled maintenance requirement, which is decided during the design configuration stage. This reinforces the argument that significant portions of the life cycle cost are committed early in the design process, and well before the production phase.

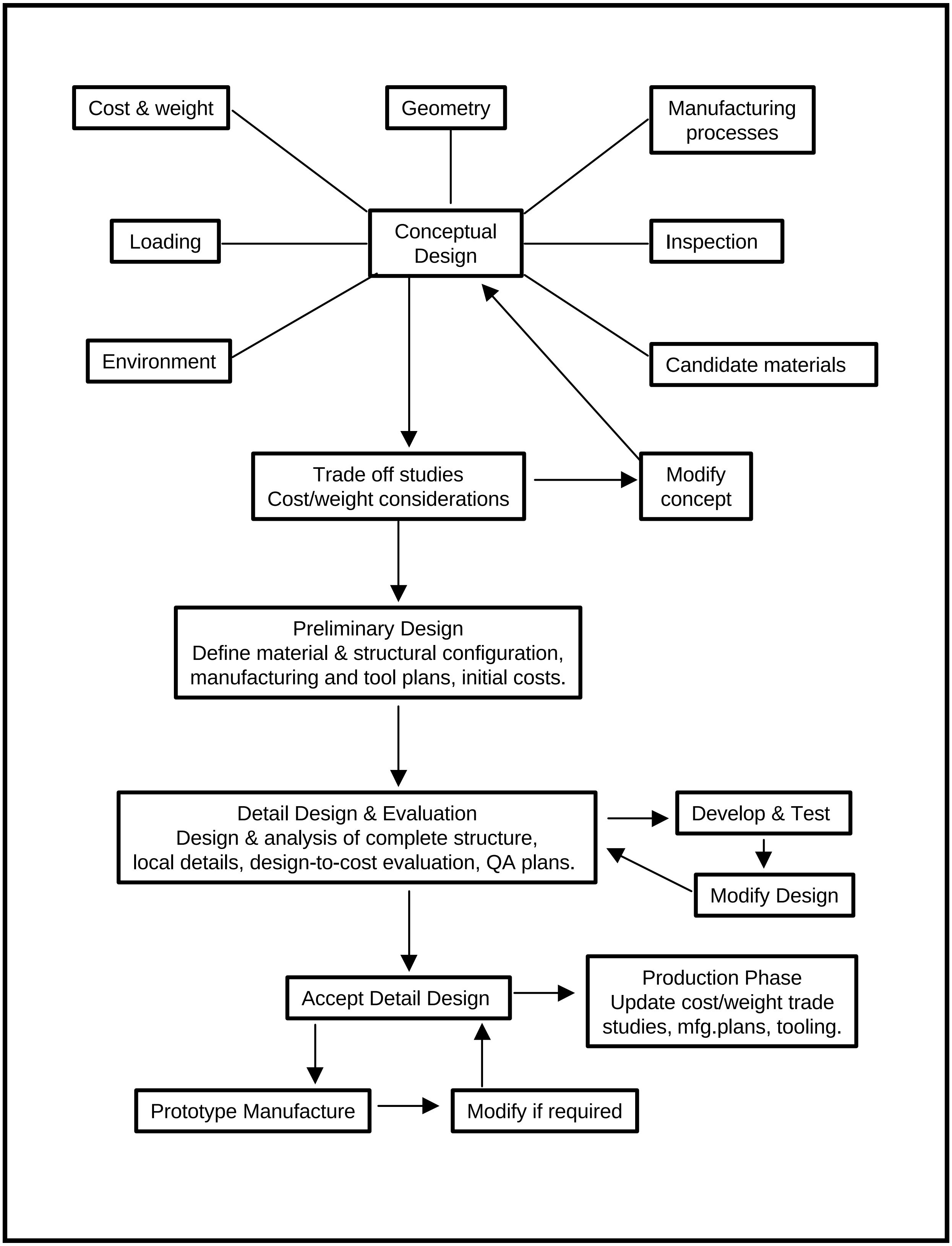
This is significant for this research, in that the DDSS is intended to provide early indication of the cost of an item, to allow the consideration of alternatives during the conceptual design stage. For the life cycle cost of the aircraft, designers must also consider the post-production support costs of their designs, including distribution, logistics support and maintenance of the aircraft. These topics are beyond the immediate scope of this research, although the costs of these post-production activities could be obtained by a relatively simple extension of the DDSS model.

2.6.7 Design Method for Advanced Composite Aircraft Components

The focus of this research is at a component design level, rather than at the level of conceptual design of a complete aircraft. This is an important distinction, and a limitation on the scope of this research. The important variables for conceptual aircraft design, such as wing loading and thrust-to-weight ratio form the basis of consideration for the design of components, in that the major objectives of the designs are to maximize the aerodynamic performance variables, while minimizing cost and weight of parts. Life cycle cost and acquisition cost are again the primary figures of merit for components making up the aircraft, and the balance of performance variable versus weight and cost will usually guide designers' final choices.

Although it is beyond the scope of this system to carry out conceptual design sizing and re-configuration of an aircraft, the output of this DDSS could provide valuable information to use in higher level aircraft design software. These high level aircraft design configuration models have mostly used the parametric cost estimating relationship or weight engineering approach, if offered at all. COSTADE is the exception, providing process level cost estimation of aircraft cost, but requiring a great deal more complexity to be specified in the design (Mabson, et al. 1994).

This DDSS is designed to support a design decision making structure similar to that proposed by Middleton (1990), which is depicted in Figure 2-1. This design methodology provides a view of the iterative design process during the conceptual design stage. Trade-off studies of the conceptual design should include evaluation of cost and weight of the part, before continuing on to preliminary and detailed design stages. As was noted in the discussion of Design for Manufacturability, it is difficult to get accurate cost estimates without detailed design drawings of the part; but it is hard to justify making detailed design and process plans at the conceptual design stage.



<u>Figure 2-1: Design Methodology for Composite Materials</u> (modified from Middleton, 1990)

This DDSS methodology is intended to support design cost estimation at the conceptual design stage, as well as at the later stage, with the proviso that the accuracy of the estimate increases with increasing detail. At an early stage, components may be modeled loosely, using history of similar components as the basis for cost estimates. As more detailed processing instructions become fixed, the cost estimating process should become more accurate, as uncertainty is reduced.

2.6.8 Design Issues for Advanced Composite Aircraft Components

In the literature there are a number of references to the design of composites in aircraft structures. Baker (1986) describes in detail the use of composite structures in aircraft, and some design rules governing fiber systems, resin systems, structural mechanics of composites, and adhesive bonding and fastening of composite materials. The book includes guidelines for damage tolerant design of composites, repair of composites in aircraft components, and non-destructive inspection techniques used for quality assurance.

A recent document was prepared by the Design Task Group of the ATA/IATA/SAE Commercial Aircraft Composite Repair Committee (SAE, 1997). It outlines case studies of composite parts damaged in service, with descriptions of procedures undertaken to repair or replace these components. It provides some insight into the type of problems experienced by airlines in operating aircraft built with a mixture of composite and aluminum components. The lack of knowledge, lack of resources, and high cost to carry out composite repairs is shown on a variety of different parts. The document shows the results of an international survey carried out by airlines and aircraft manufacturers on in-service damage to composite structures. The objectives of the committee are to standardize composite repair procedures, and to offer design directives for improved designs of composite parts. Guidelines for improving durability and repairability of structures are given.

Designers may still need to carry out trade-off studies to determine the effect of additional or alternative processing steps on the component they are designing. The

DDSS should make it possible to carry out these trade studies by offering a modified process plan, with the additional processes, or changes to material thickness, or alternative material compositions. The redone estimate can then be compared with the original, and the difference in manufacturing price can be evaluated versus possible future repair costs, maintainability issues and the life cycle cost to own or operate the aircraft.

There are also several recent articles that provide case studies of the design of composite parts for aircraft. These discuss typical process details, new processing technologies, and design innovations using new materials. Ashton, et al. (1991), provide a case study that shows the advantages in strength, weight saving and cost saving of a combination filament wound fuselage section. They provide comparative costs and production rate of hand lay-up versus prepreg (pre-impregnated with resin and catalyst) sheets, tape-laying machines and filament winding. The greater degree of automation and higher material laying rate of filament winding reduce labor and material costs, but must be offset against the higher cost of the production equipment. Also of interest is a proposed method of combining longitudinal and transverse stiffeners by tape-laying while the outer skin is filament wound. In this case, designers may be interested in comparing the relative costs of the different processes, by inputting alternative process plans, and carrying out trade studies using the results.

2.7 Design Decision Support Models

This review of design decision support models in the literature is intended as background to the current research. It serves to illustrate some of the desirable features in these systems, and also to point out limitations and disadvantages of the models. These features have, as much as possible, been incorporated into the design of the research methodology.

2.7.1 Towards more effective decision support in materials and design engineering

Edwards (1994) notes in this article that computer-based support of decision making during the design phase has not been well developed. The paper identifies the need to capture design knowledge, structure it and then make it accessible in a form that can be used to support decision making. Edwards proposes a knowledge structure for a computer-based engineering design guidelines database. The domain of the design knowledge includes the following subject categories: machine design, mechanical design, design of machine elements, engineering design, design theory, theory of technical systems, design management, and industrial design. The database is focused on conceptual and 'embodiment' stages of design, rather than on the detailed design stage. The database structure is hierarchical and has four main sections: Fundamentals: axioms, definitions, and philosophy; Design activities: morphology, management, procedures; Technical systems: structure, features, properties; Context: pre-design, design, post-design.

These guidelines are constructed as 3500 separate guidelines gathered from 75 textbooks. The database is searched interactively using browsing, keyword searches, and Boolean combinations of keywords. The use of natural language to search was apparently somewhat successful, but suffered from two major shortfalls. These were that it required reasonably advanced knowledge of the classification to use the system successfully, and that the system tends to present information which is not relevant to the specific problem of interest to the designer. It is also geared at providing rather generic advice guidelines to designers. This could perhaps be expanded to cover smaller domains more explicitly, but would require a large amount of time to be spent formalizing the knowledge base.

Boothroyd warns that the design axiom type of advisor misdirects design efforts. Firstly, they do not allow for trade-offs by using alternative materials or processes, and secondly, that they focus on simplifying at the part level, but do not consider simplifying at assembly level (Boothroyd & Dewhurst, 1991).

The other major weakness of this system is that it does not mention cost as a factor for consideration in design. The concept of using natural languages to search databases may be useful for this research. The authors state that natural language techniques have limited commercial availability, and that there may be advantages in converting to an object oriented database or hypertext rather than hierarchical structure. There may be some advantage in using the graphical capabilities of hypertext to make search guidelines easier to follow. This concept could be used in creating an activity cost hierarchy, which would group the inputs associated with a particular process (e.g. labor, machines, materials). The graphical structure could also be used to define relations between database objects.

2.7.2 A Taxonomy for Classifying Engineering Decision Problems and Support Systems

In this article, Ullman & D'Ambrosio (1995) use a design example problem to present the basic process followed by designers. An ordered structure or taxonomy is used to represent an ideal design decision support system.

The basic design decision process is said to consist of the following (refer to Table 2-1): The *structure* of the problem is defined by the completeness and quality of information describing the design space (the alternatives and criteria for describing them) and how the product is made. Next the problem *focus* is either on the product to the process of design. *Range* of the problem considers the effects of the design on other issues. *Support* or level of support defines what kind of support the designer is seeking next. This hierarchy, and the options within each class are shown in Table 2.1.

Table 2.1: Decision Problem Taxonomy (Ullman & D'Ambrosio, 1995)

STRUCTURE	DECISION SPACE	1. Problem completeness	complete, incomplete
		2. Abstraction level	quantitative, qualitative, mixed
		3. Determinism	deterministic, distributed
	PREFERENCE MODEL	4. Objective function	optimum, judgment, none
		5. Consistency	consistent, inconsistent
		6. Comparison basis	absolute, relative
	BELIEF MODEL	7. Dimensions	none, one (conf. or knowledge), two (conf. and knowledge)
		8. Belief completeness	complete, incomplete
FOCUS		9. Problem focus	product, process
RANGE		10. Range of independence	I. independent issues II. dependent issues III. interdependent
SUPPORT		11. Level of support	I. representation II outcome determination III decision analysis

Each option is defined more clearly in the paper, and the framework is then used to classify some common design approaches (e.g. probabilistic design, formal optimization, CPM/PERT, Pugh's method). Some of the definitions in this article are hard to fathom, and make for a difficult to understand decomposition of a problem. The methodology could be useful in formalizing the structure of a design decision support system for manufacturing processes.

2.7.3 Usefulness of these Models for this Study

Although the structures shown here may not be suitable to represent the design process for this research, the manner in which the decision support structure is formalized is a useful starting point for discussion. In order to model the decision process followed in design for composite manufacture, the categories defined here could be tailored to the domain of composite manufacturing design, and linked to the model representing the information flows required to support decision making. Use of this model helps to formalize the intuitive processes that occur during design. These processes are difficult to capture, and this classification schema is helpful in explicitly declaring the function and scope of each decision process. There are a number of other models for decision support that are useful in formalizing the design decision support process. Examples of these are: Bras & Emblemsvag (1995); Kharbari & Wilkins (1991); and for manufacturing knowledge databases, Metaxas & Sellis (1991).

2.8 Summary

This research based on some of the key principles in the concurrent engineering domain. The DDSS is intended to give engineering designers the information they need to improve their efforts to integrate product and process design. The review of concurrent engineering techniques and computer integrated manufacturing showed how this design decision support framework relates to current research in this field.

The literature review showed that the domain of this research is well covered in the areas of composites manufacturing processes, the justification of composite materials for aircraft, and the definition of design variables used for conceptual aircraft design. There have been significant contributions in the area of composite manufacturing cost estimation, and for parametric aircraft cost estimation. The models are still bedded in the traditional cost accounting methodology, with overhead cost allocations by broad volume-based categories, and assumptions based on the history of mostly aluminum aircraft cost from the past 40 years. In the rapidly developing field of advanced composites manufacturing, there is little established expertise in finding the best way to manufacture components. The DDSS methodology is intended to seek out the costs of these new manufacturing activities using the latest production data, and to present designers with cost information they can use to improve their efforts to Design For Manufacturability.

Activity-based accounting and cost management systems have reached a mature stage of development; the techniques for applying the method are well established, and the benefits for strategic decision making have been shown. There are some shortfalls in how the ABC systems are implemented. The method has proved to be an expensive and time-consuming addition to management information systems. The DDSS methodology uses activity-based costing principles to estimate the cost of each manufacturing activity, but only applies it to the part being investigated. By not seeking to cover *all* activities of the enterprise, all of the time, this decision support tool seeks to avoid the large costs and disruption associated with implementing a large-scale information system change.

The conceptual framework for design decision support systems has been investigated in the literature, but can be considered to be at an early stage of development. There is a wide gap between the decision support system paradigm used in the mechanical engineering design domain, and that typically used in business decision support systems. This research aims to provide engineering decision support that is more explainable to users from different disciplines, including those from engineering, production, and accounting fields.

Key features from each of the topics discussed are addressed in the research methodology. In Chapter 3, more specific guidelines show how these features are included in the development of the Design Decision Support System.

Chapter 3: METHODOLOGY

3.1 Overview of Research Methodology

This research was intended to show how product cost estimates can be modeled using the existing information sources in an advanced composites manufacturing environment. The overriding reason or purpose for this research is to provide decision making information to product designers (or managers) that will enable them to make informed design choices, gaining the most value from their production resources for the least cost. The following sections outline the basis of a methodology for a design decision support system (DDSS) that actively seeks out costs related to a product or function, by intelligently searching the existing accounting, production and engineering data sources. The research objectives were introduced in Section 1.8. These operational definitions are repeated here:

3.1.1 Research Question

The research question is *what the research intends to answer*, and *how it will expand the academic body of knowledge*. The research question this study sought to answer was: How can product cost estimates be modeled using the existing information sources in an advanced composites manufacturing environment?

3.1.2 Research Purpose

The research purpose answers the question*, what is the overriding reason for doing this research?* The purpose of this research is to provide decision making information to product designers (or managers) that will enable them to make informed design choices, gaining the most value from their production resources for the least cost.

3.1.2 Research Objective

The research objective answers the question, *what will be the results of this research, or what can be learned from this research?* The desired result of this study is a methodology for a decision support system that actively seeks out costs related to a product or function, by intelligently searching the existing accounting, production and engineering data sources. Sub-objectives are:

- To assess the needs of aircraft designers, by analyzing typical trade studies used during the conceptual design phase for aerospace components, and to satisfy the information needs to Design for Manufacturability (Boothroyd & Dewhurst, 1987).
- To model the interaction of activities and processes in the given manufacturing environment, and the associated information flows, and to measure the costs consumed by these activities and resources.
- To develop a methodology to structure the search process, and to collect and manipulate data into a manageable form for portrayal to decision-makers.
- To create a system which "learns" by capturing information from each iteration of the process, and uses the information gained to speed up or enhance future cost estimates.
- To provide a development framework to design the decision support system.

3.2 Importance of the Design Decision Support System

3.2.1 Searching the Existing Information Sources

As stated, the principal objective of the research is the development of a methodology for a decision support system that actively seeks out costs related to a product or function, by intelligently searching the existing accounting, production and engineering data sources. This concept could be of considerable value to industry, in providing a means to access the information that companies already have, but have found difficult to use in meaningful ways to help the design process. The system aims to use the existing information systems as data sources, rather than advocating replacement information systems which would entail considerably more expense and overhead to implement. One of the major barriers to implementing large scope activity-based costing systems has been the high threshold cost to implement these systems, and the heavy investment of skills and resources required to maintain them. The decision support methodology must be flexible enough to account for differences in the structures of each company's manufacturing and information systems.

3.2.2 Innovative Search Strategies

In order for this system to be implemented, search strategies were formulated to enable the collection of the data from the various information sources. In broad terms, these use templates of known cost structures to set up search patterns for the product cost. The search pattern is then used to find all of the relevant information, and then compiles the pieces of information intelligently to estimate the cost. These techniques are used within the analysis tool, and although software specific, should be of value for implementation in other similar applications.

3.2.3 Improve Value of the Product to Customers

The importance of this research is in providing a new methodology that can be implemented as a supplemental resource, enabling companies to seek out otherwise hard-to-find knowledge about production activities. This will help to expand the designers' understanding of the causal relationships between design parameters and manufacturing costs. This expansion of knowledge can then be applied to improving the value of the product to the consumer, by increasing the ratio of performance versus manufacturing cost. This improvement of value can be aligned to corporate strategic goals, as described by Shank and Govindjaran (1993). By aligning the increased value to the customer with corporate strategic goals, the enterprise focuses attention on improving its competitive position.

3.3 Overview of the Design Decision Support System Model

The conceptual model of the Design Decision Support System methodology includes the following sub-systems: the manufacturing system, the design information system, the accounting information system, the production planning system, the Design Decision Support System itself, and the interfaces with each of the other components.

In order to capture the complexity of the methodology in a graphic model, it is helpful to consider separate flowcharts for the different levels of the system. Each sub-system is described as a separate entity, and the relationships between the systems are defined. The DDSS model is discussed in three levels. The first model depicts the top level interactions between major components that affect the Design Decision Support System. This model is developed further in Section 3.4. The second model depicts the iterative cost estimation loop within the Design Decision Support System. These interactions of the DDSS with the various corporate information resources are detailed in Section 3.5. The third level details the search methods and calculations for each cost category within the DDSS methodology. These methods are developed further in Section 3.6. A brief overview of each of these levels is provided in Sections 3.3.1, 3.3.2, and 3.3.3 below.

3.3.1 Overview of Top Level Model: The Production Environment

The focus of the top level model (shown in Figure 3-1) is on describing the key components of the Design Decision Support System, and how they interact with the other systems. Section 3.4 presents detailed descriptions of the manufacturing system, and each of the supporting information systems in the target composites manufacturing environment.

The underlying manufacturing system is described first, as the basis around which all the other systems function. The manufacturing system is defined in simple terms of facilities, labor resources, equipment resources, and materials used in the production process. In addition to the basic production resources, the maintenance support sub-system is considered, as an important part of the cost of ownership of production equipment in the facility. The key objective of the DDSS is to capture all of the costs of the manufacturing resources described here, and to correctly allocate these costs to the production processes consuming these resources.

The information systems are described in order of the logical flow of information through the production process. The Design Information System is the starting point for each cost estimate, being the point at which designers interact with the rest of the system. This Design Information System is modeled on the Design Methodology for Composite Aircraft Components presented in Section 2.6.7 (Figure 2-1). This DDSS is intended to provide decision support for designers at the Conceptual Design stage, by providing cost information for designers to evaluate the effect of alternative design choices. The Process Plans and Bills of Materials produced in the Detailed Design stage are conventional inputs to the Production Planning System.

The Production Planning System captures information about production orders, materials, human resources, and equipment resources as required to control the production process. The Production Planning System is by necessity, somewhat integrated with the Accounting Information System. The description of the Production Planning System should therefore be read in association with the description of the Accounting Information System. Although separate systems, there are several points where information exchanges take place between the two systems. The model developed for this study uses descriptions of conventional production planning systems, and accounting information systems for production processes, with specific reference to the Integrated Production Information System developed by Gelinas and Oram (1996). Other sources include Murtuza (1995), Nash (1989), and Wilkinson (1993). While specific to this DDSS model, the information flows described here are common to most production and accounting information systems. Example formats of the documents relating to these accounting and manufacturing information flows were also taken from sources in production planning and accounting information texts. (Sources: Plenert, 1993; Gelinas & Oram, 1996; Murtuza, 1995; Wilkinson,1993; Horngren & Foster, 1991). Examples of these input documents are provided in Appendix D.

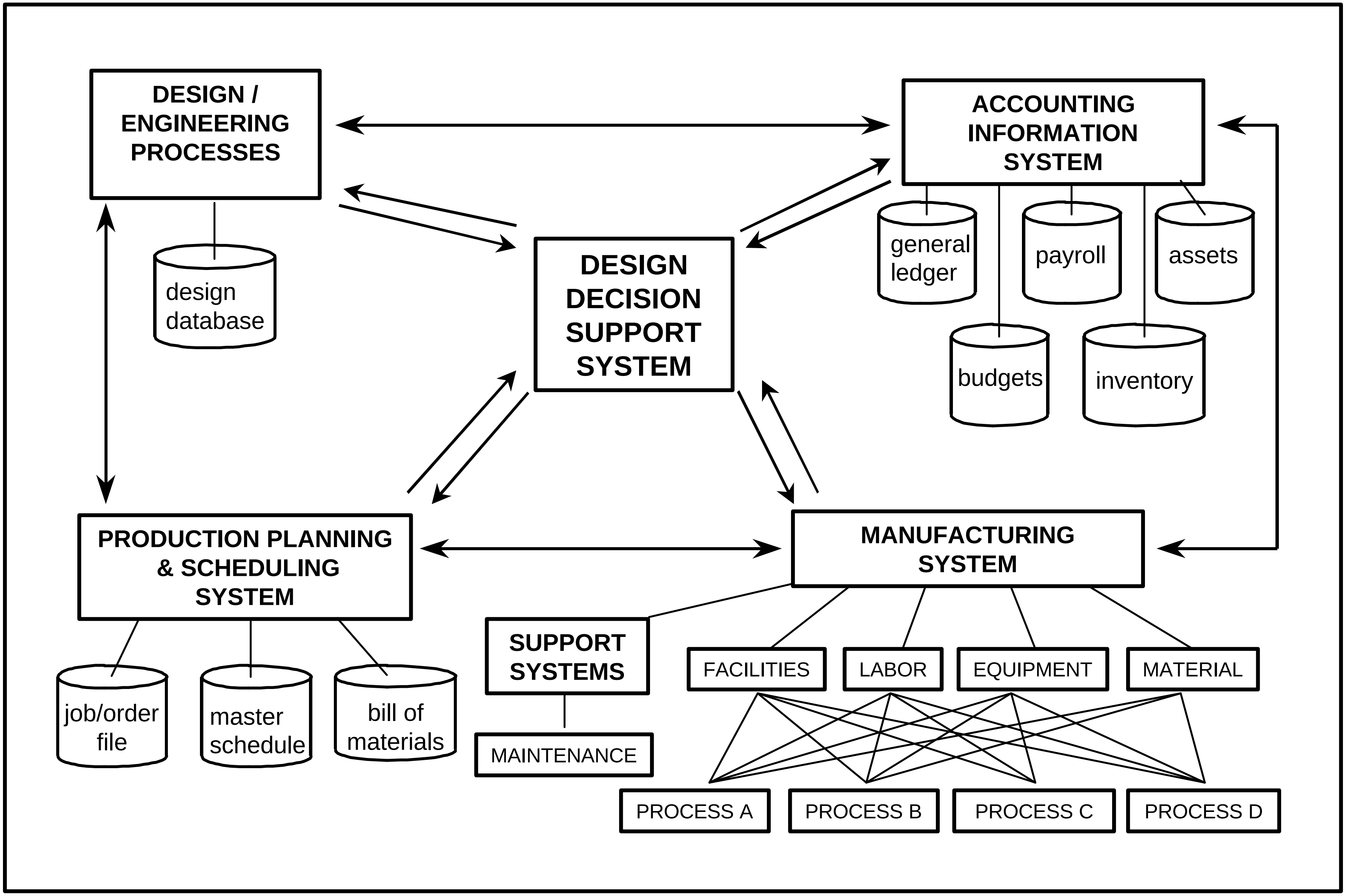


Figure 3-1: Design Decision Support System: Top Level Structure

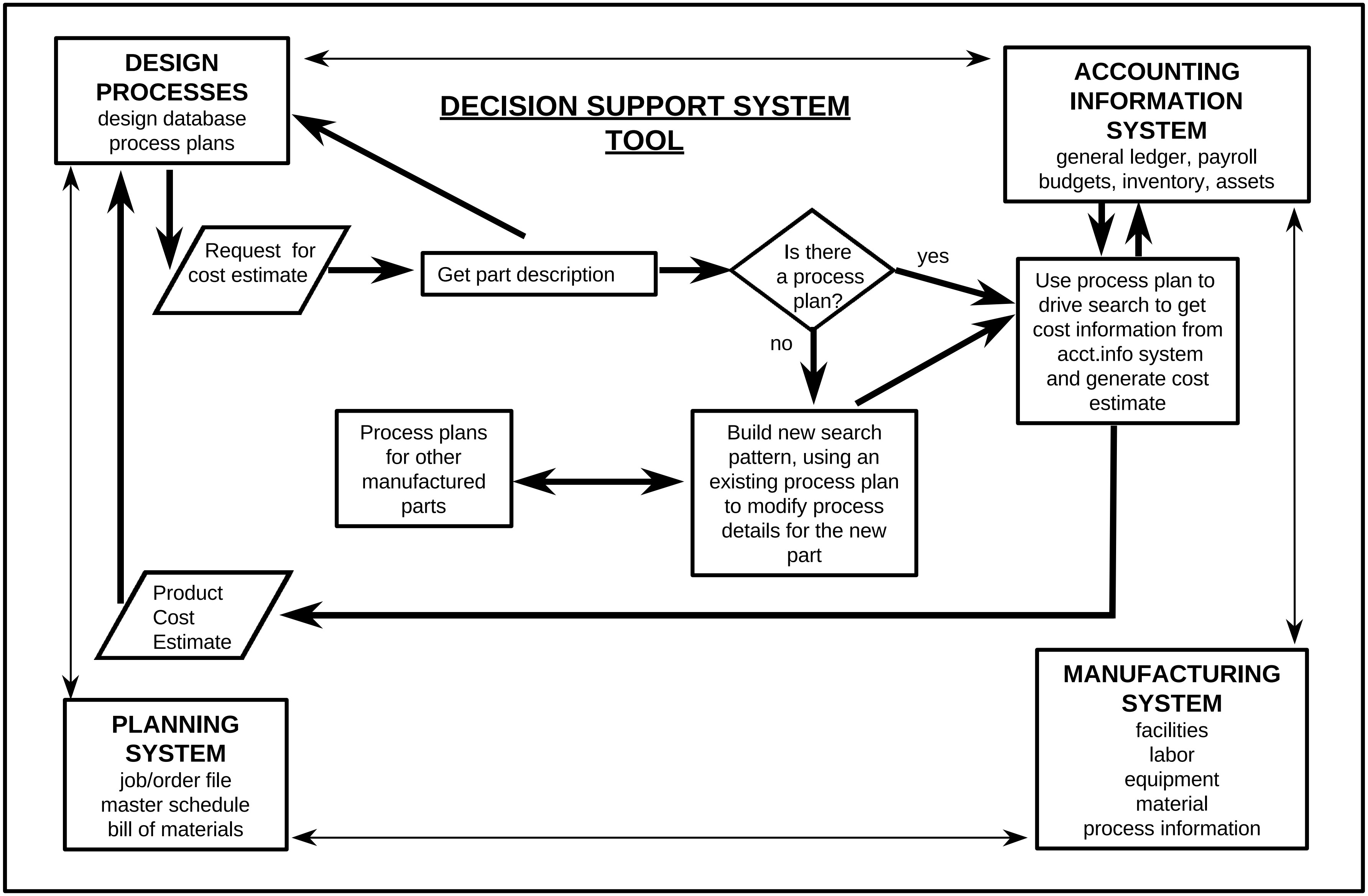


Figure 3-2: Design Decision Support System: Data Search and Analysis Model

An important feature of the Design Decision Support System methodology is that it does not disturb the existing information flows in the company's production system; it acts independently of the design, planning and accounting information systems. It interacts only with replicated copies of the information systems databases, thereby avoiding the problems and expense of reconfiguring the existing systems to specifically serve the DDSS.

3.3.2 Overview of Data Search and Analysis Model: The Cost Estimation Loop

The second level of the DDSS model describes the iterative procedure followed by designers, in developing cost estimates for the designs they wish to analyze. This is depicted graphically in Figure 3-2.

The cost estimation procedure involves first looking for prior history of making the same or similar products in this enterprise. A product description is entered, and the DDSS searches the Production Planning System databases and returns the closest match to the product that has been made previously by the firm. This product order is defined by the order number of that production job.

Based upon that order number, the DDSS then searches the Production Planning System for the detailed information on that product order. It returns the records of all the processes involved in making the product, identifying all the materials used for each process, and the human resources and the equipment resources used to carry out the processes.

The DDSS then uses these process details to create a fully worked Process Plan, including the costs of labor, materials and equipment usage. Details are extracted from predetermined fields in the Process Plan; these pieces of information then drive a further search for cost information, using structured searches through the Accounting Information System databases. The costs are then calculated by the DDSS, and inserted back into the newly created Process Plan spreadsheet. The methodology for the structured searches and cost calculations is presented in the description of the third level model of the DDSS.

An important feature of the DDSS, and one that was used extensively in creating the framework necessary to implement the methodology, is the concept of using an *object-oriented product cost* structure, and *object-oriented cost data* structure. The basic principle of the *product cost object* is that a product object may inherit certain properties or field types from that class of object. For example, a WING product object may consist of multiple sub-objects, each having properties of dimensions, functions, material components, and associated manufacturing processes. The inheritance concept is that WING object then inherits all of the sub-objects, and it is then possible to collect all of the costs for the WING object by collecting all of the costs for each of the sub-objects that went into making the WING. This concept is explained further in Section 3.5.2.

The *cost data object* structure is an important part of the DDSS methodology. For example, a flexible manufacturing cell may be considered a cost object, with each component of the cell, being a sub-object. Costs are collected for each component of the cell, by capturing all the inputs used by that component. The total cost of the cell can then be calculated, using the inherited cost information from each of the sub-objects. Cost per product output by the cell can then be calculated by appropriate allocation of costs by the amount of time to produce that product. This cost per product is then inherited by the product object.

The notion of object inheritance is useful in explaining how different components of the system are related to one another. The software implementation of the system uses relational databases, and spreadsheets to capture and manipulate information. Each database and spreadsheet is considered as an object, and each record within the database as a sub-object. Each record inherits field properties from the parent object. The structured data search method uses the values contained in these fields to drive the search through the various databases. Another convenient object that the search process uses is that of a query recordset. A recordset is a group of records found by querying a given database. Each record in the recordset is an instance of the class, each field in the recordset is a sub-object or property of that class of object. The cost data object structure is explained further in Section 3.5.3, and the object types used for the database searches are described more completely in Section 3.7, on the software implementation of the DDSS.

3.3.3 Overview of Activity-Based Cost Calculations in the DDSS

The third level of the DDSS model describes in detail the methods of calculating costs for labor, materials and equipment resources used in composite part manufacturing processes. The cost calculations are driven by the information extracted from defined fields in the Process Plan. Figure 3-3 shows schematically, an example of the detailed cost calculation methods used in the DDSS methodology. With reference to Figure 3-3, the generic process can be described. The DDSS uses fields from each row of the Process Plan, in this case, the *Material Description* and *Size Parameter* to drive the search process. For each item of material listed in the process plan/bill of materials for a product, the DDSS searches through the inventory master file, and the *Unit Cost* of the item is returned. The *Material Cost* for each item is calculated as the *Quantity* (number of units) multiplied by the *Size*, multiplied by the *Unit Cost* for that item. The Material Cost for that process activity is then inserted back into the newly created Process Plan spreadsheet for the product. Because there may be more than one material item used in any process activity, the DDSS is required to create a subset of material items for each process activity. The Material Cost returned to the Process Plan is the Sum of all the material items for that process. This procedure is explained further in Section 3.6.2.

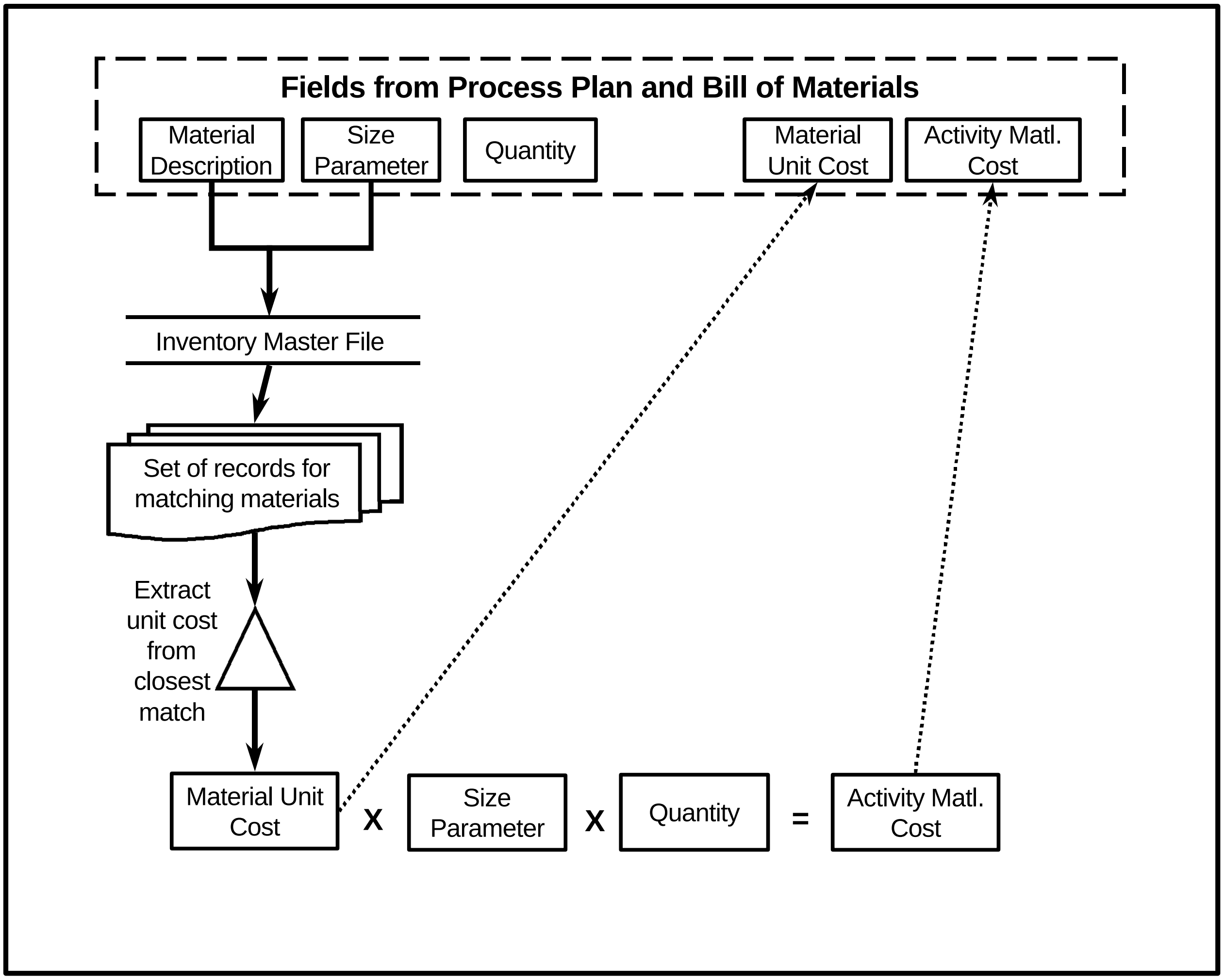


Figure 3-3: Example of Detailed Cost Calculation Method (Material Cost shown)

In similar fashion, the DDSS searches for Labor Costs and Equipment Costs associated with each process activity to make the product. The Labor Cost Calculation is detailed in Section 3.6.1. Calculating the cost of equipment involves first creating a separate worksheet to collect all of the costs associated with each equipment asset used in the manufacturing process to make the given product. The Machine Cost Summary calculation and subsequent Equipment Cost Calculation used by the DDSS is explained in Section 3.6.3

The DDSS program then steps into the next process activity and calculates all of the costs for that activity. For each process, a new structured search routine is created, and cost information is extracted from the Accounting Information System databases. The cost information is used in the calculation routines, and inserted back into the Process Plan spreadsheet. In this way the spreadsheet is built up, activity-row by activity-row. A fully worked DDSS Process Plan is shown in Table 3.2, on page 90.

3.4 Design Decision Support System: Top Level Model

The top level model (Figure 3-1) shows the interactions between the different components of the model. The links around the outside depict the flow of information in the organization, with information from design, planning, manufacturing and accounting systems being part of a shared information network. The Design Decision Support System (DDSS) operates inside of this loop. An advantage of the DDSS methodology is that it does not disturb the normal flows of information in the organization, but will use the information databases as sources of data. It is set up for the specific purpose of early design cost estimating, and interacts with the databases in each of the four major areas. These sub-systems are described more completely in the following sections, together with the key variables that the DDSS uses.

3.4.1 Interactions between Company Information Systems and the DDSS

Conventional accounting information system models provide a basis for modeling the interactions between the manufacturing system, design information system, production planning system and accounting information systems used in this research methodology. The systems models were developed for this study from models in accounting information and production planning systems literature (Gelinas & Oram, 1996; Murtuza, 1995; Nash, 1989; Wilkinson, 1993). The information flows are presented using data flow diagrams (explained in Appendix A.1), or using standard system flowchart symbols (as shown in Appendix A.2). Examples of more detailed breakdowns of accounting information systems are attached for reference in Appendix B. An assumption for this research is that the flows of information required to produce such information will be captured and recorded by the information systems. Example formats of the documents relating to accounting and manufacturing information flows were also taken from these sources. (Sources: Plenert, 1993; Gelinas & Oram, 1996; Murtuza, 1995; Wilkinson, 1993; Horngren & Foster, 1991). These sample document formats are detailed in Section 3.4.4 and Section 3.4.5. The DDSS limits its intrusion into the information system network by only connecting to the replicated database form of these records; it will have no direct interaction with physical data flows. This important limitation on the scope of the project considerably eases the problems of program development. It is also an important requirement for the system to work as a supplementary resource, not to replace or modify the existing accounting information system. This also reduces the barriers to implementation that are frequently encountered by change agents, as discussed previously in Section 2.4.9.

3.4.2 Manufacturing System

The manufacturing system consists of:

- production resources: facilities, labor, and equipment; the material and inventory control system;
- support functions such as maintenance, material handling and distribution, administration/management, and the provision of utilities.

Key variables required for inputs into the DDSS model are:

The typical structures for production processes. For each production process, there is a list of resources consumed by that activity:

Labor resources: the skill level of the operator required for the process, and the time taken to execute each process activity.

Material resources: for each process activity, the list of material inputs required in that process (obtained from the Bill of Materials for that process). Each MaterialID represents a set of entries in the Bill of Materials. Each item of material must be completely specified, and corresponds to an identical item recorded as an inventory transaction (i.e. when that material item was issued to the production order.

Equipment resources: the type of manufacturing equipment needed for each process activity. To calculate the cost of machine usage, it is necessary to factor in the cost of ownership of the machine, as well as any costs to maintain or operate the machine. To correctly allocate equipment costs it is also necessary to measure the productive output of the machine, or to record statistics of production hours worked by the machine. Information should also be captured on the production rates and constraints of machines, including the effects of breakdowns and planned maintenance on the available hours for production.

Tooling: In composites manufacturing for the aerospace industry, mold tooling is an expensive part of many production processes. The tool is manufactured in much the same way as any other part. From the mold tool design a production order is created and the mold tool is made. The mold tool is considered as a short-lived equipment asset. The DDSS considers mold tooling as a special case for the calculation of equipment cost. Essentially, the cost to make the mold tool is recorded in the asset database. When that mold tool is used in a production process, the DDSS extracts the asset cost and apportions the cost to make that tool to the product, based on the expected quantity of the product to be made with that tool. For the case study, it was assumed that the cost of the tool would be apportioned over the span of 10 of the product being made. The users could choose their preferred method to handle tooling cost. The DDSS can be configured to calculate tooling cost in a variety of ways.

3.4.3 Design Information System

The design information system incorporates the following information sources:

- The CAD/CAM database
- Design descriptions (part geometry, size, materials, functions)
- Process plans (all the activities to make the product)
- Bills of Materials (all the materials and components in the product)

Key variables are the design geometry of the parts, material specifications, and the sequence of production processes that are required to make the part. The process plan is an input to the Production Planning System, which creates a job order for each product to be made in the manufacturing system. The Job Order links to a list of Process Details to make each part, which in turn links to the Bill of Materials for each process activity. All of this information is transferred from the Design Information System to the Production Planning System.

The DDSS methodology is structured to work the Design Methodology for Composite Aircraft Parts presented in Section 2.6.7, and depicted graphically in Figure 2-1 (page 65). The DDSS uses the process plan output from the design process to estimate product costs. The procedure for product cost estimating is described in Section 3.5. The basic method is for designers to search for previous product process plans as the basis for a new product. For example, in the design of a new WING BOX structure, they may search for other WING BOX designs, probably with different geometry and sizing. Alternatively, they may search for other composite box sections, that may have been made for other purposes. By picking out the process activities that are common to both new and old designs, they can quickly modify previous process plans to account for design differences. Each activity in the process plan can be kept the same, modified, deleted, or new activities added, before estimating the cost. Table 3.1 is an example of a manually generated process plan, in spreadsheet format. Table 3.2 provides an example of the spreadsheet form of the process plan that is created by the DDSS. Page 2 of Table 3.2 shows the cost calculation fields returned by the DDSS to the designer. The designer is able to compare the relative cost of the activities to make the product, and the components of cost for each activity (i.e. labor, material, and equipment cost components).

An assumption of the methodology is that the process plans can be represented in this format, either by converting the database format that is already being used into spreadsheet form, or by capturing manually drawn process plans into spreadsheet form. Given the advanced state of computer aided design methods used in the target industry, this assumption is unlikely to present any major obstacles to implementation.

3.4.4 Production Planning / Scheduling System

The planning/scheduling system incorporates the following information sources:

- Master production schedule
- Job/order records, including process details
- Bills of material, material requisitions, material issue notices

a. Key variables

Key inputs used by the DDSS from these sources are the output measures indicating throughput of processes, job/order records to track process times (also idle times and delays), and bills of materials for calculating material resources consumed.

b. Common Forms of Information in the Production Planning System

Production/Job order: document identifies job to flow through production process. Typically incorporates following key information: Job number, part description, part ID, list of processes/activities to be carried out specifying the machine, material and staff resources for each activity. Also the quantity of pieces to be made, and the time taken to finish the activity. For the DDSS, this is the main input document, as the search for all the production activities stems from the descriptions of operations, materials, machines and human resources for each activity listed. An example job order format is provided in Appendix D.2.

Table 3.1: Manually Generated Process Plan

	Process	Operation	Material	Size	Quantity	Machine/ Tools	Operators	Proc. Time	Setup Time
1	Plycutting	Cut glass epoxy sheets	250F Glass epoxy cloth	25" x 19"	6 sheets per kit	Gerber Automated Cutter	1	30	15
2	Plycutting	Cut adhesive film sheets	250F Curing adhesive film	25" x 19"	2 sheets per kit	Gerber Automated Cutter	1	30	15
3	Honeycomb cutting	Cut honeycomb sheets	Nomex honeycomb 3-4lb	22" x 16" x 1/4 " thick	1 sheet per kit	Waterjet cutter	2	30	15
4	Bagging	Cut the film	Plastic film 36" roll	36" x 36"	2 sheets per bag	Film cutter	1	2	5
5	Bagging	Make the bag	Plastic film sheets	2 shts 36" x 36"	1 bag per kit	Heat sealer	1	5	5
6	Reinforce latch area	reinforce sections of honeycomb sheet with epoxy filler	Nomex honeycomb 3-4lb and room temp.cure epoxy filler	22" x 16" x 1/4 " thick	1 sheet per kit and 5 oz. filler	Fixture and squeegee	1	25	5
7	Lamination	Prep. the mold	Mold cleaning fluid and release agent		each kit	mold and fixture plates	1	30	
8	Lamination	Lay on sheets of prepreg and adhesive film	3 Sheets of 250F Glass Epoxy and 1 Sheet of 250F Curing Film	Each Sheet 25" x 19"	Bottom layer of kit		1	40	
9	Lamination	Use Jig to locate and Install the Honeycomb Nomex	1 Sheet of Honeycomb Nomex	22" x 16" x 1/4" thick	Middle layer of kit	Locating Jig	1	10	
10	Lamination	Lay on sheets prepreg and adhesive flim	3 Sheets of 250F Glass Epoxy and 1 Sheet of 250F Curing Film	Each sheet 25" x 19"	Top Layer of kit		1	40	
11	Lamination	Lay teflon film and breather on top of kit and mold	Sheet of Teflon Film and Breather material	Each sheet 33" x 27"	One per kit		1	10	
12	Lamination	Wrap vacuum bag around mold, kit, teflon, and breather film	Vacuum bag, kit, mold, teflon film, and breahter material	Vacuum Bag: 36" x 36"	One per kit		1	20	
13	Lamination	Draw vacuum and seal bag	Entire kit and bag		Once per kit	Plant vacuum system	1	20	
14	Lamination	Curing Composite Part in autoclave at 250F	Entire kit, vacuum bag		3 kits	Autoclave	1	240	10
15	Trimming/Finishing	Cut excess glass from door	Unfinished baggage door	25" x 19" Door	1 kit	Cutting Template and Water Jet Cutter	1	9	120
16	Shipping and Packaging	Pack Baggage Doors and Ship to Customer	Packing and Shipping materials				1	15	
17	Engineering	Design/process planning for door production	Manufacturing engineer		1 off		1	720	
18	Tooling	Mold Tooling Cost	Manufactured separately		1				

Table 3.2: Process Plan generated by DDSS (Page 1 of 2)

OrderID	ProductID	ProcessID	ProcessDesc	Start Date	End Date	Start Time	End Time	Process Time	AssetID
100	UH64BD	1	Plycutting: cut glass epoxy sheets	1/4/98	1/4/98	8:00AM	8:45AM	45	LASERCUTTER01
100	UH64BD	2	Plycutting: cut adhesive film sheets	1/5/98	1/5/98	8:00AM	8:45AM	45	LASERCUTTER01
100	UH64BD	3	Cutting Honeycomb sheets	1/6/98	1/6/98	8:00AM	8:45AM	45	WJCUTTER02
100	UH64BD	4	Bagging: film cutting	1/7/98	1/7/98	9:00AM	9:07AM	7	FILMCUTTER01
100	UH64BD	5	Bagging: heat sealing	1/7/98	1/7/98	10:00AM	10:10 AM	10	HEATSEALER01
100	UH64BD	6	Reinforce latch area	1/8/98	1/8/98	10:20AM	10:50 AM	30	
100	UH64BD	7	Mold preparation	1/9/98	1/9/98	8:15AM	8:45AM	30	
100	UH64BD	8	Lamination layup: prepreg and adhesive film	1/9/98	1/9/98	8:10AM	8:50AM	40	
100	UH64BD	9	Lamination jig setup: locate and install Nomex she	1/9/98	1/9/98	9:00AM	9:10AM	10	
100	UH64BD	10	Lamination layup: prepreg and adhesive film	1/9/98	1/9/98	9:10AM	9:50AM	40	
100	UH64BD	11	Vacuum film layup: teflon film and breather	1/9/98	1/9/98	10:00AM	10:10 AM	10	
100	UH64BD	12	Vacuum film wrap	1/9/98	1/9/98	10:15AM	10:35 AM	20	
100	UH64BD	13	Vacuum bag: draw and seal	1/9/98	1/9/98	11:00AM	11:20 AM	20	VACPUMP01
100	UH64BD	14	Curing at 250F	1/10/98	1/10/98	9:00 AM	1:00 PM	240	AUTOCLAVE04
100	UH64BD	15	Trimming and finishing	1/13/98	1/13/98	8:30:AM	10:39 AM	129	CNCMILL02
100	UH64BD	16	Packaging	1/15/98	1/15/98	2:00:PM	2:15 PM	15	
100	UH64BD	17	Engineering design (portioned)	12/1/97	12/2/97	8:00:AM	12:00 PM	720	CADCAMPC03
100	UH64BD	18	Mold Tooling Cost (portioned)	12/18/97	12/24/97	8:00 AM	5:00 PM	0	TOOLBD01

Table 3.2: Process Plan generated by DDSS (Page 2 of 2)

ProcessID	EmployeeID	NoEmployees	MaterialID	Machine CostRate	Machine Cost	EmployeeCostRate	Labor Cost	Material Cost	Process Cost
1	LC1	1	UH64BDM1	$29.51	$22.14	$18.00	$13.50	$90.00	$125.635
2	LC1	1	UH64BDM2	$29.51	$22.14	$18.00	$13.50	$ 6.00	$ 41.635
3	WC1	2	UH64BDM3	$21.67	$16.25	$18.50	$27.75	$ 50.00	$ 94.000
4	FC1	1	UH64BDM4	$3.27	$0.38	$15.00	$1.75	$ 4.00	$ 6.131
5	HS1	1		$2.07	$0.34	$14.00	$2.33	$ -	$ 2.678
6	OP2	1	UH64BDM6		$-	$10.00	$5.00	$ 16.00	$ 21.000
7	OP2	1	UH64BDM7		$-	$10.00	$5.00	$ 8.00	$ 13.000
8	OP2	1			$-	$10.00	$6.67	$ -	$ 6.667
9	OP2	1			$-	$10.00	$1.67	$ -	$ 1.667
10	OP2	1			$-	$10.00	$6.67	$ -	$ 6.667
11	OP1	1			$-	$8.00	$1.33	$ -	$ 1.333
12	OP1	1			$-	$8.00	$2.67	$ -	$ 2.667
13	OP1	1			$-	$8.00	$2.67	$ -	$ 2.667
14	OP3	1			$-	$12.00	$48.00	$ -	$ 48.000
15	OP4	1		$ 40.45	$86.97	$14.00	$30.10	$ -	$117.071
16	LA1	1	BOX321		$-	$5.00	$ 1.25	$ 2.00	$ 3.250
17	ENG2	1			$-	$35.00	$42.00	$ -	$ 42.000
18	ENG2	0		$80.00	$80.00	$ -	$ -	$ -	$ 80.000

Process Plan: describes the whole sequence of production activities required to make a product. An example is shown in Table 3.1, showing a process plan for a typical composite fabrication. The DDSS generates a fully worked process plan, using the information from the Job Order and Bill of Materials records to drive the cost estimation procedure. An example of the DDSS generated process plan is shown in Table 3.2. The cost estimating procedure is explained in detail in Section 3.5.

Bill of Materials: document related to the job order and the process plan, listing full descriptions and quantities of all raw materials and sub-components that are needed to make a certain product or order. An example bill of materials is shown in Appendix D.3.

Materials requisition: directs store to issue materials/parts to work center. May list cost, or be matched to cost later by inventory control. An example materials requisition is provided in Appendix D.4.

Move ticket / traveler: authorizes physical transfer of a production order from one work center to the next listed on the order. Records quantities made, time started and finished, job order ID. An example move ticket is provided in Appendix D.5.

c. Flow of Information in the Production Planning / Scheduling System

The flow of information in the production planning and control system is adapted from an Integrated Production Information System developed by Gelinas and Oram (1996), and other descriptions of the production cycle from accounting information systems texts. The following description of information flows is adapted from Wilkinson (1989), and Gelinas and Oram (1996). With reference to Figure 3-4:

I. The production process starts with a new job order scheduled to start into production.

II. The material requirements planning process accesses the planning databases, and then moves to develop the time phased order requirements.

III. Based on information about current status of the production system, the detailed capacity planning schedules the job for production.

IV. To start the production sequence, manufacturing orders are released to work centers, as well as preprinted move tickets that will control the flow of parts and material to each work center at the appropriate time.

V. For purchased material and parts, purchase orders are made out and sent to vendors (or via inventory/purchasing to the vendors). For material/parts to be made or drawn from inventory, the system outputs material or parts requisition to inventory control. When these parts are purchased or made, they are received by inventory control, or may be delivered directly to the work center where they are needed (accompanied by material issue notices).

VI. Materials, parts and work orders go to the work center, together with move tickets. Employees and machines are assigned as per job order, entering the start time, and when completed, the end time for each job. The job then proceeds to the next scheduled process on the manufacturing order.

VII. Completed manufacturing orders are returned together with move tickets, material issue and return notices, to shop floor control, and also to the cost accounting system (This description presumes a standard costing system).

VIII. Shop floor control updates the planning system of completed work, changes in the status of work centers.

IX. The cost accounting system updates the various databases associated with the production process, using information received. Conventional cost variance reports are sent to managers; the general ledger accounts are updated to account for the conversion of raw material and inventory stock into work-in-process, and finally into finished goods for distribution.

The Master Production Schedule contains summary as well as detailed information on all production jobs completed, or in process. The DDSS searches this database for information relating to jobs matching the specific criterion under review. For example, when searching for equipment production time, it will find all the jobs using a specified

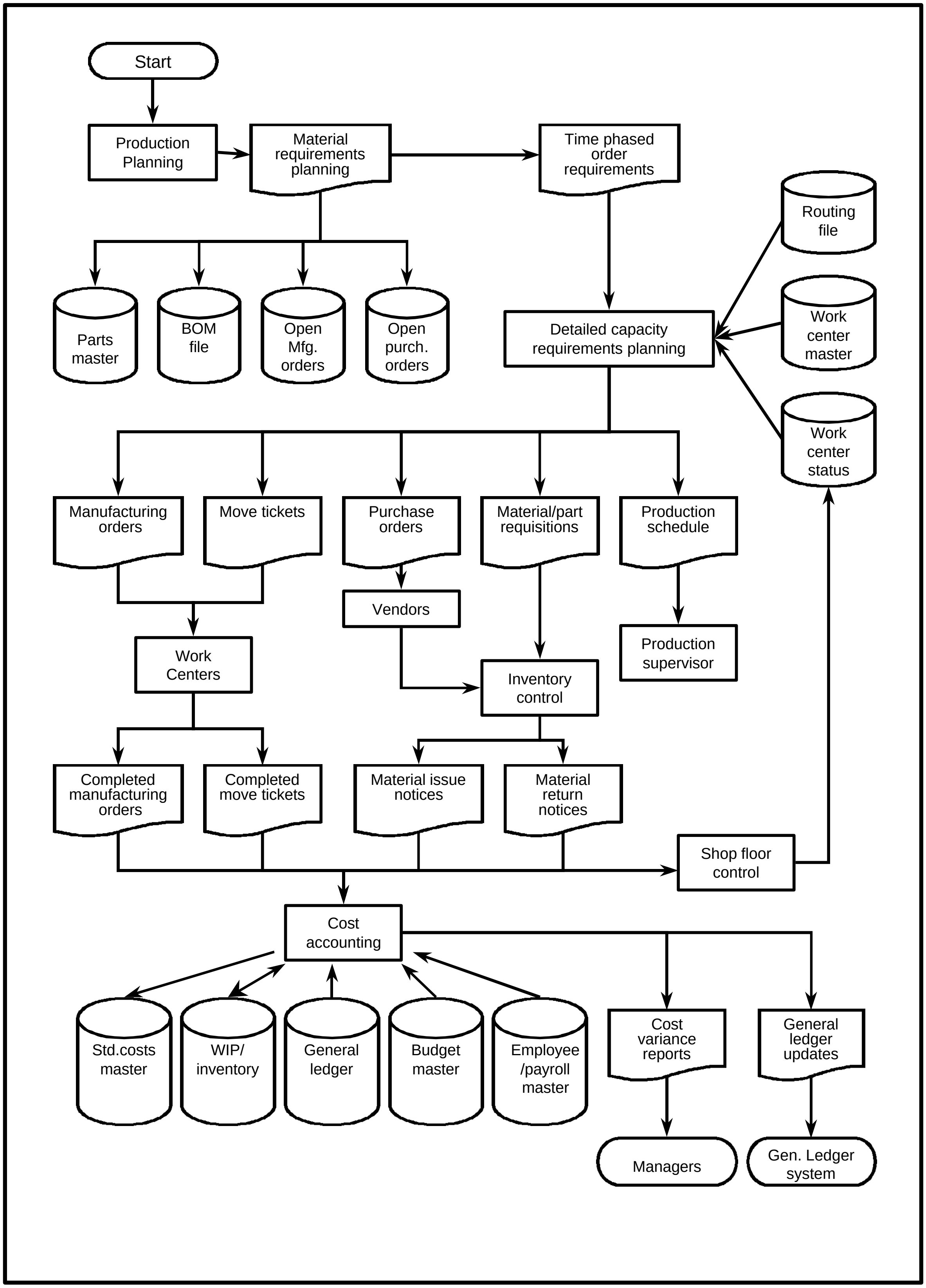


Figure 3-4: Planning and Production Information System (adapted from Gelinas & Oram, 1996)

machine over the chosen time period, and report back the total amount of time in production. When searching for records related to a specific product, the DDSS searches for all job records related to producing that product. It then reports the total number produced, and average time and resources consumed in producing that part/component. The bill of materials database is similarly searched for materials used in producing specific parts. By cross referencing to the inventory/purchases database, the cost of these materials is then reported back to the DDSS.

3.4.5 Accounting Information System

The accounting information system incorporates:

- General ledger database
- Budget files
- Employee/payroll database
- Inventory/WIP database
- Asset database

Key variables are the costs of labor, costs of owning and operating facilities, costs of purchased materials, costs of equipment ownership, and basis for allocation of these costs (i.e. time, utilization, direct, indirect).

The DDSS model limits interaction with the accounting and production system by using replicated database files. The files that are of particular interest are the employee/payroll file, the inventory/WIP file, and the asset database. The typical data flows associated with the operation of each of these systems are summarized in the following flowcharts, modified from flowcharts by Murtuza (1995), Gelinas and Oram (1996), and Wilkinson (1993).

a. Employee Database / Payroll System

With respect to the DDSS, the only interaction with the payroll system, will be to extract information on labor cost rates, and job time record information. Other flows of information in the payroll accounting system are summarized as follows, depicted schematically in Figure 3-5 (adapted from Murtuza, 1995):

1.0	Calculate hours:	Collate attendance time records and job time records
		Create report of validated attendance records
2.0	Allocate labor costs:	Get cost rates from employee/payroll master file
		Allocate labor costs to cost centers
		Make labor cost GL entries
3.0	Taxes/deductions:	Calculate taxes, health insurance, other withholdings
		Update salary information
		Send taxes, notices, withholding to government and external agencies.
4.0	Pay employees:	Calculate paychecks
		Deduct taxes and other deductions
		Make out paychecks, send to employees
		Make disbursement GL entries
		Update employee/payroll master file

The employee/payroll master file contains records for each employee. Each employee record typically contains information identifying the employee, employee payment information, leave history, and current payroll data (including running totals). A typical employee record is shown in Appendix D.6. An alternative to using cost rates for specific employees is to use employee code cost rates. This uses a summary table of cost rates for various skill levels of employees, and has the advantage for the DDSS of not requiring access to the private employment details of personnel. The DDSS prototype system uses a the employee code cost rate method, for the advantages of avoiding any issues of data privacy, and also a more flexible method, reducing barriers to implementing the methodology in different companies.

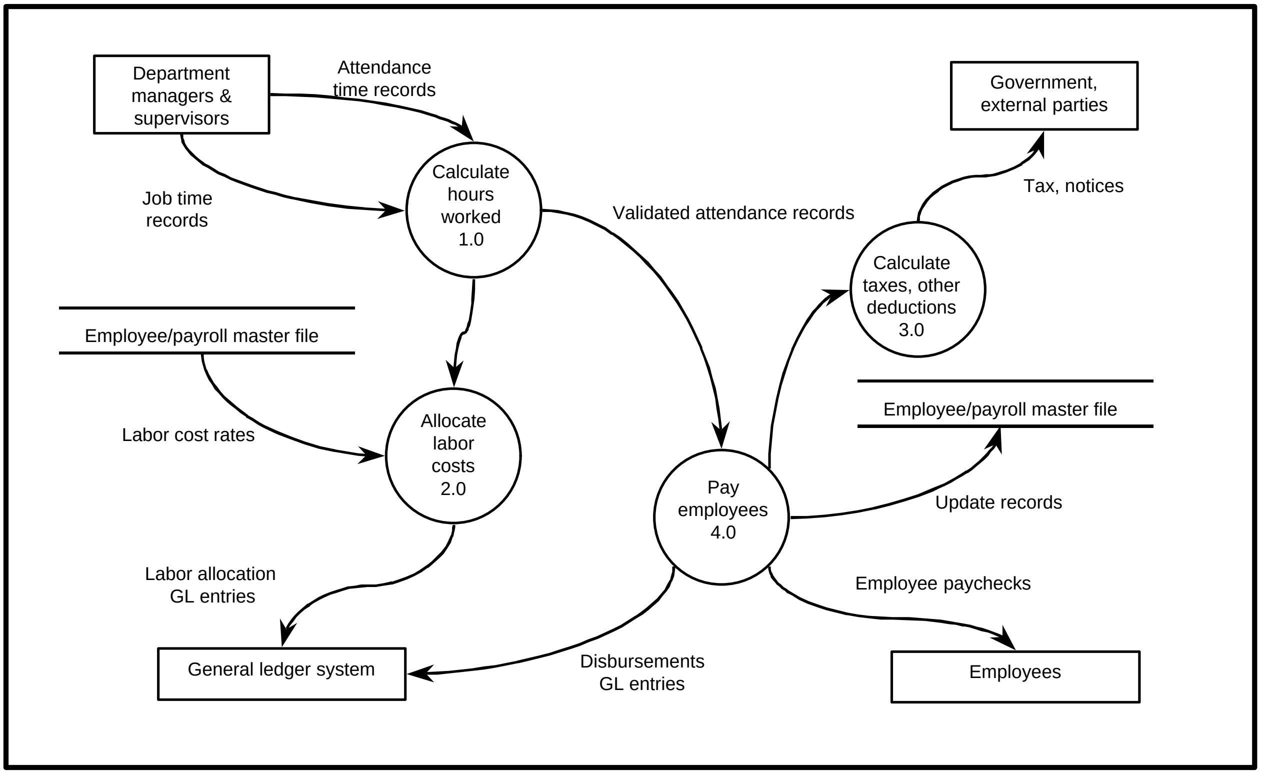


Figure 3-5: Data flow diagram of payroll system (modified from Gelinas & Oram (1996) and Murtuza (1995))

b. Inventory / WIP / Product Conversion System

The Inventory/WIP/Product conversion system is effectively integrated with the planning and production information system. The key processes are included with those described previously for the production information system in Figure 3-4. The key inputs are the process plan, job order, and bill of materials for each product order. Examples of these documents are provided in Appendix D.1, D.2 and D.3 respectively. The logical flow of information is as follows (refer to Figure 3-6):

1.0 Plan to make product: Process plan, job order and bill of materials received by inventory control.

Each item to be purchased or made is identified, and the inventory system checks if the item is currently in stock

Purchase order is made out to vendor for material/parts. to be purchased.

Items to be manufactured: job order request sent to production planning system.

Vendor supplies material/parts, with invoice.

2.0 Receive part/material: Item is received into inventory.

Purchase cost data is captured in inventory database.

Journal entry is made to general ledger for payments.

3.0 Send part/material to production: When planned for production, item is sent to work center, together with material/part issue notice, where it will be used to make the product

Update WIP/Inventory and general ledger account

4.0 Manufacture product: Product is manufactured.

When item is made, return to inventory, or direct to a work center for assembly to the product

Update WIP/Inventory file

Product sent to distribution/sales.

Update general ledger, transfer of goods from WIP to Finished goods.

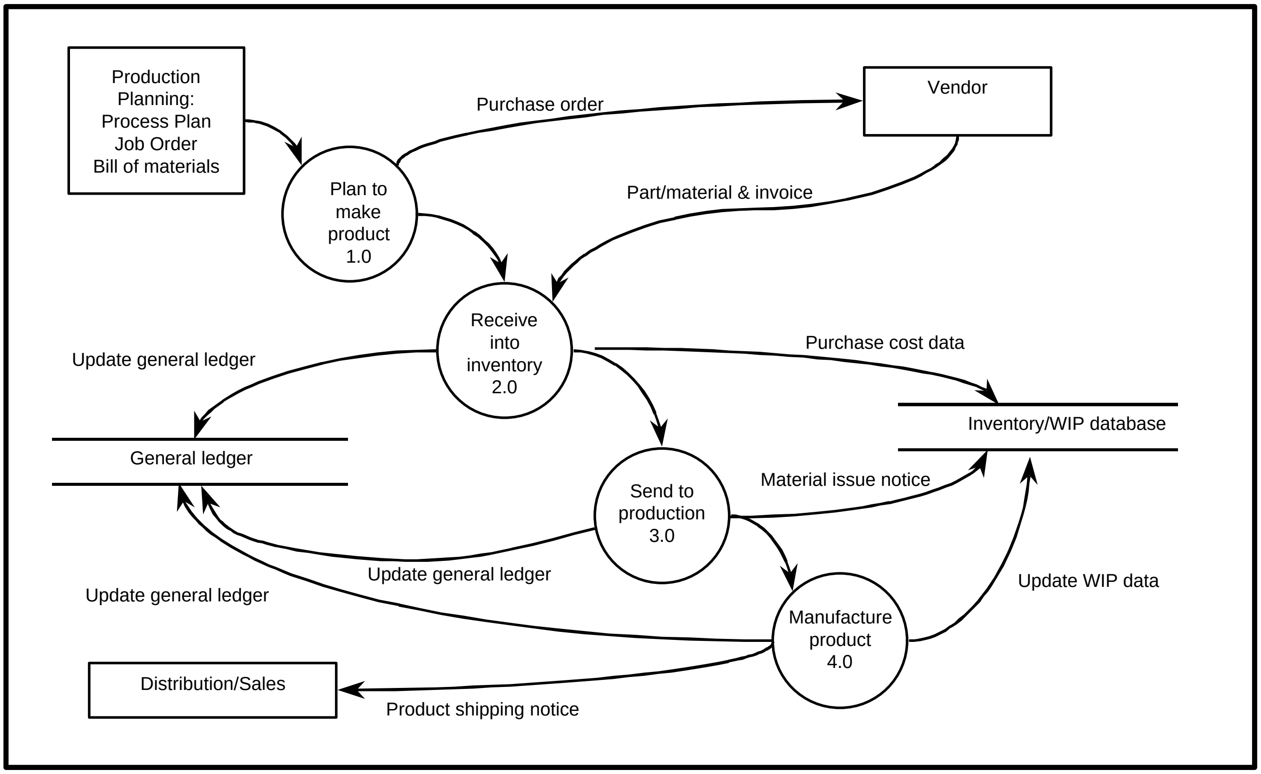


Figure 3-6: Information flow diagram for Inventory/WIP/Product conversion

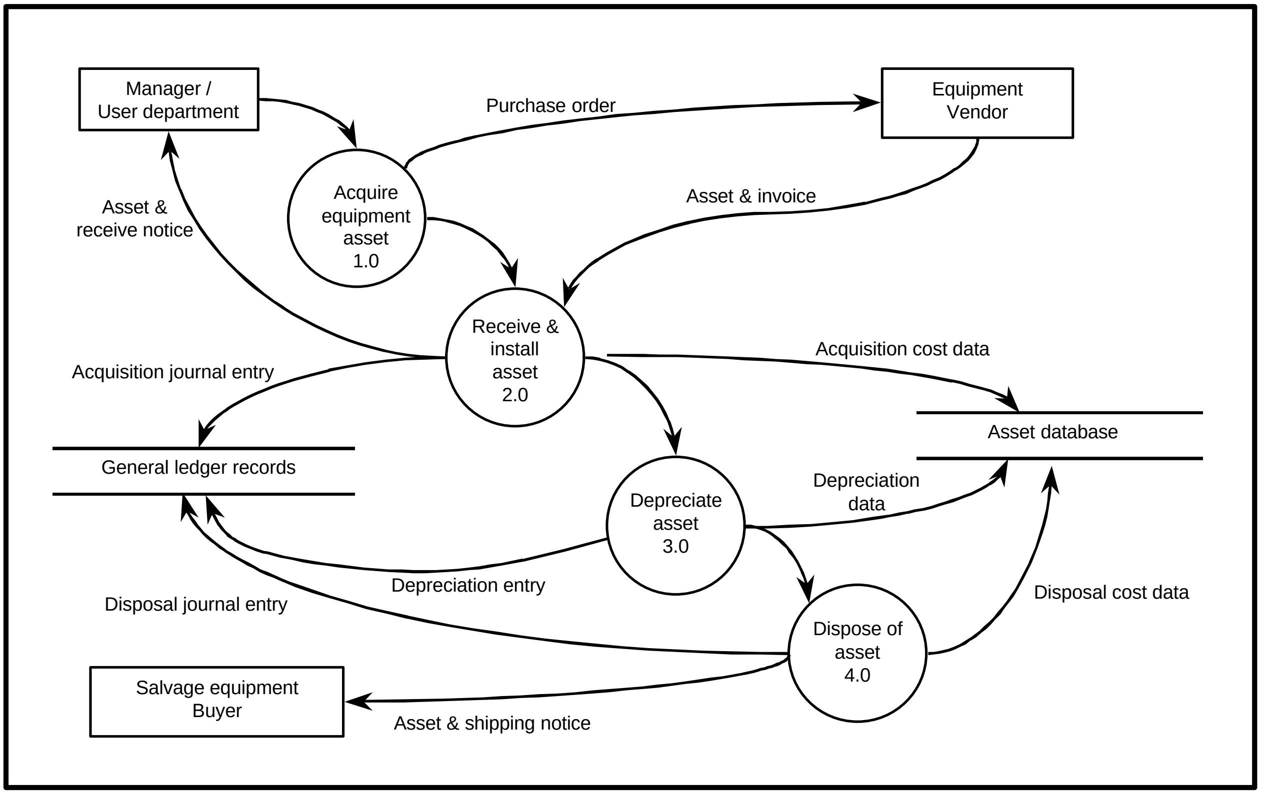


Figure 3-7: Information Flow Diagram for Asset Transactions (adapted from Wilkinson, 1991)

The DDSS uses the Bill of Materials for each product to estimate cost of materials in that product . For each purchase item listed, it searches the inventory database for the cost, and sums the total material cost of all the items for each product.

c. Equipment Asset Database

The plant asset database contains records of each piece of equipment, plant asset number, asset type code identifying the major classification of the equipment, and the location of the asset. Depreciation information such as depreciation method, current depreciated value, expected life, and expected salvage value are also recorded.

The information flows in the life of an equipment asset are summarized from Murtuza (1995), as shown in Figure 3-7:

Summary of Information Flows for Asset Transactions:

1.0	Acquire Asset:	User department requests plant asset.
		Purchase order is made out to vendor.
		Vendor supplies asset, with invoice.
2.0	Receive Asset:	Asset is received and installed.
		Acquisition cost data is captured in plant asset database.
		Acquisition journal entry is made to general ledger.
3.0	Depreciation:	Annual depreciation entry made to general ledger.
		Depreciation data recorded in plant asset database.
4.0	Asset disposal:	User department requests disposal.
		Equipment buyer purchases asset.
		Asset shipped to buyer with shipping notice.
		Disposal cost recorded in plant asset database.
		Disposal journal entry made to general ledger.

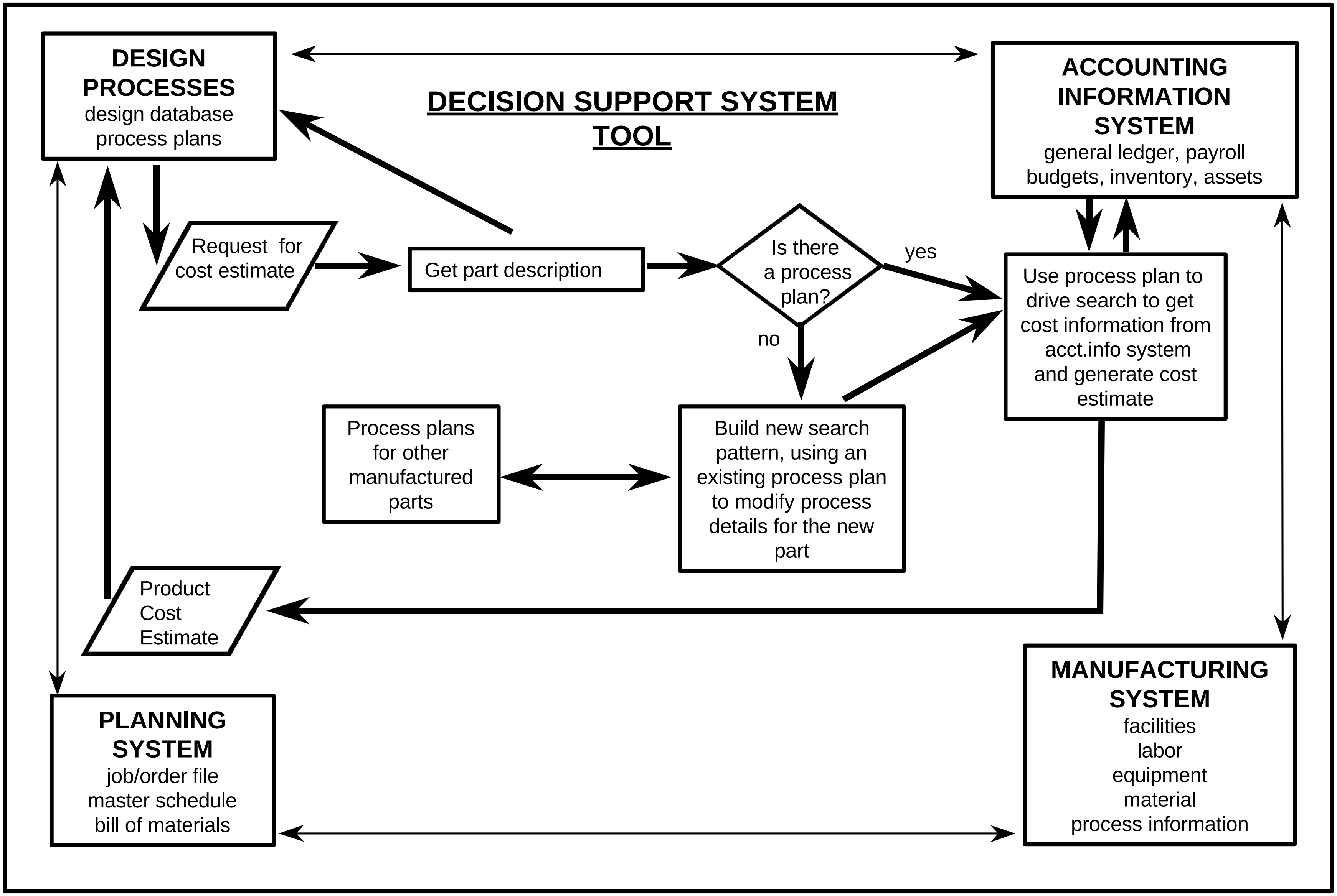


Figure 3-8: Design Decision Support System: Search / Analysis Structure

3.5 Design Decision Support System: Search / Analysis Model

3.5.1 Overview of Cost Estimating Process

The second model focuses on the cost estimating process within the analysis tool. The major components are again indicated by the linked network of information flows around the outer perimeter of the model. The inside loop represents the iterative procedure of estimating the cost for a particular product configuration. A typical cost estimation procedure in the DDSS consists of the following steps:

I. Input description of part / component.

II. Find the closest match to the same or similar product produced before by the firm.

III. Use the process details from that product order to create a fully worked and costed Process Plan spreadsheet, which is presented back to the designer.

IV. Designer is able to evaluate the results of the cost estimate; comparing the cost of each process in the part, versus the functionality it provides.

V. If a new part is to be created, a new cost estimate can be generated, by modifying the process details, e.g. change material types, size parameters, and possible process methods to suit the new design.

VI. The modified process plan is resubmitted to the DDSS

VII. The DDSS creates a new Process Plan spreadsheet, using the changed process details, but using existing knowledge of production process costs. This is again presented back to the designer.

VIII. What if? analysis. The iterative procedure can continue, with continued inputs from the designer, to evaluate the effect of possible design choices, or processing methods, on the cost to make the part.

The process is initiated by a request from a designer/engineer for a product cost estimate. A part description is entered by the designer. The cost estimation procedure involves first looking for prior history of making the same or similar products in this enterprise. A product description is entered, and the DDSS searches the Job Order database and returns the closest match to the product that has been made previously by the firm. This product order is defined by the order number of that production job.

Based upon that order number, the DDSS then searches the Process Details database (linked to the Job Order database in the Production Planning System) for the detailed information on that product order. It returns the records of all the processes involved in making the product, identifying all the materials used for each process, and the human resources and the equipment resources used to carry out the processes.

The DDSS then uses these process details to create a fully worked Process Plan, including the costs of labor, materials and equipment usage. Details are extracted from predetermined fields in the Process Plan; these pieces of information then drive a further search for cost information, using structured searches through the Accounting Information System databases. The costs are then calculated by the DDSS, and inserted back into the newly created Process Plan spreadsheet.

If there is no existing product, then a similar product must first be found and from there create a modified Process Plan. It is possible to modify the process details to fit the new part, and thereby build up a new search pattern. Process methods, material items and choices of which production machines to use, can all be varied by designer input. A new Process Plan is then created using the DDSS, returning the new cost estimate to the Designer/Engineer in the form of a new spreadsheet. The iterative procedure of design evaluation can then be continued by the designer, either accepting the current process plan, or by modifying the process plan to see the effect of further changes in the input parameters.

The data searching procedure for cost estimating by this method can be likened to a diligent human worker trying to do the same laborious task, over and over again. Experience in carrying out similar cost tracking exercises by hand indicates that the desired information is usually available in some form, somewhere in the organizational databases, but it is not always easy to find, and it is often not arranged in a convenient or useful format. Humans have far superior capabilities (compared to machines) to search through large amounts of information and to recognize patterns, and then to pick out only the important and relevant facts. The challenge with this model is to use computerized pattern matching to pick out files that relate to a product, and then pick out the relevant facts, using the same kind of process. The advantage of structured database searches (compared to humans doing the same task) is that computers never tire of doing them, and the computers can be "taught" to repeat the process very quickly, using the knowledge gained from previous searches.

3.5.2 Representation of Product and Cost Information

Integral to the DDSS methodology is an object oriented data structure to represent the various products and sub-components. The importance of this structure is to provide a development structure that allows for considerable flexibility to enhance or adapt the methodology in the future. This allows a class of products to “own” objects which in turn inherit properties or field types from the class. For example the group/assembly of products called WING may consist of multiple components such as WING_BOX, AILERON, UPPER_SKIN, LOWER_SKIN, and LEADING_EDGE. Each of these component objects may in turn “own” sub-component objects or materials or process steps which go into making that component. WING-BOX may consist of multiple plies of prepreg material, cut to a given size and shape, adhesive film, with different plies cut and placed at different alignment angles, and then bonded to sandwich panel beams made up separately. A schematic of this concept is shown in Figure 3-9. Objects may be subject to multiple inheritance, for example a glass ply material which may be used in many components, as shown in Figure 3-9.

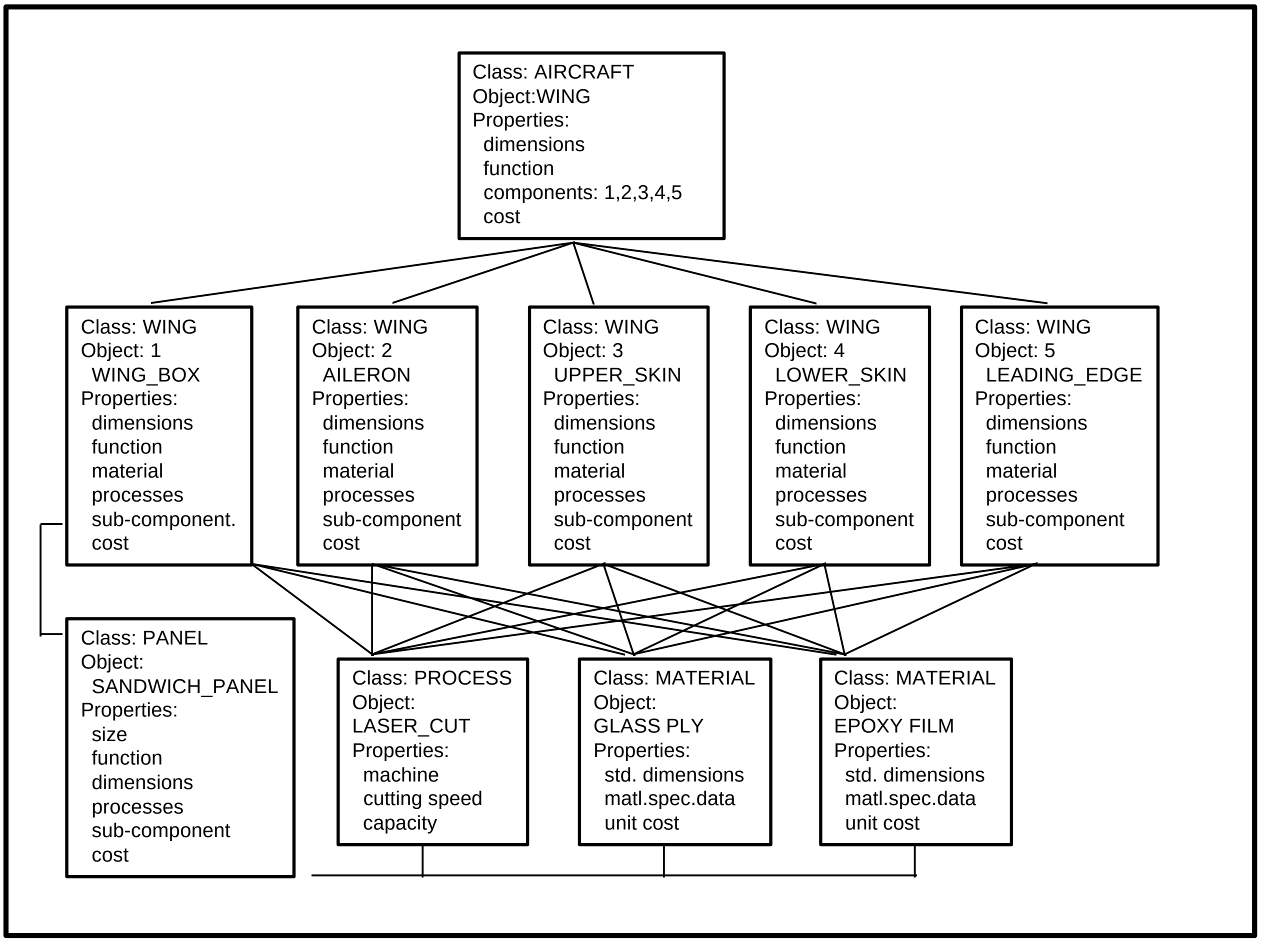


Figure 3-9: Schematic of Product Data Structure

3.5.3 Cost Data Structure

The cost structure can also be modeled using an object-class structure, as shown in Figure 3-10. For the example of a manufacturing cell, it consists of sub-objects of the various machines and resources which form the cell. These machine resources, although sub-objects of the fixed asset database, are also inherited by the manufacturing cell, at least in as far as the cost of ownership is concerned.

Costs of maintenance jobs carried out on these machines are also inherited by the machine, and hence the cell. Personnel resources may be attached to the cell for the duration of the time they spend working there, using time keeping records to allocate the appropriate portion of their cost. The total cost of the cell can then be calculated, using the inherited cost information from each of the sub-objects. Cost per product output by the cell can then be calculated by appropriate allocation of costs by the amount of time to produce that product. This cost per product is then inherited by the product cost object. The notion of object inheritance is useful in explaining how different components of the system are related. The software implementation of the system uses relational databases, and spreadsheets to capture the information. Each record is regarded as an object. Each field is a property of that object. Another convenient object that the search process uses is that of a query recordset. A recordset is a group of records found by querying a given database. Each record in the recordset is an instance of the class, each field in the recordset is a sub-object or property of that class of object. Each of these object types are described more completely in Section 3.7, on software implementation of the system.

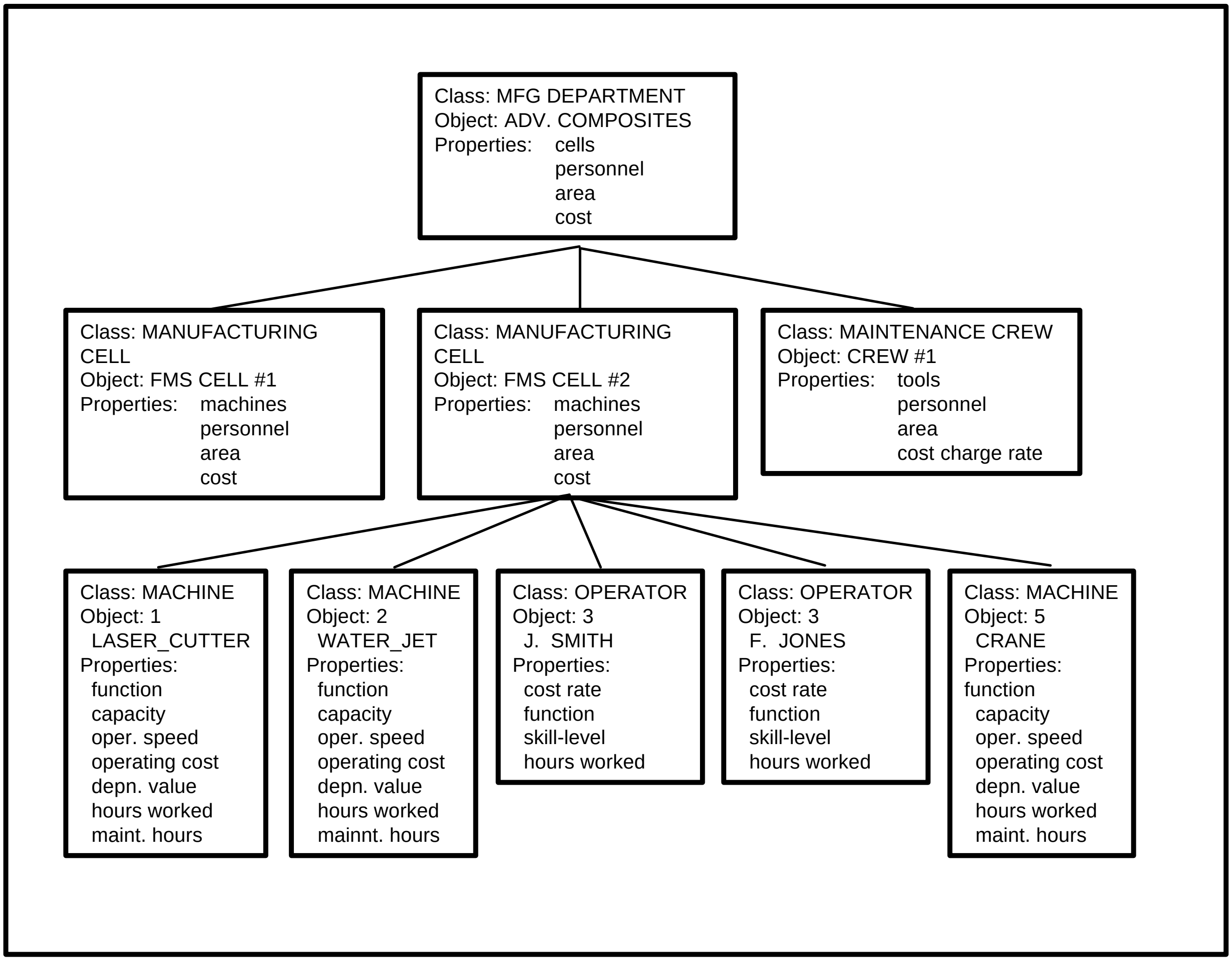


Figure 3-10: Manufacturing Cell Cost Structure

3.6 Detailed Development of Activity-Costing Methodology used in the DDSS

3.6.1 Labor Cost Calculations

Labor Times for each activity are obtained by querying the Master Production Schedule, finding the set of records that include job time for that activity. The time will be taken either from the closest match to the activity found. *Labor Cost Rates* are matched to the employee or employee type, by referencing the employee/payroll master file or a summary table of Employee Cost Rates. Companies may prefer to use *Labor Type* cost rates instead of by employee, to avoid making individual personnel database records accessible to the DDSS. The *Labor Cost* is then calculated as the *Number of Employees* of a certain skill type multiplied by the *Labor Cost Rate* for that skill-type, multiplied by the *Labor Time* for the process activity (shown schematically in Figure 3-11).

For engineering activities, the DDSS may need to provide case handling routines to search an engineering billable hours database, which would record the engineering resources used to design a particular product. This separate case handling routine would be necessary because engineers would most likely not input clock cards or fill in job orders for the time they spend on each design project. For the prototype DDSS system, engineering time for each product is entered as a separate process detail record, with the process noted as engineering design, and the engineer listed as the employee carrying out the activity. Engineering time is summarized separately from direct production labor, and is handled as a special case. The design and development time spent by the engineer on a product must be apportioned between the expected number of products to be made. The total engineering labor cost is therefore divided by the expected number of parts to be made to give the allocated engineering labor cost to each product.

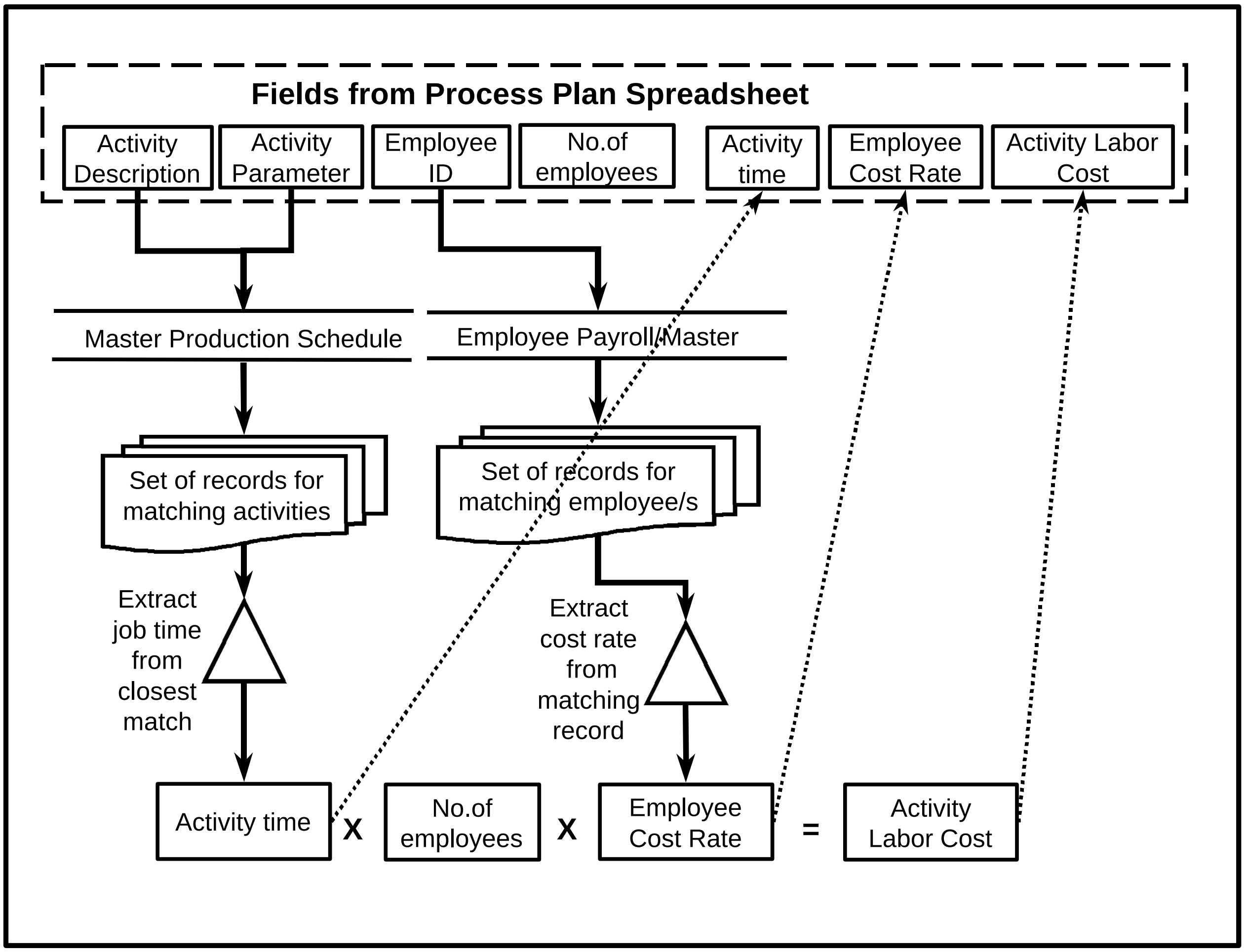


Figure 3-11: Schematic of Labor Cost Calculation

3.6.2 Material Cost Calculations

Each item of material listed in the process plan/bill of materials for a product, is looked up in the inventory master file, and the *Unit Cost* of the item is returned. The *Material Cost* for each item is calculated as the *Quantity* (number of units) multiplied by the *Size*, multiplied by the *Unit Cost* for that item (shown schematically in Figure 3-12). Companies may choose to include inventory carrying costs in the material cost for the item. This is a method to allocate the store/inventory cost directly to the materials, usually as a percentage of the cost, or as a charge per transaction. The charge per transaction method is more in keeping with activity costing principles, but a percentage of cost may be easier to apply, and account better for the cost of capital applied to holding the inventory.

The prototype DDSS model assumes that all costs are included in the cost rate charged for the item. As long as the method is consistent from one cost estimate to the next, it is immaterial to the DDSS implementation how each company chooses to allocate store overhead costs.

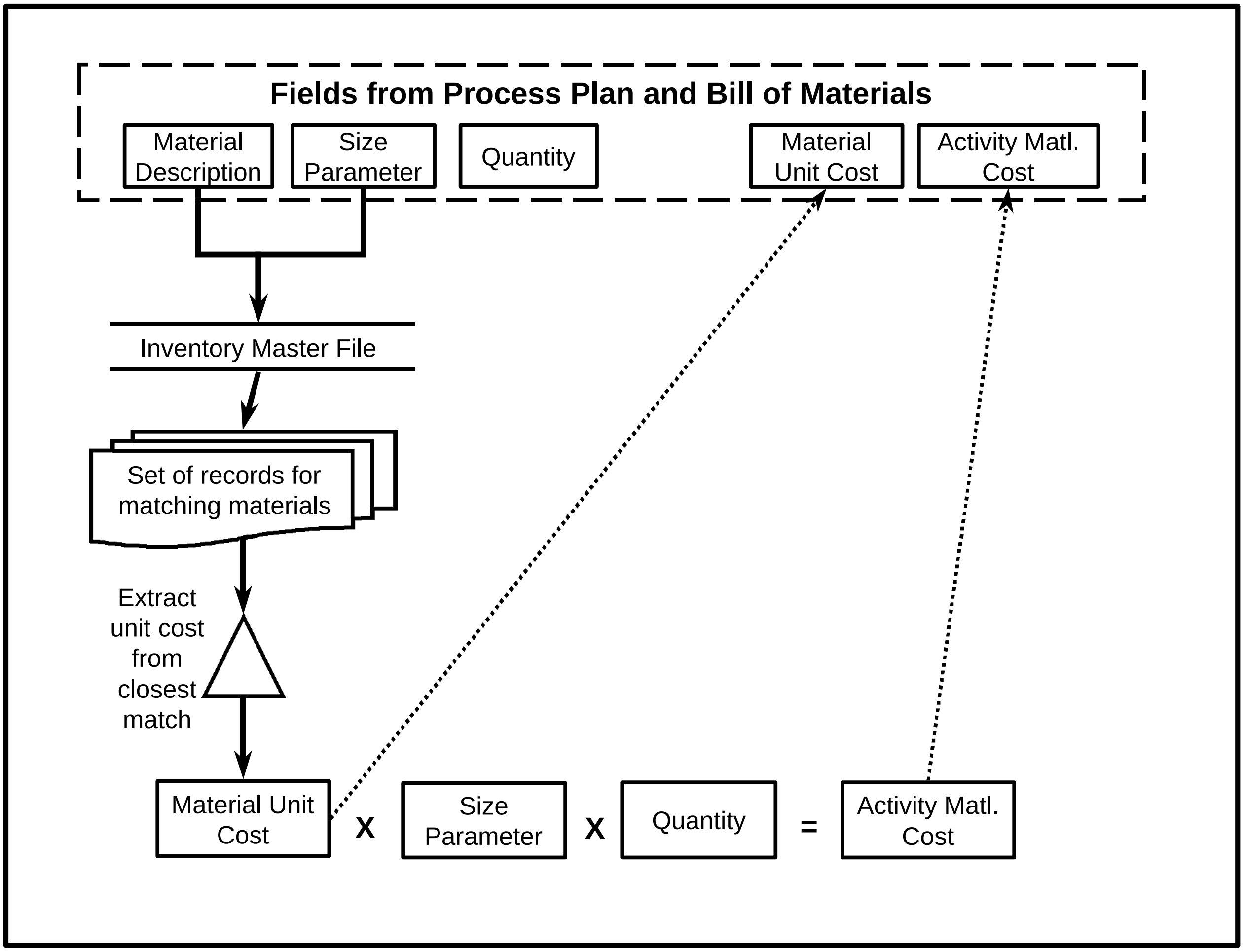


Figure 3-12: Schematic of Material Cost Calculation

3.6.3 Equipment Cost Calculations

a. *Cost of Ownership*

The cost of ownership of a machine is calculated by querying the asset database for the purchase price, salvage cost and depreciation charge for the given period. Computer-Aided Manufacturing-International (CAM-I, later the Consortium for Advanced Manufacturing-International / Cost Management Systems, CAM-I/CMS) suggests the following framework for cost of ownership of manufacturing equipment (Berliner & Brimson, 1988).

Acquisition cost	$1,000,000	
Expected life	5 years	
Depreciation charge	$200,000 per year	(straight line depreciation charge)
Adjustments to value	$70,000	(@ 7% per year increase)
Finance cost	$90,000	(@ 9% on average book value)

The machine cost per year is thus: $200,000 + $70,000 + $90,000 = $360,000

Divided by 12 for the monthly charge: $360,000 / 12 = $30,000

This figure would then be allocated to each product on a machine hour basis for the month. For example, if a product used 12 hours out of a total of 400 hours available for the month, the product would be charged 12/400 x $30,000 = $900 for the use of the machine.

Note 1: An alternative basis to cost allocation by machine hours would be by units produced by the machine, out of an expected lifetime productive capacity, but this method presumes identical units produced by a machine, which is not applicable to this manufacturing environment.

Note 2: For simplification of analysis in this study, and for ability to choose periods other than accounting financial years, assume no tax affect in calculating depreciation charges.

In *Activity Accounting*, Brimson (1991) includes the following technology-related cost categories: acquisition cost, equipment-related taxes, interest expense, energy/utility costs, facilities cost, small tools and supplies costs. Technology related activities include NC-programming, process and industrial engineering, maintenance, and operation/supervision of machine. In the DDSS methodology, each separate activity related to a product is captured in the process / activity plan. All other machine related costs are captured in the machine cost summary. This includes all maintenance activities booked to the machine, all supplies and materials booked to the machine, and all costs of ownership and operation.

b. Maintenance costs

The source of maintenance data are the job cards for maintenance staff and materials requisitions charged to the machine, taken over the given period of study. For each machine, the records will be scanned, and the set of records related to maintenance of that machine will be summarized. Summary data includes the number of hours charged to the machine by each class of worker; total costs of all materials charged to the machine; and the number of hours the machine was unavailable for production in the given time period. The labor costs can then be calculated by cross referencing to the personnel database, and the total maintenance cost reported.

c. Operating Cost

Energy consumption rate is obtained from machine specification in the asset database. Operating cost is calculated as the product of energy consumption rate and electrical energy cost rate (plus demand charge rate if applicable). If other utilities (such as water, natural gas, compressed air) are consumed, the cost charged to the machine would be similarly calculated.

d. Machine Cost Rate

Machine Hours Used (for production) of the machine is obtained by querying the production order database, and taking a summary total of all the hours recorded for that machine on production work for the period chosen. The *Total Machine Cost* is the total of *Cost of Ownership*, *Maintenance Cost* and *Operating Cost* for the machine. The *Machine Cost Rate* is than calculated as the *Total Machine Cost* divided by the *Machine Hours Used*. This *Machine Cost Rate* is the number returned to the Machine Cost Summary file. This is shown schematically in Figure 3-13.

For each cost estimate, the DDSS queries the Machine Cost Summary for the *Machine Cost Rate*, for each machine listed in the process plan. The *Machine Cost Rate* is multiplied by the *Activity Time* for that process, to give the *Activity Machine Cost*. Figure 3-14 shows the schematic of this calculation method.

3.7 Software Implementation of DDSS Methodology

In order to explain the search methods used for finding cost information in the various databases, a short description of the nomenclature is provided.

3.7.1 Nomenclature

cell: one block in a spreadsheet grid, defined by a column and row reference coordinate. e.g. A1, the block at the intersection of Column A with Row 1.

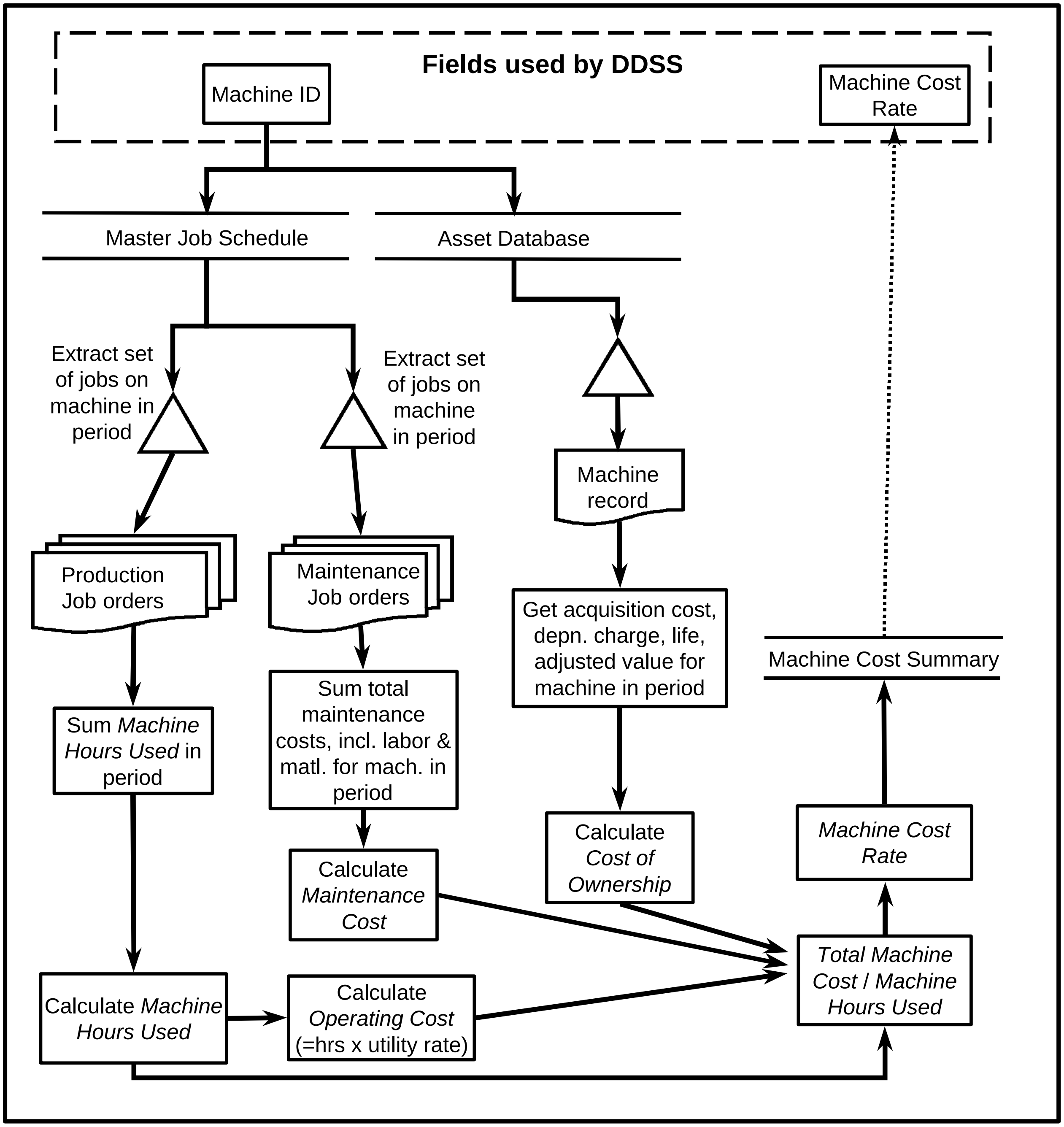
DBMS: Database Management System, the language used to define the databases, manipulate the data within the databases, and to generate summary information and reports from the data.

field/column: a range of data in a spreadsheet, defined by a column of cells in a worksheet.

matching: in this document, matching is taken to mean a comparison of string or numerical values between various fields and records. Microsoft Access and Visual Basic use the operators: (equals) = for exact match; LIKE for closest match, DISTINCT ROW for no repeat records.

query: a structured question to find information in a database. In Microsoft Access, a query returns a recordset of data matching the input parameters. Structured Query Language (SQL) is a standardized format for finding, retrieving and manipulating data in relational databases.

recordset: a group of records returned by a query, or grouped for purpose. The recordset and retains only the fields specified in the definition, which may be a subset of the original databases fields.



<u>**Figure 3-13: Schematic of Machine Cost Summary Calculation**</u>

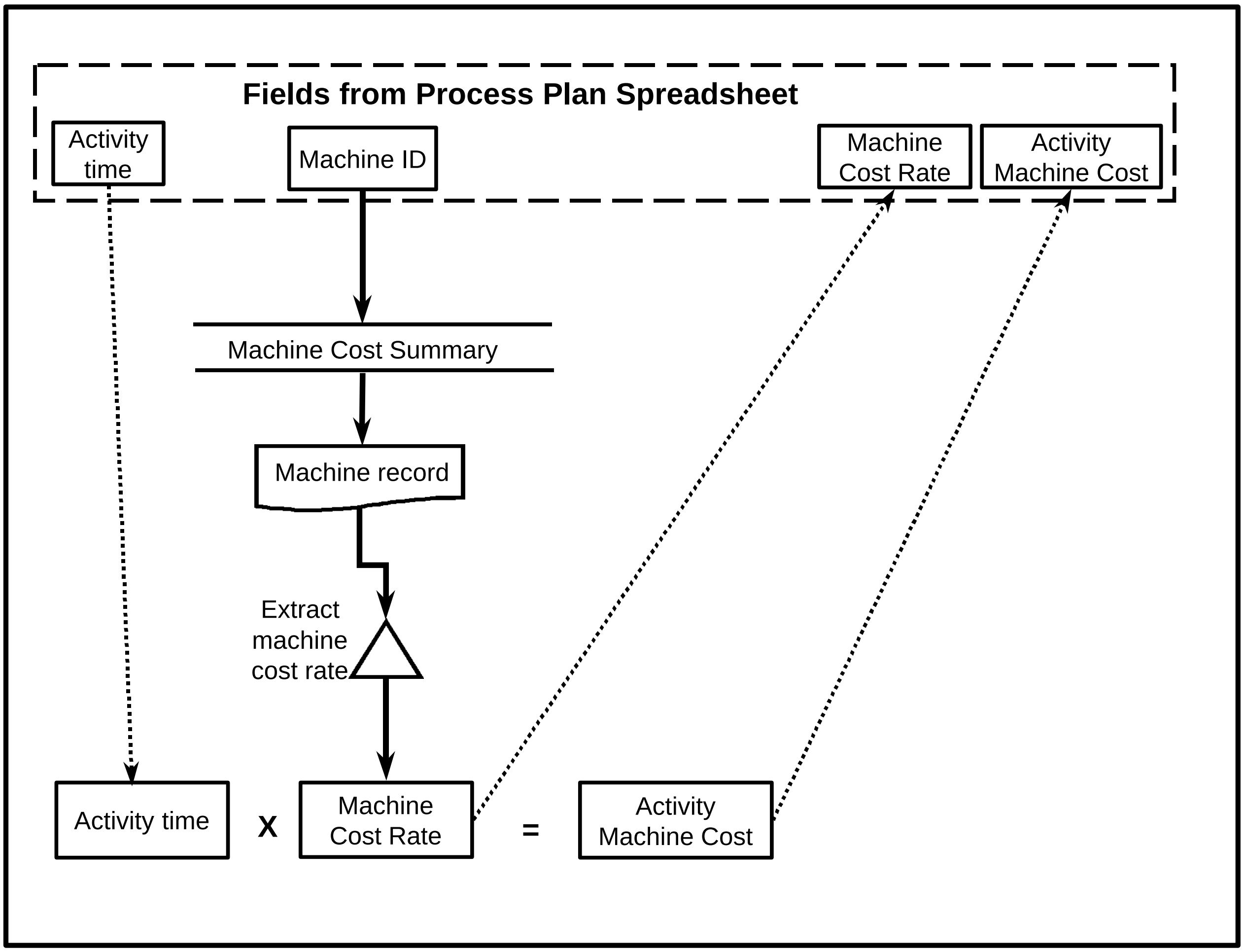


Figure 3-14: Schematic of Machine Cost Calculation for Each Activity

record/row: an individual record of a database in a spreadsheet, defined by a row of data in a worksheet, having a corresponding cell for each field in the record.

relational database: a relational database stores information in a collection of tables, each containing data about one subject. In a relational database, each table includes a field that is included in another table so the tables can share information.

spreadsheet: equivalent term for worksheet in Microsoft Excel.

string: a literal string consists of characters and numbers, evaluated as a word (not as a number).

table: a grid representation of a database, usually with fields shown as columns, and records shown as rows. Many tables may be included in a relational database.

worksheet: primary document in Microsoft Excel to store and work with data. A worksheet consists of cells organized into columns and rows and is always part of a workbook. Also called a spreadsheet.

(Reference: Microsoft Visual Basic, Microsoft Excel, Microsoft Access, Microsoft Office 97 Help)

3.7.2 Software Design Issues

A key objective for this research was to develop a prototype system showing the capabilities proposed by the methodology. The choice of software is designed to support the implementation this goal, and also to satisfy the need to use commonly available commercial software. This helps to reduce possible barriers to subsequent implementation in industry, by providing a readily portable design framework.

As a starting point, Visual Basic is used as the programming language, to create an interface between Microsoft Access databases and Microsoft Excel spreadsheets. Microsoft Access offers multiple import/conversion utilities from other common data formats (e.g. dBase, SQL, FoxPro, Paradox). The SQL (Structured Query Language) capability of both Visual Basic, and Microsoft Access will be useful if the framework is to be implemented on other software platforms, as it is a commonly used standard for database management software. The Microsoft SQL Server software also has OLE (object linking and embedding) linking capability to IBM AS/400 database software, the SAS Institute (statistics data analysis), and conforms to ANSI SQL 1992 (American National Standards Institute version of the language). SQL was originally developed by IBM for use with mainframe DBMS software. Oracle Corporation is an example of a mainframe database system using SQL as the basis of their DBMS software. This common interface enhances the *portability* and *flexibility* of the DDSS methodology for application in any organization's information system. Use of Microsoft Office compatible software also facilitates the process of documenting the DDSS, and allows access to a large commercial user base.

In order to demonstrate the validity of the system, dummy data sets were created to model some representative products, typical process plans, and associated information flows. By using a limited vocabulary for keywords (product names, processes, machines, etc.) the search routines are accomplished using relatively simple string matching functions. Future enhancements to the system may include a more extensive set of keywords, and “fuzzy” matching capability. The string matching functions already implemented allow for use of wildcard (* and ?) characters, and the "LIKE" keyword searches for the closest match to the input string. The input forms allow the current vocabulary to be presented to users as pull-down list menus during the input procedure. The system "learns", by adding new information, and expanding the vocabulary to present users with new choices and better chances to find exact matches to the input parameters.

The use of spreadsheets as the main interface with designers and other potential users allows for considerable customization of the system by users. The spreadsheet format is familiar to users across disciplines of engineering, accounting and various business or management fields. The methodology is easily explained using the spreadsheets and associated calculation formulas. Each of the database tables may also be viewed in spreadsheet format, and data fields may be added or manipulated using the companies' own software. The spreadsheet files may also be used as input files for other design tools, such as QFD analysis tools and possibly to the higher-level aircraft design sizing models.

3.7.3 Overview of the DDSS Software Implementation

The DDSS uses features of computer spreadsheets, database management software, and programming software. The starting point for each cost estimate is the descriptive name for the product. This name is checked against the list of all product orders for a matching string. If there is no exact match, then the closest match is found. The matching Order Number (OrderID) for the product is returned. Using this Order Number, the DDSS searches through the Process Detail Table for the set of processes that are listed for that product and order number. The DDSS uses each process detail record to drive the search for activity costs. This information is then written to the Process Plan spreadsheet to create a cost estimate template. This is different from the paper version of the original spreadsheet in that there are now additional blank field columns to accommodate the additional cost calculations. Table 3.1 (repeated on page 122) shows a typical example of a manually created process plan spreadsheet. Table 3.2 (repeated on page 123) shows an example of a DDSS created process plan spreadsheet.

The main difference between the two forms is that the DDSS format separates all processing details into separate fields, and in certain cases into separate database tables. In the Production Planning and Scheduling System, the Process Details and Bill of Materials database tables are required to be separate from the Job Order database tables. This is necessary because of the one-to-many relationship between a Job Order record and the associated Process Details of that job order. In other words, for each job order, there may exist an indeterminate number of process detail records.

Similarly, there may be a one-to-many relationship between each Process Detail record and the associated Bill of Materials records. In other words, for each process, there may be numerous separate material items that are inputs to that process. The DDSS format of the process plan separates out any details that may be aggregated in the manually created process plan. For example, a material description in the manually drawn up process plan (Table 3.1), has two items listed in one field, e.g. Nomex honeycomb 3-4lb and room temperature cure epoxy filler. In the database representation used by the DDSS, the Bill of Materials would contain two separate records for these items, both associated with the same process. This distinction is important, in that it better represents the underlying structure contained in the Production Planning and Scheduling System databases, and also allows for matching of each item to the Inventory database. Similarly, the size parameters are also split out into separate fields for length, width and thickness or height.

Each process is thus explicitly defined in the DDSS process plan. Each row describes a specific activity of the production process. Within each row (or Process Activity Record), there are fields that describe the material items (which is linked to the bill of materials records for the quantity and type of raw materials used), the equipment and human resources used, and the amount of time each is used in executing the process activity. To find the cost of each of these components, each known field entry is used as the starting point for a data search module, as described previously in Section 3.6. The following sections describe the program code implementation of the search and calculation methodology.

Table 3.1: Process Plan

	Process	Operation	Material	Size	Quantity	Machine/ Tools	Operators	Proc. Time	Setup Time
1	Plycutting	Cut glass epoxy sheets	250F Glass epoxy cloth	25" x 19"	6 sheets per kit	Gerber Automated Cutter	1	30	15
2	Plycutting	Cut adhesive film sheets	250F Curing adhesive film	25" x 19"	2 sheets per kit	Gerber Automated Cutter	1	30	15
3	Honeycomb cutting	Cut honeycomb sheets	Nomex honeycomb 3-4lb	22" x 16" x 1/4 " thick	1 sheet per kit	Waterjet cutter	2	30	15
4	Bagging	Cut the film	Plastic film 36" roll	36" x 36"	2 sheets per bag	Film cutter	1	2	5
5	Bagging	Make the bag	Plastic film sheets	2 shts 36" x 36"	1 bag per kit	Heat sealer	1	5	5
6	Reinforce latch area	reinforce sections of honeycomb sheet with epoxy filler	Nomex honeycomb 3-4lb and room temp.cure epoxy filler	22" x 16" x 1/4 " thick	1 sheet per kit and 5 oz. filler	Fixture and squeegee	1	25	5
7	Lamination	Prep. the mold	Mold cleaning fluid and release agent		each kit	mold and fixture plates	1	30	
8	Lamination	Lay on sheets of prepreg and adhesive film	3 Sheets of 250F Glass Epoxy and 1 Sheet of 250F Curing Film	Each Sheet 25" x 19"	Bottom layer of kit		1	40	
9	Lamination	Use Jig to locate and Install the Honeycomb Nomex	1 Sheet of Honeycomb Nomex	22" x 16" x 1/4" thick	Middle layer of kit	Locating Jig	1	10	
10	Lamination	Lay on sheets prepreg and adhesive flim	3 Sheets of 250F Glass Epoxy and 1 Sheet of 250F Curing Film	Each sheet 25" x 19"	Top Layer of kit		1	40	
11	Lamination	Lay teflon film and breather on top of kit and mold	Sheet of Teflon Film and Breather material	Each sheet 33" x 27"	One per kit		1	10	
12	Lamination	Wrap vacuum bag around mold, kit, teflon, and breather film	Vacuum bag, kit, mold, teflon film, and breahter material	Vacuum Bag: 36" x 36"	One per kit		1	20	
13	Lamination	Draw vacuum and seal bag	Entire kit and bag		Once per kit	Plant vacuum system	1	20	
14	Lamination	Curing Composite Part in autoclave at 250F	Entire kit, vacuum bag		3 kits	Autoclave	1	240	10
15	Trimming/Finishing	Cut excess glass from door	Unfinished baggage door	25" x 19" Door	1 kit	Cutting Template and Water Jet Cutter	1	9	120
16	Shipping and Packaging	Pack Baggage Doors and Ship to Customer	Packing and Shipping materials				1	15	
17	Engineering	Design/process planning for door production	Manufacturing engineer		1 off		1	720	
18	Tooling	Mold Tooling Cost	Manufactured separately		1				

Table 3.2: Process Plan generated by DDSS (Page 1 of 2)

OrderID	ProductID	ProcessID	ProcessDesc	Start Date	End Date	Start Time	End Time	Process Time	AssetID
100	UH64BD	1	Plycutting: cut glass epoxy sheets	1/4/98	1/4/98	8:00AM	8:45AM	45	LASERCUTTER01
100	UH64BD	2	Plycutting: cut adhesive film sheets	1/5/98	1/5/98	8:00AM	8:45AM	45	LASERCUTTER01
100	UH64BD	3	Cutting Honeycomb sheets	1/6/98	1/6/98	8:00AM	8:45AM	45	WJCUTTER02
100	UH64BD	4	Bagging: film cutting	1/7/98	1/7/98	9:00AM	9:07AM	7	FILMCUTTER01
100	UH64BD	5	Bagging: heat sealing	1/7/98	1/7/98	10:00AM	10:10 AM	10	HEATSEALER01
100	UH64BD	6	Reinforce latch area	1/8/98	1/8/98	10:20AM	10:50 AM	30	
100	UH64BD	7	Mold preparation	1/9/98	1/9/98	8:15AM	8:45AM	30	
100	UH64BD	8	Lamination layup: prepreg and adhesive film	1/9/98	1/9/98	8:10AM	8:50AM	40	
100	UH64BD	9	Lamination jig setup: locate and install Nomex she	1/9/98	1/9/98	9:00AM	9:10AM	10	
100	UH64BD	10	Lamination layup: prepreg and adhesive film	1/9/98	1/9/98	9:10AM	9:50AM	40	
100	UH64BD	11	Vacuum film layup: teflon film and breather	1/9/98	1/9/98	10:00AM	10:10 AM	10	
100	UH64BD	12	Vacuum film wrap	1/9/98	1/9/98	10:15AM	10:35 AM	20	
100	UH64BD	13	Vacuum bag: draw and seal	1/9/98	1/9/98	11:00AM	11:20 AM	20	VACPUMP01
100	UH64BD	14	Curing at 250F	1/10/98	1/10/98	9:00 AM	1:00 PM	240	AUTOCLAVE04
100	UH64BD	15	Trimming and finishing	1/13/98	1/13/98	8:30:AM	10:39 AM	129	CNCMILL02
100	UH64BD	16	Packaging	1/15/98	1/15/98	2:00:PM	2:15 PM	15	
100	UH64BD	17	Engineering design (portioned)	12/1/97	12/2/97	8:00:AM	12:00 PM	720	CADCAMPC03
100	UH64BD	18	Tooling Cost (portioned)	12/18/97	12/24/97	8:00 AM	5:00 PM	0	TOOLBD01

Table 3.2: Process Plan generated by DDSS (Page 2 of 2)

ProcessID	EmployeeID	NoEmployees	MaterialID	Machine CostRate	Machine Cost	EmployeeCostRate	Labor Cost	Material Cost	Process Cost
1	LC1	1	UH64BDM1	$29.51	$22.14	$18.00	$13.50	$90.00	$125.635
2	LC1	1	UH64BDM2	$29.51	$22.14	$18.00	$13.50	$ 6.00	$ 41.635
3	WC1	2	UH64BDM3	$21.67	$16.25	$18.50	$27.75	$ 50.00	$ 94.000
4	FC1	1	UH64BDM4	$3.27	$0.38	$15.00	$1.75	$ 4.00	$ 6.131
5	HS1	1		$2.07	$0.34	$14.00	$2.33	$ -	$ 2.678
6	OP2	1	UH64BDM6		$-	$10.00	$5.00	$ 16.00	$ 21.000
7	OP2	1	UH64BDM7		$-	$10.00	$5.00	$ 8.00	$ 13.000
8	OP2	1			$-	$10.00	$6.67	$ -	$ 6.667
9	OP2	1			$-	$10.00	$1.67	$ -	$ 1.667
10	OP2	1			$-	$10.00	$6.67	$ -	$ 6.667
11	OP1	1			$-	$8.00	$1.33	$ -	$ 1.333
12	OP1	1			$-	$8.00	$2.67	$ -	$ 2.667
13	OP1	1			$-	$8.00	$2.67	$ -	$ 2.667
14	OP3	1			$-	$12.00	$48.00	$ -	$ 48.000
15	OP4	1		$ 40.45	$86.97	$14.00	$30.10	$ -	$117.071
16	LA1	1	BOX321		$-	$5.00	$ 1.25	$ 2.00	$ 3.250
17	ENG2	1			$-	$35.00	$42.00	$ -	$ 42.000
18	ENG2	0			$80.00	$ -	$ -	$ -	$ 80.000

3.7.4 Labor Cost Rate

The literal string describing the skill/person executing the current process activity is extracted from the field "EmployeeID". This string is then transferred to the search module for the person/s hourly charge rate (qdfEmployeeCodeRate). The search module looks up the charge rate for the job description code, and returns the labor cost per hour. See Figure 3-15 for an extract of code, and Appendix F.3 for full details of Visual Basic Code to execute this procedure.

```
'Calculate LaborCost for each Activity, by ProcessID
        strSql3 = " PARAMETERS prmEmployeeCode Text; " & _
            "SELECT EmployeeCodeRate.EmployeeCode, EmployeeCodeRate.LaborCostRate " & _
            "From EmployeeCodeRate " & _
            "WHERE (((EmployeeCodeRate.EmployeeCode) Like [prmEmployeeCode])); "
        Set qdfEmployeeCodeRate = dbsCurrent.CreateQueryDef("", strSql3)
        qdfEmployeeCodeRate.Parameters!prmEmployeeCode = rstProcessPlan!EmployeeID
        Set rstEmployeeCostRate = qdfEmployeeCodeRate.OpenRecordset(dbOpenSnapshot,
[dbReadOnly])
        rstActivity!EmployeeCostRate = rstEmployeeCostRate!LaborCostRate.Value
        rstActivity!LaborCost = rstProcessPlan!ProcessTime.Value / 60 *
rstEmployeeCostRate!LaborCostRate.Value * rstProcessPlan!NoEmployees
        'Output the returned records in text box
        'MsgBox "Activity" & rstProcessPlan!ProcessID
        Text3.Text = rstProcessPlan!AssetID.Value & " " & rstProcessPlan!ProcessTime.Value
```

Figure 3-15: Labor Cost Calculation Code from "DDSSProject - frmActivityCost"

3.7.5 Process Activity Time

To find an activity process time, the following procedure is followed: The DDSS first searches for an order for the Product description entered. The DDSS returns the Order Number for that product order (See code module in Figure 3-16). That order number is then used to find all the Process Details for that specific Job order. For example if the product description is "baggage door", all work orders related to this process will be found. The Job Order table represents all completed orders over a given period of time. The time for the process activity is found using the closest match, or by scaling the process time using the size parameters. The closest exact match is the easier method, merely finding the closest size to the given string and using that value. Scaling using size parameters is somewhat more complex. In this case, the process may require a summary of the query worksheet. For example, the average time for hand lay-up of wing boxes may be calculated, together with some expression (such as a regression equation) for the process activity time (in terms of the size parameters). The process time can then be scaled for the current size parameters, and this process time value then returned. This procedure has an advantage over using standard times or theoretical process times, in that it returns actual process times for the same or similar products made by the firm. In doing so, it avoids the pitfalls of both the micro-process level models (which use theoretical process times), as well as the standard cost models (which use aggregated data). One of the features of the DDSS model is that it includes the idle time that is usually neglected by other cost estimation methods (or aggregated by using nebulous overhead charge-out rates). Thus it uses the *actual* time to carry out each activity, and charges cost to the product on that basis.

The returned process activity time is returned to the Process Plan spreadsheet, again to the currently blank field for this activity. The DDSS then calculates the Material Cost, Labor Cost, and Equipment Cost for the current process activity, as well as a Total Process Activity Cost. These are inserted into the Process Plan spreadsheet.

This procedure is then repeated for each line (or activity) of the process plan, in the process building up a structured estimate for the product under review. See Figure 3-16 for this code module, and Appendix F.3 for full details of Visual Basic Code to execute this procedure.

```
'Find OrderID in Factor2.JobOrders to match ProductDesc (qryProductDesc)
   strSql1 = " PARAMETERS [prmProductDesc] TEXT; " & _
      "SELECT JobOrders.OrderID, JobOrders.ProductID, JobOrders.ProductDesc, JobOrders.OrderDate, JobOrders.Quantity, JobOrders.Size " & _
      "From JobOrders " & _
      "WHERE (((JobOrders.ProductDesc) Like [prmProductDesc])); "

   Set qdfOrderID = dbsCurrent.CreateQueryDef("", strSql1)
   qdfOrderID.Parameters!prmProductDesc = Combo1.List(Combo1.ListIndex)
   Set rstOrderID = qdfOrderID.OpenRecordset
      If rstOrderID.RecordCount = 0 Then
         qdfOrderID.Parameters![prmProductDesc] = InputBox(Message, Title, Default)
         Message = "Enter ProductDesc"   ' Set prompt.
         Title = "ProductDesc Input" ' Set title.
         Default = rstJobOrders!ProductDesc  ' Set default.
      End If
'Output the returned records in captions
   rstOrderID.MoveFirst
   Text1.Text = rstOrderID!OrderID
   Text2.Text = rstOrderID!ProductID
   MsgBox "OrderID and ProductID Found"

'Set the path for the current database
Set xlsCurrent = OpenDatabase("c:\mark\Research\ProcessPlan1.xls", False, False, "Excel 8.0; HDR=YES;")
Set rstActivity = xlsCurrent.OpenRecordset("Sheet1$")
Set xlsMachCostSumm = OpenDatabase("c:\mark\Research\MachCostSumm.xls", False, False, "Excel 8.0; HDR=YES;")
'set spread = OpenDatabase("c:\Mark\spread.xls",
'Define the SQL string for the parameter query
   strSql2 = " PARAMETERS prmOrderID Long; " & _
      "SELECT ProcessDetails.OrderID, ProcessDetails.ProductID, ProcessDetails.ProcessID, ProcessDetails.ProcessDesc, ProcessDetails.StartDate, ProcessDetails.EndDate, ProcessDetails.StartTime, ProcessDetails.EndTime, ProcessDetails.ProcessTime, ProcessDetails.AssetID, ProcessDetails.EmployeeID, ProcessDetails.NoEmployees, ProcessDetails.MaterialID " & _
      "From ProcessDetails " & _
      "WHERE (((ProcessDetails.OrderID) Like [prmOrderID])); "

   Set qdfProcessPlan = dbsCurrent.CreateQueryDef("", strSql2)
'Input the parameter values
   qdfProcessPlan.Parameters![prmOrderID] = rstOrderID!OrderID

'Open the recordset of ProcessDetails matching the OrderID
Set rstProcessPlan = qdfProcessPlan.OpenRecordset
```

Figure 3-16: Code to find Order ID and Process Details matching Product Description (from DDSSProject - frmActivityCost)

3.7.6 Material Costs

The OrderID, ProcessID, and MaterialID that describes each material item are extracted from the Process Plan. These parameters are transferred into an SQL (Structured Query Language) command to search the Bill of Materials database for each material item, and link to the Inventory database to get the unit cost information on that material.

In the prototype DDSS, each of the database tables are included in the Factor2.mdb relational database. The program sets the path for the database using the hard drive filepath. In this case:

```
Set dbsCurrent = OpenDatabase("c:\mark\Research\Factor2.mdb")
```

defines for the search process which filepath and database is to be searched. This would allow for rapid tailoring of the DDSS to suit individual companies, and individual information system designs. The only requirement for the DDSS is for replicated databases to be made available on a READ only basis.

The following example SQL query command illustrates the pattern matching principle:

```
SELECT Materials.MaterialName, Materials.UnitPrice
FROM Materials
WHERE (([Materials]![MaterialName] Like "CARBON FIBER SHEET*"));
```

This query looks for a match to the literal string “CARBON FIBER SHEET” in the Material Name field of the Materials database. This query will return all records with matching descriptions. By narrowing the query to include e.g. “Sheet thickness=0.125”, only the specific records relating to the same product description and size will be returned. The wildcard character * may be used to allow for variations in the description field characters. The command “LIKE” allows for inexact matches; Using “=” instead allows only exact matches of the search string to be returned.

The query would return one or more records with the unit price of CARBON FIBER SHEET 0.125 inches thick. The program is configured to take the latest unit price for the item, as listed in the Inventory database for this material item issued. This value is inserted back into the Process Plan spreadsheet, in the currently blank field for this item (e.g. $30-00 per sheet).

The next step is to multiply the unit price by the quantity field (e.g. 6 sheets). This would then return a value of $30-00/sht x 6 shts = $180-00, which is inserted into the blank field for *MaterialCost* of the current process activity. Figure 3-17 shows the program module to calculate the Material Costs. See Appendix F.3 for full details of Visual Basic code to execute this procedure.

```
'Get set of all materials used for each activity
        strSql4 = " PARAMETERS prmOrderID2 Long, prmProcessID Short, prmMaterialID Text; " & _
          "SELECT DISTINCTROW BillMaterials.MaterialNo, BillMaterials.OrderID, BillMaterials.ProductID, BillMaterials.ProcessID, BillMaterials.MaterialID, BillMaterials.MaterialName, BillMaterials.SizeL, BillMaterials.SizeW, BillMaterials.SizeT, BillMaterials.Quantity, Inventory.MaterialID, Inventory.UnitCost " & _
         "FROM BillMaterials INNER JOIN Inventory ON BillMaterials.MaterialID = Inventory.MaterialID " & _
           "WHERE (((BillMaterials.OrderID) Like [prmOrderID2]) AND ((BillMaterials.ProcessID) Like [prmProcessID]) AND ((BillMaterials.MaterialID) Like [prmMaterialID])); "
        Set qdfMaterials = dbsCurrent.CreateQueryDef("", strSql4)
        qdfMaterials.Parameters!prmOrderID2 = rstOrderID!OrderID
        qdfMaterials.Parameters!prmProcessID = rstProcessPlan!ProcessID
        qdfMaterials.Parameters!prmMaterialID = rstProcessPlan!MaterialID
        Set rstMaterials = qdfMaterials.OpenRecordset(dbOpenSnapshot, [dbReadOnly])
            If rstMaterials.RecordCount > 0 Then
            rstActivity!MaterialCost = rstMaterials!UnitCost.Value * rstMaterials!Quantity.Value
            Else: rstActivity!MaterialCost = 0
            End If
```

Figure 3-17: Material Cost Calculation Code from "DDSSProject - frmActivityCost"

3.7.7 Equipment Resource Costs

The literal string describing the machine being used for the process activity is then extracted from the “AssetID” field. This string is transferred to an SQL command that searches the Machine Cost Summary database for cost information on that machine. This search is limited to a relatively small list of production resources.

To account for the cost of machines, a separate calculation worksheet is required, which is periodically updated to include the costs of maintenance activities, consumables, energy costs, and the capital cost of ownership. This intermediate step was thought necessary to calculate a relatively accurate hourly usage charge for each machine. This process uses the "frmMaintCost" module of the DDSS program. This worksheet first gets the list of machines used in a particular order, and the period of time to be considered.

The DDSS gets purchase cost and depreciation charge information from the assets database for each machine. Maintenance costs are found by accumulating maintenance work order costs for the given period. Machine usage time is found by searching the production work orders for the same given operating period. This information is stored, and updated as frequently as required, on a database table set up specifically for this purpose. This may be independently updated, or updated in conjunction with the DDSS. The updating process may be automated to allow these revisions to take place outside of normal working hours, to reduce their impact on computer resources. The Machine Hourly Usage charge is determined as described above, and returned to the Machine Cost Summary File.

For each activity, the *Machine Cost Summary* is queried for the given machine, and the hourly usage charge is returned to the Process Plan spreadsheet, inserted into the blank field for *MachineCostRate* of the current process activity. This value is multiplied by the *ProcessTime* for this step and will be inserted into the currently blank field for *MachineCost*. Figure 3-18 shows the code module to calculate the Machine Cost Summary, and Appendix F.2 for a full listing of the Visual Basic Code to execute this procedure.

Tooling costs are handled as a special case of the Machine Cost Calculation by the DDSS. It is assumed that the cost of the mold tool is captured after it is made. The cost is then captured in the Asset database, with the mold tool number recorded in the *AssetID* field. The *Machine Cost Rate* for a mold tool is recorded as the cost that should be apportioned to each product made using the tool. This would conventionally be applied as the total cost of the tool, divided by the expected number of products to be made using that tool. The expected number may be based on the initial order for that part, or an anticipated lifetime order quantity of that product. The choice would be made by the user, and the appropriate Machine Cost Rate would be entered. The DDSS recognizes tooling costs as a special case by scanning each process detail for the search string = " *Tooling Cost* ", that is, any process description including the words "Tooling Cost".

```
Private Sub cmdSearchMaintJobOrders_Click()
Set dataCurrent = OpenDatabase("c:\mark\Research\Factor2.mdb")
Set xlsCurrent = OpenDatabase("c:\mark\Research\MachCostSumm.xls", False, False, "Excel 8.0;
HDR=YES;")
Set rstAssets = xlsCurrent.OpenRecordset("Sheet1$")
'Execute a MoveLast and count the records.
   rstAssets.MoveLast
   intNumRecords = rstAssets.RecordCount
   MsgBox "There are " & intNumRecords & "rows in this range."
   rstAssets.MoveFirst

Do Until rstAssets.EOF
'Calculate Machine Hours Used for each machine
  strSql4 = " PARAMETERS prmAssetID Text, prmDateFrom DateTime, prmDateTo DateTime; " & _
      "SELECT ProcessDetails.AssetID, ProcessDetails.StartDate, ProcessDetails.EndDate,
ProcessDetails.ProcessTime " & _
      "From ProcessDetails " & _
      "WHERE (((ProcessDetails.AssetID) Like [prmAssetID]) AND
((ProcessDetails.StartDate)>=[prmDateFrom]) AND ((ProcessDetails.EndDate)<=[prmDateTo])); "
   Set qdfMachineHours = dataCurrent.CreateQueryDef("", strSql4)
   qdfMachineHours.Parameters!prmAssetID = "*" & rstAssets!AssetID
   qdfMachineHours.Parameters!prmDateFrom = Text1.Text
   qdfMachineHours.Parameters!prmDateTo = Text2.Text
   Set rstMachineHours = qdfMachineHours.OpenRecordset(dbOpenSnapshot, [dbReadOnly])
      If rstMachineHours.RecordCount > 0 Then
         rstMachineHours.MoveFirst
         Do Until rstMachineHours.EOF
            MachineHoursTotal = MachineHoursTotal + rstMachineHours!ProcessTime.Value / 60
            rstMachineHours.MoveNext
         Loop
      End If
' Update MachineCostSummary.MachineHours
   rstAssets.Edit
   rstAssets!MachineHours = MachineHoursTotal
   rstAssets.Update
   MachineHoursTotal = 0
'Define SQL string for MaintenanceJobs query
   strSql = " PARAMETERS prmAssetID Text, prmDateFrom DateTime, prmDateTo DateTime;" & _
      "SELECT DISTINCTROW MaintenanceJobs.MaintJobID, MaintenanceJobs.AssetID,
MaintenanceJobs.AssetName, MaintenanceJobs.StartDate, MaintenanceJobs.EndDate,
MaintenanceJobs.JobTime, MaintenanceJobs.EmployeeID, MaintenanceJobs.MaterialID,
MaintenanceJobs.MaterialCost " & _
      "From MaintenanceJobs " & _
      "WHERE (((MaintenanceJobs.AssetID) Like [prmAssetID]) AND
((MaintenanceJobs.StartDate)>[prmDateFrom]) AND ((MaintenanceJobs.EndDate)<=[prmDateTo])); "
'Input prmAssetID, prmDateFrom, prmDateTo
Set qdfMaintJobs = dataCurrent.CreateQueryDef("", strSql)
   qdfMaintJobs.Parameters!prmAssetID = rstAssets!AssetID
   qdfMaintJobs.Parameters!prmDateFrom = Text1.Text
   qdfMaintJobs.Parameters!prmDateTo = Text2.Text
```

Figure 3-18: MachCostSumm code (Page 1 of 2)

```
Set rstMaintJobs = qdfMaintJobs.OpenRecordset(dbOpenSnapshot, [dbReadOnly])
If rstMaintJobs.RecordCount > 0 Then
    rstMaintJobs.MoveFirst
    Text3.Text = rstMaintJobs.RecordCount
    Do Until rstMaintJobs.EOF

        'Calculate LaborCost for each Asset, by MaintenanceJob
        strSql2 = " PARAMETERS prmEmployeeCode Text; " & _
            "SELECT EmployeeCodeRate.EmployeeCode, EmployeeCodeRate.LaborCostRate " & _
            "From EmployeeCodeRate " & _
            "WHERE (((EmployeeCodeRate.EmployeeCode) Like [prmEmployeeCode])); "
        Set qdfEmployeeCodeRate = dataCurrent.CreateQueryDef("", strSql2)
        qdfEmployeeCodeRate.Parameters!prmEmployeeCode = rstMaintJobs!EmployeeID
        Set rstEmployeeCostRate = qdfEmployeeCodeRate.OpenRecordset(dbOpenSnapshot,
dbReadOnly])
        MaintLaborCost = MaintLaborCost + rstMaintJobs!JobTime.Value / 60 *
rstEmployeeCostRate!LaborCostRate.Value
        'Output the returned records in caption, and database forms
        'MsgBox "Jobs"
        Text3.Text =  = rstMaintJobs!AssetID.Value & " " & rstMaintJobs!JobTime.Value
        'Calculate MaterialCost for each Asset, by MaintenanceJob
        strSql3 = " PARAMETERS prmMaterialID Text; " & _
            "SELECT Inventory.MaterialID, Inventory.UnitCost From Inventory " & _
            "WHERE (((Inventory.MaterialID) Like [prmMaterialID])); "
        Set qdfMaterialCost = dataCurrent.CreateQueryDef("", strSql3)
        qdfMaterialCost.Parameters!prmMaterialID = rstMaintJobs!MaterialID
        Set rstMaterialCost = qdfMaterialCost.OpenRecordset(dbOpenSnapshot, [dbReadOnly])
        MaintMatlCost = MaintMatlCost + rstMaterialCost!UnitCost.Value * 1
        'Output the returned records in caption, and database forms
        rstMaintJobs.MoveNext
     Loop
     rstAssets.Edit
     rstAssets!MaintLaborCost = MaintLaborCost
     rstAssets!MatlCost = MaintMatlCost
     rstAssets.Update
         MaintLaborCost = 0
         MaintMatlCost = 0
    Else
    rstAssets.Edit
    rstAssets!MaintLaborCost = 0
    rstAssets!MatlCost = 0
    rstAssets.Update
  End If
' Update Calculated Fields in MachCostSumm
  rstAssets.Edit
  rstAssets!OperCost.Value = rstAssets!MachineHours.Value * rstAssets!OperCostRate.Value
  rstAssets!TotalMachineCost = rstAssets!DepnCharge / 12 + rstAssets!MaintLaborCost +
rstAssets!MatlCost + rstAssets!OperCost
  rstAssets!MachineCostRate = rstAssets!TotalMachineCost / rstAssets!MachineHours
  rstAssets.Update
  rstAssets.MoveNext
End Sub
Loop '(Do until rstAssets.EOF)
```

Figure 3-18: MachCostSumm Code (Page 2 of 2)

3.7.8 Assembled Product Costs

It should be noted that the inheritance properties of objects may be introduced at any level of the product hierarchy. For example, in consideration of a WING cost estimate, the wing process plan may use a WING BOX as a sub-assembly in one of the process activities. In this case, the Total Cost Estimate for the WING BOX would be inherited by the WING Cost Estimate, as the material cost of the WING BOX. This is consistent with the concept of interdepartmental transfer pricing, and for consistent evaluation of outsourcing decisions. In effect, the cost of a WING BOX is seen at the higher level as if it were an off-the-shelf purchase item. In aircraft construction, it is common for separate sub-assemblies to be sub-contracted to different organizations, and it is important to build in this capability. Consideration of the relative value of process activities would therefore not be considered at the level of the WING assembly, in this instance. The percentage cost of the WING BOX is however displayed. If the cost was found to be out of order with its functional value, investigation at the lower level could easily be carried out by looking at the WING BOX cost estimate. In the case of a sub-contractor built part, the designer does not have the capability to inspect the sub-contractor's cost breakdown structure. This reflects the typical reality for designers, being able to evaluate in more detail the components built within the company than parts that are out-sourced. At a practical level, a designer cannot evaluate every single component of every design, and this DDSS allows designers to choose the level of abstraction suitable for the product they are reviewing. For example, a wing designer would not consider the individual process activities involved in manufacturing structural fasteners, and would accept unit costs of bolts/rivets as a simple purchase item.

3.7.9 Design Support Interface

Defining the level of interaction which will be provided to designers is an important factor in the design of the system. In order to speed development of the prototype system, the user interface with designers was limited to simple input screens to demonstrate feasibility. Choices of decision variables are made in accordance with the design process described for composite parts in Section 2.6.7. The basis of the interaction is a product specification that names the product, and links the product description to the key properties defining the product. The Process Plan format that the DDSS provides includes information from the Job Order, Process Details, and Bill of Materials records for the part. These inputs can be entered interactively in conventional database form, either one record at a time, or using a tabular grid layout. The output of the DDSS is a Process Plan spreadsheet as depicted in Table 3.2. The spreadsheet layout is used by the DDSS during the cost estimation process, with cost figures filled in after searches through the accounting information system. The Process Plan output can then be saved as a separate file, and any of the data contained in it can then be used for further analysis, or graphic presentation of the cost information to users.

In order to demonstrate feasibility of the concept, a relatively simple interface was provided. The framework allows for considerable enhancement to allow for more complex interaction between designers and the DDSS. Enhancement of the graphic user interface (GUI) would be an important consideration during full scale implementation of the system. Experience gained during the development of the DDSS will be helpful in directing how to set up the GUI, and in deciding what level of functionality to include in future work. The initial prototype software returns a total cost per component to the designer, together with a spreadsheet showing the breakdown of that cost. By changing the product description parameters, and recalculating the cost estimate, the designers are able to determine the effect of changes in the key design parameters.

3.7.10 Graphic Display of Cost Breakdown Structure

Additional summary fields are added to the spreadsheet to describe the breakdown of costs as a percentage of the total. This data may be displayed in a pie chart for easier visualization of the cost breakdown structure. Examples of pie-charts are shown in Figures 3-19, 3-20, and 3-21. The costs may be depicted as a traditional cost breakdown, showing the percentage of cost due to labor, materials, equipment, and other overhead, as shown in Figure 3-19. If more detail is required, users may want to analyze the cost breakdown of a particular process (as shown in Figure 3-20), to find the significant cost factors. Alternatively, designers may choose to look at the percentage contribution of each activity in the process plan, as shown in Figure 3-21. For the purposes of value analysis or QFD analysis, these pie charts could serve to focus the efforts of designers and managers on the major contributing factors to cost versus function of the product.

3.7.11 Design Modifications

Designers can evaluate the sensitivity of the cost estimate to various factors by changing any one of the fields in the Process Details. In the prototype software, alternative product designs are input using variations of the product description and order numbers, with a set of process details replicated for each design. The cost estimate is then re-evaluated, and the changes can be noted. Implementation of the DDSS in a working form (as opposed to the prototype demonstration version) would require that users could choose whether to keep or undo the design parameter changes. By investigating the effect of changes on the percentage of cost associated with each activity, designers can evaluate whether the cost of an activity is proportional to its functionality. Value analysis techniques may be able to formally incorporate this data, for example by importing the cost data into a Quality Function Deployment (QFD) matrix.

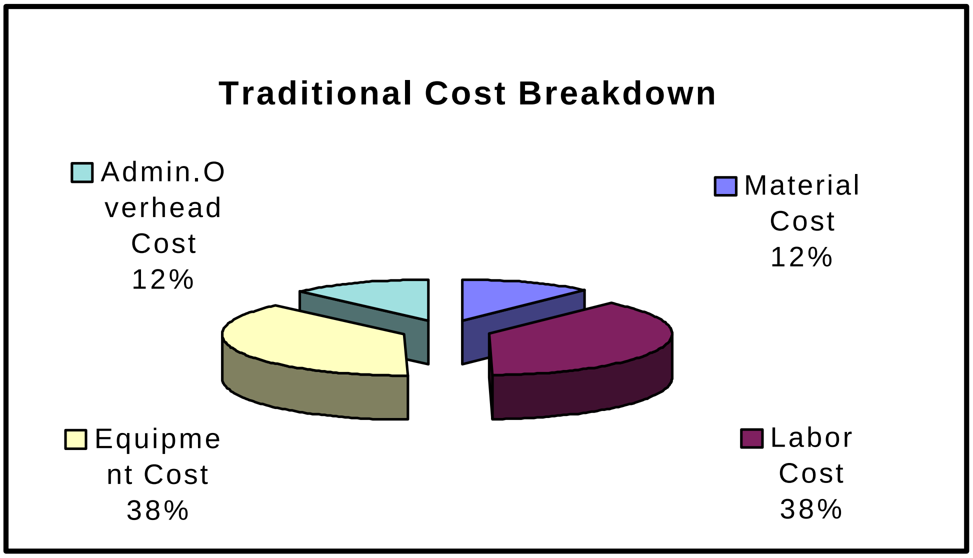


Figure 3-19: Cost Breakdown by Cost Category

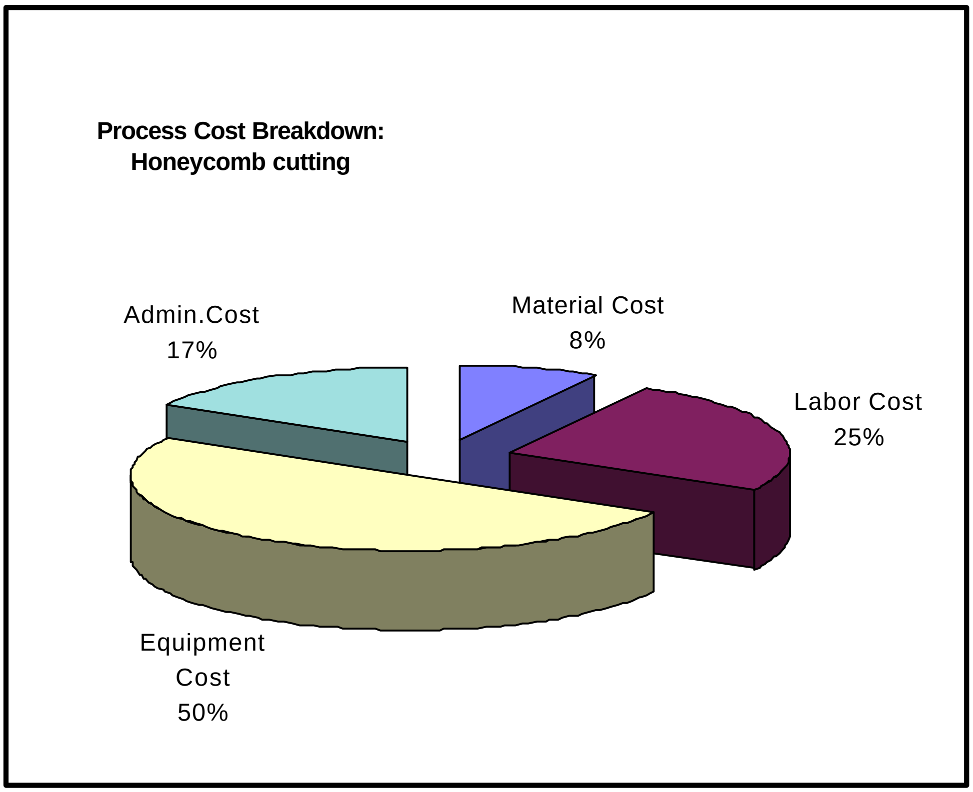


Figure 3-20: Cost Breakdown of Specific Process Activity

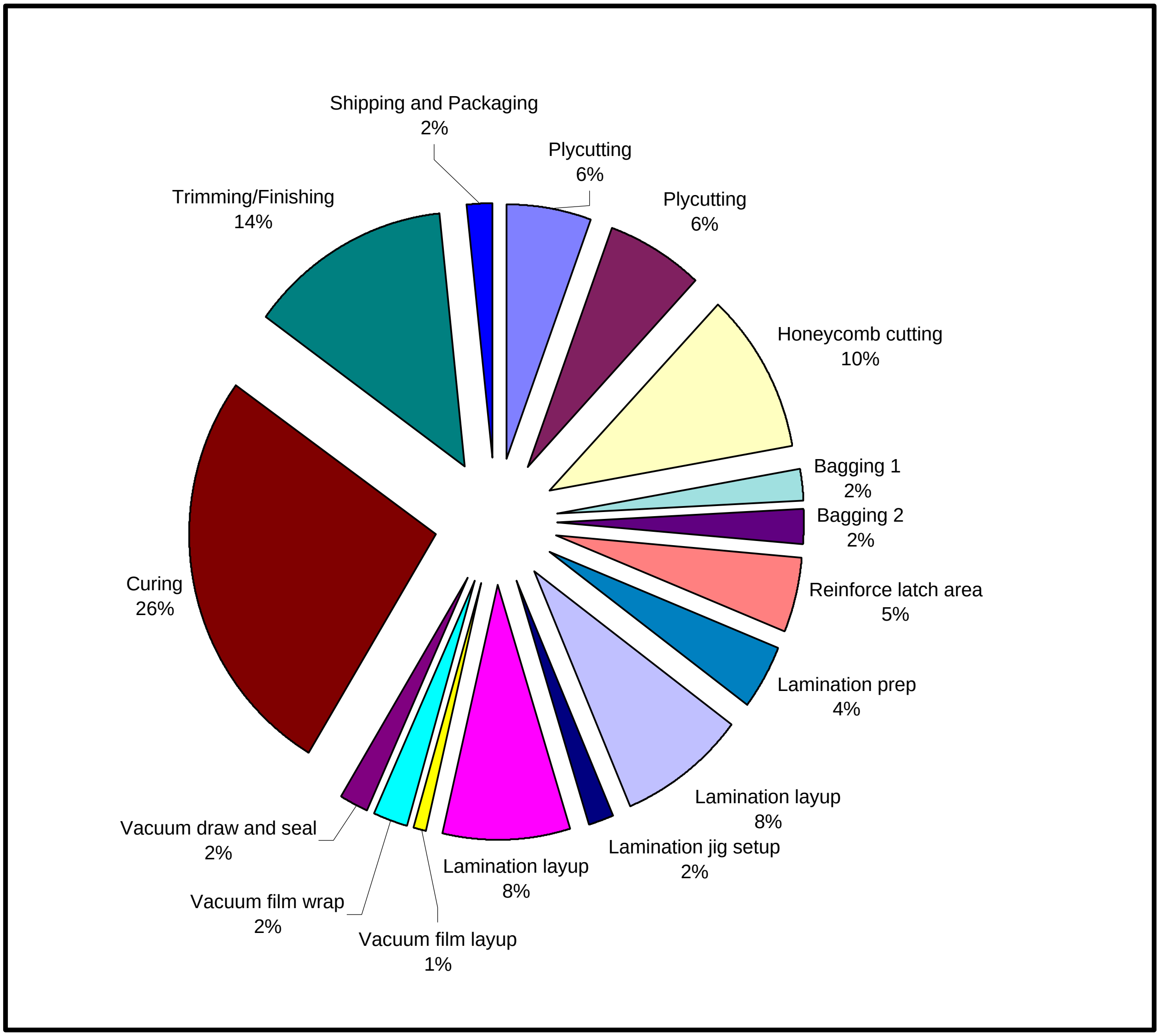


Figure 3-21: Cost Breakdown by Process Activity Cost

3.8 Summary of the Design Decision Support Framework

In this methodology, the formal statement of the research problem was given, and the objectives of the research were described. The preliminary model to implement the system includes the probable sources and formats of data, flowcharts for the cost estimation process, and a scheme to model and manipulate the product cost data. The methodology utilizes activity-based costing and process cost estimating techniques described in the earlier discussion (Section 2.4). Finally, a software framework describes a prototype implementation of the research methodology, utilizing commercially available software.

The importance of this research lies in the development of a methodology that can be implemented as a supplemental resource, enabling companies to seek out otherwise hard-to-find knowledge about production activities. This knowledge may be applied to expand the designers' understanding of the causal relationships between design parameters and manufacturing costs. This expansion of knowledge can then be applied to improving the value of the product to the consumer, by increasing the ratio of performance versus manufacturing cost.

Chapter 4: IMPLEMENTATION CASE STUDY

4.1 Overview of Implementation Case Study

The purpose of the implementation case study is to demonstrate the feasibility of the DDSS methodology to seek out the cost data from different sources, and to generate a process plan, showing the estimated cost of each activity listed in the process plan. The case study shows one implementation of the cost estimation methodology, to illustrate the typical sources of data that would be used, and the workings of the methodology in searching for data, and calculating the costs of the manufacturing processes. It is intended to show the value of this methodology in being able to quickly generate the cost estimate from the existing data, by collecting information from the enterprise's own facility, and to present the designer with a spreadsheet form of that cost estimate.

To show how the methodology would work in a composites manufacturing environment, a typical composite product cost is estimated using the prototype software implementation of the methodology. A process plan is generated by the DDSS, using the data provided by working the case study using manual inputs. The various input documents used by the DDSS software are provided for reference, and are the subset of database records that were accessed for this case study. The calculation follows exactly, the methodology described in Section 3.6 for the DDSS. The DDSS software program is prompted to find the Process Details from the given product description. It uses the database records to create a new Process Plan spreadsheet. The DDSS uses the parameters in the process plan to drive the search for information from a variety of data sources, and the DDSS then applies the activity costing methods to automatically calculate the cost of the product. The DDSS-generated process plan calculations are checked by inspection, tracing the labor cost calculations, material cost calculations and equipment cost calculations for each item, to confirm that the method was executed correctly. The procedure of modifying the design by changing parameters in the process plan is then tested by varying materials, equipment and labor methods and checking the resulting change in the product cost estimate. A suggested implementation guide provides a procedural method to implement the DDSS methodology in a given manufacturing setting. This guide also considers some of the management decisions that would be necessary during the implementation process, to decide on the boundaries of the system under consideration, and on choices to handle some of the special cases for cost allocation that may arise.

4.2 Description of Case Study Data

4.2.1 Choice of Product

The product chosen is a composite baggage door for a military helicopter. This was an example formulated in conjunction with a composite products manufacturer, with costs calculated from industry information. The part is typical of many parts in the industry, requiring first that tooling be designed and made, material plies being cut to size and laid-up by hand; a vacuum bagging process, curing in an autoclave, and finally trimming and finishing operations.

4.2.2 Case Study Process Plan

The manual process plan for the composite baggage door is summarized in spreadsheet form in Table 4.1. This format is typical of a manually generated process plan. The process plan for this case study was formulated with the assistance of a manufacturing engineer from a composites manufacturing company. The information used in the case study is realistic information for this type of part, and the cost information was their assessment of approximate costs in that production facility. The purpose of this case study is to demonstrate that the methodology is successful in locating all of the information in the corporate databases, and manipulating this information into a usable form for designers. The process plan is represented in the databases by records created specifically to represent this case, along with other data that describes manufacturing processes for other products. The databases were constructed using the top-level model of the production facility, as presented in Section 3.4. The Job Order and Process Details databases, Bill of Materials database, Inventory database, Employee Cost Rate database, Maintenance Job Order database and Machine Cost Summary worksheet for the case study are described in the following sections.

4.2.3 Job Order and Process Details

In Section 3.4.4, the information flows required to have a component manufactured were described with reference to the Production Planning System. Example formats of Job Orders including the Process Details were provided in Appendix D.2. These formats were used to represent example manufacturing processes used in this case study. Table 4.2 presents the records that were extracted from the *ProcessDetails* database table to be used in this case study. The *ProcessDetails* database also contains other process detail records for other production orders that could be made in the example production facility. The DDSS software uses the product name (denoted as the *ProductID*) to first identify the job order (denoted as the *OrderID*) to make that product, as explained previously in Section 3.5, and in the description of the software implementation, in Section 3.7. The DDSS program then constructs a data query using the *OrderID* parameter (since the part has been made before), and the set of all *ProcessDetail* records matching that *OrderID* are returned. The example records shown in Table 4.2 represent the set of records matching the query for the Baggage Door (denoted as *OrderID* = 100) in the database. The records listed here include all of the data fields that are captured in the data query, and will be appended to the Process Plan spreadsheet being constructed. In Figure 4-1 the origins of the database fields in the DDSS-generated Process Plan are depicted. The process detail records provide data for the descriptive fields shown on the left-hand side of the process plan. The DDSS-generated process plan is shown in Table 4.9 (page 162) and can be seen to include all of the information from the process detail recordset, as well as the calculated fields showing the labor cost, material cost and equipment cost to perform each process activity listed here. The *AssetID*, *EmployeeID* and *MaterialID* fields are used to drive the data search process to trace the costs of each activity. The *ProcessTime* and *NoEmployees* fields will be used in the calculation methods, as described previously in Section 3.6.

Table 4.1: Process plan for composite baggage door

	Process	Operation	Material	Size	Quantity	Machine/ Tools	Operators	Proc. Time	Setup Time
1	Plycutting	Cut glass epoxy sheets	250F Glass epoxy cloth	25" x 19"	6 sheets per kit	Gerber Automated Cutter	1	30	15
2	Plycutting	Cut adhesive film sheets	250F Curing adhesive film	25" x 19"	2 sheets per kit	Gerber Automated Cutter	1	30	15
3	Honeycomb cutting	Cut honeycomb sheets	Nomex honeycomb 3-4lb	22" x 16" x 1/4 " thick	1 sheet per kit	Waterjet cutter	2	30	15
4	Bagging	Cut the film	Plastic film 36" roll	36" x 36"	2 sheets per bag	Film cutter	1	2	5
5	Bagging	Make the bag	Plastic film sheets	2 shts 36" x 36"	1 bag per kit	Heat sealer	1	5	5
6	Reinforce latch area	reinforce sections of honeycomb sheet with epoxy filler	Nomex honeycomb 3-4lb and room temp.cure epoxy filler	22" x 16" x 1/4 " thick	1 sheet per kit and 5 oz. filler	Fixture and squeegee	1	25	5
7	Lamination	Prep. the mold	Mold cleaning fluid and release agent		each kit	mold and fixture plates	1	30	
8	Lamination	Lay on sheets of prepreg and adhesive film	3 Sheets of 250F Glass Epoxy and 1 Sheet of 250F Curing Film	Each Sheet 25" x 19"	Bottom layer of kit		1	40	
9	Lamination	Use Jig to locate and Install the Honeycomb Nomex	1 Sheet of Honeycomb Nomex	22" x 16" x 1/4" thick	Middle layer of kit	Locating Jig	1	10	
10	Lamination	Lay on sheets prepreg and adhesive flim	3 Sheets of 250F Glass Epoxy and 1 Sheet of 250F Curing Film	Each sheet 25" x 19"	Top Layer of kit		1	40	
11	Lamination	Lay teflon film and breather on top of kit and mold	Sheet of Teflon Film and Breather material	Each sheet 33" x 27"	One per kit		1	10	
12	Lamination	Wrap vacuum bag around mold, kit, teflon, and breather film	Vacuum bag, kit, mold, teflon film, and breahter material	Vacuum Bag: 36" x 36"	One per kit		1	20	
13	Lamination	Draw vacuum and seal bag	Entire kit and bag		Once per kit	Plant vacuum system	1	20	
14	Lamination	Curing Composite Part in autoclave at 250F	Entire kit, vacuum bag		3 kits	Autoclave	1	240	10
15	Trimming/Finishing	Cut excess glass from door	Unfinished baggage door	25" x 19" Door	1 kit	Cutting Template and Water Jet Cutter	1	9	120
16	Shipping and Packaging	Pack Baggage Doors and Ship to Customer	Packing and Shipping materials				1	15	
17	Engineering	Design/process planning for door production	Manufacturing engineer		1 off		1	720	
18	Tooling	Mold Tooling Cost	Manufactured separately		1				

Table 4.2: Process Detail records (from *ProcessDetails* database) for Helicopter Baggage Door

OrderID	ProductID	ProcessID	ProcessDesc	Start Date	End Date	Start Time	End Time	Process Time	AssetID	Employee ID	NoEmployees	MaterialID
100	UH64BD	1	Plycutting: cut glass epoxy sheets	1/4/98	1/4/98	8:00 AM	8:45 AM	45	LASERCUTTER01	LC1	1	UH64BDM1
100	UH64BD	2	Plycutting: cut adhesive film sheets	1/5/98	1/5/98	8:00 AM	8:45 AM	45	LASERCUTTER01	LC1	1	UH64BDM2
100	UH64BD	3	Cutting Honeycomb sheets	1/6/98	1/6/98	8:00 AM	8:45 AM	45	WJCUTTER02	WC1	2	UH64BDM3
100	UH64BD	4	Bagging: film cutting	1/7/98	1/7/98	9:00 AM	9:07 AM	7	FILMCUTTER01	FC1	1	UH64BDM4
100	UH64BD	5	Bagging: heat sealing	1/7/98	1/7/98	10:00AM	10:10 AM	10	HEATSEALER01	HS1	1	
100	UH64BD	6	Reinforce latch area	1/8/98	1/8/98	10:20AM	10:50 AM	30		OP2	1	UH64BDM6
100	UH64BD	7	Mold preparation	1/9/98	1/9/98	8:15 AM	8:45 AM	30		OP2	1	UH64BDM7
100	UH64BD	8	Lamination layup: prepreg and adhesive film	1/9/98	1/9/98	8:10 AM	8:50 AM	40		OP2	1	
100	UH64BD	9	Lamination jig setup: locate and install Nomex she	1/9/98	1/9/98	9:00 AM	9:10 AM	10		OP2	1	
100	UH64BD	10	Lamination layup: prepreg and adhesive film	1/9/98	1/9/98	9:10 AM	9:50 AM	40		OP2	1	
100	UH64BD	11	Vacuum film layup: teflon film and breather	1/9/98	1/9/98	10:00AM	10:10 AM	10		OP1	1	
100	UH64BD	12	Vacuum film wrap	1/9/98	1/9/98	10:15AM	10:35 AM	20		OP1	1	
100	UH64BD	13	Vacuum bag: draw and seal	1/9/98	1/9/98	11:00AM	11:20 AM	20	VACPUMP01	OP1	1	
100	UH64BD	14	Curing at 250F	1/10/98	1/10/98	9:00 AM	1:00 PM	240	AUTOCLAVE04	OP3	1	
100	UH64BD	15	Trimming and finishing	1/13/98	1/13/98	8:30: AM	10:39 AM	129	CNCMILL02	OP4	1	
100	UH64BD	16	Packaging	1/15/98	1/15/98	2:00: PM	2:15 PM	15		LA1	1	BOX321
100	UH64BD	17	Engineering design (portioned)	12/1/97	12/2/97	8:00: AM	12:00 PM	720	CADCAMPC03	ENG2	1	
100	UH64BD	18	Tooling Cost (portioned)	12/18/97	12/24/97	8:00 AM	5:00 PM	0	TOOLBD01	ENG2	0	

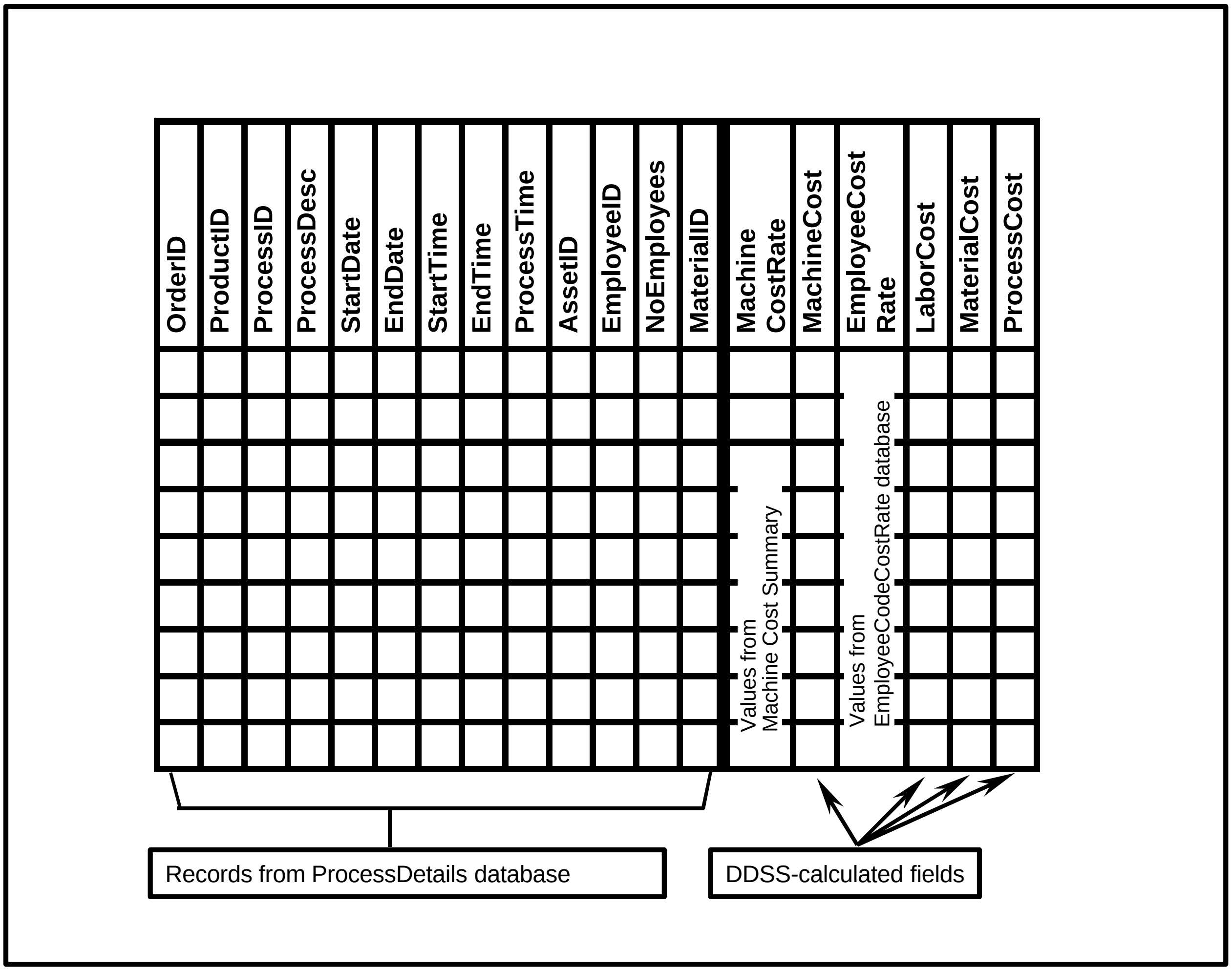


Figure 4-1: Origins of DDSS-generated Process Plan Data Fields

4.2.4 Bill of Materials

The bill of materials for each part is linked to the order number (*OrderID*), product number (*ProductID*), and process detail record (*ProcessID*). For each process having material items, the bill of materials details the material description, size parameters, and quantity used by the process. The material item number (*MaterialID*) is the unique identifier of a particular type of material. Size units are assumed given in inches. Where other units are given, e.g. for the epoxy filler material used in one of the processes, the quantity (8) represents 8 units of the product, in this case 8 oz., as described by the unit cost parameter.

Table 4.3 shows the sample paper format of the Bill of Materials, with material items created to represent each of the material items described in the process plan for the baggage door. This bill of materials was created for this case study, and represents typical data that is used in industry. This typical format for a Bill of Materials and the information contained in it was described previously in Section 3.4, and a sample format provided in Appendix D.3.

Table 4.3: Bill of Materials for Composite Baggage Door (sample paper format)

OrderID		100				
Product ID		UH64BD01				
ProductDescription		Helicopter Baggage Door				
Authorization		MAE				
Date		Jan 3, 1998				
Proc.#	**Material#**	**Material Description**	**Size L**	**Size W**	**Size T**	**Qty**
1	UH64BDM1	250F Glass epoxy cloth	25	19	0.125	6
2	UH64BDM2	250F Curing adhesive film	25	19	0.062	2
3	UH64BDM3	Nomex honeycomb 3-4lb	22	16	0.50	1
4	UH64BDM4	Plastic film 36" roll	36	36	0.05	2
6	UH64BDM6	Epoxy filler	-	-	-	8
7	UH64BDM7	Mold cleaning fluid and release agent	-	-	-	8
16	BOX321	Cardboard box	36	24	12	1

The database form of the Bill of Materials for the given case study is shown in Table 4.4, and was extracted from the *BillMaterials* database table. The database form of the bill of materials is different from the paper format shown in Table 4.3, in that it has a separate record for each material item listed, rather than one record with a list of multiple items. This is a necessary representation of the material data, to allow access to individual material items, and for cross referencing to the cost of those items, as captured in the Inventory database.

Table 4.4: Database Form of Bill of Materials (BillMaterials Table of Factor2.mdb)

Material No	OrderID	ProductID	ProcessID	MaterialID	MaterialName	Size L	Size W	SizeT	Qty
1	100	UH64BD01	1	UH64BDM1	250F Glass epoxy cloth	25	19	0.125	6
2	100	UH64BD01	2	UH64BDM2	250F Curing adhesive film	25	19	0.062	2
3	100	UH64BD01	3	UH64BDM3	Nomex honeycomb 3-4lb	22	16	0.50	1
4	100	UH64BD01	4	UH64BDM4	Plastic film 36" roll	36	36	0.05	2
13	100	UH64BD01	6	UH64BDM6	Epoxy filler	-	-	-	8
6	100	UH64BD01	7	UH64BDM7	Mold cleaning fluid and	-	-	-	8
12	100	UH64BD01	16	BOX321	Cardboard box	36	24	12	1

During the cost estimation process, the set of records relating to a specific production order are located by first defining the product order that was used to create that product, and then finding the set of process details that were defined to make that part. The relevant records in the Bill of Materials table are found with an SQL query using the *OrderID* parameter in the *Job Orders* table, and the *ProcessID* parameter from the *Process Details* table. This recordset returned by the query represents all of the material items used in a specific process activity. For this case study, there were 7 processes that used material; these are all listed here. The *ProcessID* field refers to the process that listed the specific material item for use. *MaterialName* and *Size* parameters are self explanatory, the *Qty* field refers to the quantity of that material item used in that specific process.

4.2.5 Inventory Database Table

As described previously in Section 3.4.5, the Inventory database contains records of the costs of all items purchased or manufactured by the company. Relevant to the example of the baggage door, each material item used in the production process is listed in the Bill of Materials, and cross-listed in the Inventory database table. This information is captured from materials requisitions created by the production control system, as was described in Section 3.4.4, and from materials issues from Inventory to get the required material items to the location in the manufacturing plant scheduled to use that item during the production process. The information captured in each material record follows the sample data format presented for material requisitions described in Section 3.4.4, and shown in Appendix D.4.

Table 4.5: Database Form of Inventory Table (from Factor2.mdb)

ID	MaterialID	Material Name	Supplier ID	Category	Location	Unit Cost	Qty	Order Cost	Size Len.	Size Wid.	Size Thick.	Grade
13	UH64BDM1	GLASS EPOXY SHT	GLASS CO		STORE P	$15.00	6	$90.00	25	19	.025	2X
14	UH64BDM2	ADHESIVE FILM SHT	CHEMA CO		STORE P	$3.00	2	$6.00	25	19	.005	A
15	UH64BDM3	NOMEX HCOMB SHT	ADVTECH		STORE P	$50.00	1	$50.00	22	16	1	N1
16	UH64BDM4	TEFLON FILM	CHEM CO		STORE P	$2.00	5	$10.00	60	48	.005	A
18	UH64BDM6	EPOXY RESIN PACK	CHEMB CO		STORE P	$2.00	8	$16.00				POX1
19	UH64BDM7	MOLD RELEASE FLUID	CHEMB CO		STORE P	$1.00	8	$8.00				
28	BOX321	CARDBOARD BOX	BOXCO		STORE D	$2.00	1	$2.00	36	24	12	

The data shown in Table 4.5 was extracted from the Inventory database to show how material items in the Inventory database are cross-linked to the material items referred to in the Bill of Materials for a given product. In the database representation, the Inventory record contains information on the order cost for the material, and the unit cost for that item. The quantity (*Qty*) field in the Inventory database represents the order quantity for that material item. The DDSS software uses the *MaterialID* parameter from the *BillMaterials* database table to construct a search query into the Inventory database, as described previously in Section 3.7.6. The records in the Inventory table are matched using the *MaterialID* parameter, and the *Unit Cost* parameter is obtained from the Inventory database, and inserted back into the spreadsheet representation of the process plan. This *UnitCost* of the material item is used by the DDSS to calculate the *Material Cost* in the DDSS-generated Process Plan. The sample records for this case (matching *MaterialID* values from the *BillMaterials* table) are shown in Table 4.5. As in the Bill of Materials (Table 4.4), there are 7 material items used in this product, and 7 matching records found in the Inventory database.

4.2.6 Employee Code Cost Rate Table

The data presented in this table provides the labor cost rates for various categories of skilled labor involved in the production of the example product. The data shown in Table 4.6 was created for the purposes of the case study, to show how such data may be represented. As described previously in Section 3.6.1, this database table is accessed to find the labor cost rate for the purposes of calculating labor costs for each process activity. The data query uses the *EmployeeID* parameter from the *ProcessDetails* record to find the appropriate Labor Cost Rate. The *LaborCostRate* value is then returned to the spreadsheet process plan, and inserted into the *LaborCostRate* field. The cost rate data for different salary scales should be obtainable from the accounting information system databases. As described previously in Section 3.6, in this implementation, it was considered preferable to access generic employee cost codes rather than have to access individual employee cost rates. This choice would be a decision for the implementation team; the DDSS software can accommodate either method. The cost rate determined for employees could also choose use a method similar to the machine cost summary worksheet to include other costs of personnel administration; for this implementation, it is assumed that the labor cost rates cover the full cost of employment of each skill level.

Table 4.6: Database Form of Employee Code Cost Rate Table (from Factor2.mdb)

EmployeeCode	EmployeeCostRate
ENG1	$30.00
ENG2	$35.00
ENG3	$40.00
FC1	$15.00
HS1	$14.00
LA1	$5.00
LA2	$6.00
LA3	$7.00
LC1	$18.00
LC2	$20.00
MAINT1	$18.00
MAINT2	$20.00
MAINT3	$23.00
MAINT4	$25.00
OP1	$8.00
OP2	$10.00
OP3	$12.00
OP4	$14.00
WC1	$18.50
WC2	$20.50

4.2.7 Maintenance Job Order Records

To illustrate the functioning of the DDSS in computing the cost of equipment used in production, it was necessary to create a set of records representing maintenance work carried out on various production machines in the plant. Table 4.7 represents a sample of the maintenance records created for the purpose of this case study. The *AssetID* parameter in this database can be cross-referenced with the *AssetID* referred to in the *ProcessDetail* records, identifying which production equipment is used during each manufacturing activity. The *AssetID* field is cross-referenced to asset records in the *FixedAsset* database, as described in Section 3.4. Each maintenance job has a unique job order number (*MaintJobID*), assigned at the time the work is carried out. The AssetName, date and time fields are self explanatory. The *MaintJobDesc* field describes the work carried out on the machine. *EmployeeID* identifies the labor skill required to carry out the task (e.g. a service kit, or replacement part), and is cross-referenced to employee codes in the EmployeeCodeCostRate database. *MaterialID* identifies the material item required to carry out the work, and is cross-referenced to the same material item in the Inventory database. In this implementation, the *MaterialCost* is assumed by the DDSS to have been inserted back into the Maintenance Job Order database. For each machine, there may be single-, multiple-, or no maintenance records for a given period, which realistically models typical maintenance history of production machines.

Table 4.7: Maintenance Job Order Records for Equipment Assets used in this case

MaintJobID	AssetID	AssetName	MaintJobDesc	Department	EmployeeID	Start Date	End Date	Start Time	End Time	Job Time	Material ID	MaterialCost
201	AUTOCLAVE04	AUTOCLAVE	Replace heat controller	CURING	MAINT2	1/5/98	1/5/98	8:00 AM	3:00 PM	420	SCHOLZ400	$1,000
202	WJCUTTER01	PROFILE CUTTER-WATER JET	Repair and replace nozzles	PLYCUTTING	MAINT3	1/10/98	1/10/98	9:00 AM	12:00 PM	180	DESI200	$300
203	AUTOCLAVE01	AUTOCLAVE	Replace heater coils	CURING	MAINT2	1/6/98	1/6/98	8:00 AM	2:00 PM	360	ACME101	$200
204	LASERCUTTER01	LASER CUTTER	Replace parts	PLYCUTTING	MAINT2	1/23/98	1/23/98	2:00 PM	4:00 PM	120	ABC103	$45
205	WJCUTTER02	PROFILE CUTTER-WATER JET	Service PM	PLYCUTTING	MAINT1	1/26/98	1/26/98	10:00 AM	2:30 PM	270	PM145	$50
206	HEATSEALER01	HEAT SEALER	Breakdown repair	BAGGING	MAINT1	1/14/28	1/14/98	2:30 PM	3:30 PM	60	ABC108	$80
207	FILMCUTTER01	FILM CUTTER	Adjustment/ Setup	BAGGING	MAINT2	1/18/98	1/18/98	1:00 PM	1:30 PM	30	PMFILM1	$35
208	CNCMILL02	CNCMILL	Service overhaul	MACHINING	MAINT3	1/11/98	1/11/98	8:00 AM	6:00 PM	600	KE50	$800
209	LASERCUTTER01	LASER CUTTER	Service PM	PLYCUTTING	MAINT2	1/23/98	1/23/98	2:00 PM	4:00 PM	120	ABC103	$45
210	LASERCUTTER01	LASER CUTTER	Calibrate machine	PLYCUTTING	MAINT2	1/23/98	1/13/98	11:00 AM	11:30 AM	30	ABC106	$10
211	WJCUTTER02	PROFILE CUTTER-WATER JET	Breakdown repair	PLYCUTTING	MAINT2	1/15/98	1/15/98	10:00 AM	2:30 PM	270	DESI002	$450

4.3 DDSS Process Plan Calculation of Costs

The DDSS-generated Process Plan is shown in Table 4.9 (page 162). As explained previously in Section 3.7.3, the DDSS-generated Process Plan is different from the manually generated plan in that information is parsed out into separate fields, in order to match the format of data used in the Production Planning System and Accounting Information System databases. As shown in Figure 4-1 (page 145), the data describing the process activities is extracted from the *ProcessDetails* database, and inserted into the spreadsheet (on the left-hand side). The DDSS software fetches data from the *Machine Cost Summary*, the *EmployeeCostCodeRate* database, *BillMaterials* database, and *Inventory* database, to calculate the values inserted into the *MachineCost*, *LaborCost*, *MaterialCost* and *ProcessCost* fields (on the right-hand side). The calculation of process activity costs for this case study are described in the following sections:

4.3.1 Material Cost Calculation

As described previously in Section 3.6, the material cost calculation is executed for each process activity listed in the process plan. For each material item listed, the quantity of material used is calculated from the size parameters and description of the material. This quantity is multiplied by the unit cost rate for that material, obtained from the Inventory database. Note that for inexact matches with the supplied material sizes, the material cost should be calculated for the whole of the smallest *sufficient* unit size (assume that cut-off waste from material cannot be re-used). Individual items are then summed for the total material cost of the product. In the prototype software, the cost is determined to be the cost of the item as issued by the store.

For example, from Table 4.2, the *ProcessDetails* record matching *OrderID* = 100, *ProductID* = UH64BD, *ProcessID* = 1 (plycutting glass epoxy sheets), lists the *MaterialID* as UH64BDM1, as shown here:

OrderID	ProductID	ProcessID	ProcessDesc	Start Date	End Date	Start Time	End Time	Process Time	AssetID	Employee ID	NoEmployees	MaterialID
100	UH64BD	1	Plycutting: cut glass epoxy sheets	1/4/98	1/4/98	8:00 AM	8:45 AM	45	LASERCUTTER01	LC1	1	UH64BDM1

In the *BillMaterials* database, the *MaterialID* = UH64BDM1 provides details of that material item: 6 sheets of 250F glass epoxy cloth, of the given size.

MaterialNo	OrderID	ProductID	ProcessID	MaterialID	MaterialName	SizeL	SizeW	SizeT	Qty
1	100	UH64BD01	1	UH64BDM1	250F Glass epoxy cloth	25	19	0.125	6

In the Inventory database, *MaterialID* = UH64BDM1 provides details of the cost of that material item, as shown here (extract from Table 4.5). The *UnitCost* of $15 per sheet is returned by the data search query, and is multiplied by the *Quantity* field value (= 6) to give the Material Cost for this item as $90.00, which is inserted into the DDSS-generated process plan, in the *MaterialCost* field for *ProcessID* = 1. This is shown in the first row of Table 4.9.

ID	MaterialID	Material Name	Supplier ID	Category	Location	Unit Cost	Qty	Order Cost	Size Len.	Size Wid.	Size Thick.	Grade
13	UH64BDM1	GLASS EPOXY SHT	GLASS CO		STORE P	$15.00	6	$90.00	25	19	.025	2X

By inspection, each of the material items listed in the DDSS-generated Process Plan has been correctly matched with each *MaterialID* in the Bill of Materials, and the cost from the Inventory record for each material item has been inserted in the *Material Cost* field of the DDSS-generated Process Plan.

4.3.2 Labor Cost Calculation

As described previously in Section 3.6, the labor cost calculation is executed for each process activity listed in the Process Plan. For each activity/process time, the cost of labor resources consumed is calculated by multiplying that time by the cost rate for the labor resource, as obtained from the *Employee Code Rate* database. The *EmployeeID* field in the Process Plan represents the skill or labor class of employee needed to complete the activity. Individual items are then summed for the total labor cost included in the product.

For example, from Table 4.2, the *ProcessDetails* record matching *OrderID* = 100, *ProductID* = UH64BD, *ProcessID* = 1 (plycutting glass epoxy sheets), lists the *ProcessTime* = 45 minutes, and the *EmployeeID* = LC1, and the number of employees (NoEmployees) = 1, as shown here:

OrderID	ProductID	ProcessID	ProcessDesc	Start Date	End Date	Start Time	End Time	Process Time	AssetID	Employee ID	NoEmployees	MaterialID
100	UH64BD	1	Plycutting: cut glass epoxy sheets	1/4/98	1/4/98	8:00 AM	8:45 AM	45	LASERCUTTER01	LC1	1	UH64BDM1

From the Employee Code Cost Rate database table (Table 4.6), the *LaborCostRate* for the employee type LC1 is $18.00 per hour. The *LaborCost* is calculated by the DDSS as the ProcessTime (in hours) times the Labor Cost Rate times the number of employees:

45 minutes / 60 x $ 18.00 x 1 = $13.50

The value for Labor cost is then inserted into the LaborCost field for ProcessID = 1. This is shown in the first row of the DDSS-generated Process Plan shown in Table 4.9.

Engineering time is summarized separately from direct production labor, and is handled as a special case, as described previously in Section 3.7. The design and development time spent by the engineer on this product must be apportioned between the expected number of products to be made. The choice of how many products to apportion the cost over, and the period of time, is a management decision, and may take account of their marketing strategy for this product. For example, if they wanted to aggressively price the product to make a big sale, they may choose to apportion engineering and development costs over a larger number of products, assuming that the order will be forthcoming. A more conservative strategy would be to allocate the cost over the initial order, and to accept the development costs earlier in the expected product life cycle. Another consideration would be to separate engineering design costs from engineering manufacturing planning costs, and to treat the two costs differently. Engineering design cost may be a one-time only cost, whereas manufacturing planning costs may be accrued over the lifetime of the product, with some additional effort required for each repeat product order.

In this case, the total engineering labor cost of $420 is divided by the expected number of parts to be made (in this case, assumed to be 10), to give the allocated engineering labor cost to each product of $42. This is shown for the engineering process activity (*ProcessID* = 17) of Table 4.9.

By inspection of the results in the *Labor Cost* field, the costs have been correctly calculated by the DDSS using the given *Process Time*, *Employee Cost Rate*, and *NoEmployees* values for each process record listed in this case.

4.3.3 Equipment Cost Calculation

As described previously in Section 3.6, the equipment cost calculation uses an intermediate *Machine Cost Summary* worksheet to calculate the cost rate for each production machine. This worksheet captures the cost of ownership, all the maintenance costs, and the operating cost for each equipment asset. It also captures the number of machine hours worked by the machine in the period under review, as the basis of the Machine Cost Rate. The equipment activity cost is then calculated using the direct process activity rate multiplied by the machine cost rate.

This method of collecting costs that may not be directly assigned to a product, and calculating an appropriate activity cost rate to allocate the costs to products could be adapted for other indirect cost assignments. This technique is more typical of activity-based costing for entire organizations, where the purpose of the system is to make more appropriate cost allocations, by choosing more numerous, and sometimes newly derived cost drivers to allocate costs to the various products or services of the enterprise.

For each activity/process time, the cost of equipment resources is calculated by multiplying the job time with the cost rate for that equipment resource. The cost rate for the equipment resource includes the maintenance and operating costs of the machine, and the time is calculated as the time engaged by the machine on that job, rather than on just the physical processing time. This includes any idle time and setup time during the given process/activity. The *Machine Cost Summary* generated by the DDSS for this case is shown in Table 4.8.

For example, for the WaterJet Profile Cutter identified as AssetID = WJCUTTER02, located in the Plycutting Department. The maintenance labor cost is calculated by referring back to the Maintenance Job Order database, shown in Table 4.7. The DDSS software searches for all maintenance jobs carried out in the period under review (for the case study, the period was a month from 1/1/98 to 1/31/98). In this case there were two jobs, as shown below (extracted from Table 4.7).

MaintJobID	**AssetID**	**AssetName**	**MaintJobDesc**	**Department**	**EmployeeID**	**Start Date**	**End Date**	**Start Time**	**End Time**	**Job Time**	**Material ID**	**MaterialCost**
205	WJCUTTER02	PROFILE CUTTER-WATER JET	Service PM	PLYCUTTING	MAINT1	1/26/98	1/26/98	10:00 AM	2:30 PM	270	PM145	$50
211	WJCUTTER02	PROFILE CUTTER-WATER JET	Breakdown repair	PLYCUTTING	MAINT2	1/15/98	1/15/98	10:00 AM	2:30 PM	270	DESI002	$450

The maintenance labor cost is calculated as the Job Time (in hours) multiplied by the *EmployeeCostCodeRate* (matched to the *EmployeeID* parameter). For the two jobs:

MaintJobID 205: 270 / 60 x 18 = \$81

MaintJobID 211: 270 / 60 x 20 = \$90

which results in a sum of labor cost = 81 + 90 = \$171

This calculated value is inserted into the *MachineCostSummary* worksheet in the *LaborCost* field for this machine.

The material cost is similarly summed for the set of maintenance jobs carried out on this machine in the period under review:

$50 (from *MaintJobID* 205) + $ 450 (from *MaintJobID* 211) = $500

This calculated value is inserted into the *MachineCostSummary* worksheet in the *MaterialCost* field for this machine.

The *Depreciation Charge* for the machine is $50,000 per year, assumed to be pro-rated in equal monthly charges.

$50,000 / 12 = $4,166.67 per month

The calculation of depreciation charges is dependent on choices of depreciation methods for financial reporting purposes. For this implementation of the DDSS methodology, the depreciation method and annual depreciation charge was obtained from the *FixedAsset* database. It is possible to accommodate other choices of where this information may be obtained, and how the depreciation should be calculated. These decisions would have to be tailored to suit the management and financial reporting decisions of the specific manufacturing environment.

AssetID	AssetName	Make	Model	Department	Serial Number	Acquisition Cost	Acquisition Date	Life	Depreciation Method	Depreciation Rate
WJCUTTER02	PROFILE CUTTER-WATER JET	GERBER	GWJ450	PLYCUTTING	204525	$500,000	4/30/93	10	Straight Line	$50,000

Current Value	Description	Power	Depn Charge	Adjustment	Maint Labor Cost	Matl Cost	Machine Hours	Oper Cost Rate	Oper Cost	TotalMachine Cost	Machine Cost Rate
$300,000		4	$50,000		$171	$500	234.08	1	$234.08	$5,071.75	$21.67

The number of hours worked by the machine is calculated by the DDSS software, by searching the set of production job orders that use this machine, and summing the total of all process times listed. This was detailed in Section 3.6, and searches the *ProcessDetails* database for the facility, over the period under consideration, using the *AssetID* of the given machine as the search parameter. This value is returned in the *MachineHours* field, shown here to be 234.08 hours. This value will be used to calculate the *Machine Cost Rate*, by dividing the total cost of the machine for the given period, by the total number of hours it was used for production work.

The operating cost is calculated as the number of machine hours worked, multiplied by the Operating Cost Rate (*OperCostRate* = $1 / hour, for this case).

234.08 hours x 1 = $234.08 for the month under review.

This value is then inserted into the *OperCost* field of the *Machine Cost Summary*, as shown above. In this implementation, the operating cost rates for all the machines were given as unity, for ease of tracing calculation of the *Operating Cost*. An alternative to this approach would be to use the *Power* field for each machine (the rated power to drive the machine, in kilowatt-hours), and to multiply that value by the electrical power supply cost for the given production facility.

Total machine cost is then the sum of *MaintLaborCost*, *Material Cost*, *DepnCharge*, and *OperCost* for each machine:

MaintLabor Cost	$171.00
MatlCost	$500.00
DepnCharge	$4166.67
OperCost	$234.08
Total Machine Cost	$5071.75

This value is calculated by the DDSS program and inserted into the *TotalMachineCost* field as shown in Table 4.8.

The *Machine Cost Rate* is calculated by the DDSS program as the *Total Machine Cost* divided by the *Machine Hours*:

TotalMachineCost divided by *Machine Hours* = *Machine Cost Rate*

$5071.75 / 234.08 hours = $21.67 per machine hour

This value is calculated and inserted into the *MachineCostRate* field of the *Machine Cost Summary* worksheet as shown in Table 4.8. The *Machine Cost Rate* is used by the DDSS software to calculate the equipment cost for each machine used in a manufacturing process. The *Machine Cost Rate* is multiplied by the *ProcessTime* to give an activity-based cost allocation for that machine, allocating the complete cost of ownership of that machine to the jobs using the machine, by the portion of time used to carry out the specific manufacturing activity. The *Machine Cost Summary* calculates the *Machine Cost Rate* for each machine listed in the *Fixed Asset* database for the production facility. In implementing the DDSS methodology in a given manufacturing environment, consideration should be given to define the scope of the project, and which resources to include in the system. In the implementation guide (Section 4.6), considerations to choose activities and to determine appropriate activity rates are discussed, with suggestions on how to accommodate special cases that may arise.

As described previously in Section 3.7.7, the mold tooling costs for this DDSS implementation are handled as a special case. The cost to manufacture the mold tool has been captured in the *FixedAsset* database, and is apportioned out to the product as the cost of the tool, divided by the expected number of products to be made using this tool. The decision of how many items to amortize the cost of the tool is a management decision, and any implementation of the DDSS methodology would need to address this issue. Management may decide to apportion the cost of mold tools (or other fixtures) to the first order of the component, or over the expected number of parts to be ordered in the next year, or over the extended product life cycle, depending on their strategic interests.

For this case study, the mold tool cost was given as $800 (*AssetID* = TOOLBD01), and will be portioned out over 10 items to be produced. Thus, for the product cost calculation method used here, tooling cost for each product is $80, which is then designated as the *Machine Cost Rate* for the mold tool used in this case (as shown in the last row of Table 4.8).

Table 4.8: Machine Cost Summary Table (generated by DDSS for Baggage Door Order ID = 100) (Page 1 of 2)

AssetID	AssetName	Make	Model	Department	Serial Number	Acquisition Cost	Acquisition Date	Life	Depreciation Method	Depreciation Rate
AUTOCLAVE04	AUTOCLAVE	SCHOLTZ	SCAC1	CURING	736453	$250,000	8/15/92	10	Straight Line	$25,000
CNCMILL02	CNCMILL	KEARNS	KC40	MACHINING	274572	$360,000	8/15/92	10	Straight Line	$36,000
FILMCUTTER01	FILM CUTTER	GERBER	FM200	BAGGING	654657	$40,000	10/30/96	10	Straight Line	$4,000
HEATSEALER01	HEAT SEALER	ABC	HS1	BAGGING	223465	$8,000	7/1/92	8	Straight Line	$1,000
LASERCUTTER01	LASER CUTTER	GERBER	LC450	PLYCUTTING	273657	$1,000,000	8/30/92	15	Straight Line	$66,667
VACPUMP01	VACUUM PUMP	ABC	X1	BAGGING	745836	$3,000	10/3/95	10	Straight Line	$300
WJCUTTER02	PROFILE CUTTER-WATER JET	GERBER	GWJ450	PLYCUTTING	204525	$500,000	4/30/93	10	Straight Line	$50,000
TOOLBD01	BAGGAGE DOOR MOLD TOOL	OWN	XX	FABRICATION	T1892	$800	18/12/97	1	Straight Line	$800

Table 4.8: Machine Cost Summary Table (generated by DDSS for Baggage Door Order ID = 100) (Page 2 of 2)

Current Value	Description	Power	Depn Charge	Adjustment	MaintLabor Cost	MatlCost	Machine Hours	Oper Cost Rate	Oper Cost	TotalMachine Cost	Machine Cost Rate
$125,000		15	$25,000		$140	$1,000	187.33	1	$187.33	$3,410.67	$18.21
$180,000		3	$36,000		$230	$800	102.15	1	$102.15	$4,132.15	$40.45
$36,000		0.5	$4,000		$10	$35	166.78	1	$166.78	$545.12	$3.27
$3,000		2	$533		$18	$80	133.50	1	$133.50	$275.94	$2.07
$666,665		10	$66,666		$90	$100	201.50	1	$201.50	$5,947.06	$29.51
$2,400		2	$300.00		$ -	$ -	117.00	1	$117.00	$142.00	$1.21
$300,000		4	$50,000		$171	$500	234.08	1	$234.08	$5,071.75	$21.67
$800		0	$ -		$ -	$ -	0.00	0	$ -	$800.00	$80.00

4.3.4 Process Activity Cost

In the DDSS-generated Process Plan, for each activity listed in the Process Details to manufacture the part, the software seeks out the costs of Labor, materials, and equipment used in the process. The data is collected and the calculated fields on the right-hand side of the Process Plan are then filled in, as shown previously in Figure 4-1 (page 145). This is shown in Table 4.9 for each activity, with the values inserted into the fields for *MachineCostRate*, *MachineCost*, *EmployeeCostRate*, *LaborCost*, *MaterialCost*, and finally *ProcessCost*. The Process Cost is simply the sum of *MachineCost*, *LaborCost*, and *MaterialCost* for each manufacturing process activity. The DDSS program calculates these results for each row in the worksheet, and thereby builds up the manufacturing cost estimate for the product.

Table 4.9: DDSS generated Process plan for composite baggage door (Page 1 of 2)

OrderID	ProductID	ProcessID	ProcessDesc	Start Date	End Date	Start Time	End Time	Process Time	AssetID
100	UH64BD	1	Plycutting: cut glass epoxy sheets	1/4/98	1/4/98	8:00AM	8:45AM	45	LASERCUTTER01
100	UH64BD	2	Plycutting: cut adhesive film sheets	1/5/98	1/5/98	8:00AM	8:45AM	45	LASERCUTTER01
100	UH64BD	3	Cutting Honeycomb sheets	1/6/98	1/6/98	8:00AM	8:45AM	45	WJCUTTER02
100	UH64BD	4	Bagging: film cutting	1/7/98	1/7/98	9:00AM	9:07AM	7	FILMCUTTER01
100	UH64BD	5	Bagging: heat sealing	1/7/98	1/7/98	10:00AM	10:10 AM	10	HEATSEALER01
100	UH64BD	6	Reinforce latch area	1/8/98	1/8/98	10:20AM	10:50 AM	30	
100	UH64BD	7	Mold preparation	1/9/98	1/9/98	8:15AM	8:45AM	30	
100	UH64BD	8	Lamination layup: prepreg and adhesive film	1/9/98	1/9/98	8:10AM	8:50AM	40	
100	UH64BD	9	Lamination jig setup: locate and install Nomex she	1/9/98	1/9/98	9:00AM	9:10AM	10	
100	UH64BD	10	Lamination layup: prepreg and adhesive film	1/9/98	1/9/98	9:10AM	9:50AM	40	
100	UH64BD	11	Vacuum film layup: teflon film and breather	1/9/98	1/9/98	10:00AM	10:10 AM	10	
100	UH64BD	12	Vacuum film wrap	1/9/98	1/9/98	10:15AM	10:35 AM	20	
100	UH64BD	13	Vacuum bag: draw and seal	1/9/98	1/9/98	11:00AM	11:20 AM	20	VACPUMP01
100	UH64BD	14	Curing at 250F	1/10/98	1/10/98	9:00 AM	1:00 PM	240	AUTOCLAVE04
100	UH64BD	15	Trimming and finishing	1/13/98	1/13/98	8:30:AM	10:39 AM	129	CNCMILL02
100	UH64BD	16	Packaging	1/15/98	1/15/98	2:00:PM	2:15 PM	15	
100	UH64BD	17	Engineering design (portioned)	12/1/97	12/2/97	8:00:AM	12:00 PM	720	CADCAMPC03
100	UH64BD	18	Tooling Cost (portioned)	12/18/97	12/24/97	8:00 AM	5:00 PM	0	TOOLBD01

Table 4.9: Process Plan generated by DDSS (Page 2 of 2)

ProcessID	EmployeeID	NoEmployees	MaterialID	Machine CostRate	Machine Cost	EmployeeCostRate	Labor Cost	Material Cost	Process Cost
1	LC1	1	UH64BDM1	$29.51	$22.14	$18.00	$13.50	$90.00	$125.635
2	LC1	1	UH64BDM2	$29.51	$22.14	$18.00	$13.50	$ 6.00	$ 41.635
3	WC1	2	UH64BDM3	$21.67	$16.25	$18.50	$27.75	$ 50.00	$ 94.000
4	FC1	1	UH64BDM4	$3.27	$0.38	$15.00	$1.75	$ 4.00	$ 6.131
5	HS1	1		$2.07	$0.34	$14.00	$2.33	$ -	$ 2.678
6	OP2	1	UH64BDM6		$-	$10.00	$5.00	$ 16.00	$ 21.000
7	OP2	1	UH64BDM7		$-	$10.00	$5.00	$ 8.00	$ 13.000
8	OP2	1			$-	$10.00	$6.67	$ -	$ 6.667
9	OP2	1			$-	$10.00	$1.67	$ -	$ 1.667
10	OP2	1			$-	$10.00	$6.67	$ -	$ 6.667
11	OP1	1			$-	$8.00	$1.33	$ -	$ 1.333
12	OP1	1			$-	$8.00	$2.67	$ -	$ 2.667
13	OP1	1			$-	$8.00	$2.67	$ -	$ 2.667
14	OP3	1			$-	$12.00	$48.00	$ -	$ 48.000
15	OP4	1		$ 40.45	$86.97	$14.00	$30.10	$ -	$117.071
16	LA1	1	BOX321		$-	$5.00	$ 1.25	$ 2.00	$ 3.250
17	ENG2	1			$-	$35.00	$42.00	$ -	$ 42.000
18	ENG2	0		$80.00	$80.00	$ -	$ -	$ -	$ 80.000

4.4 Modifying the Design

The procedure of design iteration for which the DDSS methodology was designed (described in Section 3.5) is demonstrated in simple fashion for this case study. The initial cost estimate for the baggage door is generated by the DDSS software, using the process details from the original production order for the part. The designer is then able to modify the process details for each activity in the process plan, to modify the design structure of the part, or the production methods employed to make the part. The DDSS then uses the modified process details to construct a new cost estimate, and present this back to the designer in the form of a modified process plan spreadsheet.

To show the sensitivity of the DDSS to "what if" questions from the designers, this section describes the procedure to change some of the process/activity choices by choosing alternative procedures, materials or equipment resources. The case study was expanded to show the effect of changing some of the process parameters. This example modifies the first activity (*ProcessID* = 1, *ProcessDesc* = Plycutting: cut glass/epoxy sheets) listed in the sequence of processes to make the baggage door. The material item was changed from a Glass/Epoxy woven sheet (*MaterialID* = UH64BDM1) to a Carbon/Epoxy woven sheet (*MaterialID* = UH64BDM8). The production machine for the process was changed from a laser cutter to a water jet cutter. The process time was changed from 45 minutes to 40 minutes. The employee skill level (or employee code) was changed from LC1 to WC1. These changes were made by modifying the process detail for the first process, as shown in Table 4.10. The Bill of Materials had the new material item added, as shown in Table 4.11. A corresponding entry was added to the Inventory table, as shown in Table 4.12.

Table 4.10: Modified Entry of Process Detail for the Baggage Door (extract from ProcessDetail Table of Factor2.mdb)

OrderID	ProductID	ProcessID	Process Desc	Start Date	End Date	Start Time	End Time	Process Time	AssetID	EmployeeID	NoEmployees	MaterialID
100	UH64BD01	1	Plycutting: cut carbon epoxy sheets	1/4/98	1/4/98	8:00 AM	8:40 AM	40	WJCUTTER02	WC1	1	UH64BDM8

Table 4.11: Alternative Material Item added to Bill of Materials Table (extract from BillMaterials Table of Factor2.mdb)

Material No	OrderID	ProductID	ProcessID	MaterialID	MaterialName	Size L	Size W	SizeT	Qty
1	100	UH64BD01	1	UH64BDM8	250F Carbon epoxy cloth	25	19	0.125	6

Table 4.12: Alternative Material Item added to Inventory Table (extract from Inventory Table of Factor2.mdb)

ID	MaterialID	Material Name	Supplier ID	Category	Location	Unit Cost	Qty	Order Cost	Size Len.	Size Wid.	Size Thick.	Grade
29	UH64BDM8	GLASS EPOXY SHT	CHEM CO		STORE P	$25.00	6	$150.00	25	19	.125	2X

The modified process was then submitted to the DDSS model to generate a new cost estimate. The results of the changes are only seen in the first process activity. All other activity cost calculations gave the same results as before. The results of the modified Process Plan are shown in Table 4.13 below. The original values for the process are shown for ease of reference (extracted from Table 4.9).

This procedure to consider the cost effects of design and manufacturing process choices allows designers the opportunity to quickly analyze the effects of changing the different parameters. Other possible changes that could be considered are: sizes or thickness of materials used; number of material plies; alignment of fibers in alternate plies; manual processing methods versus automated processes.

Table 4.13: DDSS Generated Process Plan showing result of modified Process 1

OrderID	ProductID	ProcessID	ProcessDesc	Start Date	End Date	Start Time	End Time	Process Time	AssetID
100	UH64BD	1(Modified)	Plycutting: cut carbon epoxy sheets	1/4/98	1/4/98	8:00AM	8:40AM	40	WJCUTTER 02
100	UH64BD	1(original)	Plycutting: cut glass epoxy sheets	1/4/98	1/4/98	8:00AM	8:45AM	45	LASERCUTT ER01

ProcessID	EmployeeID	NoEmployees	MaterialID	Machine CostRate	Machine Cost	EmployeeCostRate	Labor Cost	Material Cost	Process Cost
1 Modified	LC1	1	UH64BDM8	$21.67	$14.44	$18.50	$12.33	$150.00	$176.778
1 Original	LC1	1	UH64BDM1	$29.51	$22.14	$18.00	$13.50	$90.00	$125.635

This method of modifying design parameters of an existing design may also be applied to new products. The designer would have to use a similar structure as a starting point for the process, but could import process details from a number of different parts to make up what would then become the new component's process plan. By using existing information about processes, the expert knowledge of manufacturing process planners may be made more accessible to designers who may not be as familiar with the composite design and manufacturing processes. This is one benefit of the DDSS methodology, providing a tool to expand the knowledge base for the design of composite products.

4.5 Graphic Display of Results

The results of the design modifications can be displayed graphically using the spreadsheet graphing capability. These graphs can be tailored to match the user requirement, and can be automatically created from each new Process Plan generated by the DDSS. The cost breakdown for the modified process 1 (described above) is shown in Figure 4-2. The cost breakdown of the original process is shown in Figure 4-3. An activity cost breakdown for the modified baggage door is shown in Figure 4-4. These are simple examples of charts used in this implementation; the spreadsheet format of the DDSS-generated Process Plan gives users a wide variety of choices to present information back to the designers and/or other users of this information.

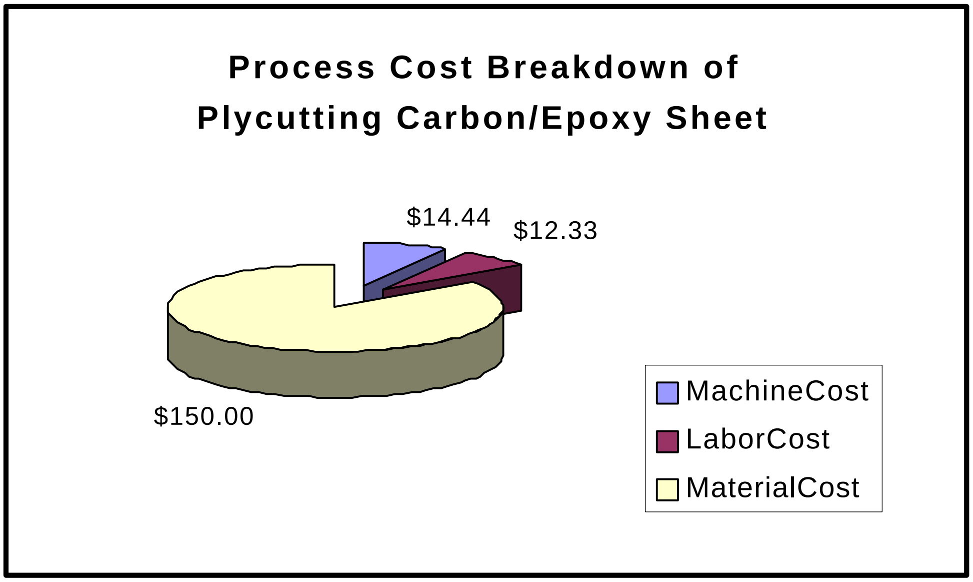


Figure 4-2: Cost Breakdown of Modified Plycutting Process

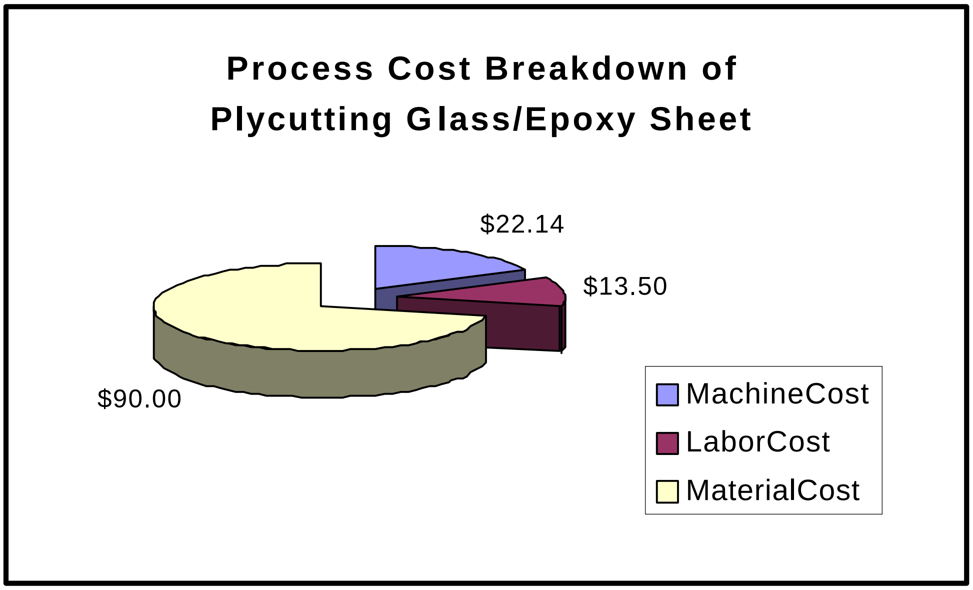


Figure 4-3: Cost Breakdown of Original Plycutting Process

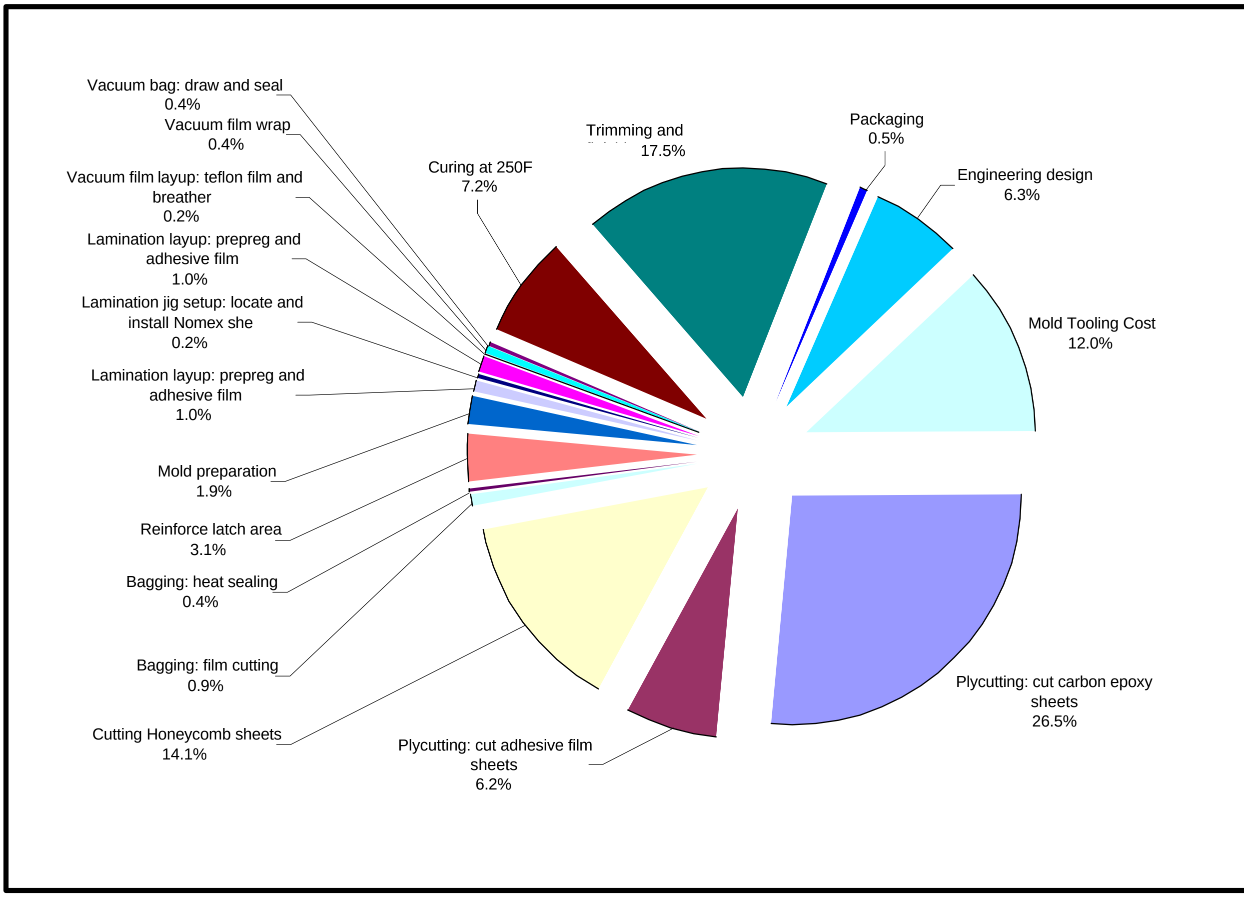


Figure 4-4: Activity Cost Breakdown for Modified Baggage Door

4.6 Guidelines for Pilot Implementation of the DDSS Methodology in a Composite Manufacturing Facility

The implementation of the DDSS methodology in a composites manufacturing facility should follow a similar procedure to those suggested in the literature for general application of an activity-based costing project. Cooper (1990), Brimson (1991), Turney (1991), and Sharman (1995), each provide versions of procedures to follow during implementation of activity-based costing projects. Although the procedures vary in the number of steps, and the grouping of actions within the phases, there is much commonality between these 'recipes' for success. In preparing a recipe specific to the target composites manufacturing environment, the broad principles of the procedure are illustrated with examples of specific decisions required of the project implementation team. The procedure is given first in summary fashion, and then expanded to cover details of actions to be addressed in that phase. The key differences between the approach for this DDSS implementation, versus a full activity-based costing implementation are also discussed:

4.6.1 Summary of DDSS Implementation Procedure:

Step 1. Secure support from top-level management for the project. This step is crucial to the success of the project, as it ensures that the project will receive the necessary resources (personnel, equipment, funds/budget authority).

Step 2. Decide scope of project and formulate specific objectives of the study. For example, is the pilot project to span the whole plant, or just one sector of the plant?

Step 3. Select a multidisciplinary team to investigate the system to be modeled. The team should include representatives from production, engineering, accounting and management.

Step 4. Analyze the production facility. Use expert opinions to identify the core processes carried out in the plant, and the outputs of each process.

Step 5. Focus on the core processes of the system: identify the common elements in the processing methods, and identify the boundaries of each subsystem to be studied.

Step 6. Identify what documentation flows in the production system would allow one to capture inputs and outputs of each process.

Step 7. Draw up a data source table, showing the links between the information and the source document for that information, and the database, fieldname, and characteristic values of the information.

Step 8. Decide on the interaction method with potential users of the system, and the extent of the information that will be provided to the users.

Step 9. Carry out some manual case studies using the latest data, and some of the candidate products. Deal with the additional complexity revealed by the case studies.

Step 10. Customize the DDSS framework to work with the available data. Set up necessary conversion utilities to transform databases, set up filename/fieldname/parameter alias table.

Step 11. Trial run of DDSS/Troubleshooting phase. Use the DDSS to carry out product cost estimation on a limited set of products. Troubleshoot the resulting bugs and problems.

Step 12. Evaluate/review worked results with team. Review the case studies, identifying any unresolved issues regarding activities, special case-handling and possible modifications to the system.

Step 13. Ongoing Project Management: training users, using the system, project reviews, documentation and modifications to the system when necessary.

4.6.2 Detailed Implementation Procedure

Step 1: Secure support from top-level management for the project.

This step is crucial to the success of the project, as it ensures that the project will receive the necessary resources (personnel, equipment, funds/budget authority). At this stage, one should secure a mandate to carry out the project.

Step 2: Define Scope of Project and Objectives

It is important to identify the scope of the project, and the objectives that are to be achieved. Establish a charter for the project, clearly stating the scope of the project, the specific objectives of the project, and the resources that will be made available (who, what, and the duration of the project). For example, is the pilot project to span the whole plant, or just one sector? Specifically, one needs to decide on an appropriate level of accuracy, and the required level of process detail to achieve the desired accuracy of costing. Cooper (1990) gives the example of an ABC system that worked to the nearest dollar, rather than to four decimal points of a dollar as the conventional cost accounting system worked. In the case of this design decision support system, their may be other accommodations to be made, allowing that as long as the allocations are consistent, the design trade studies are interested in the *variation* of costs between different processing methods, rather than on absolute accuracy of the cost estimate. This is a key difference between the objectives of the DDSS approach versus some activity-based cost systems described in the literature.

Step 3: Select a Multi-disciplinary Project Team

The team should include representatives from production, engineering, accounting and management. For successful implementation it is important to get capable personnel, with detailed knowledge and expertise of the production system and products made by the company. These team members should be given sufficient time to fulfill their obligations to the project (authorized and supported by management). Team members should also be chosen for their enthusiasm for the project; members with a stake in the successful implementation will likely contribute more to ensure that it works.

Step 4: Analyze the production facility: Preliminary Investigation

Use expert opinions (of team and others) to identify the core processes carried out in the plant, and the outputs of each process. Key to this phase is the concept of Pareto analysis: to identify the approximately 20 percent of activities that account for 80 percent of the productive output, and perhaps, the major cost factors in the plant. Identifying major distorting factors in current product costing methods is helpful in ensuring that the new system avoids those flaws. For example, in a composite manufacturing facility, the cost of the autoclave, a key production resource, and a constraining bottleneck on throughput of the plant, was pooled together with general overhead and allocated to products on the basis of labor hours. Clearly a major source of product cost distortion, and one that needed to be addressed.

Step 5: Focus on Core Processes

Focussing on those core processes, identify the common elements in the processing methods, and identify the boundaries of each subsystem to be studied. Although process details may change, one should be able to identify 20-30 key production processes, of which as few as 10 processes may be common to every product. For each process, the team should decide what is necessary for that process activity to be carried out. For example, for water-jet cutting activities, identify all of the resources used up in typical process activities passing through that area. In this case, one might identify the equipment, the personnel associated with the plant, and the materials used in the process. Choose appropriate activity rates. Where at all possible, direct assignment of costs should be made, using cost tracing, rather than pooling costs and allocating by some secondary cost driver. Preferred methods: machine hours for equipment, labor time for labor activities, direct material cost from the bill of materials. As described previously, the equipment charge out rate is defined in the Machine Cost Summary worksheet, and should include all costs of ownership, maintenance and operation. Complicating the situation are products that share equipment, for example, different products sharing space in an autoclave. In this case, a simplifying assumption would need to be made, either to allocate the whole of the cost of the autoclave for the duration of the process, or a percentage of the capacity. These are issues that must be decided by the project team, but should be directed first towards a practical solution, and one that can be achieved using existing methods of data collection.

Step 6: Identify information flows in the Production System

Identify what documentation flows in the production system would allow one to capture each of the inputs into the process. For each piece of information, list the source document and the location of that data in the various information systems of the company. From the DDSS model, one would expect to find certain common elements in similar places. For example, the job order records will likely identify the machine used in any particular process. Bills of materials will be used to capture material items, and Inventory records will contain the carrying cost of each material item. Nevertheless, each company has its own peculiarities, and the costing system must account for these. The basic premise of the DDSS implementation is to use information captured in the existing databases of the company. In this way, there may be something of a departure from other ABC-implementations, which advocate some new data collection methods, and choice of substantially different cost drivers to allocate costs to products. The DDSS is focussed on using actual times from the processes, as recorded in the production system records. Each company has its own unique set of circumstances, and may be at a different stage of development, in terms of the integration of manufacturing with other information systems. Assessing the information flows and sources of data is important to determining how much needs to be done (so called "Gap Analysis"). Some companies may already have direct cost tracking for materials, but less advanced systems for recording labor times. Whatever the case may be the team should take advantage of the best information available, and tailor the cost system to match.

Step 7: Compile Data Source Table

Draw up a data source table, showing the links between the information and the source document for that information, and the database, fieldname, and characteristic values of the information item. This step is essentially a summary of the model to be used for implementation. These definitions serve to clarify how cost estimates will be built up, and the exact source of each piece of information. Any gaps in the system should also be pinpointed at this stage. The summary serves as the guide to building the structured data searches required during the cost estimation phase (for the DDSS).

Step 8: Decide on User Interface Requirements

Decide on the interaction method with potential users of the system, and the extent of the information that will be provided to the users. Format of portrayal should also be decided. Knowledge of who the users will be, and what information they need is critical; the multidisciplinary project team should interview potential users of the system, to promote buy-in to the project. For example, a pilot implementation may only provide information back in text format, while the next generation of the system would build a graphic user interface with more interactive functions available.

Step 9: Conduct Case Studies on Candidate Products

Analyze case studies using the latest data, and some of the candidate products. Use all the prospective data resources and source documents planned to be used in the pilot project. The results of the case studies should be reviewed with potential users of the system, and verified for possible inaccuracies. This step should give a "heads-up" for potential problems, usually found in handling the additional complexity of the situation. Special case handling is often necessary, but again implementation must make decisions on the cost-to-benefit ratio of additional information. For example, in the case of a facility using a very simple method of material handling between process activities, the additional complexity of allocating the material costs may not be worth the effort. In this case, the cost of two small forklift trucks and drivers, and some handcarts are so small relative to the production costs as to be neglected for the purposes of comparing product costs. Where it is clear that a material handling system is part of a manufacturing cell, that cost should be captured with the cost of the direct production equipment in that cell. These decisions rely to some extent on the project charter: team members must decide whether the increased accuracy of handling special cases justifies the additional complexity of programming, training, and increased data collection overhead that may be necessary.

Step 10: Customize the DDSS to work with the existing data

Customize the DDSS framework to work with the available data. Specific actions here: set file paths and file names for each of the database files to be accessed. Compile a list of alias names for fieldnames and parameters used in the software. Where database formats are incompatible, translation routines must be set up. For example, if Oracle databases are being used in the accounting system, one would set up the ODBC (Open Database Connectivity) utility for the DDSS to manipulate records in those files directly. For files that will be periodically updated from external systems, a procedure should be devised to take the replicated databases from the source information system, and systematically update the databases that are being used by the cost system.

Step 11: Trial Run of DDSS/Troubleshooting phase.

Run some trials with the software, using a limited set of data, including some trials equivalent to the manually drawn up case studies. By analyzing the results it is possible to validate the results of the costing system deterministically. It may be necessary to train a limited number of potential users from outside the project team, to ensure that team members are not overlooking problem situations because of their familiarity with the system.

Step 12: Evaluation/Review of Results

Evaluate the worked results with team. Review the calculation methods used, decisions on activity boundaries, methods for activity rate calculations, and assumptions made in setting up the system. Again this review should include some outsiders (to the team), to ensure a fair and objective evaluation of the results. Where necessary, modify the system. Again, decisions should take account of the original objectives of the system, and specifically the level of accuracy that is sufficient for the decisions that will be made using the cost information. For a design decision support system, the need is for objective comparison between different manufacturing methods; absolute accuracy is not required.

Step 13: Ongoing Project Management and Review

Training of new users of the system is an essential part of the implementation process. Before the system can be used effectively, the team must undertake to train users, or set up training programs for the enterprise to continue. This stage is also important to encourage users to take "ownership" of the system. The pilot implementation of the system usually takes place with the project team still assigned to the project, but measures should be taken to capture the knowledge of the team for future reference, and for later modifications to the system. The review process should be ongoing. Any system is likely to have some unforeseen problems. Only by addressing the problems in the pilot system head-on, is any full-scale system likely to be successful, or even to be given the go ahead by top management.

4.6.3 Procedure for Establishing Activity Rates

The process of establishing activity rates for a given process follows from some of the procedural implementation steps described above. In Step 4, the team identifies the key processes or production activities. In Step 5, the boundaries of each process are determined, and all components and inputs of that activity are identified. The output or product of any process should also be established, and how the input costs will be assigned to the product. This process involves some negotiation and discussion to decide on the trade-off between absolute accuracy and what is sufficient for the purposes of the given system. In the Design Decision Support System implementation, the emphasis is on establishing consistent assignment of costs to products, using information stored in the production information system, accounting information system and engineering information system. The DDSS system is different from a full activity-based costing system in using actual (existing) data records for most activities, rather than choosing a mixture of existing data together with some surrogate cost drivers from new data (that will be an additional requirement for the system to collect). The advantage for the DDSS approach is in minimizing the disruption to existing information flows and data collection methods. The disadvantage is that the DDSS is focussed only on activities that can be clearly linked to products. The broader reach of the full scale activity-based costing method is intended to cover the allocation of some of the higher level overhead costs to ensure that products are priced correctly to recover the overhead of the enterprise as a whole.

In the DDSS system, almost all of the process activities are traced directly. For equipment, the machine cost rate is calculated using an intermediate machine cost summary worksheet. This worksheet captures the cost of ownership, all the maintenance costs, and the operating cost for each equipment asset. It also captures the number of machine hours worked by the machine in the period under review, as the basis of the Machine Cost Rate. The equipment activity cost is then calculated using the direct process activity rate multiplied by the machine cost rate. It is possible that some indirectly used equipment could be included with certain equipment types. For example, if an overhead gantry crane services two large production machines, the cost of the crane could be collected and shared equally between those two production machines. This again is part of the decision process for the team in establishing the boundaries of a particular production process or activity.

For engineering activities, the hours attributable to specific products are captured in much the same manner as for a process detail record, that is capturing the skill level of the engineer, and the time spent on that project. The same argument may be applied to other functional divisions of the firm. For example, if marketing costs for the different products could be identified, these could also be assigned directly to the product, by creating a marketing process record, associating time (and thus costs) to the production order for that product.

Cost Tracing versus Cost Allocation

Turney (1991) distinguishes between cost tracing and cost allocation, and recommends using cost tracing whenever possible. He provides the following definitions and examples:

> *Tracing* is the assignment of costs based on specific data. For example, supplies consumed in machine maintenance can be traced directly to this activity (assuming that records are kept). This creates an unambiguous assignment of cost.
>
> *Allocation* is the indirect assignment of cost. For example, the cost of administering can be allocated to the benefiting activities. A common method is to use the relative effort devoted by non-administrative employees to the primary activities.
>
> (Turney, 1991)

Turney suggests only using allocation when resources are shared by many activities, where measurement is impractical or costly, and when tracing would cost too much relative to the value of that information. Another important decision should be whether to include costs that are unaffected by process decisions. For example, if facility costs are charged per square foot of area taken up, one would have to question whether the cost would go away if the machine were not occupying the space. Similarly, for allocation of administrative overhead costs to a production facility, one should question whether any decision made in that production facility would make any of the administrative overhead cost disappear. In the author's view, it may be more appropriate to allocate some administrative overhead to staff costs (for work carried out administering payroll systems), marketing staff overhead as part of the selling cost for each product, and other administrative costs should be addressed separately by management. The objective of the Design Decision Support System is to compare manufacturing costs of different products, and without considerable modification, it would be difficult to include measures to allocate indirect administrative overhead to specific products.

Deciding whether to allocate the cost of other business-sustaining activities to product costs is a strategic decision, to be decided when setting the mandate for the cost system. Management salaries, accounting information systems staff, and general administration are clearly necessary activities to sustain the business, but cannot be clearly linked to production processes. This is a separate issue from manufacturing cost, and needs to be addressed at a higher level. Cost recovery of this nature may be better suited to conventional standard costing. A cost recovery charge may need to be added as a levy/tax on each product sold, either per item, or by some percentage of value of each item. Keeping this cost outside of the manufacturing cost may improve the visibility of the administrative overload, rather than hiding it inside product cost. In the author's view this addresses the issue of "how lean is your structure?" If you can't identify how a specific activity relates to producing or selling products, that activity may be a candidate for elimination.

Chapter 5: CONCLUSIONS

5.1 Overview of the Research

This research developed a methodology to generate product cost estimates using the existing information sources in an advanced composites manufacturing environment. The overriding reason or purpose for this research was to provide decision making information to product designers (or managers) that will enable them to make informed design choices, gaining the most value from their production resources for the least cost.

The initial research identified a need for better methods to evaluate the cost of newly developed manufacturing methods, to make better-informed decisions on designs using these processes and materials. Further research identified the main related areas of research relevant to this topic. Concurrent engineering techniques and computer integrated manufacturing developments provide the thrust for the research effort. The concepts of Design for Manufacturability, target costing, and the strategic use of cost information to compete in the global market all contribute to the usefulness of improved cost-benefit information. The contribution of cost management systems to this research was explored, identifying similarities and differences between the objectives of this study, versus implementations of activity-based costing in industry. Other manufacturing cost models were reviewed, highlighting some important features of the cost models. The design decision needs of aircraft designers were evaluated, especially with regard to providing information to conduct trade studies, and overcoming some of the barriers that have been identified in introducing composite structures in aircraft designs.

This DDSS methodology fills a gap between the parametric cost estimation models available for aircraft design, and the large scale, and highly complex manufacturing cost models that require considerable investment of time and resources to install and maintain.

The development of the methodology for this study was carried out in three phases. The first phase developed a model of the composites production environment in which the Design Decision Support System functions. This is the top level model of the DDSS described in Section 3.4, depicted graphically in Figure 3-1. The second phase modeled the interaction between the designer and the decision support system to execute the cost estimation process. This model was described as the Data Search and Analysis Model of Section 3.5, depicted graphically in Figure 3-2. The third stage developed the functional procedures necessary to carry out the desired product cost estimation using activity-costing principles. These functional procedures were described in Section 3.6, and the software implementation in Section 3.7.

5.1.1 The Production Environment: Top Level Model of the DDSS

The top level model (depicted in Figure 3-1) defines the production environment of the study, describing the key components of the Design Decision Support System, and how they interact with the other systems. Section 3.4 described the manufacturing system, and each of the supporting information systems in the target composites manufacturing environment.

The underlying manufacturing system was defined in terms of the facilities, labor resources, equipment resources, and materials used in the production process. In addition to the basic production resources, the maintenance-support sub-system is considered, as an important part of the cost of ownership of production equipment in the facility. The key objective of the DDSS is to capture all of the costs of the manufacturing resources and to correctly allocate these costs to the production processes consuming these resources.

The information systems are described in order of the logical flow of information through the production process. The Design Information System is the starting point for each cost estimate, being the point at which designers interact with the rest of the system. This Design Information System is modeled on the Design Methodology for

Composite Aircraft Components presented in Section 2.6.7 (Figure 2-1). This DDSS is intended to provide decision support for designers at the conceptual design stage, by providing cost information for designers to evaluate the effect of alternative design choices. The Process Plans and Bills of Materials produced in the detailed design stage are conventional inputs to the Production Planning System.

The Production Planning System captures information about production orders, materials, human resources and equipment resources as required to control the production process. The Accounting Information System records the transactions taking place in the factory for financial reporting purposes. The model of the Production Planning System developed for this study uses descriptions of conventional production planning systems, and accounting information systems for production processes, with specific reference to the Integrated Production Information System developed by Gelinas and Oram (1996). Although the Production Planning System and the Accounting Information System are separate entities, there are several exchanges of information exchanges between the two systems, and the description of the Accounting Information System should be read in conjunction with the description of the Production Planning System. Understanding the interactions between the systems is critical for this research, as is a clear view of the information resources maintained by each information system. While developed specifically for this DDSS model, the information flows described here are common to most production and accounting information systems. The sample formats of the documents relating to these accounting and manufacturing information flows were also taken from sources in production planning and accounting information texts.

An important feature of the Design Decision Support System methodology is that it does not disturb the existing information flows in the company's production system; it acts independently of the design, planning and accounting information systems. The DDSS limits its intrusion into the information system network by only connecting to the replicated database form of these records; it will have no direct interaction with physical data flows. This approach seeks to avoid the problems and expense of reconfiguring the existing systems to specifically serve the DDSS.

5.1.2 Data Search and Analysis Model: The Cost Estimation Loop

The second level of the DDSS model describes the iterative procedure followed by designers in developing cost estimates for the designs they wish to analyze. This is depicted graphically in Figure 3-2. The cost estimation procedure was described in Section 3.5. The cost estimation procedure involves first looking for prior history of making the same or similar products in this enterprise. A product description is entered, and the DDSS searches the Production Planning System databases and returns the closest match to the product that has been made previously by the firm. This product order is defined by the order number of that production job. Based upon that order number, the DDSS then searches the Production Planning System for the detailed information on that product order. It returns the records of all the processes involved in making the product, identifying all the materials used for each process, and the human resources and the equipment resources used to carry out the processes.

The DDSS then uses these process details to create a fully worked Process Plan, including the costs of labor, materials and equipment usage. Details are extracted from predetermined fields in the Process Plan; these pieces of information then drive a further search for cost information, using structured searches through the Accounting Information System databases. The costs are then calculated by the DDSS, and inserted back into the newly created Process Plan spreadsheet.

Object-Oriented Product Cost Structure

An important feature of the DDSS, and one that was used extensively in creating the framework necessary to implement the methodology, is the use of an *object-oriented product cost* structure, and *object-oriented cost data* structure. The basic principle of the *product cost object* is that a product object may inherit certain properties or field types from that class of object. For example, a product object may consist of multiple sub-objects, each having properties of dimensions, functions, material components, and associated manufacturing processes. The object model fits well with activity costing principles, in that it is possible to collect all of the costs for a given product object by collecting all of the costs for each of the sub-objects that went into the parent object.

The *object-oriented cost data* structure is another important building block for implementation of the DDSS methodology. Costs are collected for each process, by capturing all the inputs used in that process. The total cost of the process can then be calculated, using the inherited cost information from each of the sub-objects. Cost per product is calculated by summing all of the costs attached to the process cost objects that went into making the product.

The notion of object inheritance is also useful in explaining how different components of the Design Decision Support System are related to one another. The software implementation of the system uses relational databases and spreadsheets to capture and manipulate information. Each database and spreadsheet is considered as an object, and each record within the database as a sub-object. Each record inherits field properties from the parent object. The structured data search method uses the values contained in these fields to drive the search through the various databases. Another convenient object that the search process uses is that of a query recordset. A recordset is a group of records found by querying a given database. Each record in the recordset is an instance of the class, each field in the recordset is a sub-object or property of that class of object. The cost data object structure was explained in Section 3.5.3, and the object types used for the database searches were described more completely in Section 3.7, on the software implementation of the DDSS.

5.1.4 Activity-Costing Model in the DDSS

The third level of the DDSS model describes in detail the methods of calculating costs for labor, materials and equipment resources used in composite part manufacturing processes. The cost calculations are driven by the information extracted from defined fields in the Process Plan. Section 3.6 detailed the development of activity-cost models for labor costs, material costs, and the cost of equipment used in production. These models reflect the detailed methodology developed for the Design Decision Support system.

For each process activity, a structured search routine is created using the values of certain process parameters to construct pattern-matching queries into the various databases. These data searches are executed using a form of Structured Query Language (SQL), that allows the data to be manipulated directly by the DDSS program, to collect and structure the information back into the Process Plan. The complexity of the DDSS methodology required that models be developed specifically for each of the cost categories.

Material cost calculations require concurrent interaction between the job order database, process details database, bill of materials database, and the inventory database. Labor cost calculations involve concurrent interaction with the job orders database, process details database, and employee cost rate database. Machine cost calculations require that for each equipment asset used in the manufacturing process, an intermediate machine cost summary worksheet be formulated, to account for the total cost of ownership of the equipment. The machine cost rates take account of all the costs to own and operate each machine, as well as information from the process details database on machine utilization. The machine cost rate is an intermediate output of the DDSS, made available in spreadsheet format. The machine cost calculation carried out during a product cost estimation process uses cost rate information from the machine cost summary worksheet, as well as process times from the job order and process detail database. The detailed description of each of these cost calculation methods was described in Section 3.6, and the software implementation of each routine in Section 3.7.

The cost estimate is built up, activity-row by activity-row, iterating through the procedure of finding process parameters, searching for cost information, using that information in the activity-cost modules, and inserting that information back into the spreadsheet. The cost estimate is returned to the designer in the form of a Process Plan spreadsheet, as depicted in Table 3.2.

The research contribution of this study is evaluated in the following sections, with reference to the objectives originally proposed for the research. Some limitations of the models are described, and ideas for application of the research for other uses are explored. Finally, related topics for future research are identified.

5.2 Research Contribution

The DDSS methodology is evaluated here in terms of whether it achieves its stated purpose and the overall research goal, as well as the individual objectives, sub-objectives,.and qualitative measures of performance set out in the Methodology (Chapter 3). The research question, purpose and objectives are restated here for convenience, together with an assessment of the DDSS to satisfy each requirement.

5.2.1 Research Question

The research question this study sought to answer was:
How can product cost estimates be modeled using the existing information sources in an advanced composites manufacturing environment?

The DDSS methodology uses accepted techniques of activity-based costing to construct cost estimates on-the-fly. Each time the user prompts the system for an estimate, a new estimate is constructed, using the best and most up-to-date information available. The DDSS was modeled on common accounting information systems and production information systems suggested in accounting literature. The DDSS is capable of being tailored to use an enterprise's own databases, retrieving the necessary pieces of information to construct the estimate, but not changing any of the source data.

5.2.2 Research Purpose

The research purpose of this study was:

To provide decision making information to product designers (or managers) that will enable them to make informed design choices, gaining the most value from their production resources for the least cost.

The DDSS was designed to present product cost information back to designers, at an early stage in the design process, in a manner that allows them to immediately see the cost effect of different manufacturing processes. Users are also able to modify design and manufacturing details to seek improvement in the functional value of their designs, while reducing the production cost.

5.2.3 Research Objectives

The desired result of this study was defined in the Research Objective (Section 1.8) as:

A methodology for a decision support system that actively seeks out costs related to a product or function, by intelligently searching the existing accounting, production and engineering data sources.

The methodology uses activity-based costing techniques to construct each cost estimate. It uses the information from the product process plan as a guide to search through the databases from the accounting, production and engineering information systems. The cost estimate can then be viewed showing breakdowns by component, activity, or cost category (labor, materials and machine).

Sub-objectives were also defined:

Sub-objective 1: To assess the needs of aircraft designers, by analyzing typical trade studies used during the conceptual design phase for aerospace components, and to satisfy the information needs to Design for Manufacturability (Boothroyd and Dewhurst, 1987).

The DDSS returns sufficient cost data to analyze the cost of each item in the product, and provide cost breakdowns in terms of traditional cost categories, by activity or process, or by aggregated cost for assemblies or sub-assemblies. By allowing designers to input alternative processes or process parameters, the effect on cost can quickly be determined by designers. This enables them to collect the information they need to carry out trade studies on components.

Sub-objective 2: To model the interaction of activities and processes in the given manufacturing setting, and the associated information flows, and to measure the costs consumed by these activities and resources.

The methodology has been structured using accepted activity-based costing techniques, and can easily be configured for an individual company's production and information systems. The DDSS program allows users to define each of the databases that will be searched for each item of cost information. The methodology uses historical data on a read-only basis, thereby avoiding the requirement for direct interaction with accounting information systems and production information systems. Periodic updates to the replicated databases allow the DDSS to use the latest available information for cost estimation.

Sub-objective 3: To develop a methodology to structure the search process, and to collect and manipulate data into a manageable form for portrayal to decision makers.

The DDSS methodology uses a simple spreadsheet format of the process plan to drive all of the information searching routines. The output of the information search is output to a user-configured spreadsheet table. The users can easily specify *which* information, the *type* of information, *categories* for aggregation, and *formats* of information portrayal to decision makers.

Sub-objective 4: To create a system which "learns" by capturing information from each iteration of the process, and uses the information gained to speed up or enhance future cost estimates.

Each cost estimate is saved in the form of a spreadsheet analysis. To update the cost estimate, the user calls up the old cost estimate, and reruns the estimation process. By incorporating the latest accounting and production data, the accuracy of the estimate is improved. As the database of DDSS product cost estimates is increased with each new estimate, the body of knowledge about these new processes is expanded for future enquiries.

Sub-objective 5: To provide a development framework to design the decision support system.

The theoretical basis for the DDSS is based on accepted activity-based costing principles. The choice of activities is decided by the users, and is not limited to only composites manufacturing processes. The methodology will allow users to look at any process or activity in the enterprise, and to capture cost information about those activities. The DDSS search methodology uses the Visual Basic programming platform, in conjunction with Microsoft Office software, which will allow a variety of business users to enhance the system for their own use. This provides a ready platform for future developments and enhancements to the decision support system. In section 5.4 the scope of this system for other applications will be considered, together with the suggestions for further research work in this domain.

5.2.4 Qualitative Measures of Success

Other performance measures considered important were that the Design Decision Support System should satisfy the following expectations:

- **Explainable**: the methodology should be easily explained to and understood by potential users of the system.
- **Flexibility**: the framework should allow for a flexible approach to configure it for different manufacturing and operating systems, and to allow for subsequent modifications to the system.
- **Cost**: the potential benefit of the system should significantly outweigh the cost to implement it.
- **Portability**: it should be possible to adapt the methodology for use on different software platforms.

The approach to designing the DDSS was to use commonly used business software as the framework, which would make the system more accessible to users across different functional disciplines. The methodology relies heavily on activity-based costing techniques, which have been studied in depth, and covered extensively in product costing and management accounting literature. The cost estimating method is therefore easily ***explainable*** to users in engineering, production, and accounting fields. This compares favorably to the methods using exponential equations and scaling factors as used in COSTADE (Mabson et al., 1994). These cost scaling functions were modeled using the paradigm of Hooke's Law spring equations and thermodynamic entropy, which *may* make sense to engineers, but might be difficult to fathom for production staff and accountants.

The ***cost*** to implement the system in any given production environment is small in comparison to other activity-based cost systems, or parametric costing systems. The system has the advantage that it does not require any re-design of the existing accounting information system or production information system. This helps to reduce the barriers of organizational resistance against implementing any new decision support system. The simplicity of explanation and use may also enable organizations take over the system without continued support from (expensive) systems design consultants.

The ***portability*** of the system is assured by virtue of the combination of a widely used office software package together with the Visual Basic programming language, which allows for easy encapsulation into object-oriented code modules. The databases used for the prototype were constructed using Microsoft Access, but the program would be compatible with a number of major database formats. (e.g. Paradox, FoxPro, Dbase, Lotus). The search routines use SQL (Structured Query Language) syntax, which is an industry standard for Database Management Software. This would allow compatibility with some of the mainframe DBMS and databases (e.g. Oracle). The use of Microsoft Excel spreadsheets as the main input and output interface, provide an easy to understand (and explain) paradigm for engineers, accountants and other managers.

The ***flexibility*** of the DDSS has already been described, allowing users to define the databases to be searched, the form of data inputs and outputs to decision makers, and the use of widely used business software for ease of access. Cost calculation methods may be changed in the spreadsheet output, making that a user-definable option. Users may extend this methodology to measure outputs of any business activity, as long as they can capture the source of each piece of measured information in a database form.

5.2.5 Integrated Product and Process Design Research Agenda

The contribution of this work to the body of research in this field should also be considered with respect to the research agenda for information technology in manufacturing determined by the Committee to Study Information Technology and Manufacturing (CSTB, 1995). As described in Section 2.1.3, they determined the following key research questions and objectives in the area of integrated product and process design:

1. "How should information associated with products be captured and represented?
2. How can manufacturing processes be represented?
3. How should tools be constructed that support product design?"

The objectives of this study are relevant especially to the third research question. As stated by the CSTB report,

> "An integral aspect of product design is how to make trade-offs (e.g. among cost, performance, reliability, between space allocations, between making or buying a component, between long term operating costs and initial costs, and so on). Designers would benefit greatly from tools that would help them evaluate these trade-offs in a rigorous and systematic manner. Presentation and display tools for visualizing various design alternatives would also help the designer." (CSTB, 1995)

To limit the scope of the problem to a solvable piece of the puzzle, assumptions were made to simplify the first two questions for this study. It was assumed that process plans could be described in a simple spreadsheet format, for the purposes of activity-based cost estimating. It is to the third question that the DDSS makes a contribution to the current body of knowledge. It provides a novel methodology for a design decision support tool, intended to support product design. Especially in the area of advanced composites manufacturing, there is a comparatively small knowledge base. To take advantage of a company's developing expertise, the DDSS searches recent jobs and picks out details of costs applicable to different processing activities. In this manner, designers are able to integrate the latest expertise into their design decision making. As noted previously (in Section 2.2), one of the main objectives of concurrent engineering has been to integrate interdisciplinary knowledge and make it available early in the design process.

5.3 Innovations of the Design Decision Support System

5.3.1 Searching the Existing Information Sources

As stated, the principal objective of the research was the development of a methodology for a decision support system that actively seeks out costs related to a product or function, by intelligently searching the existing accounting, production and engineering data sources. This tool could be of considerable value to industry, in that it may provide a means to access the information that companies already have, but have found difficult to use in meaningful ways to help the design process. The system aims to use the existing information systems as data sources, rather than advocating replacement information systems which would entail considerably more expense and overhead to implement. One of the major barriers to implementing large scope activity-based costing systems has been the high threshold cost to implement these systems, and the heavy investment of skills and resources required to maintain them. This methodology has been designed to account for differences in the structures of each company's manufacturing and information systems, and allow for individual customization of the information inputs and outputs.

5.3.2 Innovative Search Strategies

In order for this system to be implemented, search strategies were formulated to enable the collection of the data from the various information sources. In broad terms, these use templates of known cost structures to set up search patterns for the product cost. The search pattern is then used to find all of the relevant information, and then compiles the pieces of information intelligently to estimate the cost. These techniques are used within the analysis tool, and although software specific, should be of value for implementation in other similar applications.

5.3.3 Improve Value of the Product to Customers

The importance of this research is in providing a new methodology that can be implemented as a supplemental resource, enabling companies to seek out otherwise hard-to-find knowledge about production activities. This can then be used to expand the designers' understanding of the causal relationships between design parameters and manufacturing costs. This expansion of knowledge can then be applied to improving the value of the product to the consumer, by increasing the ratio of performance versus manufacturing cost. This improvement of value can be aligned achieving corporate strategic goals, as described by Shank and Govindjaran (1993).

5.4 Implementation Case Study

To demonstrate the feasibility of the DDSS methodology, a typical composite product cost was estimated using the prototype software implementation of the methodology. The product cost for a composite baggage door was calculated by manually finding information inputs from a variety of sources, and then computing a cost breakdown structure using a spreadsheet. The calculation used the same work breakdown structure as the DDSS. The software was shown to replicate the manually drawn cost estimate for the same part, with the estimate driven by the process plan, as formulated in spreadsheet format. The DDSS used the parameters in the process plan to drive the search for information from a variety of data sources, and the tool then applies the activity costing methodology to automatically generate a spreadsheet to estimate the cost of the product. The results were identical, and the operation of the software could be seen as the various costs were added to the process plan spreadsheet.

The use of the methodology to modify design and manufacturing details was then tested by varying sizes, materials, equipment and labor methods and checking the resulting change in the cost estimate. Sample outputs of the modified design cost estimates were presented in a form deemed to be useful to designers of composite aircraft components.

This prototype software implements the DDSS methodology presented. Each of the subroutines to seek out specific pieces of information in different database sources was explicitly defined, and was shown to work exactly in the manner described. One major limitation of the program is the lack of a robust interface for interaction with designers, other than by spreadsheet and database entry tables. The expertise to develop the software further is readily available from computer programmers; the contribution of this research is not on the software tool, but rather on the theoretical development and application of the methodology to this area of manufacturing information systems design.

5.5 Scope for Wider Application

5.5.1 Business Processes other than Manufacturing

The methodology implemented in the DDSS may be used for other manufacturing processes, or any other business processes. The search process is driven by each activity record in the Process/Activity Plan Spreadsheet. Conceptually, there is no difference in the procedure to find cost information about any activity identified in the value chain. It may be necessary to add a case-handling routine in the search process that allows the routine to look in different databases, dependent on the category of activity. For example, activities related to marketing and distribution may fall outside of the job order tracking database. In this instance, billing records and dispatch records would need to be searched for the times assigned to these tasks. In this fashion, the method could be applied to life cycle costing, maintenance activity costing, and supply chain logistics, tracking the costs of inputs to various products, and following through to operating and ultimately disposal of the products.

5.5.2 Performance Measurement Decision Support

The method could also be utilized for performance measurement outside of purely cost information. It would be relatively straightforward to adapt the information search function to work as the data collection component of a business decision support system. Instead of looking for cost fields in production databases, one could seek out measures of productive output, or to analyze the non-value adding activities carried out in an enterprise. In the literature review, the various tools of concurrent engineering included the use of activity measurements for performance measurement, and a number of references suggest a mixture of financial, operations, and customer-focussed measurements that contribute to world-class competitiveness. If one takes the view that managers are quick to improve the underlying activities that they are being measured by, one can readily assume that the maximum benefits are achieved early. By the familiar Pareto principle, some performance measures will quickly outlive their usefulness, as most of the benefits will be achieved by addressing just the priority items. Application of the DDSS methodology to performance measurement would allow managers to extract measures of performance from a variety of information sources, without making a substantial investment in changing the information collection system. This makes the threshold cost-benefit ratio for performance measurements easier to overcome. The lower cost and lower visibility of the measurement process may also allow decision-makers to drop a measurement from their arsenal, as soon as it is no longer useful. This is sometimes hard for change agents to do, especially if considerable time and effort was invested to convince users that they needed to measure it in the first place.

5.6 Further Research Opportunities

5.6.1 Enhanced Graphic User Interface

The prototype DDSS has a simple user interface created to demonstrate feasibility of the method. It could be made more useful to designers if the various input parameters could be varied using some form of graphic user interface. Cost outputs of the parameters could then be graphically displayed in the form of a comparison of alternative design scenarios, custom-made to suit the paradigm of the aircraft designers. For example, the comparative costs of various designs could be charted versus the weight of each of those designs.

5.6.2 Validate in Industry Setting

The current system was validated using an example process plan from a mainly manually fabricated part. Although the cost estimating process would not be substantially different for fully automated processing, or a combination of manual and automated processing, it would be a test of the robustness of the software to handle more complex situations. It may be of considerable commercial value to validate the system working with production data from a composites manufacturer. Most companies are reluctant to provide such data to outsiders, but may be more open to consider co-operative work conducted on-site.

5.6.3 Link to Quality Function Deployment/Value Analysis

The prototype DDSS provided limited outputs of cost information to users. Simple charting methods were used to depict the data to users for further analysis. It would be relatively simple to integrate these outputs directly with a QFD analysis/value analysis tool. For example, in QFD analysis, the customer is often asked to rank the importance of various product functions, and these are mapped to the relative costs of performing those functions. This tool could be used to look at multiple configurations of the product, and return the cost of each of the activities performed to manufacture it. This would show the value analysis team if any activity has an inordinately high cost relative to the customer's value of that functionality. By reworking the process/activity plan, the team can work on finding less costly ways to satisfy the customer wants.

5.6.4 Robust Connections to Networked Databases

In this study, no attempt was made to allow on-line interaction with networked databases. It may be desirable in future to provide this capability. An extension of the material cost system may be possible by linking to vendors' material supply catalogues, enabling designers to access materials that are not currently used by their firm. With more companies doing business in multiple geographic locations, across the globe, there are considerable efforts to provide tools for integrating design, planning and management activities in businesses. The Visual Basic and Microsoft Office platform for the DDSS allow for considerable interaction with internet or intranet linked databases. It is possible to configure the existing program to use network linked databases, by changing the path string, but it was beyond the scope of this study to program a robust interface with network capabilities. The need for access to remote databases may not yet have arrived, but the growth of so-called virtual companies may make this type of interaction a necessary component in the future.

REFERENCES

Aalbrechtse, R. J. (1993). Target Costing, in *Handbook of Cost Management, 1994 Edition* (ed. B. J. Brinker). Boston, MA: Warren Gorham Lamont.

American National Standards Institute (1970). Flowchart Symbols and Their Usage in Information Processing, Publ. no. ANSI X3.5 New York: American National Standards Institute.

Answari, S. L., Bell, J., & CAM-I Target Cost Core Group (1997). *Target Costing: The Next Frontier in Strategic Cost Management*. Burr Ridge, IL: Irwin Professional Publishing.

Ashton, L. J., Huntsman, S. D., Allman, M. G., Strong, A. B. & Rotz, C. A. (1991). Filament winding of composite isogrid fuselage structures. in *Composites in Manufacturing*. (ed. Strong, A. B.). Dearborn, Michigan: SME.

Baker, A. A. (1986). Component Form and Manufacture, in *Composite Materials for Aircraft Structures* (eds. Hoskin, B. C. & Baker, A. A.). New York: AIAA.

Berliner, C. and Brimson, J. A. (eds.)(1988). *Cost Management for Today's Advanced Manufacturing: The CAM-I Conceptual Design*. Boston, MA: Harvard Business School Press.

Blanchard, B. S. & Fabrycky, W. J. (1990). *Systems Engineering and Analysis*. Englewood Cliffs, N.J.: Prentice Hall.

Boothroyd, G. & Dewhurst, P. (1987). *Product Design for Assembly Handbook*. Wakefield, RI: Boothroyd Dewhurst, Inc..

Boothroyd, G. & Dewhurst, P. (1991). Product design for manufacture and assembly, in *Design for Manufacture*. (eds. Corbett, J., Dooner, M., Meleka, J., and Pym, C.). Wokingham, England: Addison-Wesley Publishing Co.

Bras, B. & Emblemsvag, J. (1995). The use of activity-based costing, uncertainty, and dissassembly action charts in demanufacture cost assessments. *DE-Vol.82, 1995 Design Engineering Technical Conf.*, Vol.1, ASME 1995.

Brimson, J. A. (1991). *Activity Accounting*. New York: John Wiley & Sons, Inc..

Brinker B. J. (ed.) (1993). *Handbook of Cost Management, 1994 Edition.* Boston, MA: Warren Gorham Lamont.

Computer and Automated Systems Association of the Society of Manufacturing Engineers (CASA/SME) (1993). CASA/SME Manufacturing Enterprise Wheel (3rd ed.). Dearborn, MI: Society of Manufacturing Engineers.

Cooper, R. (1990). Implementing an Activity-Based Cost System. *J. of Cost Management* (Spring): 33-42.

Cooper, R. & Kaplan, R. S. (1991). *The Design of Cost Management Systems: Text, cases, and readings.* Englewood Cliffs, N.J.: Prentice Hall.

Computer Science and Telecommunications Board (CSTB), Manufacturing Studies Board, National Research Council (1995). *Information technology for manufacturing: a research agenda*. Washington, D.C: National Academy Press.

Davis Jr., J., Shuart, M., & Bowles, D. (Eds.) (1995) *Proc. 5th NASA/DoD Advanced Composites Technology Conference*, Aug 1994, Seattle, WA. NASA Conference Publication 3294, May 1995, volume 1, part 1.

Dieter, G. E. (1983). *Engineering Design: a Materials and Processing Approach*. Tokyo: McGraw-Hill.

Edwards, K. L. (1994). Towards more effective decision support in materials and design engineering. *Materials and Design*: 15(5): 251-258.

Fallon, W. P., & Garbo, S. P. (1995). Material usage and selection on the RAH-66 Comanche. In Proc. 40th International SAMPE Symposium, May 8-11, 1995. Covina, CA: SAMPE. pp.760-773.

Funke, C. (1997). Concurrent engineering in the aircraft industry and its relationship to the development process. In *Proc. 1st SAE Aerospace Manufacturing Technology Conference, June 1997*. Warrendale, Pennsylvania: SAE. pp.231 – 241.

Gelinas, U. J. & Oram, A. E. (1996). Integrated Production Systems. in *Accounting Information Systems* (3rd ed.). Cincinnatti, Ohio: South-Western College Publishing.

Gutowski, T., Henderson, R., & Shipp, C. (1991). Manufacturing Costs for Advanced Composites Aerospace Parts. *SAMPE Journal*: 27 (3): 37-43.

Gutowski, T., Hoult, D., Dillon, G., Neoh, E., Muter, S., & Tse, M. (1994). Development of a theoretical cost model for advanced composite fabrication. *Composites Manufacturing* 5 (4): 231-239.

Harmon, B. & Arnold, S. A. (1991). Cost Implications of Composite Materials in Military Airframes. In *Advanced Composite Materials: New Developments and Applications Conf. Proc., Detroit, Mi.*, Sep.30-Oct.3, 1991.

Hayes, R. H., & Abernathy, W. J. (1980). Managing Our Way to Economic Decline. *Harvard Business Review* (July-August): 67-77.

Herrera, A. (1997). The effectiveness of Design for Manufacturing and Assembly as applied to the design of the AH64D helicopter. In *Proc. 1st SAE Aerospace Manufacturing Technology Conference, June 1997*. Warrendale, Pennsylvania: SAE. pp.217 – 230.

Hess, R. W., & Romanoff, H. P. (1987). Aircraft Airframe Cost Estimating Relationships. Rept. R-3255-AF, Santa Monica, Ca: Rand Corp.

Horngren, C. T., & Foster, G. (1991). *Cost accounting: a managerial emphasis*. (7th ed.). Englewood Cliffs, N.J.: Prentice Hall.

Hoskin, B. C. & Baker, A. A. (Eds.) (1986). *Composite materials for aircraft structures*. New York: AIAA.

Humphrey, R. J., Venters, K. R., Witnoskey, L. (1995). NASA Baseline Aluminum Aircraft Cost Model, In *Proc. 5th NASA/DoD Advanced Composites Technology Conference*, Aug 1994, Seattle, WA. NASA Conference Publication 3294, May 1995, vol 1, part 1, pp 182-203.

Iden, M. & Pham, D. (1995). Boeing empennage manufacturing. In Proc. 40th International SAMPE Symposium, May 8-11, 1995. Covina, CA: SAMPE. pp.421-432.

Jensen, S. C., Rettie, I. H., & Barber, E. A. (1979). Role of Figures of Merit in Design Optimization and Technology Assessment. AAIA Paper 79-0234R presented at 17th Aerospace Sciences Meeting, New Orleans, La, Jan.15-17, 1979.

Jo, H. H., Parsaei, H. R., & Sullivan, W. G. (1993). Principles of concurrent engineering. In *Concurrent Engineering: Contemporary issues and modern design tools*. London: Chapman and Hall.

Johnson, H. T. (1991). Activity-Based Management: Past, Present and Future. *Engineering Economy*, Vol 36, No.3, Spring 1991, pp. 219-238

Johnson, H. T. (1992). It's time to stop overselling activity-based concepts. *Management Accounting*, Sep. 1992: 26-35.

Johnson, H. T., & Kaplan, R. S. (1987). *Relevance Lost: The Rise and Fall of Management Accounting*. Boston: Harvard Business School Press.

Johnson, H. T., & Sapp, R. W. (1992). Memo to global competitors: it is time to replace cost accounting with process based information. In *Economics of Advanced Manufacturing Systems*, ed. H. R. Parsei & A. Mital, London: Chapman & Hall:, pp.179-188.

Johnson, V. S. (1990). Minimizing Life Cycle Cost for Subsonic Commercial Aircraft. *Journal of Aircraft*, vol. 27, pp. 139-145.

Karbhari, V. M. & Wilkins, D. J. (1991). Decision Support Systems for the Concurrent Engineering of Composites. in *Proc. of 7th Ann. Advanced Composites Conf.* Materials Park, Ohio: ASM International.

LeBlanc, D. J. (1976). Advanced Composites Cost Estimating Manual, vol. 1, AFFDL-TR-76-87, Northrop Corporation.

Lubin, G. (ed.) (1982). Handbook of composites. New York: Van Nostrand Rheinhold.

Mabson, G. E., Flynn, B. W., Ilcewicz, L. B., & Graesser, D. L. (1994). The use of COSTADE in developing Composite Commercial Aircraft Fuselage Structures. in *Proc. of 35th AIAA/ASME/ASCE/AHS/ASC Conf.* Hilton Head, SC, April 18-20, Part 3: 1384-1393.

Maisel, L. & Morrissey, E. (1993). Using Activity-Based Costing to Improve Performance. In *Handbook of Cost Management, 1994 Edition* (edit. B. J. Brinker). Boston: Warren Gorham Lamont.

McCusker, M. J., & Walleigh, R. (1993). Design for Manufacturability, in *Handbook of Cost Management, 1994 Edition* (edit. B. J. Brinker). Boston: Warren Gorham Lamont.

McNair, C. J. (1993). *World Class Accounting and Finance*. Homewood, Illinois: Business One Irwin.

Metaxas, D. & Sellis, T. (1991). A frame-based model for large manufacturing databases. *Journal of Intelligent Manufacturing*. 2: 53-60.

Middleton, D. H. (ed.) (1990). *Composite Materials in Aircraft Structures*. Harlow, Essex, UK: Longman Scientific & Technical, pp.362-367.

Mietrach, D. (1991). Advanced castings in aircraft structures: a way to reduce costs, in Design for Manufacture. (eds. Corbett, J., Dooner, M., Meleka, J., & Pym, C.). Wokingham, England: Addison-Wesley Publishing Co.

Murtuza, A. (1995). *The New Accounting Manual - A Guide to the Documentation Process*. New York: John Wiley & Sons, Inc..

NASA (1996 a). Parametric Cost Estimating Reference Manual: Airframe Cost Model: http://www.jsc.nasa.gov/bu2/airframe.html

NASA (1996 b). Parametric Cost Estimating Handbook http://www.jsc.nasa.gov/bu2/pcehg.html

Nash, J. F. (1989). The Production Cycle. in *Accounting Information Systems* (2nd ed.). Boston, Massachusetts: PWS-Kent Publishing Company.

Niu, M. C. (1992). *Composite Airframe Structures*. Hong Kong: Conmilit Press.

Ostwald, P. F. (1984). *Cost Estimating*. (2nd ed.). Englewood Cliffs, N.J.: Prentice Hall.

Player, R. S. & Keys, D. E. (1995a). Lessons from the ABM Battlefield: Getting Off to the Right Start. *J. of Cost Management*(Spring): 25-38.

Player, R. S. & Keys, D. E. (1995b). Lessons from the ABM Battlefield: developing the Pilot. *J. of Cost Management* (Summer):20-35.

Player, R. S. & Keys, D. E. (1996). Lessons from the ABM Battlefield: Moving from Pilot to Mainstream. *J. of Cost Management* (Fall): 31-41.

Plenert, G. J. (1993). *The Plant Operations Handbook: A Tactical Guide to Everyday Management*. Homewood, Illinois: Business One Irwin.

Porter, M. E. (1985). *Competitive Advantage*. New York: The Free Press.

Raffish, N., & Turney, P. B. B. (1991). “Glossary of Activity-Based Management.” J. of Cost Management. Vol 5, No.3.

Ramkumar, R. L., Vastava, R. B., & Saha, S. K. (1991). Manufacturing Cost Model for Composites. In *Proc. 23rd International SAMPE Technical Conf.* (Oct 21-24): 982-994.

Raymer, D. P. (1989). *Aircraft Design: A Conceptual Approach*. Washington DC: AIAA.

Resetar, S. A., Rogers, J. C., & Hess, R. W. (1991). Advanced Airframe Structural Materials: A Primer and Cost Estimating Methodology. Rept. R-4016-AF, Santa Monica, Ca: Rand Corp.

Rohani, M. & Dean, E. B. (1996). Toward Manufacturing and Cost Considerations in Multidisciplinary Aircraft Design. in *37th AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics and Materials Conference.* Salt Lake City, Utah, April 15-17, 1996.

Roskam, J. (1985). *Airplane Design: Part V: Component Weight Estimation*. Ottowa, Kansas: Roskam Aviation and Engineering Corp.

SAE (1997). Design of Durable, Repairable, and Maintainable Aircraft Composites. Warrendale, Pennsylvania: SAE.

Sahr, B., Moore, B., & Riedell, J. (1995). Advanced manufacturing technologies for composite aircraft structures based on prepreg materials. In 40th International SAMPE Symposium, May 8-11, 1995. Covina, CA: SAMPE. pp.381-395.

Schwartz, M. M. (1992). Composite Materials Handbook 2nd Edition. Ed. M. Shwarz. New York: McGraw-Hill.

Scoville, T. W. (1997). The role of castings in part consolidation. In Proc. 1st SAE Aerospace Manufacturing Technology Conference, June 1997. Warrendale, Pennsylvania: SAE. pp.111 – 120.

Shank, J. K. & Govindarajan, V. (1993). *Strategic Cost Management*. New York: The Free Press.

Sharman, P. A. (1995). Activity-Based Costing Implementation Applications. In *Handbook of Cost Management: 1996 Edition* (ed. B. J. Brinker). Boston, MA.: Warren Gorham Lamont.

Stewart, R. D., Wyskida, R. M., & Johannes, J. D. (1995). *Cost Estimator's Reference Manual, 2nd edition*. New York: John Wiley & Sons.

Turner, G. F. (1995). Advanced composite materials in European aircraft present and future. 40th International SAMPE Symposium, May 8-11, 1995. Covina, CA: SAMPE. pp.366-380.

Turney, P. (1991). *Common Cents: The ABC Performance Breakthrough*. Hillsboro, OR: Cost Technology.

Tyll, J. S., Eaglesham, M.A, Schetz, J. A., Deisenroth, M., Mook, D. T. (1996). An mdo design methodology for the concurrent aerodynamic/cost design of Maglev vehicles. *AAIA Conference Seattle*. (Aug). AIAA.

Ullman, D. G. & D'Ambrosio, B. (1995). A Taxonomy for Classifying Engineering Decision Problems and Support Systems. *DE Vol 83, 1995 Design Engineering Technical Conference*. Vol.2, ASME.

Velocci, A. L. Jr. (1996). Airlines to Manufacturers: Lower your prices, *Aviation Week & Space Technology*, November 25: pp.40.

Walden, D. C. (1990). Applications of Composites in Commercial Airplanes. In *Structural Composites: Design and Processing Technologies: Proc. of 6th Annual ASM/ESD Advanced Composites Conference, Detroit, Mi., 8-11 Oct., 1990*. Materials Park, Ohio: ASM International.

Wilkinson, J. (1993). *Accounting Information Systems: Essential Concepts & Applications*, (2nd ed.). New York: John Wiley & Sons.

Wong, J. P., Imam, I. N., Khosravi-Kamrani, A., Parsaei, H. R., & Tayyari, F. (1992). A Totally Integrated Manufacturing Cost Estimating System (TIMCES). in *Economics of Advanced Manufacturing Systems* (eds. Parsaei, H. R. & Mital, A.). London: Chapman-Hall: 201-224.

Appendix A: Documenting the Information Flows

Appendix A.1: Data Flow Diagrams

A format for Data Flow Diagrams (DFDs) which use common terminology from Gelinas and Oram (1996), Wilkinson (1993), Murtuza (1995), is shown in the Figure A.1. Summary descriptions of the purpose of the different data flow models and guidelines for using them follows (modified from Gelinas and Oram, 1996).

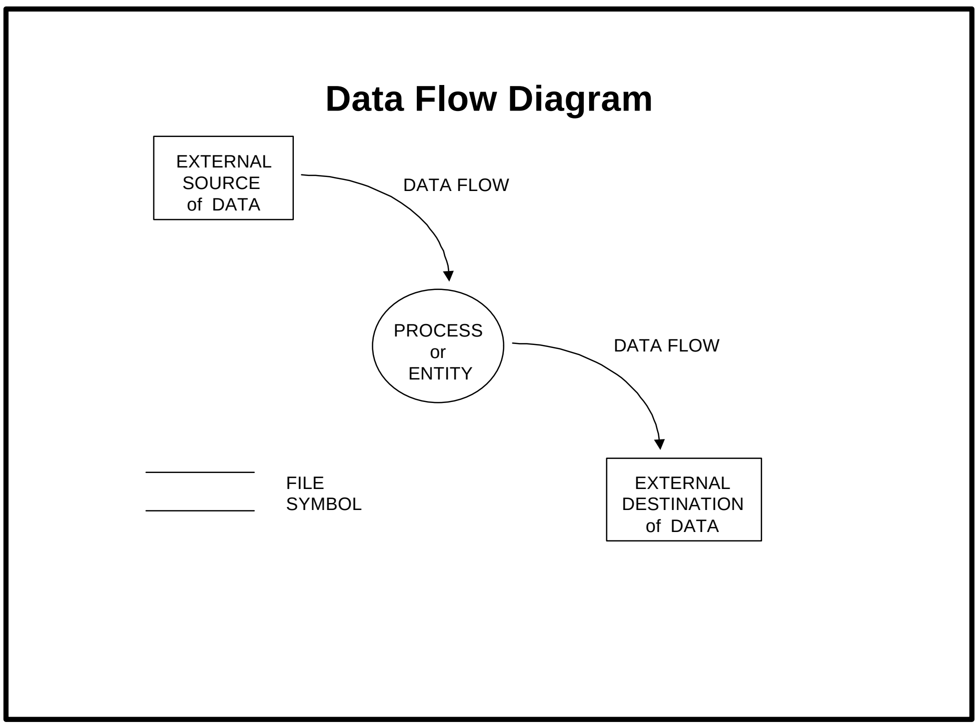


Figure A-1: Context Level Data Flow Diagram

Context level DFDs define the *top level* description of information flows into, and then out of the system. The data flow arc represents the interface between external components and the process entity or system being examined.

Physical DFDs graphically show the external and internal entities, and the flows of data into and out of these entities. This describes where, how and by whom the system's processes take place.

Logical DFDs (level 0) show the the systems' processes and the flow of data into and out of the processes. The tasks of the system are described functionally, without specifying how, where, and by whom the tasks will be done.

DFD Guidelines:

1. Include *within* the system context (bubble) any entity that performs one or more information processing activities.
2. For now, include only *normal* processing routines, *not* exception routines or error routines, on context diagrams, physical DFDs, and level 0 logical DFDs.
3. Include on all the systems documentation all (and only) activities and entities described in the system narrative-no more, no less.
4. When multiple entities operate identically, depict only one to represent all.
5. For clarity, draw a data flow for each flow into and out of a file.
6. If a file is logically necessary (i.e. because of a delay between processes), include a file in the diagrams, whether or not it is mentioned in the narrative.
7. Group activities if they occur in the same place and at the same time.
8. Group activities if they occur at the same time but in different places.
9. Group activities that seem to be logically related
10. To make the DFD readable, use between five and seven bubbles.
11. Data flows should only enter an operation entity (block) when only operations functions will be carried out by the entity. Data flows should enter an operation entity bubble if the entity is to perform an information processing activity.
12. On a physical DFD, reading and writing to computer files should take place through a process bubble.
13. On a logical DFD, data flows cannot go from higher to lower numbered bubbles.

Appendix A.2: Systems Flowcharts

ANSI standard flowchart symbols will be used to depict the interaction between databases and information systems in the Decision Support System. Included for reference is a summary of the most commonly used symbols (ANSI X 3.5, 1970).

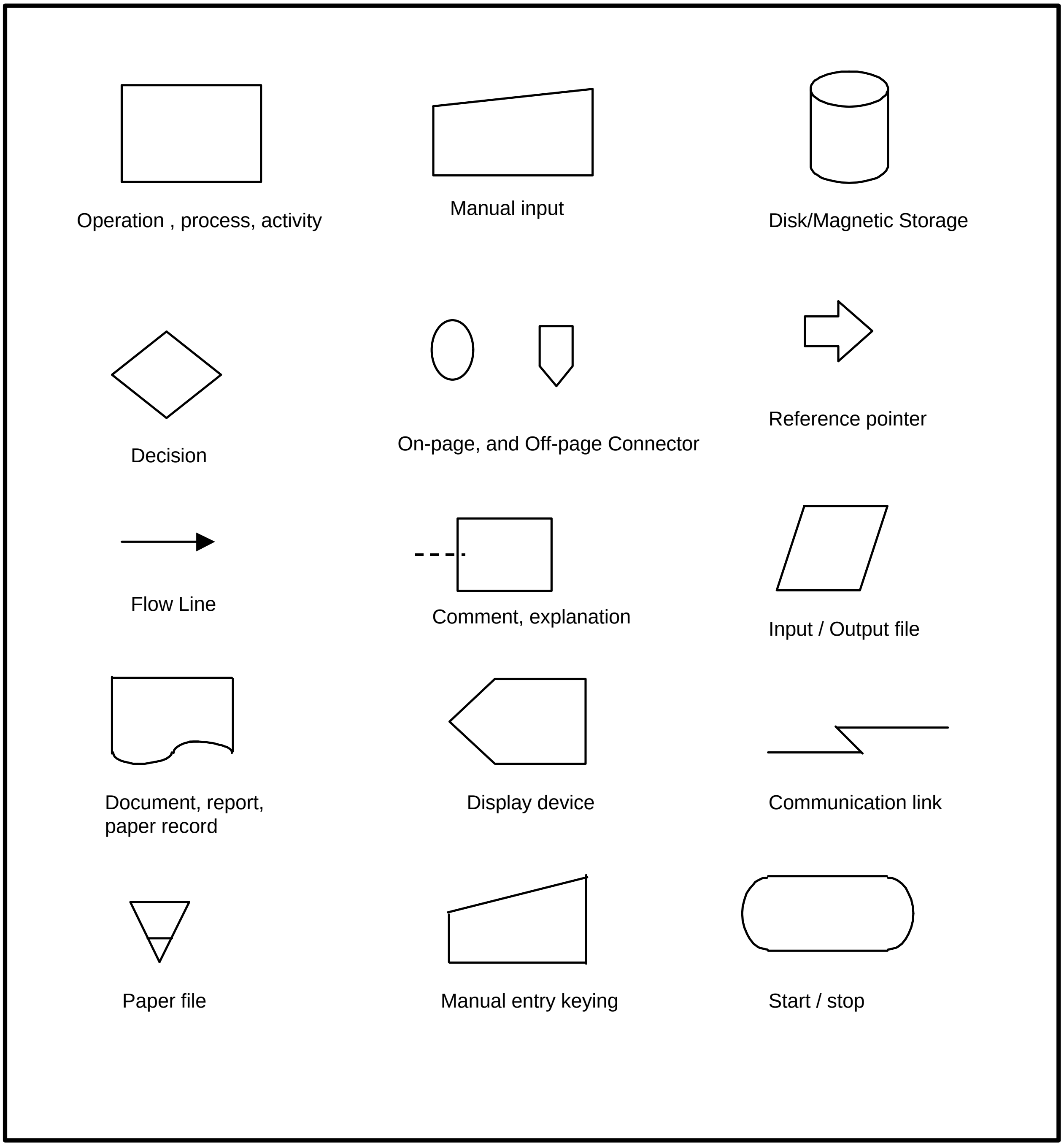


Figure A-2: Flow Chart Symbols

Appendix B: Flowcharts of the Production Cycle in Accounting Information Systems

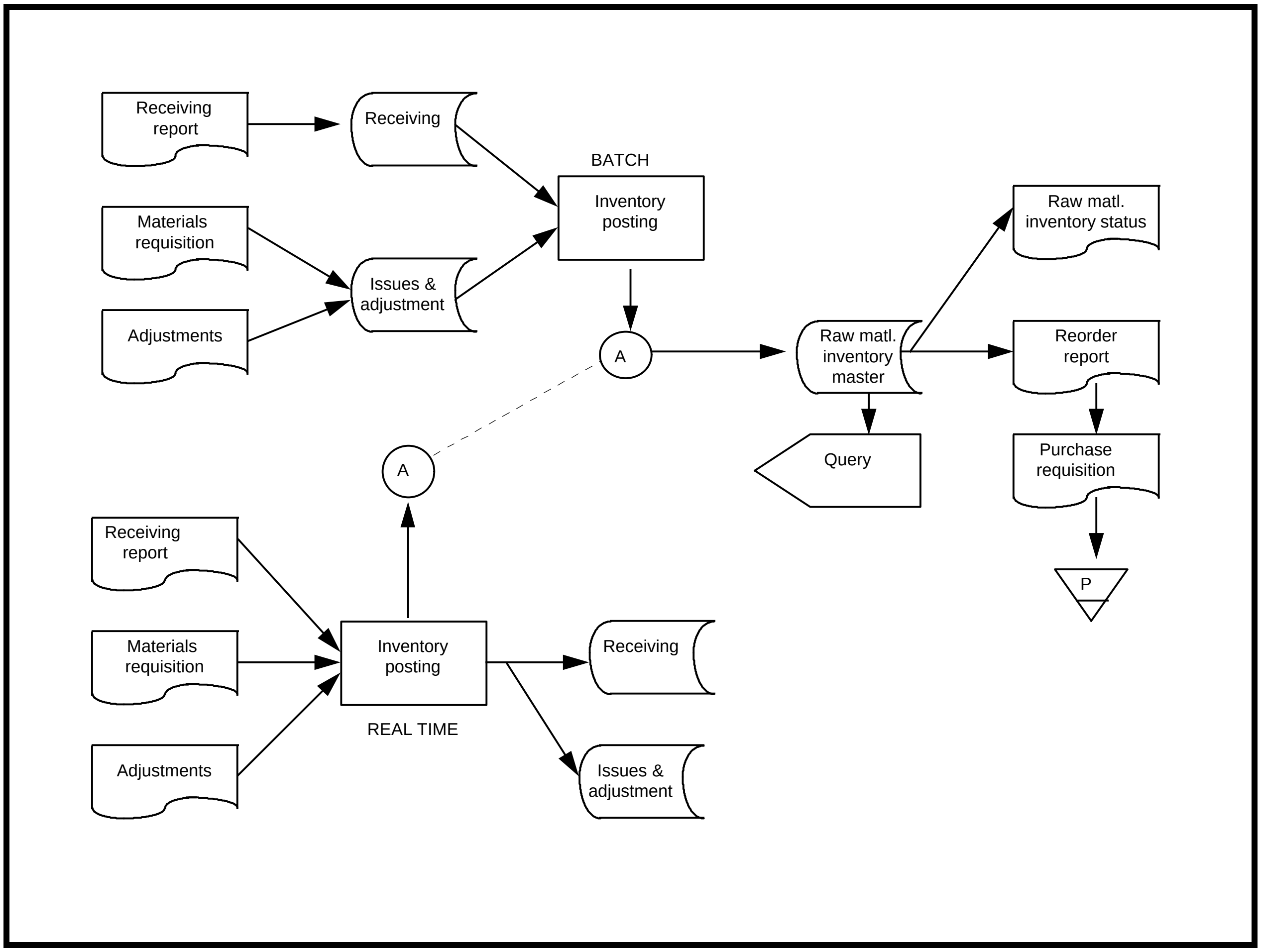


Figure B-1: Processing of raw material to inventory (modified from Nash, 1989)

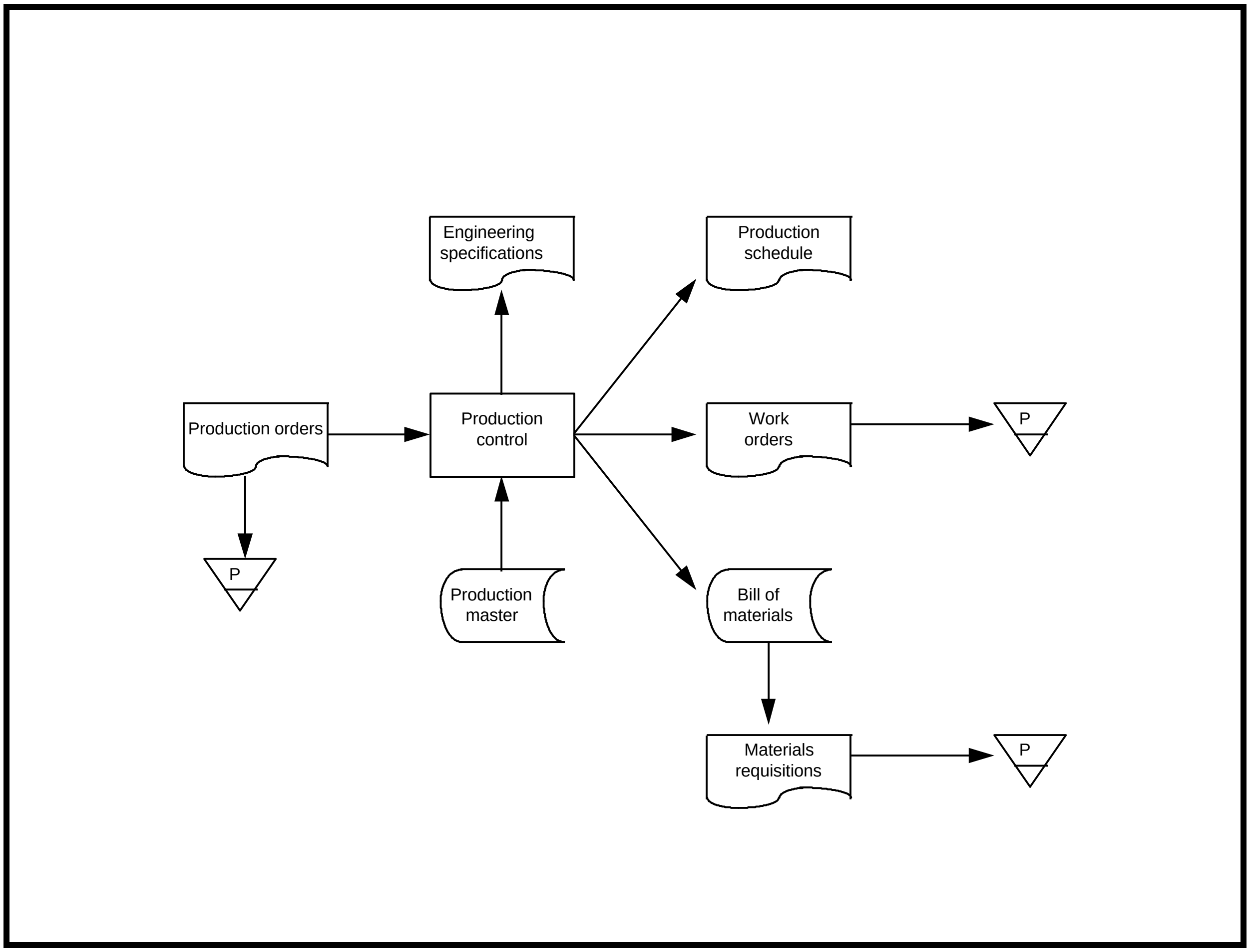
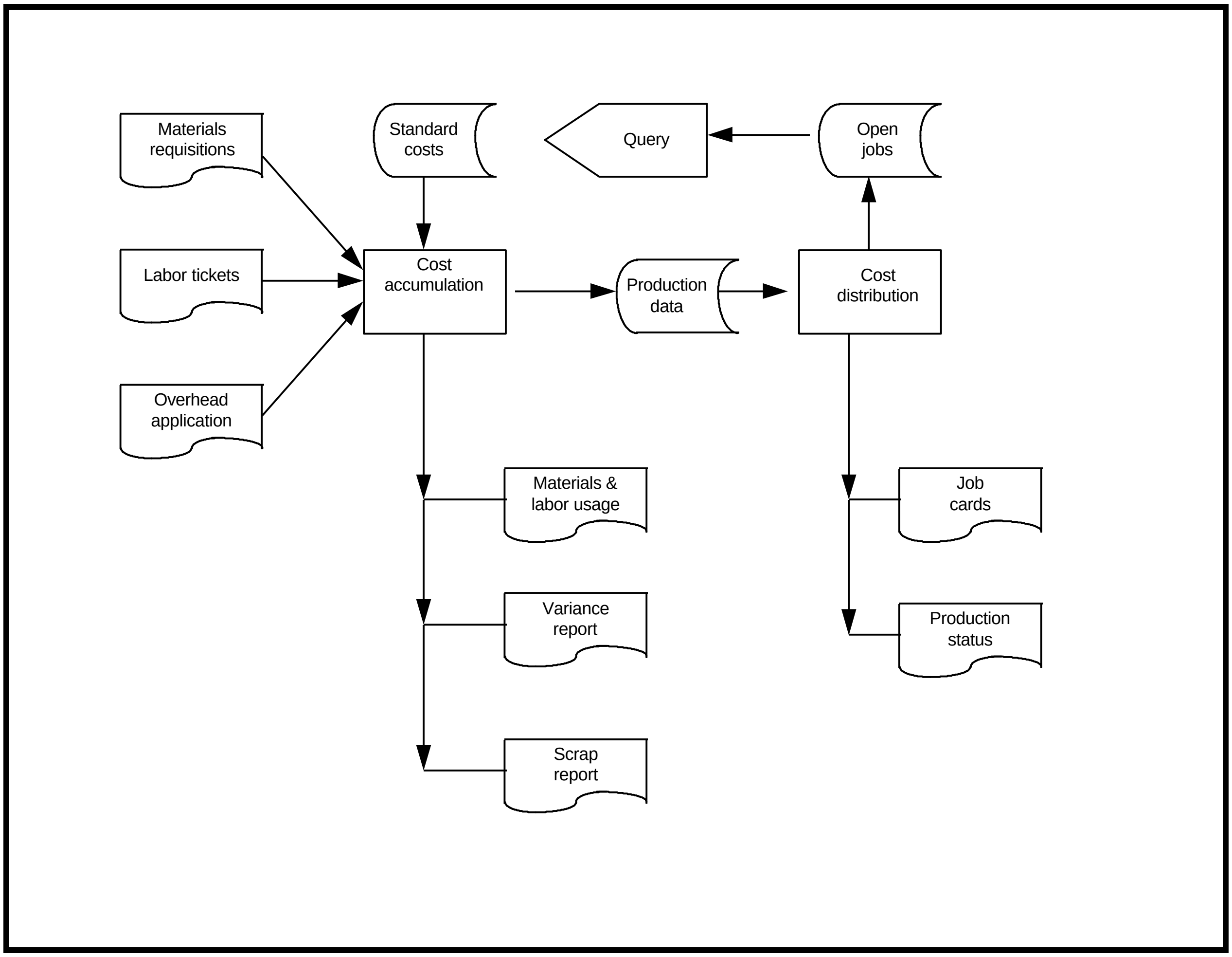
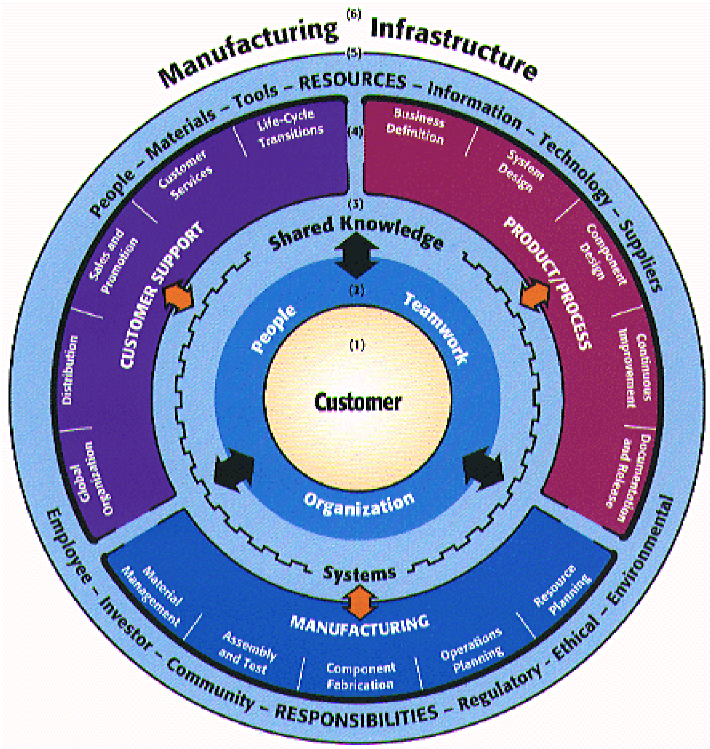


Figure B-2: Initiation of the production process (from Nash, 1989)



<u>Figure B-3: Accumulation and distribution of production costs</u> (from Nash, 1989)

Appendix C: CASA/SME New Manufacturing Enterprise Wheel



The CASA/SME Manufacturing Enterprise Wheel was developed by the Computer and Automated Systems Association of the Society of Manufacturing Engineers (CASA/SME). It was developed and refined by the 1991, 1992, and 1993 CASA/SME Boards of Advisors and CASA/SME Technical Forum Committees.

Appendix D: Example Formats of Source Data

Appendix D.1: Process Plan Example

	Process	Operation	Material	Size	Quantity	Machine/ Tools	Operators	Proc. Time	Setup Time
1	Plycutting	Cut glass epoxy sheets	250F Glass epoxy cloth	25" x 19"	6 sheets per kit	Gerber Automated Cutter	1	30	15
2	Plycutting	Cut adhesive film sheets	250F Curing adhesive film	25" x 19"	2 sheets per kit	Gerber Automated Cutter	1	30	15
3	Honeycomb cutting	Cut honeycomb sheets	Nomex honeycomb 3-4lb	22" x 16" x 1/4 " thick	1 sheet per kit	Waterjet cutter	2	30	15
4	Bagging	Cut the film	Plastic film 36" roll	36" x 36"	2 sheets per bag	Film cutter	1	2	5
5	Bagging	Make the bag	Plastic film sheets	2 shts 36" x 36"	1 bag per kit	Heat sealer	1	5	5
6	Reinforce latch area	reinforce sections of honeycomb sheet with epoxy filler	Nomex honeycomb 3-4lb and room temp.cure epoxy filler	22" x 16" x 1/4 " thick	1 sheet per kit and 5 oz. filler	Fixture and squeegee	1	25	5
7	Lamination	Prep. the mold	Mold cleaning fluid and release agent		each kit	mold and fixture plates	1	30	
8	Lamination	Lay on sheets of prepreg and adhesive film	3 Sheets of 250F Glass Epoxy and 1 Sheet of 250F Curing Film	Each Sheet 25" x 19"	Bottom layer of kit		1	40	
9	Lamination	Use Jig to locate and Install the Honeycomb Nomex	1 Sheet of Honeycomb Nomex	22" x 16" x 1/4" thick	Middle layer of kit	Locating Jig	1	10	
10	Lamination	Lay on sheets prepreg and adhesive flim	3 Sheets of 250F Glass Epoxy and 1 Sheet of 250F Curing Film	Each sheet 25" x 19"	Top Layer of kit		1	40	
11	Lamination	Lay teflon film and breather on top of kit and mold	Sheet of Teflon Film and Breather material	Each sheet 33" x 27"	One per kit		1	10	
12	Lamination	Wrap vacuum bag around mold, kit, teflon, and breather film	Vacuum bag, kit, mold, teflon film, and breahter material	Vacuum Bag: 36" x 36"	One per kit		1	20	
13	Lamination	Draw vacuum and seal bag	Entire kit and bag		Once per kit	Plant vacuum system	1	20	
14	Lamination	Curing Composite Part in autoclave at 250F	Entire kit, vacuum bag		3 kits	Autoclave	1	240	10
15	Trimming/Finishing	Cut excess glass from door	Unfinished baggage door	25" x 19" Door	1 kit	Cutting Template and Water Jet Cutter	1	9	120
16	Shipping and Packaging	Pack Baggage Doors and Ship to Customer	Packing and Shipping materials				1	15	
17	Engineering	Design/process planning for door production	Manufacturing engineer		1 off		1	720	

Appendix D.2: Job order format

Job Orders	Table: JobOrders
Job order number	JobOrderID primary key
Customer name and/or number	CustID
Date ordered	OrderDate
Date started in production	StartDate
Date to be completed	CompDate
Product ID number	ProductID
Product description	ProdDesc
Quantity	Quantity
Size/weight	Size
Operation number (R)	OperationID
Operation description (R)	OperationDesc
Date scheduled (R)	SchedDate
Time started (R)	StartTime
Time completed (R)	CompTime
Machine number (R)	AssetID
Special instructions (R)	Comment
Work center / dept. number (R)	DepartmentID
Inspection results (R)	InspectResult

(R) signifies row repeated for as many operations on the order

Reference: adapted from Murtuza, 1995

Appendix D.3: Bill of Materials Example

ABC Manufacturing Company Bill of Materials				
OrderID	1567			
Product ID	BDAH64			
ProductDescription	Baggage Door AH-64			
Authorization	AKAJOE			
Date	5/7/97			
Part No	***Material***	***Size***	***Quantity***	***Cost***
BDS01	ply carbon	25" x 30" x 0.25"	2	$300-00
BDS05	ply adhesive	30" x 35"	3	$10-00
BDS16	nomex sheet	25" x 30" x 1.25"	1	$80-00

Reference: adapted from Wilkinson (1993).

Appendix D.4: Materials Requisition Example

ABC Manufacturing Company Materials Requisition Form	
Job Number	534
Department	WING FABRICATION
Debit Account	Work-In-Process
Authorized by	General Ledger
Description	Carbon Fiber Tape
Date	2/5/97
Size	0.1" x 2"
Quantity	50 '
Unit Cost	$ 2.50
Amount	$ 125.00

Reference: adapted from Horngren & Foster (1991).

Appendix D.5: Move Ticket Example

ABC Manufacturing Company Move Ticket		
Job Number	534	
Location	*Dept AXZ*	
Move to.	*Dept* ABG	
For Operations	A12, A14	
Machine No.	0562	
Date Started	2/5/97	
Date Finished	2/5/97	
Time Started	14h00	
Time Finished	14h50	
Quantity	5	
Received by	[signature]	
Posted by	[signature]	

Reference: adapted from Gelinas & Oram (1996).

<u>Appendix D.6: Typical Employee Record Format</u>

Category	Field	Comments, example data
Employee identification	employee identification/code	Social Security No.
	department/position code	Dept.A, PositionID 004
	personal data	name, address, telephone.
	demographic data *	race, age, sex, handicaps
	employee status *	active, inactive, terminated
	career with company *	date hired, date next review, etc
Employee payment terms	tax status *	filing status, exemptions
	payment code	indicates overtime status, frequency of payment, salary/wage/commision
	salary/wage/commission rate	$36,000-00 per year
	overtime rate	@ 0.5 x normal rate
Leave history	vacation leave accrual rate *	14 days / year
	sick leave accrual rate *	14 days / year
	accrued vacation leave *	10 days
	accrued sick leave *	10 days
	vac. leave used in period *	0 days
	sick leave used in period *	0 days
Current payroll	gross pay	$3000-00 per month
	payroll deductions *	FIT, SIT, FICA, Health Ins.
	hours worked	180 hours / 180 possible
	net pay	$2,400-00 per month
	YTD/QTD payroll history *	cumulative totals

Reference: adapted from Gelinas & Oram (1996).

Appendix D.7:   Employee Time Ticket Example

ABC Manufacturing Company Time Ticket	
Employee Number	138
Date	2/5/97
Job Number	413
Operation	Laser cut laminate
Account	Work-In-Progress
Department	Plycutting
Start Time	4:10pm
End Time	4:45pm
Quantity worked	10
Quantity rejected	0
Rate	$ 9.00 /hr

Reference: adapted from Horngren & Foster (1991).

Appendix D.8: Employee Clock Card Example

ABC Manufacturing Company Clock Card							
Employee Number	138						
Employee Name	Joe Bloggs						
Department	Wing Fabrication						
Week ending	2/10/97						
					Excess Hours		
Date	Time In	Time Out	Time In	Time Out	Time In	Time Out	Total Hours
2/4							
2/5	7:55	12:01	12:58	5:01			8
2/6	7:54	12:02	12:57	5:02	6:00	8:00	10
2/7	7:56	12:01	1:00	5:01			8
2/8	7:55	12:01	12:59	5:01			8
2/9	7:54	12:03	12:58	5:04			8
2/10							

Regular Time	40	*hours @ Rate*	$15.00	$600.00
Overtime	2	*hours @ Rate*	$9.00	$18.00
Gross				$618.00

Reference: adapted from Horngren & Foster (1991).

Appendix E: Terminology/Glossary of terms

CI	Customer Involvement on Product Team
CIM	Computer Integrated Manufacturing
DAPCA IV	Development and Procurement Costs of Aircraft (Hess & Romanoff, 1987)
DDSS	Design Decision Support System
DFM	Design For Manufacturability (Boothroyd & Dewhurst, 1991)
DFX	Design for X-ability
DPA	Digital Preassembly/Mock-up
DPD	Digital Product Definition
IPT	Integrated Product Teams
LM	Lean Manufacturing
QFD	Quality Function Deployment
SI	Supplier Involvement on Product Team
TQM	Total Quality Management

Appendix F: Visual Basic Code for DDSS Prototype

Appendix F1: DDSSProject - frmMain(code)

```
Option Explicit
Private Declare Function OSWinHelp% Lib "user32" Alias "WinHelpA" (ByVal hwnd&, ByVal HelpFile$,
ByVal wCommand%, dwData As Any)
Private Sub MDIForm_Load()
   Me.Left = GetSetting(App.Title, "Settings", "MainLeft", 1000)
   Me.Top = GetSetting(App.Title, "Settings", "MainTop", 1000)
   Me.Width = GetSetting(App.Title, "Settings", "MainWidth", 6500)
   Me.Height = GetSetting(App.Title, "Settings", "MainHeight", 6500)
   LoadNewDoc
End Sub

Private Sub LoadNewDoc()
   Static lDocumentCount As Long
   Dim frmD As frmDocument

   lDocumentCount = lDocumentCount + 1
   Set frmD = New frmDocument
   frmD.Caption = "Document " & lDocumentCount
   frmD.Show
End Sub

Private Sub MDIForm_Unload(Cancel As Integer)
   If Me.WindowState <> vbMinimized Then
      SaveSetting App.Title, "Settings", "MainLeft", Me.Left
      SaveSetting App.Title, "Settings", "MainTop", Me.Top
      SaveSetting App.Title, "Settings", "MainWidth", Me.Width
      SaveSetting App.Title, "Settings", "MainHeight", Me.Height
   End If
End Sub

Private Sub mnuSearchDataActivityCost_Click()
   Dim f As New frmActivityCost
   f.Show
End Sub

Private Sub mnuSearchDataMaintCostSummary_Click()
   Dim f As New frmMaintCost
   f.Show
End Sub

Private Sub mnuViewDataProducts_Click()
   Dim f As New frmProducts
   f.Show
End Sub

Private Sub mnuViewDataProcessDetails_Click()
   Dim f As New frmProcessDetails
   f.Show
End Sub

Private Sub mnuViewDataMaintenanceJobs_Click()
   Dim f As New frmMaintenanceJobs
   f.Show
```

```
End Sub

Private Sub mnuViewDataJobOrders_Click()
    Dim f As New frmJobOrders
    f.Show
End Sub

Private Sub mnuViewDataInventory_Click()
    Dim f As New frmInventory
    f.Show
End Sub

Private Sub mnuViewDataFixedAssets_Click()
    Dim f As New frmFixedAssets
    f.Show
End Sub

Private Sub mnuViewDataEmployees_Click()
    Dim f As New frmEmployees
    f.Show
End Sub

Private Sub mnuViewDataEmployeeCodeRate_Click()
    Dim f As New frmEmployeeCodeRate
    f.Show
End Sub

Private Sub mnuViewDataBillMaterials_Click()
    Dim f As New frmBillMaterials
    f.Show
End Sub

Private Sub mnuHelpAbout_Click()
    frmAbout.Show vbModal, Me
End Sub

Private Sub mnuViewOptions_Click()
    'To Do
    MsgBox "Options Dialog Code goes here!"
End Sub

Private Sub mnuViewStatusBar_Click()
    If mnuViewStatusBar.Checked Then
        sbStatusBar.Visible = False
        mnuViewStatusBar.Checked = False
    Else
        sbStatusBar.Visible = True
        mnuViewStatusBar.Checked = True
    End If
End Sub

Private Sub mnuViewToolbar_Click()
    If mnuViewToolbar.Checked Then
        tbToolBar.Visible = False
        mnuViewToolbar.Checked = False
    Else
```

```
        tbToolBar.Visible = True
        mnuViewToolbar.Checked = True
    End If
End Sub

Private Sub tbToolBar_ButtonClick(ByVal Button As ComctlLib.Button)
    Select Case Button.Key
        Case "New"
            LoadNewDoc
        Case "New"
            mnuFileNew_Click
        Case "Open"
            mnuFileOpen_Click
        Case "Save"
            mnuFileSave_Click
        Case "Print"
            mnuFilePrint_Click
        Case "Cut"
            mnuEditCut_Click
        Case "Copy"
            mnuEditCopy_Click
        Case "Paste"
            mnuEditPaste_Click
        Case "Bold"
            'To Do
            MsgBox "Bold Code goes here!"
        Case "Italic"
            'To Do
            MsgBox "Italic Code goes here!"
        Case "Underline"
            'To Do
            MsgBox "Underline Code goes here!"
        Case "Left"
            'To Do
            MsgBox "Left Code goes here!"
        Case "Center"
            'To Do
            MsgBox "Center Code goes here!"
        Case "Right"
            'To Do
            MsgBox "Right Code goes here!"
    End Select
End Sub

Private Sub mnuHelpContents_Click()
    Dim nRet As Integer
    'if there is no helpfile for this project display a message to the user
    'you can set the HelpFile for your application in the
    'Project Properties dialog
    If Len(App.HelpFile) = 0 Then
        MsgBox "Unable to display Help Contents. There is no Help associated with this project.",
vbInformation, Me.Caption
    Else
        On Error Resume Next
        nRet = OSWinHelp(Me.hwnd, App.HelpFile, 3, 0)
        If Err Then
```

```
        MsgBox Err.Description
      End If
   End If
End Sub

Private Sub mnuHelpSearch_Click()
Dim nRet As Integer
   'if there is no helpfile for this project display a message to the user
   'you can set the HelpFile for your application in the
   'Project Properties dialog
   If Len(App.HelpFile) = 0 Then
      MsgBox "Unable to display Help Contents. There is no Help associated with this project.",
vbInformation, Me.Caption
   Else
      On Error Resume Next
      nRet = OSWinHelp(Me.hwnd, App.HelpFile, 261, 0)
      If Err Then
        MsgBox Err.Description
      End If
   End If
End Sub

Private Sub mnuWindowArrangeIcons_Click()
   Me.Arrange vbArrangeIcons
End Sub

Private Sub mnuWindowCascade_Click()
   Me.Arrange vbCascade
End Sub

Private Sub mnuWindowNewWindow_Click()
   'To Do
   MsgBox "New Window Code goes here!"
End Sub

Private Sub mnuWindowTileHorizontal_Click()
   Me.Arrange vbTileHorizontal
End Sub

Private Sub mnuWindowTileVertical_Click()
   Me.Arrange vbTileVertical
End Sub

Private Sub mnuViewRefresh_Click()
   'To Do
   MsgBox "Refresh Code goes here!"
End Sub

Private Sub mnuEditCopy_Click()
   'To Do
   MsgBox "Copy Code goes here!"
End Sub

Private Sub mnuEditCut_Click()
   'To Do
   MsgBox "Cut Code goes here!"
```

```
End Sub

Private Sub mnuEditPaste_Click()
    'To Do
    MsgBox "Paste Code goes here!"
End Sub

Private Sub mnuEditPasteSpecial_Click()
    'To Do
    MsgBox "Paste Special Code goes here!"
End Sub

Private Sub mnuEditUndo_Click()
    'To Do
    MsgBox "Undo Code goes here!"
End Sub

Private Sub mnuFileOpen_Click()
    Dim sFile As String

    With dlgCommonDialog
        'To Do
        'set the flags and attributes of the
        'common dialog control
        .Filter = "All Files (*.*)|*.*"
        .ShowOpen
        If Len(.filename) = 0 Then
            Exit Sub
        End If
        sFile = .filename
    End With
    'To Do
    'process the opened file
End Sub

Private Sub mnuFileClose_Click()
    'To Do
    MsgBox "Close Code goes here!"
End Sub

Private Sub mnuFileSave_Click()
    'To Do
    MsgBox "Save Code goes here!"
End Sub

Private Sub mnuFileSaveAs_Click()
    'To Do
    'Setup the common dialog control
    'prior to calling ShowSave
    dlgCommonDialog.ShowSave
End Sub

Private Sub mnuFileSaveAll_Click()
    'To Do
    MsgBox "Save All Code goes here!"
End Sub
```

```
Private Sub mnuFileProperties_Click()
    'To Do
    MsgBox "Properties Code goes here!"
End Sub

Private Sub mnuFilePageSetup_Click()
    dlgCommonDialog.ShowPrinter
End Sub

Private Sub mnuFilePrintPreview_Click()
    'To Do
    MsgBox "Print Preview Code goes here!"
End Sub

Private Sub mnuFilePrint_Click()
    'To Do
    MsgBox "Print Code goes here!"
End Sub

Private Sub mnuFileSend_Click()
    'To Do
    MsgBox "Send Code goes here!"
End Sub

Private Sub mnuFileMRU_Click(Index As Integer)
    'To Do
    MsgBox "MRU Code goes here!"
End Sub

Private Sub mnuFileExit_Click()
    'unload the form
    Unload Me
End Sub

Private Sub mnuFileNew_Click()
    LoadNewDoc
End Sub
```

Appendix F2: DDSSProject - frmMaintCost(code)

```
Option Explicit
'Databases
Dim dataCurrent As Database
Dim xlsCurrent As Database
'Integers
Dim intNumRecords As Integer
Public prmAssetID As Parameter
Public prmDateFrom As Parameter
Public prmDateTo As Parameter
Dim prmEmployeeCode As Parameter
Dim prmMaterialID As Parameter
'QueryDefs
Dim qdfEmployeeCodeRate As QueryDef
Dim qdfMachineHours As QueryDef
Public qdfMaintJobs As QueryDef
Dim qdfMaterialCost As QueryDef
'Recordsets
Public rstAssets As Recordset
Dim rstEmployeeCostRate As Recordset
Dim rstMachineHours As Recordset
Dim rstMaintJobs As Recordset
Dim rstMaterialCost As Recordset
'Strings
Dim dummyCaption As String
Dim strSql As String
Dim strSql2 As String
Dim strSql3 As String
Dim strSql4 As String
'Variables
Dim MachineHoursTotal As Variant
Dim MaintLaborCost As Variant
Dim MaintMatlCost As Variant

Private Sub cmdSearchMaintJobOrders_Click()
Set dataCurrent = OpenDatabase("c:\mark\Research\Factor2.mdb")
Set xlsCurrent = OpenDatabase("c:\mark\Research\MachCostSumm.xls", False, False, "Excel 8.0;
HDR=YES;")
Set rstAssets = xlsCurrent.OpenRecordset("Sheet1$")

'Execute a MoveLast and count the records.
   rstAssets.MoveLast
   intNumRecords = rstAssets.RecordCount
   MsgBox "There are " & intNumRecords & _
       " rows in this range."
   rstAssets.MoveFirst

Do Until rstAssets.EOF
'Calculate Machine Hours Used for each machine
   strSql4 = " PARAMETERS prmAssetID Text, prmDateFrom DateTime, prmDateTo DateTime; " & _
       "SELECT ProcessDetails.AssetID, ProcessDetails.StartDate, ProcessDetails.EndDate,
ProcessDetails.ProcessTime " & _
       "From ProcessDetails " & _
```

```
        "WHERE (((ProcessDetails.AssetID) Like [prmAssetID]) AND
((ProcessDetails.StartDate)>=[prmDateFrom]) AND ((ProcessDetails.EndDate)<=[prmDateTo])); "
    Set qdfMachineHours = dataCurrent.CreateQueryDef("", strSql4)
    qdfMachineHours.Parameters!prmAssetID = "*" & rstAssets!AssetID
    qdfMachineHours.Parameters!prmDateFrom = Text1.Text
    qdfMachineHours.Parameters!prmDateTo = Text2.Text
    Set rstMachineHours = qdfMachineHours.OpenRecordset(dbOpenSnapshot, [dbReadOnly])
        If rstMachineHours.RecordCount > 0 Then
            rstMachineHours.MoveFirst
            Do Until rstMachineHours.EOF
                MachineHoursTotal = MachineHoursTotal + rstMachineHours!ProcessTime.Value / 60
                rstMachineHours.MoveNext
            Loop
        End If
' Update MachineCostSummary.MachineHours
    rstAssets.Edit
    rstAssets!MachineHours = MachineHoursTotal
    rstAssets.Update
    MachineHoursTotal = 0

'Define SQL string for MaintenanceJobs query
    strSql = " PARAMETERS prmAssetID Text, prmDateFrom DateTime, prmDateTo DateTime;" & _
        "SELECT DISTINCTROW MaintenanceJobs.MaintJobID, MaintenanceJobs.AssetID,
MaintenanceJobs.AssetName, MaintenanceJobs.StartDate, MaintenanceJobs.EndDate,
MaintenanceJobs.JobTime, MaintenanceJobs.EmployeeID, MaintenanceJobs.MaterialID,
MaintenanceJobs.MaterialCost " & _
        "From MaintenanceJobs " & _
        "WHERE (((MaintenanceJobs.AssetID) Like [prmAssetID]) AND
((MaintenanceJobs.StartDate)>[prmDateFrom]) AND ((MaintenanceJobs.EndDate)<=[prmDateTo])); "

'Input prmAssetID, prmDateFrom, prmDateTo
Set qdfMaintJobs = dataCurrent.CreateQueryDef("", strSql)
    qdfMaintJobs.Parameters!prmAssetID = rstAssets!AssetID
    qdfMaintJobs.Parameters!prmDateFrom = Text1.Text
    qdfMaintJobs.Parameters!prmDateTo = Text2.Text

Set rstMaintJobs = qdfMaintJobs.OpenRecordset(dbOpenSnapshot, [dbReadOnly])
If rstMaintJobs.RecordCount > 0 Then
    rstMaintJobs.MoveFirst
    Text3.Text = rstMaintJobs.RecordCount
    Do Until rstMaintJobs.EOF

        'Calculate LaborCost for each Asset, by MaintenanceJob
        strSql2 = " PARAMETERS prmEmployeeCode Text; " & _
            "SELECT EmployeeCodeRate.EmployeeCode, EmployeeCodeRate.LaborCostRate " & _
            "From EmployeeCodeRate " & _
            "WHERE (((EmployeeCodeRate.EmployeeCode) Like [prmEmployeeCode])); "
        Set qdfEmployeeCodeRate = dataCurrent.CreateQueryDef("", strSql2)
        qdfEmployeeCodeRate.Parameters!prmEmployeeCode = rstMaintJobs!EmployeeID

        Set rstEmployeeCostRate = qdfEmployeeCodeRate.OpenRecordset(dbOpenSnapshot,
[dbReadOnly])
        MaintLaborCost = MaintLaborCost + rstMaintJobs!JobTime.Value / 60 *
rstEmployeeCostRate!LaborCostRate.Value
        'Output the returned records in caption, and database forms
        'MsgBox "Jobs"
```

```
        dummyCaption = rstMaintJobs!AssetID.Value & " " & rstMaintJobs!JobTime.Value
        Text3.Text = dummyCaption

        'Calculate MaterialCost for each Asset, by MaintenanceJob
        strSql3 = " PARAMETERS prmMaterialID Text; " & _
            "SELECT Inventory.MaterialID, Inventory.UnitCost " & _
            "From Inventory " & _
            "WHERE (((Inventory.MaterialID) Like [prmMaterialID])); "
        Set qdfMaterialCost = dataCurrent.CreateQueryDef("", strSql3)
        qdfMaterialCost.Parameters!prmMaterialID = rstMaintJobs!MaterialID
        Set rstMaterialCost = qdfMaterialCost.OpenRecordset(dbOpenSnapshot, [dbReadOnly])
        MaintMatlCost = MaintMatlCost + rstMaterialCost!UnitCost.Value * 1
        'Output the returned records in caption, and database forms

        rstMaintJobs.MoveNext
     Loop
     rstAssets.Edit
     rstAssets!MaintLaborCost = MaintLaborCost
     rstAssets!MatlCost = MaintMatlCost
     rstAssets.Update
          MaintLaborCost = 0
          MaintMatlCost = 0
    Else
    rstAssets.Edit
    rstAssets!MaintLaborCost = 0
    rstAssets!MatlCost = 0
    rstAssets.Update
  End If

' Update Calculated Fields in MachCostSumm
  rstAssets.Edit
  rstAssets!OperCost.Value = rstAssets!MachineHours.Value * rstAssets!OperCostRate.Value
  rstAssets!TotalMachineCost = rstAssets!DepnCharge / 12 + rstAssets!MaintLaborCost +
rstAssets!MatlCost + rstAssets!OperCost
  rstAssets!MachineCostRate = rstAssets!TotalMachineCost / rstAssets!MachineHours
  rstAssets.Update
  rstAssets.MoveNext

Loop '(Do until rstAssets.EOF)
    rstAssets.Close
'    xlsCurrent("Sheet1").Calculate
'    xlsCurrent.Worksheet("Sheet1$").SaveAs ("MachCostSumm1")
    dataCurrent.Close
    xlsCurrent.Close
MsgBox "All finished"

End Sub
```

Appendix F3: DDSSProject - frmActivityCost (code)

```
'VARIABLE DECLARATIONS
Option Explicit
'Strings
Dim Default As String
Dim Message As String
Dim Title As String
Dim strSql1 As String
Dim strSql2 As String
Dim strSql3 As String
Dim strSql4 As String
Dim strSql5 As String
'Databases
Dim dbsCurrent As Database
Dim xlsCurrent As Database
Dim xlsMachCostSumm As Database
'Integer Variables
Dim intNumRecords As Integer
'Parameters
Dim prmAssetID As Parameter
Dim prmEmployeeCode As Parameter
Dim prmMaterialID As Parameter
Dim prmOrderID As Parameter
Dim prmOrderID2 As Parameter
Dim prmProcessID As Parameter
Dim prmProductDesc As Parameter
'Recordsets
Dim rstActivity As Recordset
Dim rstMachCostRate As Recordset
Dim rstMaterials As Recordset
Dim rstEmployeeCostRate As Recordset
Public rstOrderID As Recordset
Public rstProcessPlan As Recordset
'QueryDefs
Dim qdfMachCostRate As QueryDef
Dim qdfMaterialCost As QueryDef
Dim qdfMaterials As QueryDef
Dim qdfEmployeeCodeRate As QueryDef
Public qdfProcessPlan As QueryDef
Public qdfOrderID As QueryDef
'Variables
Dim LaborCost As Currency
Dim MachineCost As Currency
Dim MaterialCost As Currency
Dim ProcessCost As Currency
```

```
Private Sub cmdSearchOrderID_Click()
Set dbsCurrent = OpenDatabase("c:\mark\Research\Factor2.mdb")

'Find OrderID in Factor2.JobOrders to match ProductDesc (qryProductDesc)
   strSql1 = " PARAMETERS [prmProductDesc] TEXT; " & _
      "SELECT JobOrders.OrderID, JobOrders.ProductID, JobOrders.ProductDesc, JobOrders.OrderDate, JobOrders.Quantity, JobOrders.Size " & _
      "From JobOrders " & _
      "WHERE (((JobOrders.ProductDesc) Like [prmProductDesc])); "

   Set qdfOrderID = dbsCurrent.CreateQueryDef("", strSql1)
   qdfOrderID.Parameters!prmProductDesc = Combo1.List(Combo1.ListIndex)
   Set rstOrderID = qdfOrderID.OpenRecordset
      If rstOrderID.RecordCount = 0 Then
         qdfOrderID.Parameters![prmProductDesc] = InputBox(Message, Title, Default)
         Message = "Enter ProductDesc"   ' Set prompt.
         Title = "ProductDesc Input" ' Set title.
         Default = rstJobOrders!ProductDesc  ' Set default.
      End If

'Output the returned records in captions
   rstOrderID.MoveFirst
   Text1.Text = rstOrderID!OrderID
   Text2.Text = rstOrderID!ProductID
   MsgBox "OrderID and ProductID Found"

'Set the path for the current database
Set xlsCurrent = OpenDatabase("c:\mark\Research\ProcessPlan1.xls", False, False, "Excel 8.0; HDR=YES;")
Set rstActivity = xlsCurrent.OpenRecordset("Sheet1$")
Set xlsMachCostSumm = OpenDatabase("c:\mark\Research\MachCostSumm.xls", False, False, "Excel 8.0; HDR=YES;")
'set spread = OpenDatabase("c:\Mark\spread.xls",
'Define the SQL string for the parameter query
   strSql2 = " PARAMETERS prmOrderID Long; " & _
      "SELECT ProcessDetails.OrderID, ProcessDetails.ProductID, ProcessDetails.ProcessID, ProcessDetails.ProcessDesc, ProcessDetails.StartDate, ProcessDetails.EndDate, ProcessDetails.StartTime, ProcessDetails.EndTime, ProcessDetails.ProcessTime, ProcessDetails.AssetID, ProcessDetails.EmployeeID, ProcessDetails.NoEmployees, ProcessDetails.MaterialID " & _
      "From ProcessDetails " & _
      "WHERE (((ProcessDetails.OrderID) Like [prmOrderID])); "

   Set qdfProcessPlan = dbsCurrent.CreateQueryDef("", strSql2)
'Input the parameter values
   qdfProcessPlan.Parameters![prmOrderID] = rstOrderID!OrderID

'Open the recordset of ProcessDetails matching the OrderID
 Set rstProcessPlan = qdfProcessPlan.OpenRecordset

     'If rstProcess is empty, ask user for alternative ProductName to search for
      If rstProcessPlan.RecordCount = 0 Then
         Message = "Enter Alternative OrderID"   ' Set prompt.
         Title = "No match for OrderID" ' Set title.
         Default = rstProcessPlan!ProductName  ' Set default.
         qdfProcessPlan.Parameters![ProductIDprm] = InputBox(Message, Title, Default)
```

```
            Set rstProcessPlan = qdfProcessPlan.OpenRecordset()
                'If still no match, ask user for alternative process
                If rstProcessPlan.RecordCount = 0 Then
                    Message = "Enter Alternative ProcessID"   ' Set prompt.
                    Title = "No match for ProcessID" ' Set title.
                    Default = rstProcessPlan!ProcessID  ' Set default.
                    qdfProcessPlan.Parameters![ProcessIDprm] = InputBox(Message, Title, Default)
                    Set rstProcessPlan = qdfProcessPlan.OpenRecordset()
                End If
        End If

'Output the returned records in captions, and replicate information to the spreadsheet
    rstProcessPlan.MoveFirst
    Do Until rstProcessPlan.EOF
        Text3.Text = rstProcessPlan!ProcessID.Value
        Text4.Text = rstProcessPlan!ProcessDesc.Value
        MsgBox "Process" & rstProcessPlan!ProcessID
        rstActivity.AddNew
        rstActivity!OrderID = rstOrderID!OrderID
        rstActivity!ProductID = rstOrderID!ProductID
        rstActivity!ProcessID = rstProcessPlan!ProcessID
        rstActivity!ProcessDesc = rstProcessPlan!ProcessDesc
        rstActivity!StartDate = rstProcessPlan!StartDate
        rstActivity!EndDate = rstProcessPlan!EndDate
        rstActivity!StartTime = rstProcessPlan!StartTime
        rstActivity!EndTime = rstProcessPlan!EndTime
        rstActivity!ProcessTime = rstProcessPlan!ProcessTime
        rstActivity!AssetID = rstProcessPlan!AssetID
        rstActivity!EmployeeID = rstProcessPlan!EmployeeID
        rstActivity!NoEmployees = rstProcessPlan!NoEmployees
        rstActivity!MaterialID = rstProcessPlan!MaterialID

'Calculate LaborCost for each Activity, by ProcessID
        strSql3 = " PARAMETERS prmEmployeeCode Text; " & _
            "SELECT EmployeeCodeRate.EmployeeCode, EmployeeCodeRate.LaborCostRate " & _
            "From EmployeeCodeRate " & _
            "WHERE (((EmployeeCodeRate.EmployeeCode) Like [prmEmployeeCode])); "
        Set qdfEmployeeCodeRate = dbsCurrent.CreateQueryDef("", strSql3)
        qdfEmployeeCodeRate.Parameters!prmEmployeeCode = rstProcessPlan!EmployeeID
        Set rstEmployeeCostRate = qdfEmployeeCodeRate.OpenRecordset(dbOpenSnapshot,
[dbReadOnly])
        rstActivity!EmployeeCostRate = rstEmployeeCostRate!LaborCostRate.Value
        rstActivity!LaborCost = rstProcessPlan!ProcessTime.Value / 60 *
rstEmployeeCostRate!LaborCostRate.Value * rstProcessPlan!NoEmployees
        'Output the returned records in text box
        'MsgBox "Activity" & rstProcessPlan!ProcessID
        Text3.Text = rstProcessPlan!AssetID.Value & " " & rstProcessPlan!ProcessTime.Value
```

```
'Get set of all materials used for each activity
        strSql4 = " PARAMETERS prmOrderID2 Long, prmProcessID Short, prmMaterialID Text; " & _
           "SELECT DISTINCTROW BillMaterials.MaterialNo, BillMaterials.OrderID, BillMaterials.ProductID, BillMaterials.ProcessID, BillMaterials.MaterialID, BillMaterials.MaterialName, BillMaterials.SizeL, BillMaterials.SizeW, BillMaterials.SizeT, BillMaterials.Quantity, Inventory.MaterialID, Inventory.UnitCost " & _
          "FROM BillMaterials INNER JOIN Inventory ON BillMaterials.MaterialID = Inventory.MaterialID " & _
            "WHERE (((BillMaterials.OrderID) Like [prmOrderID2]) AND ((BillMaterials.ProcessID) Like [prmProcessID]) AND ((BillMaterials.MaterialID) Like [prmMaterialID])); "
        Set qdfMaterials = dbsCurrent.CreateQueryDef("", strSql4)
        qdfMaterials.Parameters!prmOrderID2 = rstOrderID!OrderID
        qdfMaterials.Parameters!prmProcessID = rstProcessPlan!ProcessID
        qdfMaterials.Parameters!prmMaterialID = rstProcessPlan!MaterialID
        Set rstMaterials = qdfMaterials.OpenRecordset(dbOpenSnapshot, [dbReadOnly])
            If rstMaterials.RecordCount > 0 Then
            rstActivity!MaterialCost = rstMaterials!UnitCost.Value * rstMaterials!Quantity.Value
            Else: rstActivity!MaterialCost = 0
            End If

'Calculate Machine Cost for each Activity
        strSql5 = " PARAMETERS prmAssetID Text;" & _
            "SELECT Sheet1$.AssetID, Sheet1$.MachineCostRate, Sheet1$.AssetName " & _
            "From [Sheet1$] " & _
            "WHERE (((Sheet1$.AssetID) Like [prmAssetID])); "
        Set qdfMachCostRate = xlsMachCostSumm.CreateQueryDef("", strSql5)
        qdfMachCostRate.Parameters!prmAssetID = rstProcessPlan!AssetID
        Set rstMachCostRate = qdfMachCostRate.OpenRecordset(dbOpenSnapshot, [dbReadOnly])

            If rstMachCostRate.RecordCount > 0 Then
            rstActivity!MachineCostRate = rstMachCostRate!MachineCostRate
                    If rstActivity!ProcessDesc = "*Tooling Cost*"
                    rstActivity!MachineCost = MachineCostRate!MachineCostRate * 1
                    End If
                    End If
            rstActivity!MachineCost = rstActivity!MachineCostRate * rstProcessPlan!ProcessTime / 60
        Else: rstActivity!MachineCost = 0
        End If

'Calculate Total Process Cost (for each Activity listed)
        LaborCost = rstActivity!LaborCost
        MaterialCost = rstActivity!MaterialCost
        MachineCost = rstActivity!MachineCost
        ProcessCost = LaborCost + MaterialCost + MachineCost
        rstActivity!ProcessCost.Value = ProcessCost

    rstActivity.Update
    rstProcessPlan.MoveNext

    Loop
    dbsCurrent.Close
    xlsCurrent.Close
    xlsMachCostSumm.Close
MsgBox "All finished"

End Sub
```

VITA

Mark Alan Eaglesham

Mark Eaglesham studied and worked as a research and teaching assistant in the Industrial and Systems Engineering Department at Virginia Tech, in Blacksburg, Virginia. His current research interests are in modeling manufacturing costs and developing decision support systems for design and for performance measurement systems. Other research interests are in the design of automated manufacturing equipment, and modeling and analyzing manufacturing systems. Previous experience includes mechanical engineering design of cargo handling equipment and technical management in the Port of Durban Container Terminal, South Africa. He is currently a student member of the IIE and ASME, and is an associate member of the Chartered Institute of Secretaries and Administrators, Southern African Division. He will be pursuing a career in the manufacturing industry in Australia, following the completion of this dissertation.